THE DEVELOPMENT OF A GEOGRAPHIC INFORMATION SYSTEMS BASED ATLAS OF SOUTHERN AFRICAN FRESHWATER FISH, AND ITS APPLICATION TO BIOGEOGRAPHIC ANALYSIS

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ABSTRACT

A Geographic Information Systems (GIS) atlas of southern African freshwater fish was developed for the SADC countries from natural history collection specimens, hydrological, topographical and climatological data. The primary purpose of the development of the atlas of freshwater fish was the construction of a practical framework to transform vast amounts of existing biological data for use in research and management of aquatic resources. The database of freshwater fish collection specimens that was incorporated into the atlas, was developed in association with ALCOM (Aquatic Resources Management for Local Community Development Programme).

The development of advanced computing and GIS technology has increased the scope of biological atlas projects by facilitating the integration of large amounts of spatial data to produce derived databases for specific applications. The atlas of freshwater fish was constructed using *TNTmips* GIS software as the most practical system available for managing and analysing biological data with a spatial component. The atlas contains 35 180 comprehensive distribution records of 735 species of fish. It has many applications as an inventory of ichthyofaunal spatial biodiversity, including those of conservation planning, environmental assessment and biogeographic research. Biogeographic studies have traditionally been subjective due to the logistical problems of working with large amounts of distribution data, although some small-scale quantitative research has been carried out in the past. The content of the atlas of freshwater fish is tested with respect to these previous studies, on known patterns of freshwater fish distributions, and the analytical capability of the atlas is tested and demonstrated with some new preliminary approaches to the analysis of freshwater fish distributions in southern Africa.

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Dedicated to my Father

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CHAPTER 1

GENERAL INTRODUCTION

Atlasing in Africa

An atlas may be traditionally defined as "a volume of tables, charts, or plates that systematically illustrates a particular subject" (Anon. 1996). The production of geographical atlases began in Africa in the late 1800s with the mapping of territories and resource availability by colonial powers (Adenyini 1985). Since then, data collection, analysis and mapping have been patchy. This is a consequence of political instability, the lack of skilled manpower, poor infrastructure and economic concerns in the region. Unfortunately, these factors also limit rapid technological development, hindering atlasing in both its manual and digital forms (Pettit 1999).

The distributions of terrestrial taxa are better known than those of fish as they are usually more visible, leading to a keener awareness of their variation through the demand for and publication of field guides for amateur naturalists. Field guides for birds and terrestrial vertebrates of southern Africa (including distribution maps), for example, have been in publication for decades, whereas there has been limited exposure for fishes (Skelton 1993).

The mapping of freshwater fish in southern Africa to date has either concentrated on detailed mapping at large scales (single drainage basins, for example), or range maps for more species at national level (Gaigher *et al.* 1980, Skelton 1993). Neither of these formats is ideal for detailed analysis of spatial variation in fish distributions (Harrison 1989). Range maps lack the specific locations of specimens, and extrapolation between points of collection may mask discontinuous fish distributions. Detailed mapping is limited to a small area due to the constraints of printing, and the "bigger picture" at regional or national level cannot be effectively illustrated (Davis *et al.* 1991). A digital atlas would remove the need for an *a priori* choice of scales during the developmental phase, as the end user determines the nature of the display of freshwater fish distributions.

The mapping of point information would hence be facilitated at any scale, providing an invaluable interactive reference for research and management throughout the subcontinent. The need for reliable information on southern African biodiversity is well recognised, and an extensive digital base of existing freshwater fish would be an important baseline contribution to the furthering of ichthyological knowledge.

The development of digital atlases in southern Africa has included a Population Atlas of Kenya (1995), a South African Environmental Potential Atlas (1998), a Digital National Atlas of Tanzania (1996) and a Tourism Potential Atlas of Swaziland (1998) (Van Viegen 1996, Pettit 1999). More specific biological atlases are the acclaimed Southern African Bird Atlas (Harrison *et al.* 1997) and the ongoing Frog Atlas Project, modelled on the Bird Atlas.

Distribution of freshwater fish in southern Africa

The distribution of freshwater fishes in southern Africa is a consequence of a number of biotic and abiotic factors. These include the connection or isolation of catchments (through historical, climatic or geologic events), the ability of fish to disperse, speciation processes (an effect of the duration of isolation of a species and its relative degree of specialisation), the consequences of disease, physico-chemical conditions (eg. water temperature, salinity and pH), biotic interactions (eg. competitive exclusion), the size of the river basin and the diversity of available aquatic habitats (Jubb & Farquarson 1965, Bowmaker *et al.* 1978, Lévêque 1997). Primary, or true freshwater fish, are physiologically confined to freshwater, and geographic connections between freshwater bodies are essential in order to effect their distribution (Myers 1937, Darlington 1957). Physical characteristics of the landscape dictate the possible range of a species whereas the environmental tolerance of a species has more of an effect on the success, abundance and frequency of a species within an area (Hughes *et al.* 1987).

Species richness is greatest in central Africa, which is characterised by diverse tropical faunas, in contrast to the comparatively poor richness in the south-west where a temperate component predominates (Bowmaker *et al.* 1978).

The decline in abundance from north to south is discontinuous, it decreases rapidly in the northern Kwazulu-Natal region on the east coast and in Namibia, south of the Cunene River, on the west coast (Skelton 1994, Hay *et al.* 1999).

Biogeographic study of freshwater fish in southern Africa

The biogeography of African freshwater fish has been formally and informally studied. Boulenger (1905) provided the first broad biogeographic account of African fish diversity. His ideas have subsequently been expanded on (Crass 1962, Gabie 1965, Gaigher & McPott 1973, Bowmaker *et al.* 1978, Greenwood 1983, Jackson 1986, Skelton *et al.* 1995).

The early literature was primarily concerned with check lists and the publication of new species distribution records (Barnard 1943, Jubb 1953, 1964) together with syntheses that were concerned with correlating species distribution patterns with causative geological and climatic histories (Bell-Cross 1965, Balon 1974).

Roberts (1975) presented the currently accepted scheme of ten ichthyofaunal provinces. Africa was divided up into the Maghreb, the Nilo–Sudan, the Upper Guinea, the Lower Guinea, the Zaire, the Quanza, the Zambezi, the East Coast, the Cape and the Malagasy. These provinces were based on large-scale patterns identified by Boulenger (1905) and Myers (1937). They were not considered strict biogeographical areas in an analytical or phylogenetic sense, but were used as a regional basis for comparison of faunal diversity (Skelton 1994). In many cases, the number and extent of these provinces reflected the state of knowledge of African freshwater fishes; their boundaries changing as new taxa were described or phyletic relationships were reassessed (Skelton 1986). Some previous attempts to recognise ichthyofaunal regions or provinces have been based on fundamentally superficial, and often unsubstantiated, knowledge of the distribution and occurrence of fish species (Greenwood 1983, Hugueny & Lévêque 1994). The boundaries of freshwater fish faunal regions have not, as yet, been tested in a "naive" or objective manner (Matthews 1998), due mainly to the impracticality of working with extremely large data sets outside of a computing environment.

Ichthyofaunal assemblage patterns can be used to define aquatic ecoregions, or ecologically distinct regions that may be used for assessment, management and ecological studies (Hawkes *et al.* 1986, Hughes *et al.* 1987, Anon. 1999a).

Some catchment based studies of freshwater fish distribution patterns have previously incorporated a similarity, or commonality index, to quantify the degree of similarity between fish faunal groups (Skelton 1994, Hay *et al.* 1999, Krebs 1999). The use of such a quantitative measure of faunal similarity is a useful quantitative tool in biogeographic studies, but southern African studies have been restricted to a local scale.

Natural history collections as information resources

Museums and natural history collections store quantities of biological information with both a spatial and a temporal aspect (Freitag *et al.* 1998). The collection specimens represent a long-term data set of the history of knowledge of an organism. Their preservation is therefore essential to preserve the integrity of published scientific information (Hall 1994, Cotterill 1997). Voucher specimens are necessary for taxonomic validation and to substantiate new distribution records (Burgman *et al.* 1995, De Moor 1996) so the institutionalisation of these collections ensures their efficient maintenance and management for future generations of scientists. As the pace of environmental degradation and the need to quantify and conserve biological diversity increases, so too does the value and utility of museum collections.

Collections form a basis for accurately determining the distribution of species, thereby providing information on threats and possible impacts to different taxa (Skelton *et al.* 1995). The process by which these decisions are made is often undocumented, qualitative and subjective (Burgman *et al.* 1995).

For example, specimen records have been mapped on paper, but are rapidly outdated as further fish collections are made and nomenclature is revised (Skelton & Verheust 1998).

The scale of analysis is predetermined by mapping capabilities, making any change from national scale to local scale almost impossible and invariably inaccurate (Stuckenberg 1969). Patterns of distribution are also extremely difficult to determine on paper as the amount of information displayed is limited by space in two dimensions. The sheer volume of information available slows data management and impedes analysis. In addition, inaccuracies may be introduced during transcription, which lead to the loss of details and facts, as well as perpetuating taxonomic errors (Ahearn *et al.* 1990, Nico & Fuller 1999).

Geographic Information Systems in southern Africa

Over the past twenty years, there has been a marked increase in the amount and availability of spatially referenced data. This has been aided by the increased awareness of the importance of the spatial aspect in biology, and the use of global positioning systems (GPS) for the precise recording of collection specimen co-ordinates. Efficient information transfer between organisations has been facilitated through the increased use of the internet (Davis *et al.* 1991).

A Geographic Information System (GIS) is an information system that is designed to work with spatial data. It comprises both a database system and a set of operations for working with geographically referenced information (Wijers 1993). GISs have the technological ability to manipulate and analyse vast quantities of spatially referenced biological data (Wijers 1993, Goodchild 1994). Species distribution maps can be regularly updated and edited at low cost and high efficiency, while up to date hardcopy maps can be produced on a regular basis as required, which benefits environmental research and planning. The analytical capacity of a GIS provides considerable potential for scientific research through integrated spatial data analysis and the modelling of future spatially referenced trends (Giles & Nielsen 1992, Lombard *et al.* 1992, Miller & Allen 1994, Paw 1994, Ross 1995).

Any GIS should enable the creation of creating complex objects from basic building blocks. An obvious example is where one map layer is overlaid with another, a condition is applied, and a new map layer is created to meet the conditions (a selection can be designed using a contour map layer and a layer of dams, for example, to produce a new map layer: all dams higher than 500m above sea level) (Gatrell 1991). Output data generated in this way is new information not necessarily present in the source database (Giles & Nielsen 1992). These output data may be displayed on a map or as numerical data which can then serve as source data for further modelling within the GIS application or with other software programmes (Lombard *et al.* 1992).

Recent advances in computing systems and automated cartography have facilitated faster and more accurate digital map production (Davis *et al.* 1991). Where transparent maps are limited in the amount of information they can display, computer based mapping systems can store, manipulate and display relatively unrestricted amounts of data (Giles & Nielsen 1992). Digital Geographic Information Systems (GIS) have greatly increased the scope for atlas projects by allowing the integration of distribution maps and other attribute data in a series of interactive "layers", synonymous with the overlay and visualisation of transparent sheets, each of which contains specific attribute information (Antenucci *et al.* 1991b, Giles & Nielsen 1992). As listed in Table 1.1, digital atlases have a number of characteristics not present in the traditional paper-based atlases.

As a multifunctional tool suitable for applications of regional or larger scales (Giles & Nielsen 1992, Wijers 1993), a GIS can now be considered an essential tool in the development of a dynamic atlas of freshwater fish in southern Africa.

Table 1.1 Characteristics of conventional and digital atlases (adapted from Pettit 1999).

Characteristics of a conventional atlas	**Characteristics of a digital atlas**
Often seen as a series of small-scale maps bound in a book.	Digital book of geographic maps at any scale, comprising both graphics and associated descriptive information.
Map order requires careful thought.	Map order is not a concern – images can be linked in multiple directions.
Page size limits the number of images that can be included.	Stores large amounts of both spatial and attribute data that can be manipulated and analysed. Limitation is the computer memory and storage capacity.
Maps are static. The user has no influence over the parameters or display.	The user has control over the map parameters displayed such as the map content and legend.
Once outdated, paper maps are difficult and time-consuming to update.	Quick, efficient, cost effective production and updates.
Presentation in book format can be unwieldy to use and store due to size.	Presentation on disk is condensed, easy to use and to store. The digital nature of the data facilitates multiple users and internet access.
Analysis is limited. Patterns can be identified depending on the presentation of the maps. The nature of the analysis is not determined by the user.	Graphic and attribute data can be manipulated and analysed by any user according to their specific requirements.
Complete coverage for developed countries. Outdated or incomplete coverage for many developing countries.	Patchy data coverage due to lack of digital data, but rapid updates integrate new data as it becomes available.
Initial costs high, for cartographic skills and publication. Costs remain high for updates and successive editions.	Initial costs very high, for GIS software, hardware and GIS skills. Very low cost of updating digital atlas and distribution of new versions through electronic media.
Cartographic skills required.	GIS skills required with good knowledge of cartographic principles.

Aim and objectives

The aim of this study was to develop a Geographic Information System based atlas of freshwater fish for the Southern African Development Community (SADC) region, and to demonstrate its potential for application in biogeographic research.

According to the Environmental Science Research Institute, any project making use of a GIS requires the careful organisation of a series of steps (Anon. 1993). The first outlines the objectives of the project, the second presents the database design, the third involves building the database and the fourth assesses the capabilities of the product through analytical tasks and the final step involves presenting the results.

Several specific objectives were outlined relating to the design and development of the atlas and its potential application, specifically to biogeographic research.

1. A freshwater fish distribution database was established as an accurate, dynamic inventory of all available freshwater specimen records. All the available collection records of freshwater fish in southern Africa were collected and compiled into a database that could be easily accessed, applied and updated when necessary. The database was designed for use as an entity in itself, as well as with the potential for integration into a Geographic Information System.

2. The Geographic Information Systems atlas of freshwater fish was developed, incorporating the freshwater fish database and other pertinent spatially referenced information. GIS based software was chosen for the atlas as it allowed the most scope for the display and analysis of large data sets as well as potential for future expansion of the atlas.

3. The utility of the atlas of freshwater fish was explored with respect to its scope as a tool for use in various fields, and some significant future applications for a larger information base were suggested.

It was essential to test the integrity of the atlas before statements could be made about its analytical utility (Lombard *et al.* 1992). Two main approaches were taken to test the atlas of freshwater fish. The first considered data verification as part of the developmental process (Objective 2). The second involved an experimental test of the atlas as a tool for research (Objectives 4 and 5).

4. The atlas of freshwater fish was tested with respect to the quality of its distribution data and its utility as a tool for the identification of patterns of freshwater fish distributions.

5. A test of the capacity of the atlas for applied Geographic Information Systems analysis of freshwater fish distribution patterns was carried out. An analysis of species richness, drainage basin area and environmental gradients was performed within the GIS.

Thesis outline

The thesis is divided into eight chapters and six appendices. A list of abbreviations and a glossary are also appended.

Chapter 2 covers the general methodology. The approach and general methods used in the development and application of the database of freshwater fish and the atlas of freshwater fish are discussed. The scope of the thesis, some limitations encountered and means of quality control are reviewed. In Chapter 3, the development of the database of freshwater fish is discussed with reference to detailed methods of data collection and database development. The contents and structure of the database, data input, retrieval, the mapping of fish distributions and future development of the database of freshwater fish is discussed. Chapter 4 is concerned with the development of the Geographic Information Systems atlas of freshwater fish for southern Africa. Detailed methods are discussed and the full contents and structure of the atlas is described in the results.

In Chapter 5, fish point distributions are used to investigate regional patterns of freshwater fish distribution in southern Africa. In Chapter 6, the capacity of the atlas of freshwater fish is tested with regard to applied Geographic Information Systems analysis. The potential for application of the atlas, future directions, and publication is discussed in Chapter 7. Chapter 8 is concerned with the general discussion.

Appendix A contains a list of source maps used in point co-ordinate determination from locality descriptions and Appendix B contains a list of the freshwater fish species in the atlas. Appendix C contains a list of the megabasins in the atlas for the entire SADC region used in the biogeographic analyses. Appendix D contains a numbered list of the map layers in the atlas of freshwater fish, indicating the source of the data and the map layer type. Appendix E contains a diagram of each of the digital map layers in the atlas and Appendix F contains a point distribution map of each fish species in the atlas.

CHAPTER 2

GENERAL METHODS

Introduction

The atlas of freshwater fish was initiated jointly by the JLB Smith Institute of Ichthyology and ALCOM (Aquatic Resource Management for Local Community Programme). ALCOM is a Food and Agriculture Organisation (FAO) initiative, funded by Belgium and Sweden, and is based in Harare, Zimbabwe. The aim of ALCOM is to improve the standard of living of rural populations in South African Development Community (SADC) member countries through the practise of efficient aquatic resource management techniques (Skelton & Verheust 1998). ALCOM has used fish distribution information from *A Complete Guide to the Freshwater Fishes of Southern Africa* (Skelton 1993) as part of a decision support tool for the determination of suitable fish species to stock in dams. This information was released as part of the ALCOM SACD Water Resource Database CD-ROM (1998) (Verheust & Johnson 1999).

The Atlas of Freshwater Fish has three major components:

1. Database of freshwater fish

The database of freshwater fish (Chapter 3) was designed jointly by the JLB Smith Institute of Ichthyology and ALCOM. It was initially established with the import of specimen records from five museum collections in 1997. The design of the database, capture of the records and software setup was by ALCOM, but the subsequent work is credited to the JLB Smith Institute. Since its inception, it has been checked, corrected, the design modified, maintained and regularly updated with new specimen records.

2. Water resource database

The water resource database was developed by ALCOM as the base for fish and fishery related research and development work (Verheust & Johnson 1998a). It consists of three data sets, a surface water database, a river database and a watershed database.

The river database was derived from the Digital Chart of the World (DCW) river layer at the 1: 1 000 000 scale. This database is extensive, illustrating over 40 000 river stretches; all the major rivers and tributaries of the SADC nations. The watershed database component was developed in collaboration with the World Wide Fund for Nature (WWF) which is planning to use it for the mapping and analysis of aquatic species conservation aspects. The watershed delineation is equally extensive, consisting of 1157 watersheds based on DCW rivers combined with the United States Geological Survey (USGS) digital elevation model for Africa.

3. Map layers from the FAO/SADC Regional Remote Sensing Project

The regional remote sensing project (RRSP) has established a uniform regional standard vector dataset for administrative, topographical, land use and transport layers for the SADC region at 1: 1 000 000 scale, based on the digital chart of the world. The digital map layers used are from the 0.9a version CD-ROM, released in 1997.
The main objective of the Regional Remote Sensing Project (RRSP)[1] is to strengthen national and regional capabilities in the areas of remote sensing and Geographic Information Systems for use in early warning systems for food security (Anon. 1997).

Approach

Natural history museum collection records were used as the only source data for species distributions. Each record has some type of spatial information in the form of point co-ordinates or a locality description that was used to assign geographical co-ordinates. Point locations were kept as the indicators of species distribution as they are independent of scale (a point has no size and retains its precision at all scales).

This study, in contrast to previous work, made no attempt to assume distribution ranges by extrapolation, as some ranges are discontinuous and a single range may be an oversimplification of a natural situation (Butterfield *et al.* 1994, Lawes & Piper 1998).

Published distribution records were not incorporated into the atlas as taxonomic errors are not easily picked up. Early published records of *Barbus anoplus*, for example, refer to more than one species, none of them the species *B. anoplus* as we recognise it today (Barnard 1943). Literature records do not allow for verification, whereas collection records are linked to an actual specimen that may be accessioned and referred to if the record needs confirmation. Published records were, however, used to substantiate the range of outlying species distributions, and may be incorporated into the atlas as additional information at a later stage if required. The identification of every specimen in the collection data has not been checked at this stage, and some taxonomic errors may be present. A degree of consistency is assumed as all the collections used at this stage are well recognised and specimens have been classified by qualified scientists. An extensive check of specimen identity will have to be undertaken to confirm this, but the electronic nature of the database will allow rapid updates of any modifications.

Quarter degree squares, or other grid based systems have been used in previous biodiversity studies (Brain & Meester 1964, Lombard 1995a, 1995b). This method was not followed for the fish atlas as a grid is scale dependent. For example, if a single base distribution record was entered into one $\frac{1}{4}°$ grid-cell on a map, and the grid size later changed to a 1° grid cell size, the presence of the single distribution point becomes 'present' over a much larger area. Similarly, if the grid cell size was decreased to $\frac{1}{8}°$, the single species record would have to be shown for all four cells as the point locality information for the original sample would have been lost (Brooks 1985, Lawes & Piper 1998). Grid cells do not fit in with most physical boundaries (watersheds or country borders), so implementing management strategies based on a grid cell analysis may be impractical (Lombard 1995b). Retaining point distribution data in the atlas of freshwater fish does not preclude the use of grid cell based data analysis if this is necessary in the future.

Watersheds, or catchment boundaries, were used in this study as natural area delimiters for species distribution analysis. The advantage of this method is that river systems are isolated and subdivided for the analysis and comparison of fish fauna and one region will never contain waters from more than a single river system. River conservation and management policy is becoming increasingly catchment based in order to regulate water and land use in the system as a whole. Fragmented management may lead to the conflict of interests regarding water use and possible exploitation of some sections of the drainage basin at the expense of others (Eekhout *et al.* 1997).

Data availability in Africa is particularly poor, and the lack of data is one of the biggest stumbling blocks when implementing a GIS (Adenyini 1985). A comprehensive set of natural history collection data was required to establish the atlas of freshwater fish. Existing historical collection data were therefore used since the option of carrying out specifically designed collecting expeditions was unrealistically expensive in terms of both time and money (Chapman & Busby 1994, Freitag *et al.* 1998). There was an urgent need to convert existing biodiversity information into accessible systems (Van Jaarsveld *et al.* 1998), so the priority for the atlas of freshwater fish was to produce an operational system using existing resources, with scope for expansion in the future. The incorporation of fish specimen records into a database dramatically increases their potential value for application in all fields of use (Miller & Allen 1994).

Databases

The term database refers to a large collection of data in a computer, organised so that it can be expanded, updated and retrieved for various uses. The data may be organised as a single file or as multiple sets of files (Antenucci *et al.* 1991a). The spreadsheet programme, *Approach* (© Lotus Development Corporation, 1995), was used to establish the database of freshwater fish from collection records as it is easy to use and compatible with many spreadsheet and text file formats.

This spreadsheet programme offers many of the same facilities as others, such as *Access* (© Microsoft, 1995), but ALCOM made use of *Approach*, so the decision was made to keep our systems as compatible as possible.

Geographic Information System Design

A Geographic Information System (GIS) was chosen to develop the atlas of freshwater fish as it has the capacity to organise and analyse large spatial data sets. The physical and environmental factors influencing the distribution of fish and museum collection records all have a spatial component. A GIS, being the most powerful computing tool available, was chosen to maximise the potential application of the atlas. Some other advantages of the GIS approach are that data were maintained in a physically compact form, and they were maintained and extracted at low cost and high speed. Computerised tools allowed a variety of rapid, cost-effective database manipulation at a number of scales (measurement, overlay, transformation, design) and the rapid and repeated testing of models was made possible. Graphic and non-graphic information could be merged and manipulated simultaneously, while it facilitated the integration of the different data sources, spatial analysis and decision making processes within a common information flow context (Dangermond 1990, Davis *et al.* 1990, Pettit 1999).

A GIS consists of computer hardware, software, 'liveware' or users, and digital data. Separate map layers form the building blocks of the spatial database and allow ease of interpretation and versatility of analysis (Asante & Maidment 1998, Wijers 1993). Geographic data may be stored in either a vector or raster based format. A vector based systems represent objects using points, vectors (lines) and polygons (Dangermond 1990). In raster based systems, data are stored in a grid of equal sized cells or pixels. Information in each cell is generalised and represented as a single unique value (Lombard *et al.* 1992, Wijers 1993, Asante & Maidment 1998). A GIS uses two data categories, geographic and attribute (Antenucci *et al.* 1991b, MacDougall 1996). Geographic data are digital descriptions of spatially distributed features. These map objects are defined by co-ordinates that relate them to their real counterparts on the surface of the earth.

The graphic data are used to generate a digital map display while the non-graphic or attribute data are linked to each of the digital map objects to describe characteristics of these features. The attributes are linked to map objects through common field identifiers and may be managed separately from the graphic data (Antenucci *et al.* 1991b). Among the attributes of a database are variables that describe the topological relationships among map elements, such as areas or perimeters of polygons and lengths of vectors (Lombard *et al.* 1992).

Many Geographic Information Systems are available, each with different features. In the past, GIS programmes were differentiated in terms of their capabilities of analysing raster (including remote sensed data that is raster based) or vector based data. This dichotomy has become less important in recent years as most modern software is capable of simultaneously analysing both categories of spatial data (Davis *et al.* 1991, Lombard *et al.* 1992). Combining all categories, some Geographic Information Systems use varying design approaches for graphic and non-graphic data, and manage each type with software best suited to its characteristics (Antenucci *et al.* 1991b).

Some limitations of Geographic Information Systems in general are the high cost of the initial acquisition of the hardware and software for the system, the cost of training personnel, and the cost and associated technical problems of converting existing geographic records into automated files. A large amount of technical and financial resources are needed to maintain and update automated files and decision makers often have insufficient knowledge of the capabilities of the GIS with which they are working (Giles & Nielsen 1992).

The nature of the project and its end use determines which GIS is the most effective (De Man 1990). Some factors to take into consideration include the ability of the GIS to interface successfully with image analysis packages for remote sensed data, the ability of modules within the GIS to deal with very large data sets (many modules have a size limit), and the cost of the system (Brooks 1985).

TNTmips (© MicroImages, Inc.) was chosen as the Geographic Information System that could meet the developmental and analytical requirements of an atlas of freshwater fish. It is a versatile and powerful GIS with software for editing, viewing and analysis of raster, vector, CAD (computer aided drawing) and TIN (triangulated irregular network) layers built into a single package. It has the ability to interface with image analysis tools for remote sensed data and it copes well with extremely large spatial data sets. Software support was available from the local distributing company (Geodatec, Grahamstown), and the cost of the system, which may have been prohibitive, was split between a number of students who are using the software.

Data quality control and limitations

"A Geographic Information System is a tool, its value is determined solely by the manner in which it is applied" (De Mers 1999). Similarly, the quality of the data output is dependent on the quality of the data input. As a consequence, development of the system must proceed within a systematic and co-ordinated framework (Lombard *et al.* 1992, Lawes & Piper 1998). Data standards must be defined and applied to all source data as errors are easily introduced with data capture (Harrison 1989) and their propagation must be avoided (Leth-Nissen 1993, Michelmore 1994, Van Viegen 1996). No GIS can be guaranteed to be completely error free, but all possible measures have been taken to reduce error. The geographic validation of suspect fish distribution records is particularly important as spurious errors may be present in museum archives (Chapman & Busby 1994, Hall 1994).

Sampling bias

Sampling bias may be introduced when fish collections are made extensively in certain areas by a few scientists (McAllister *et al.* 1994) or with a specific objective, such as the collection of a rare species. Freshwater fish do not all have the same chance of being sampled by traditional equipment; electrofishing, for example, is less likely to collect mormyrids than cyprinids (Hawkes *et al.* 1986).

Presence/absence data was the only source of data used in this study. This lessens the impact of sampling bias than would be the case if numbers of specimens were used as a measure of abundance. There is a greater chance of an expedition collecting a representative fish sample by species than there is of getting one representative by number (Burgman *et al.* 1995). In addition, most museums preserve an arbitrary number of specimens out of the total number collected. Considering that no distinction was made between species absence and insufficient sampling effort, 'false negatives' were unavoidably introduced into the database. Another problem that arose was that presence/absence records gave each species the same weighting irrespective if it had been sampled once in one hundred years, or if it was common in a system. Rare and sensitive species are often better documented than more ubiquitous species as they are more likely to be preserved (Butterfield *et al.* 1994). In most mapping schemes, it is neither possible to count the actual number of individuals present, nor to estimate their density directly (Lawes & Piper 1998). The Atlas of Southern African Birds uses reporting rate as a surrogate for abundance (Harrison *et al.* 1997), but the resources were not available for a similar approach with the fish atlas. The data collection aspect alone of the bird atlas occupied 7500 volunteers and a number of professionals over five years (Van Jaarsveld *et al.* 1998).

Despite these limitations, current biodiversity databases (consisting primarily of binary data) remain the most reliable option for conservation and biogeographical studies that is currently available (Lombard 1995a, Lawes & Piper 1998). The bias inherent in collection data sets such as these does, however, become reduced with an increase in database size and the time period of sampling.

Scope

The scope of the atlas project was limited to the continental SADC countries, south of and including Tanzania, Angola and Zambia (The Congo, Mauritius and Seychelles excluded), and southern Africa was defined as the subcontinent south of the latitude 0.75° S for the purpose of this study (Figure 2.1).

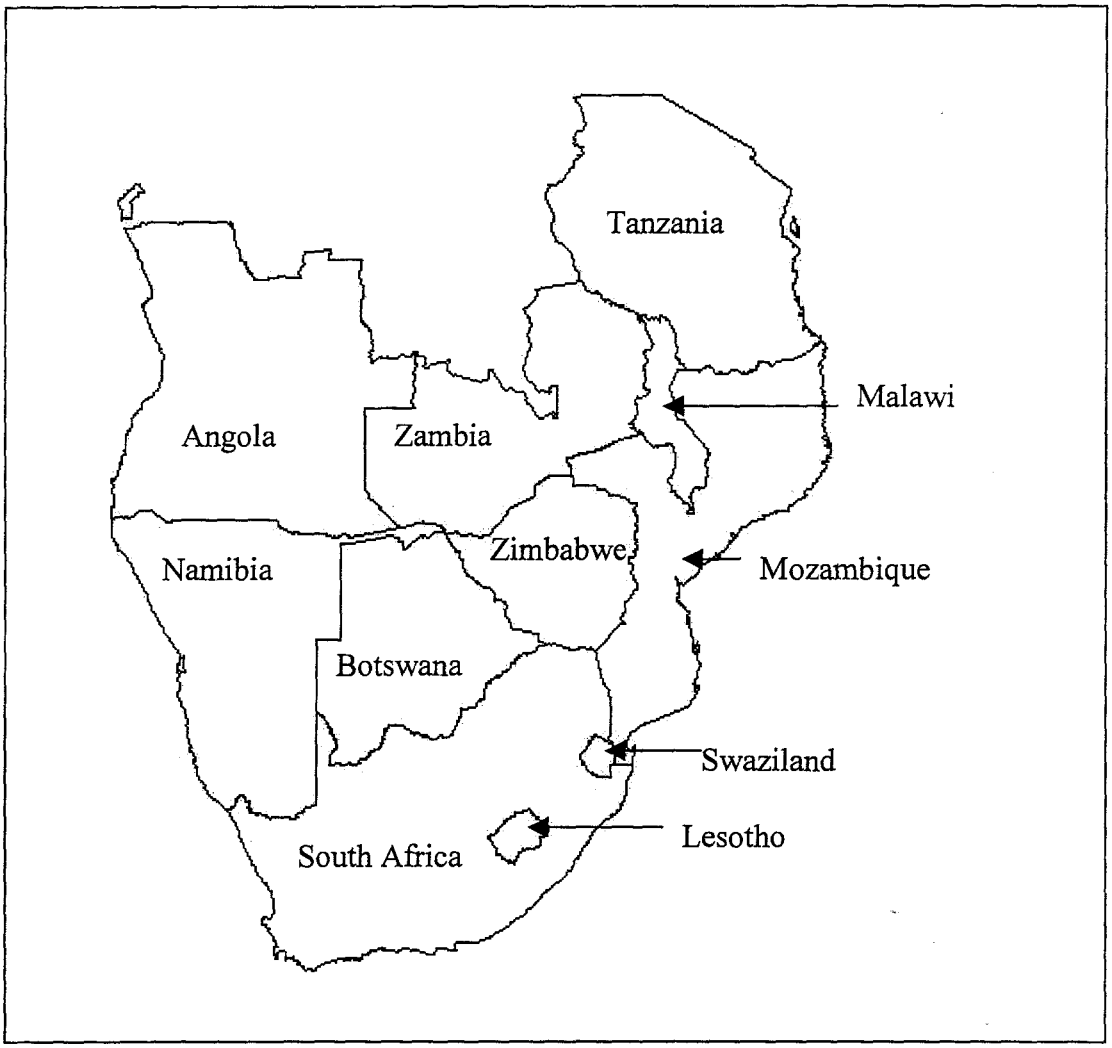


Figure 2.1 Countries comprising the Southern African Development Community (SADC).

The drainage of southern Africa (Figure 2.2) comprises five large systems penetrating the interior and some smaller inland systems which rarely extend beyond the continental escarpment, separated by small coastal drainages (Skelton 1990). Larger river systems include the Congo (2 000 172 km^2), Zambezi (1 374 030 km^2), Cunene (112 328 km^2), Limpopo (421 683 km^2), Etosha (161 170 km^2) and Orange (977 553 km^2) Rivers (Verheust & Johnson 1998b). All these systems have completely separate waters except the Okavango River that retains a sporadic connection with the Zambezi System.

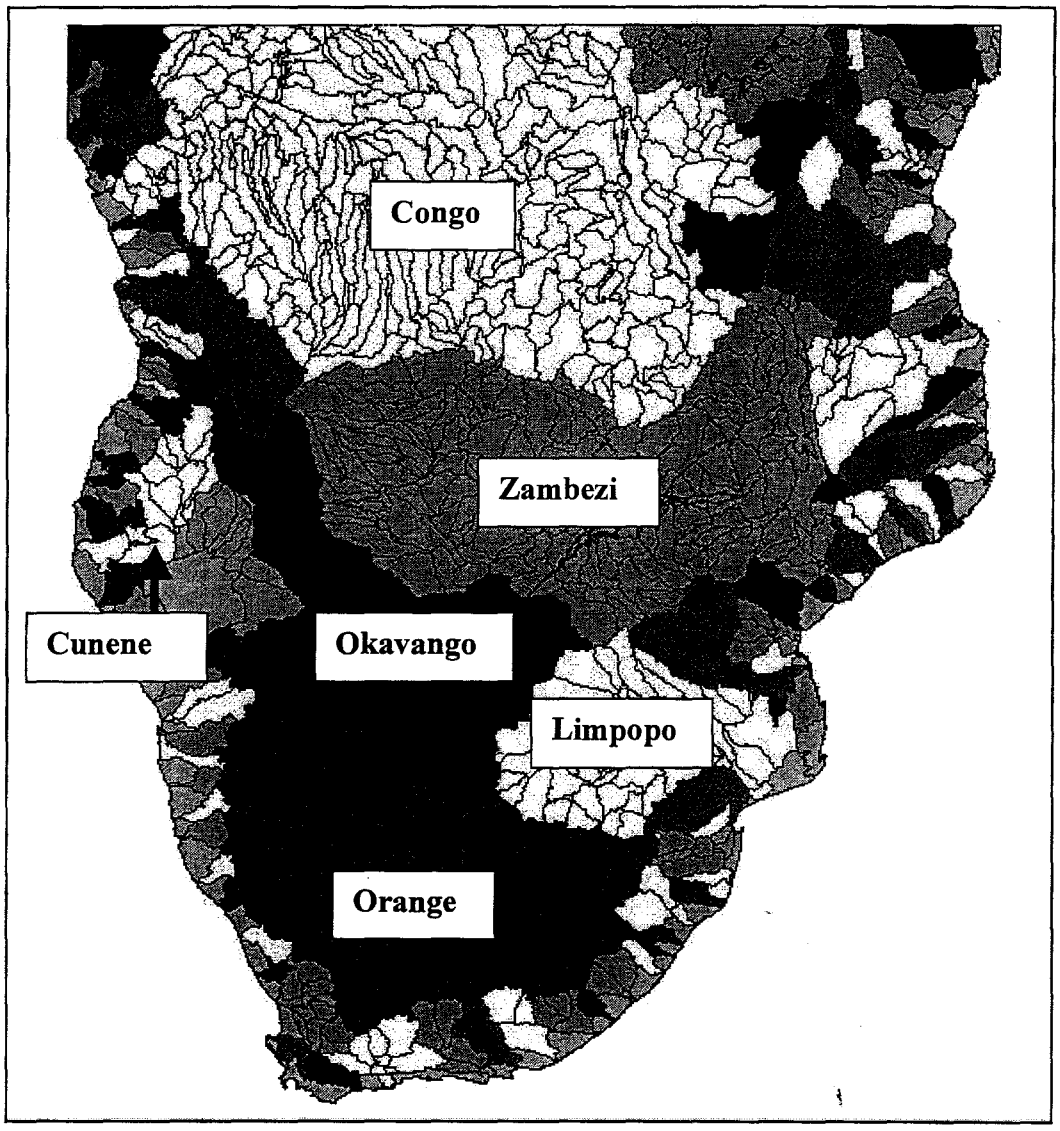


Figure 2.2 Representative megabasins situated in southern Africa. Watershed subdivision is indicated in grey-scale.

Species considered in the atlas

The database of freshwater fish and the atlas of freshwater fish were designed to include all the species found in the inland waters of the SADC countries, including those classified as introduced. Anadromous and catradromous species were also considered together with marine and estuarine species occurring in fresh water. Subgroups of these fish can be selected and used in isolation if required.

CHAPTER 3

DEVELOPMENT OF THE DATABASE OF FRESHWATER FISH

Introduction

An initiative known as the BioMap Project is underway to produce a digital inventory of all biological data in South Africa (Lombard 1995a, Van Jaarsveld & Lombard 1995), but these efforts are being hampered by the paucity of accessible information. Many museum databases still remain uncomputerised and curators may limit access to their collections (Hall 1994). Little information is circulated about existing data and the sharing of data is relatively rare. New data tend to be collected for research instead of expanding existing data resources (Bassole 1998, Matambanadzo 1998). Some computerised databases are limited because they lack geo–referenced data or the ability to rapidly access and integrate information with other spatial data (Ahearn *et al.* 1990). Scientific data related to collection specimens are gathered for a variety of different reasons (Chapman & Busby 1994) and field notes are usually very difficult to adapt to alternative applications (Miller & Allen 1994).

The size of most natural history collections tended to prohibit any comprehensive applied use of the specimens on a large scale, but the technological advances in computing systems over the past decade have facilitated the extraction and utilisation of much of this untapped information (Skelton *et al.* 1995, Verheust *et al.* 1998). The computerisation of collections has already proved to be invaluable to systematists, taxonomists and ecologists, merely through allowing faster and more efficient access to specimen record data of interest (Burgman *et al.* 1995).

The JLB Smith Institute of Ichthyology and ALCOM jointly initiated the database of freshwater fish from natural history collections to take the application and accessibility of collection specimens one step further, with the integration of a number of freshwater fish collection records in a dynamic information system.

Methods

Source of data

Fish collection records were obtained from the following five museum collections; permission being obtained for their use before any records were included.

1. The JLB Smith Institute of Ichthyology (Grahamstown, South Africa)
2. The Albany Museum (Grahamstown, South Africa)
3. The National Museum of Natural History (Bulawayo, Zimbabwe)
4. The Royal Ontario Museum (Ontario, Canada)
5. The National Museum (Windhoek, Namibia)

Fish collection records were extracted into *Excel* (© Microsoft, 1997), or in a suitable database format where necessary, and then sent by Dr R. Winterbottom (Royal Ontario Museum), Dr J. Cambray (Albany Museum) and Mr A. Bentley (JLB Smith Institute of Ichthyology). Hardcopy records were obtained from Mr P. Maconi (The National Museum of Natural History, Bulawayo) and Mrs E. Griffen (National Museum of Namibia, Windhoek) which were then entered into *Excel* manually, by Mrs J. Stockwell of the JLB Smith Institute of Ichthyology. Mr A. Bentley assisted with the manipulation of data files.

Assimilation of the specimen records into the database of freshwater fish

The fish collection records from all five sources were imported into a single database file, *fish_rec.dbf* by ALCOM, Harare. This was facilitated by modifying all the separate files into a standardised database format (*.dbf*). All the files were then imported into a single database and a unique identifier was added to each record as a sequential number. These unique identifiers are used in the linking of database files with additional attribute information.

Design of the database

Approach (© Lotus Development Corporation, 1995) was used as the software management system for the database. The file *fish_rec.dbf* was used as the core database file and was linked to an approach file named *fish_rec.apr* that contains templates for the display of the database contents. Additional attribute information was collected in the following categories and linked to the core database:

1. Synonyms for all valid species names
2. A four letter code for each species name
3. A drawing of each fish species where available
4. Drainage and megabasin area information (Verheust & Johnson 1998b)

The four database files were all created and edited in an *Excel* spreadsheet, imported into *Approach* as database files and linked to the core database (*fish_rec.dbf*). New active fields for each of the databases were then added to the form view of the approach file and customised for ease of use.

Design of the approach file

The form view of the database was adapted from a design by ALCOM, Harare. As the database was developed and expanded, additional fields were added to the form view and additional crosstabs were created for specific queries. Links to mapping packages were created by ALCOM, Harare.

Editing and testing of the database

Over 8 000 records lacked geographical co-ordinates. These were assigned, where possible, from map sources (Appendix A), atlases (Anon. 1984, Anon. 1987) and global locality databases on the Internet (Electronic citation 1, Hall 1994). A consistent co-ordinate system format is necessary for the accurate plotting of spatial data, and is required if the data are to be used analytically (Michelmore 1994). Decimal degrees were chosen as a standard for the database, being the simplest system for use.

Identification of the correct place name often required research into the context of the collection. In many cases, assignment of co-ordinates was impossible due to insufficient detail (Chapman & Busby 1994), place names having changed, or due to incomprehensible spelling. These records have been excluded from the database, but are easily accessible for incorporation at a later stage should they be required.

A consistent, valid species nomenclature was implemented. All species names and species codes were checked against the most recent publications to ensure accuracy, and synonyms were identified (Daget *et al.* 1984, Skelton 1993, Eschmeyer 1998).

Because of the constant threat of introducing spatial data errors (Hughes *et al.* 1987, Chapman & Busby 1994), every means was employed to find and correct them. Computer generated species distribution maps were produced, each species distribution was checked manually against known ranges of distribution, and errors were corrected as far as possible (Skelton 1993). Point co-ordinates were also cross-checked against locality descriptions.

Results

The database of freshwater fish presently contains 35180 georeferenced specimen records. These represent collections made from 1887 to 1999 in thirteen countries of southern Africa. There are a total of 735 species represented from 65 families. The database contains records from five natural history collections; the contribution of each is illustrated in Figure 3.1.

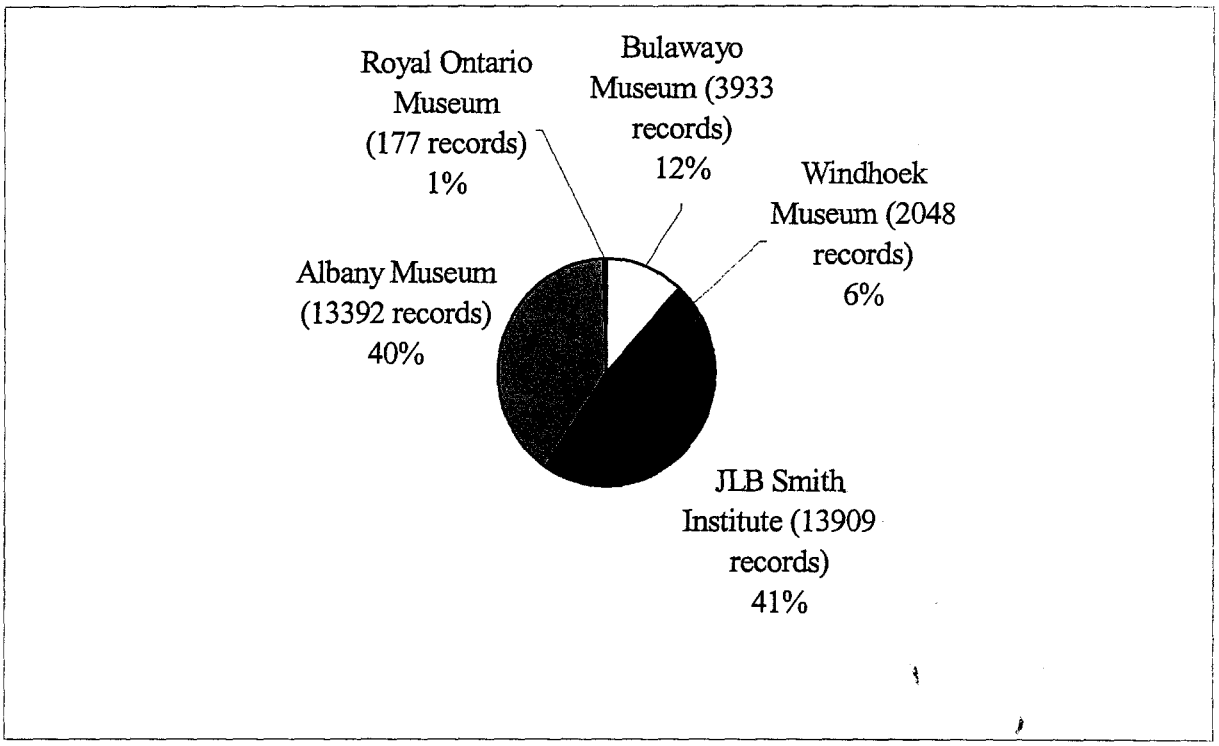


Figure 3.1 Graph illustrating the record number and percentage contribution of each of the five natural history museum collections incorporated into the database of freshwater fish.

The database of freshwater fish consists of five linked database file components (Figure 3.2).

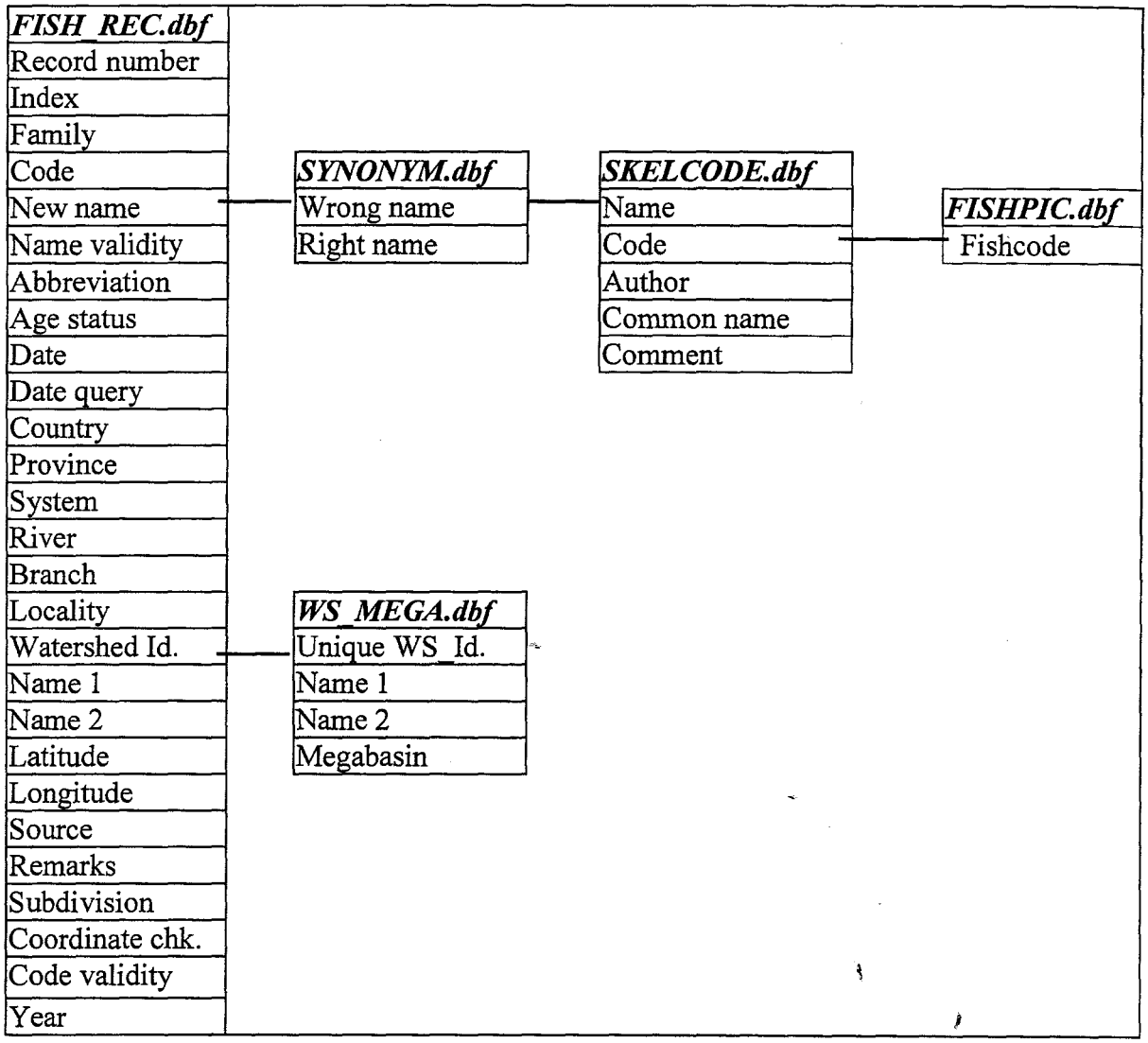


Figure 3.2 Diagram illustrating components of the database of freshwater fish and its linkage structure.

1. *Fish_rec.dbf* is the core database file of specimen records. It contains 29 data fields (Table 3.1), each of which provides essential information about every record in the database. Appendix B contains a list of all the freshwater fish species included in the database.

2. *Synonym.dbf* is linked to *Fish_rec.dbf* (Figure 3.2) and contains a list of all valid names and synonyms (Table 3.2).

3. *Skelcode.dbf* is linked to *Synonym.dbf* (Figure 3.2). It was provided by Paul Skelton (J.L.B. Smith Institute of Ichthyology, Grahamstown) and provides a reference for each species based on a four letter code (Table 3.3). The species code is based on the generic initial and first three letters of the species name, or where this creates a duplicate code, on the first subsequent letter in the species name.

4. *Fishpic.dbf* is linked to *Skelcode.dbf* (Figure 3.2) and contains pictures of fish, identified by their four letter reference code (Table 3.4). All fish illustrations were scanned by Ms L. Fargher from drawings produced by Dave Voorvelt and Liz Tarr of the J.L.B. Smith Institute of Ichthyology for publication in *A Complete Guide to the Freshwater Fishes of Southern Africa* (Skelton 1993). Some species not covered by the publication are not yet represented with illustrations.

5. *WS_mega.dbf* is a database file that is linked to the unique watershed identifier in the *Fish_rec.dbf* file (Figure 3.2). *WS_mega.dbf* identifies the megabasin in which the catchment is found and provides additional information in the form of synonyms for catchment names (Table 3.5). Appendix C lists the megabasins in the atlas as subdivisions of the SADC drainage area. The Zambezi basin has been divided into four megabasins (Upper Zambezi, Middle Zambezi, Lower Zambezi, Kafue) as, although they share common waters, physical barriers between these systems present obstacles to the dispersal of some freshwater fish (Tweddle *et al.* 1979).

The database of freshwater fish has an active basic form view which displays twenty-seven of the database fields (Figure 3.3) from various files (Table 3.6). Four macro buttons were designed by ALCOM to export and map selected fish records.

The Record List worksheet (Figure 3.4) displays each record in the database as a row in the table, with each field or data category as a column. Linked information is included, and the record in the row that is highlighted in the record list worksheet (1125 in this example) is the one that would be displayed in the form view.

Table 3.1 Field definition and description for data categories within the database *Fish_rec.dbf.*

Field name	Description	Data type	Size	Example
Record number	Unique Id. number for the database	Numeric	**10**	36929
Index	Id. number from the source collection	Numeric	**8**	2
Family	Family name	Text	**25**	Amphiliidae
Code	Eschmeyer family code	Text	**6**	150
New name	Valid name	Text	**39**	*Amphilius cryptobullatus*
Name validity	Check for validity	Text	**10**	X
Abbreviation	Four letter species code	Text	**5**	Acry
Age status	Maturity	Text	**2**	juvenile
Date	Date	Text	**9**	19701116
Date query	Check for reliability	Text	**2**	X
Country	Country name	Text	**18**	Zambia
Province	Province name	Text	**15**	Northern
System	River System name	Text	**30**	Lake Mweru
River	River name	Text	**30**	Lualaba River
Branch	River branch name	Text	**30**	Nsenga Stream
Locality	Locality name or description	Text	**30**	right bank
Watershed	Drainage Id. Number	Text	**5**	458
Name 1	Drainage or catchment name	Text	**30**	Luango
Name 2	Drainage or catchment name	Text	**43**	Lufubu
Latitude	Latitude in decimal degrees (negative = South)	Numeric	**3.2**	-10.33
Longitude	Longitude in decimal degrees (negative = West)	Numeric	**3.2**	29.33
Source	Collection or Museum source name	Text	**20**	Royal Ontario Museum
Remarks	Remarks	Text	**50**	eg. hand net
Subdivision	Megabasin subdivision	Text	**10**	eg. upper system
Coordinate check	Check for co-ordinates present	Calculated		If(FISH_REC. LONGITUDE>0,1,0)
Code validity	Check for species code validity	Calculated		If(Skelcode.name>0,1,0)
Year	Year check	Calculated		Middle(FISH_REC. DATE,1,4)

Table 3.2 Field definitions and descriptions for data categories within the file *Synonym.dbf.*

Field name	Description	Data type	Size	Example
Wrong name	All valid and invalid species names	Text	39	*Barbus anoplus*
Right name	All valid names	Text	39	*Barbus anoplus*

Table 3.3 Field definitions and descriptions for data categories within the file *Skelcode.dbf.*

Field name	Description	Data type	Size	Example
Code	Four letter species code	Text	6	Bano
Name	Valid name	Text	35	*Barbus anoplus*
Author	Scientist name	Text	44	Weber
Common name	Common name for fish species	Text	41	chubbyhead barb
Comment	comment	Text	16	

Table 3.4 Field definitions and descriptions for data categories within the file *Fishpic.dbf.*

Field name	Description	Data type	Size	Example
Fishcode	Four letter species code	Text	4	Bano
Fishpic	Picture of the fish species	Pictureplus	fixed	

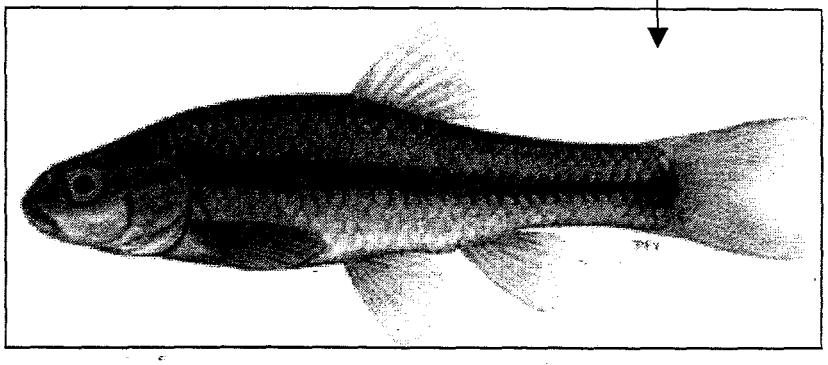


Table 3.5 Field definitions and descriptions for data categories within the file *WS_mega.dbf.*

Field name	Description	Data type	Size	Example
Unique Id.	Drainage Id. Number	Text	8	458
Name 1	Drainage or catchment name	Text	29	Luango
Name 2	Drainage or catchment name	Text	43	Lufubu
Megabasin	Megabasin name	Text	29	Congo

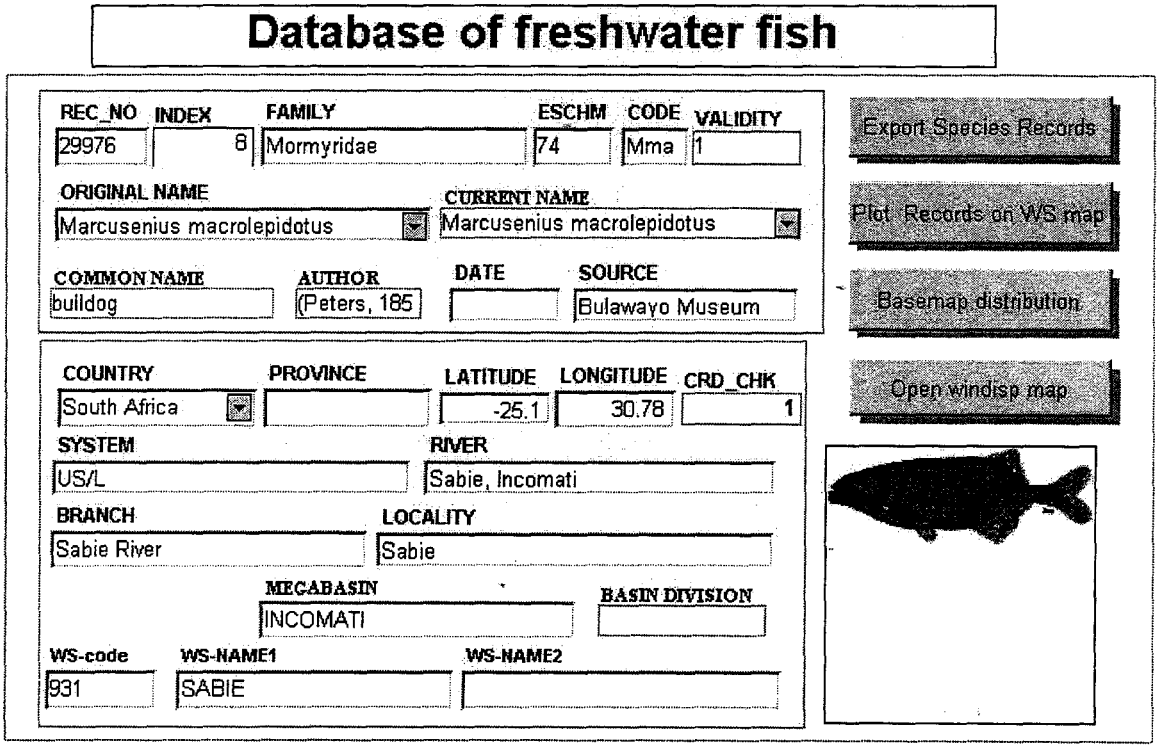
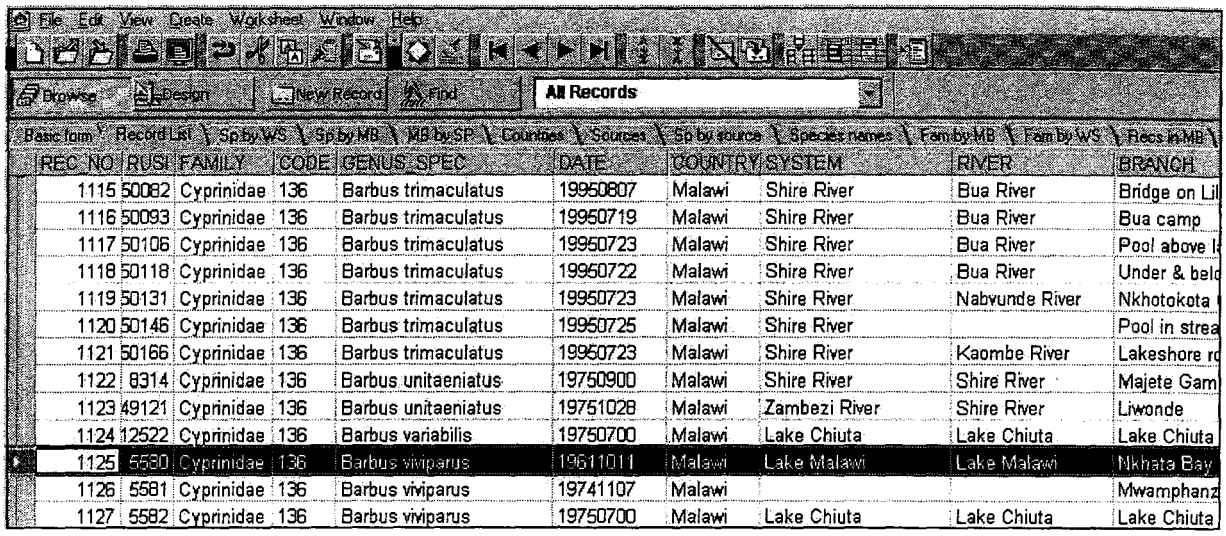


Figure 3.3 Basic form view of a single record in the database of freshwater fish.

Table 3.6 Source database location of information for each record compiled in the database of freshwater fish. Each of these fields is displayed in the form view.

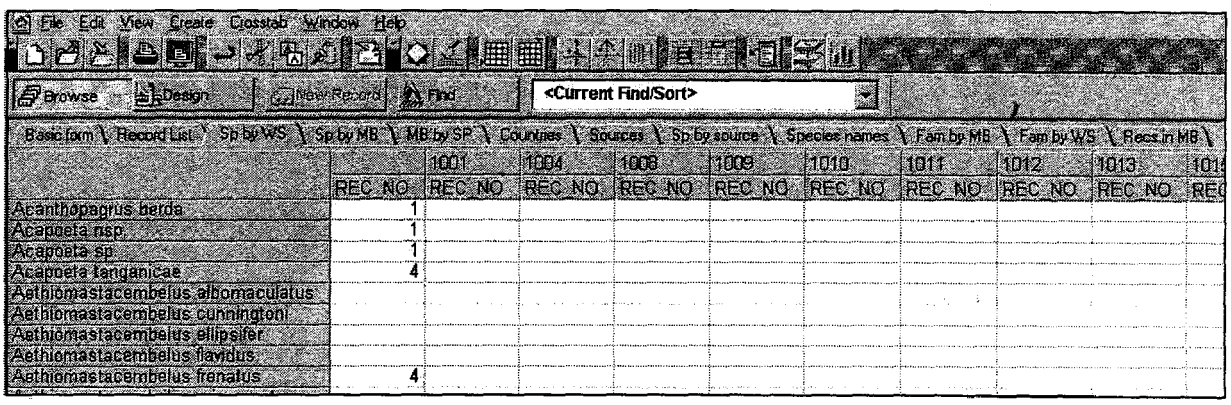
Data fields in basic form view	**Source file**
Rec_no	*Fish_rec.dbf*
Index	*Fish_rec.dbf*
Family	*Fish_rec.dbf*
Eschmeyer number	*Fish_rec.dbf*
Code	*Fish_rec.dbf*
Validity	*Fish_rec.dbf*
Original name	*Fish_rec.dbf*
Current name	*Synonym.dbf*
Common name	*Skelcode.dbf*
Author	*Skelcode.dbf*
Date	*Fish_rec.dbf*
Source	*Fish_rec.dbf*
Country	*Fish_rec.dbf*
Province	*Fish_rec.dbf*
Latitude	*Fish_rec.dbf*
Longitude	*Fish_rec.dbf*
Coordinate check	*Fish_rec.dbf*
System	*Fish_rec.dbf*
River	*Fish_rec.dbf*
Branch	*Fish_rec.dbf*
Locality	*Fish_rec.dbf*
Megabasin	*WS_mega.dbf*
Basin division	*Fish_rec.dbf*
WS - code	*Fish_rec.dbf*
WS Name 1	*WS_mega.dbf*
WS Name 2	*WS_mega.dbf*
Fish Picture	*Fishpic.dbf*



REC_NO	RUSI	FAMILY	CODE	GENUS_SPEC	DATE	COUNTRY	SYSTEM	RIVER	BRANCH
1115	50082	Cyprinidae	136	Barbus trimaculatus	19950807	Malawi	Shire River	Bua River	Bridge on Lil
1116	50093	Cyprinidae	136	Barbus trimaculatus	19950719	Malawi	Shire River	Bua River	Bua camp
1117	50106	Cyprinidae	136	Barbus trimaculatus	19950723	Malawi	Shire River	Bua River	Pool above I
1118	50118	Cyprinidae	136	Barbus trimaculatus	19950722	Malawi	Shire River	Bua River	Under & belo
1119	50131	Cyprinidae	136	Barbus trimaculatus	19950723	Malawi	Shire River	Nabvunde River	Nkhotokota
1120	50146	Cyprinidae	136	Barbus trimaculatus	19950725	Malawi	Shire River		Pool in strea
1121	50166	Cyprinidae	136	Barbus trimaculatus	19950723	Malawi	Shire River	Kaombe River	Lakeshore ro
1122	8314	Cyprinidae	136	Barbus unitaeniatus	19750900	Malawi	Shire River	Shire River	Majete Gam
1123	49121	Cyprinidae	136	Barbus unitaeniatus	19751028	Malawi	Zambezi River	Shire River	Liwonde
1124	12522	Cyprinidae	136	Barbus variabilis	19750700	Malawi	Lake Chiuta	Lake Chiuta	Lake Chiuta
1125	5580	Cyprinidae	136	Barbus viviparus	19611011	Malawi	Lake Malawi	Lake Malawi	Nkhata Bay
1126	5581	Cyprinidae	136	Barbus viviparus	19741107	Malawi			Mwamphanz
1127	5582	Cyprinidae	136	Barbus viviparus	19750700	Malawi	Lake Chiuta	Lake Chiuta	Lake Chiuta

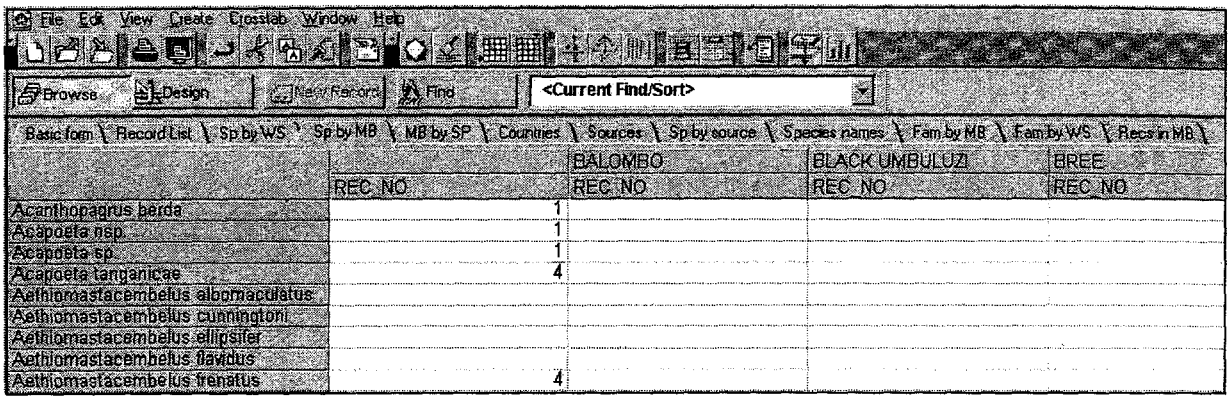
Figure 3.4 Record list page of the database of freshwater fish is a worksheet that displays a single record in each row and a unique field in each column.

A crosstab is a worksheet that displays database information in a user-defined format. For example, Crosstab *Sp by WS* (Figure 3.5) indicates the number of specimens of each species (in rows) in each watershed (identified by the unique watershed number, columns). Figures 3.6-3.14 illustrate the other crosstabs designed for the database.



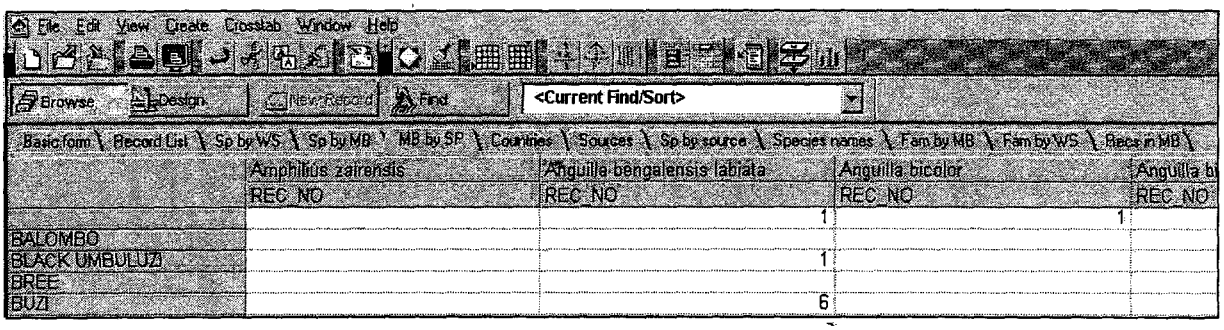
	1001	1004	1008	1009	1010	1011	1012	1013	101
	REC_NO	REC_NO	REC_NO	REC_NO	REC_NO	REC_NO	REC_NO	REC_NO	REC
Acanthopagrus berda	1								
Acapoeta nsp	1								
Acapoeta sp	1								
Acapoeta tanganicae	4								
Aethiomastacembelus albomaculatus									
Aethiomastacembelus cunningtoni									
Aethiomastacembelus ellipsifer									
Aethiomastacembelus flavidus									
Aethiomastacembelus frenatus	4								

Figure 3.5 Crosstab *Sp by WS* indicating the number of specimens of each species (rows) by watersheds (columns).



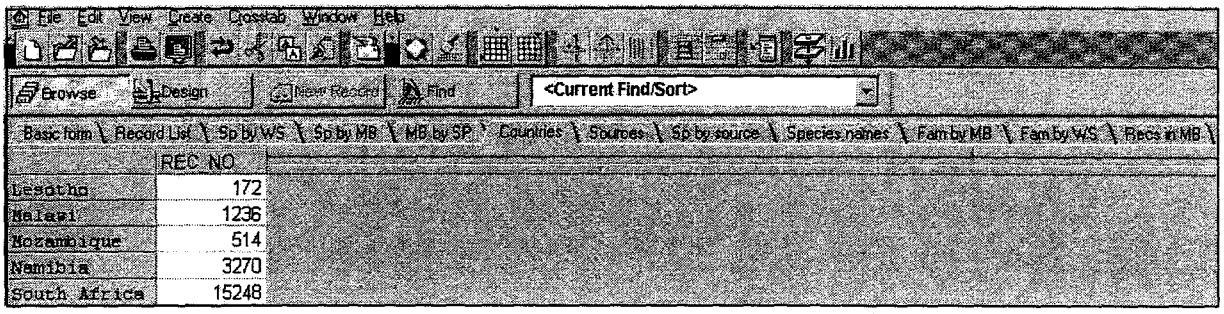
	BALOMBO	BLACK UMBULUZI	BREE
	REC_NO	REC_NO	REC_NO
Acanthopagrus berda	1		
Acapoeta nsp.	1		
Acapoeta sp.	1		
Acapoeta tanganicae	4		
Aethiomastacembelus albomaculatus			
Aethiomastacembelus cunningtoni			
Aethiomastacembelus ellipsifer			
Aethiomastacembelus flavidus			
Aethiomastacembelus frenatus	4		

Figure 3.6 Crosstab *Sp by MB* indicating the number of specimens of each species (rows) by megabasins (columns).



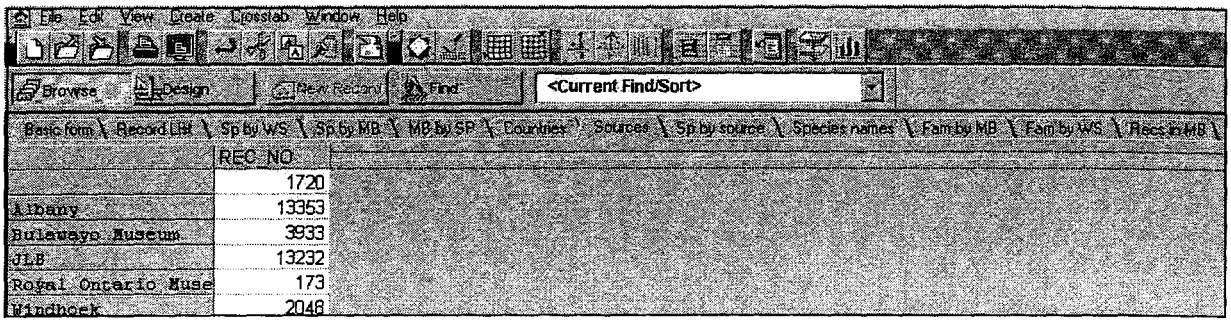
	Amphilius zairensis	Anguilla bengalensis labiata	Anguilla bicolor	Anguilla b
	REC_NO	REC_NO	REC_NO	REC_NO
BALOMBO		1	1	
BLACK UMBULUZI		1		
BREE				
BUZI		6		

Figure 3.7 Crosstab *MB by SP* indicates the number of specimens of each species (columns) by megabasins (rows).



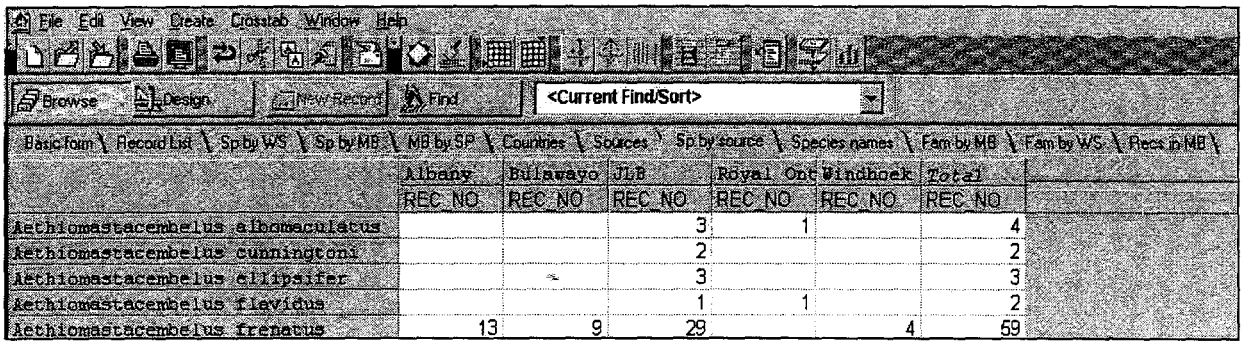
	REC_NO
Lesotho	172
Malawi	1236
Mozambique	514
Namibia	3270
South Africa	15248

Figure 3.8 Crosstab *Countries* indicating the number of specimens (column) collected by country (rows).



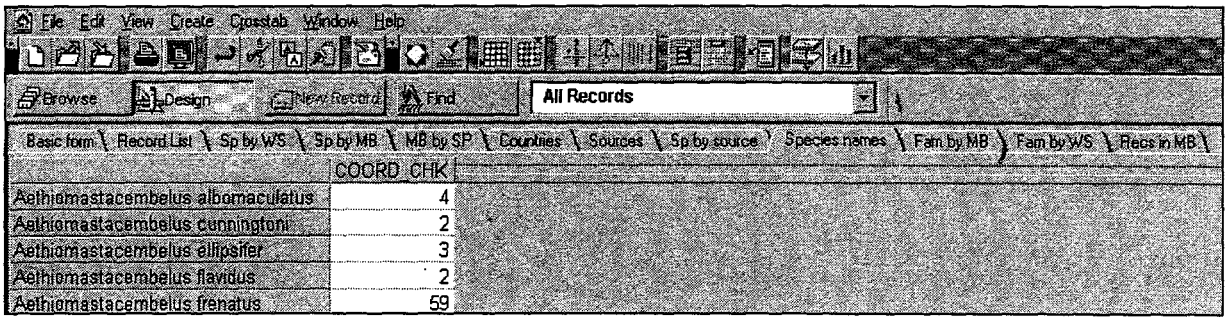
	REC_NO
	1720
Albany	13353
Bulawayo Museum	3933
JLB	13232
Royal Ontario Muse	173
Windhoek	2048

Figure 3.9 Crosstab *Sources* indicating the number of specimens (column) present in museum collection archives (rows).



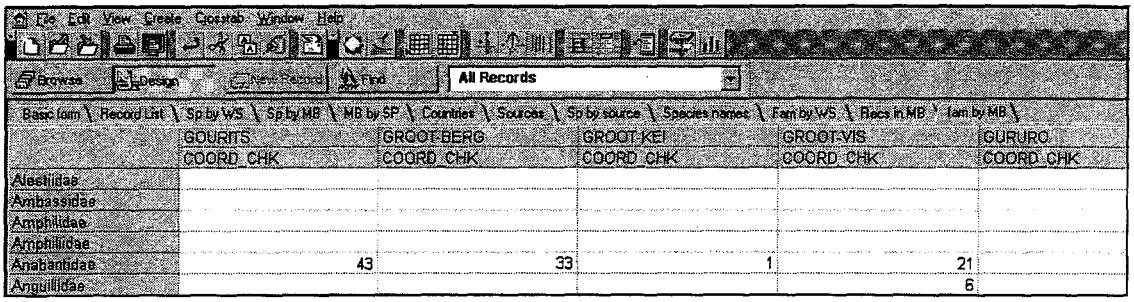
	Albany REC_NO	Bulawayo REC_NO	JLB REC_NO	Royal Ont REC_NO	Windhoek REC_NO	Total REC_NO
Aethiomastacembelus albomaculatus			3	1		4
Aethiomastacembelus cunningtoni			2			2
Aethiomastacembelus ellipsifer			3			3
Aethiomastacembelus flavidus			1	1		2
Aethiomastacembelus frenatus	13	9	29		4	59

Figure 3.10 Crosstab *Sp by source* indicates the number of specimens of each species (rows) by museum collections (columns).



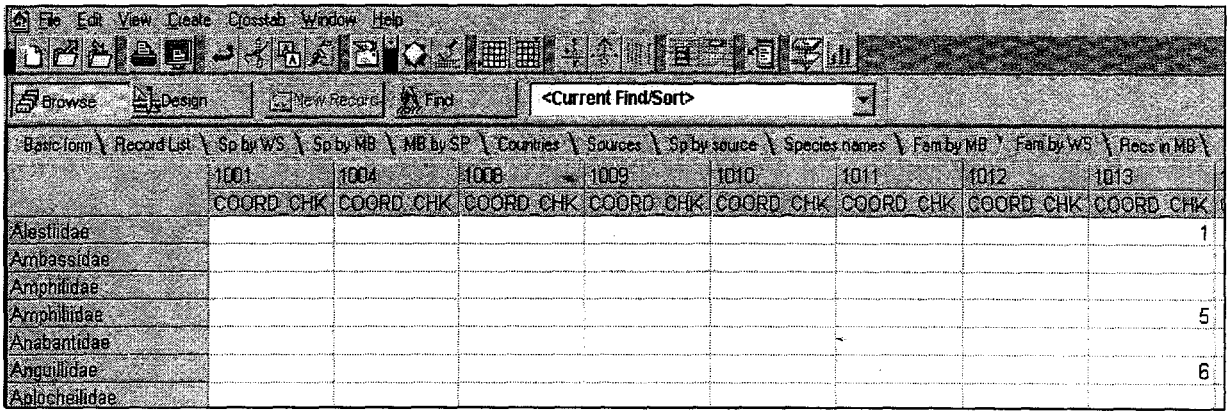
	COORD_CHK
Aethiomastacembelus albomaculatus	4
Aethiomastacembelus cunningtoni	2
Aethiomastacembelus ellipsifer	3
Aethiomastacembelus flavidus	2
Aethiomastacembelus frenatus	59

Figure 3.11 Crosstab *Species names* indicating the number of specimens (column) of each species (rows) present in the database.



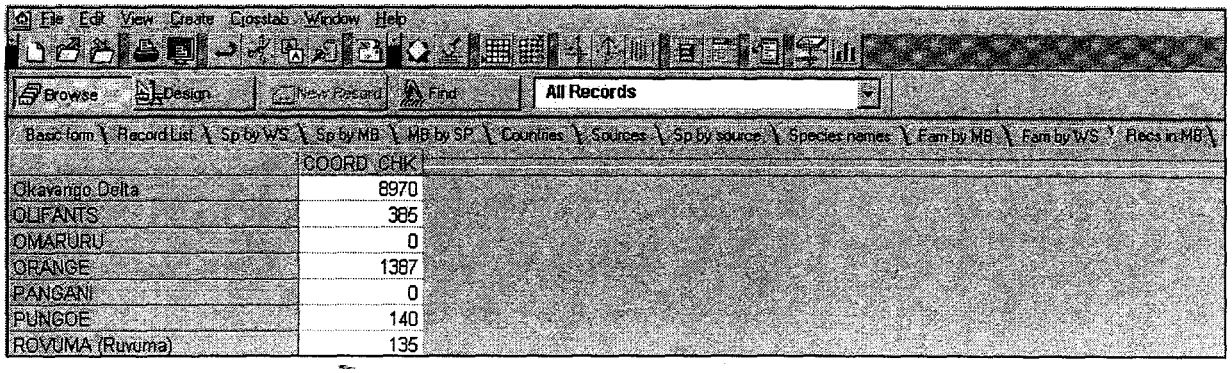
	GOURITS	GROOT-BERG	GROOT-KEI	GROOT-VIS	GURURO
	COORD_CHK	COORD_CHK	COORD_CHK	COORD_CHK	COORD_CHK
Alestiidae					
Ambassidae					
Amphiliidae					
Anabantidae	43	33	1	21	
Anguillidae				6	

Figure 3.12 Crosstab *Fam by MB* indicating the number of specimens of each family (rows) found by megabasins (columns).



	1001	1004	1008	1009	1010	1011	1012	1013
	COORD_CHK	COORD_CHK	COORD_CHK	COORD_CHK	COORD_CHK	COORD_CHK	COORD_CHK	COORD_CHK
Alestiidae								1
Ambassidae								
Amphiliidae								
Anabantidae								5
Anguillidae								
Aplocheilidae								6

Figure 3.13 Crosstab *Fam by WS* indicating the number of specimens of each family (rows) found by watershed (columns).



	COORD_CHK
Okavango Delta	8970
OLIFANTS	385
OMARURU	0
ORANGE	1387
PANGANI	0
PUNGOE	140
ROVUMA (Ruvuma)	135

Figure 3.14 Crosstab *Recs in MB* indicating the number of specimens (column) collected by megabasin (rows).

Data input

A new specimen record can be entered into the database by clicking onto the New Record button in the basic form view. This opens a blank record page (Figure 3.15) which is then completed. A drop down list for the species name ensures correct spelling and valid nomenclature. Once the new record fields are completed and saved, the specimen record is added as a row in the record list worksheet with a unique identification number.

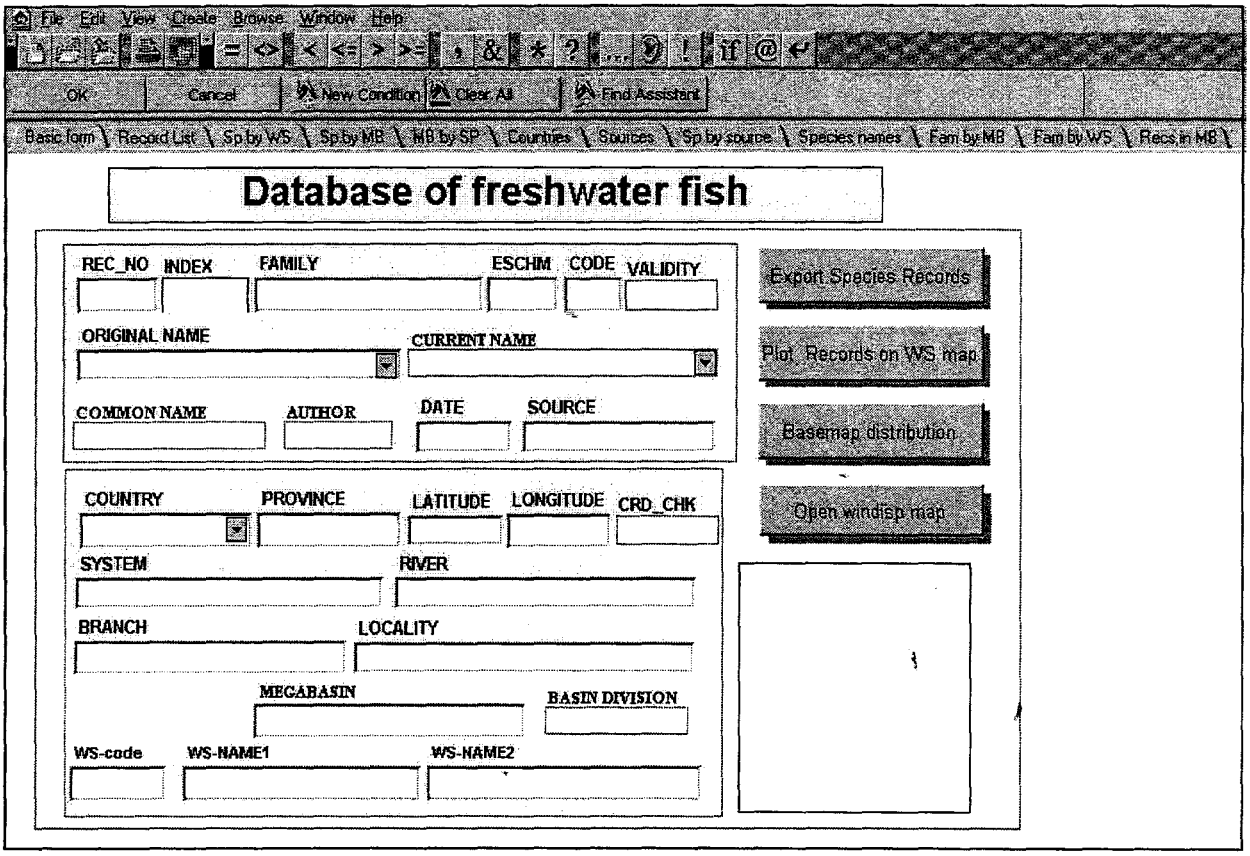


Figure 3.15 Blank record page view for new record entry into the database of freshwater fish.

An entire database file containing many new records may be added into the database of freshwater fish. This method is only possible if:

1. The new database file is saved in DBASE IV format
2. Each field in the new database is named identically to each field in the database of freshwater fish
3. Each field in the new database has an identical field definition to each field in the *Fish_rec.dbf* database file (Table 3.1)

The new database is imported by selecting *File / Import data....* in the database of freshwater fish. The new database is then specified and the new records are added.

Data retrieval

The database of freshwater fish opens with *All records* selected (Figure 3.3). A search for a subset of records may be conducted by clicking the *Find* button that opens a blank form page. A species name, location, or any other condition is then entered as required, and activating the search will create a subset of specimen records that meet these parameters. Once a subset of records is active in the database, all the macro buttons are programmed to map this set only, so that the results of a query can be displayed.

At present, the database interface allows for

1. Species point or range distribution visualisation at any scale.
2. The determination of a species list for any drainage area
3. An analysis of sampling patterns and species occurrence by collection
4. Visualisation of drawings of any freshwater fish species
5. The tracing of the taxonomic history of any species; to identify the author, common names, synonyms, and to determine where specimens are held.

Mapping of fish distributions

Automated mapping systems provide the link between database systems and graphical display (Cowen 1988). The ability to visualise database information directly is a powerful tool. Any information can be updated as frequently as required, and changes are visible immediately (Skrdla 1997). An interface was designed by ALCOM, Harare, combining the database with simple mapping software to allow the visualisation of species point distributions on a base map as well as distribution on a watershed basis (Verheust & Johnson 1998a).

Mapviewer (© Golden Software Inc., 1996) is a commercially developed software package allowing the rapid mapping of vector features. Windisp3 is a simple raster and vector mapping programme. It is freely available and can be downloaded off the Internet (Electronic citation 2).

Four macro buttons are present in the database form view (Figure 3.3) to facilitate species mapping.

Macro 1. Export Species Records

This macro creates and exports an ASCII file (*.bna*) in comma delimited format. It is used to store the point distribution information in the following format:

"id1", "id2", 1, longitude, latitude

This file is automatically imported into Windisp3 when the programme is running, and the file can be manually imported into Mapviewer for display of the point distributions (Verheust & Johnson 1998a).

Macro 2. Plot Records on WS map

This is a simple macro that creates and exports a data file in comma delimited ASCII format. This format stores an identifier polygon for the watershed in which species distribution points occur, as well as a colour code that allows the selected polygons to be mapped in colour. The file has the following structure:

"id1", data1, data2, ..., colourcode

Mapviewer is opened and the data file is used to colour polygons selectively with the required colour (Verheust *et al.* 1998). This allows rapid identification of relevant catchment areas within megabasins (Figure 3.16).

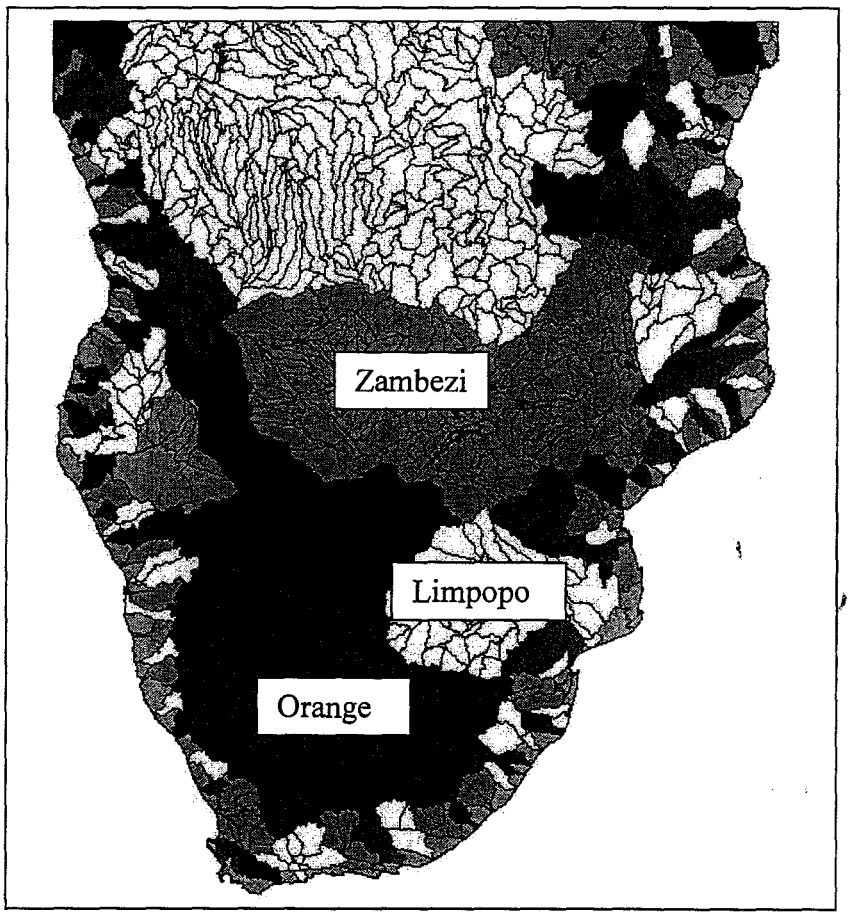


Figure 3.16. Map of southern African megabasins, showing smaller drainage areas, used as a base map on which to plot species distribution points (three examples labelled).

Macro 3. Basemap distribution

Species distributions are plotted using Mapviewer software. The macro creates and exports a data file (*SUB_BAS.gsm*) in comma-delimited ASCII format, which maps only the sub basins (Figure 3.17) in which the fish species points are located (Verheust & Johnson 1998a).

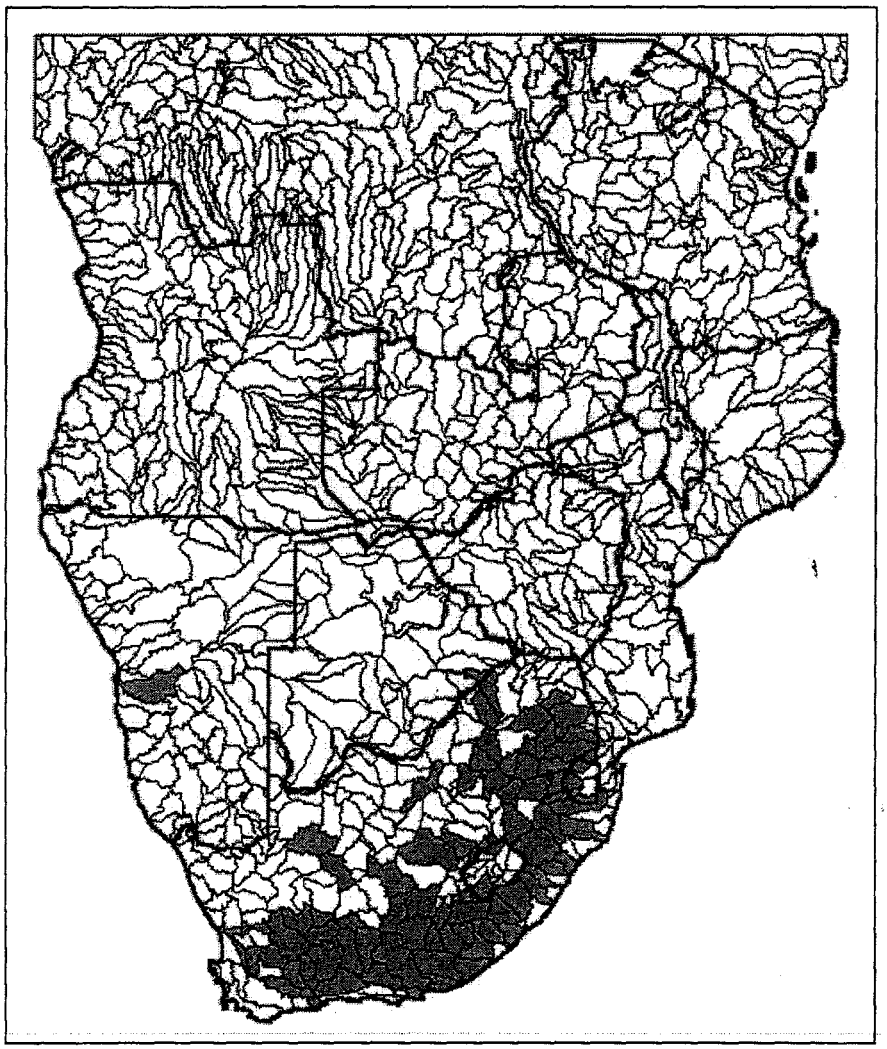


Figure 3.17 Catchments coloured grey indicate the presence of records for *Barbus anoplus* in the database of freshwater fish.

Macro 4. Open Windisp map

This macro opens the Windisp3 programme and automatically imports the species record file in *.bna* format (Macro 1) into the active project file. Other data layers that are open in the active project file were provided by ALCOM, Harare.

1. A digital elevation model (DEM)
2. A layer of all the watersheds in the SADC region
3. A layer of all the rivers in the SADC region

The species record file and other data layers may then be displayed as required (Figure 3.18).

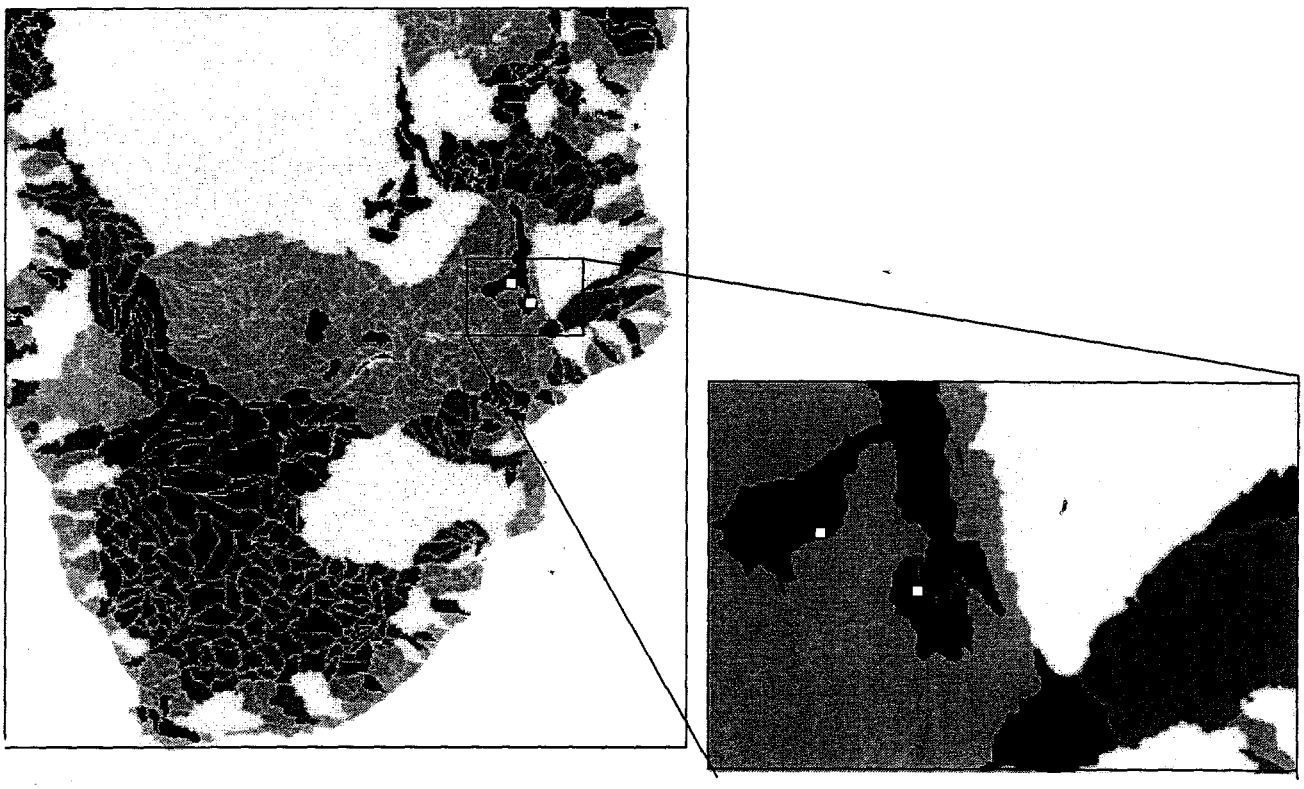


Figure 3.18 Species distribution points from the database of freshwater fish, plotted on a megabasin basemap using the Windisp 3 mapping programme.

Discussion

"Current biodiversity information, that can be accessed easily, is needed by national governments and international development agencies as they attempt to integrate conservation and sustainable development goals." (Ahearn *et al.* 1990).

The database of freshwater fish was designed to incorporate all the natural history collections that are presently accessible, but not to limit its future scope when more data become available. As fish specimens are continuously collected, new specimens will be added as new records in the database. New fields may be added should the need arise, and new databases may be linked to the database of freshwater fish to provide additional attribute information to previously existing records. Work is currently underway to incorporate further specimen records from other international collections that will prove to be valuable additions to the existing records. As the database grows in size, some of the gaps in the spatial distribution of recorded specimens will be filled with records from new areas.

A better representation of species collected over time will be seen with a more extensive database. At present, changes in species distributions over time can be seen, but most species do not have enough records in the database to make conclusive statements about these changes. Specimens can be sourced to their geographical point of collection as well as to the collection in which they are housed, and species lists can be generated for any given area.

Previous experience has shown that the success of information networks hinges on the philosophy with which they were developed, and a number of criteria are suggested to be crucial to encourage participation and information exchange. The venture should be non-profit making and the financial support should be based on grants and subscribers who should have free access to databases to which they have contributed. Software and other facilities for record keeping should be given to subscribers and profits made in the short term should be re-invested in the software (Lombard *et al.* 1992, Van Jaarsveld & Lombard 1995).

The database of freshwater fish meets these requirements, and with an effective management policy in place, will prove to be a dynamic and reliable information resource. Consistent access control, database management and the maintenance of standards of definition and quality are all essential to protect the integrity of the database (Bassole 1998). The database should be accessible to all interested parties to perform species or regional searches and queries. This will be made possible through access at the JLB Smith Institute in Grahamstown, and conceivably through distribution on CD-ROM. The database has been designed to stand alone as a digital information resource, useful for the rapid retrieval and mapping of fish distribution information.

More sophisticated investigations of fish distributions for conservation and management purposes need a more powerful computing platform; hence the development of an atlas of southern African freshwater fish from the basic distribution information incorporated into the database.

CHAPTER 4

DEVELOPMENT OF THE ATLAS OF FRESHWATER FISH

Introduction

Worldwide concern for the loss of biological diversity over the past decade has provided some impetus for the development of biodiversity databases and biological atlas projects in order to get the information on the world's biota into an accessible format (Ahearn *et al.* 1990). This Geographic Information Systems atlas of southern African freshwater fish is the first of its kind, and as such can be seen as contributing towards this global trend of consolidation and refining of biodiversity information.

The atlas of freshwater fish was developed to provide a tool for the research and management of freshwater resources through the integration of the database of freshwater fish with other spatial data. The utility of a dynamic Geographic Information Systems (GIS) atlas far surpasses that of a database, like the database of southern African freshwater fish, in the analytical power it brings to the study of spatial distributions. The application of GIS in the field of ichthyology and freshwater fisheries management has been limited until now, due to limitations of budget, skills, and the lack of good quality, comprehensive data sets (Verheust *et al.* 1998). With the development of the database of freshwater fish (as discussed in the previous chapter) and the development of a water resource database (by ALCOM), the development of a SADC Atlas of Freshwater Fishes has become feasible.

Methods

Hardware and software requirements

The Atlas of Freshwater Fish was set up using a *TNTmips* v5.8 based Geographic Information System running off an Intel Pentium II (233MHz) processor with a 2 GB hard drive and 64 MB RAM.

Atlas design

The interpretation and analysis of freshwater fish distributions requires a frame of reference in the Geographic Information System, provided by other spatially referenced data. Six categories of information were regarded as indispensable to the establishment of a functional atlas of this type.

1. Topographical layers (a means to indicate elevation)
2. Administrative boundaries (national and sub–national boundaries)
3. Hydrological features (rivers, lakes and dams)
4. Climate layers (precipitation and temperature surfaces)
5. Freshwater fish data points
6. Surface water body data points

Basic land use information was freely obtainable, and was included in the database. This additional information can be expanded as further resources become available with map layers such as detailed land use categories, environmental layers, vegetation type and other remote sensed data.

Sources of data

The spatial data layers used in the construction of the atlas of freshwater fish were incorporated from a variety of sources.

1. Database of southern African freshwater fish (Chapter 3)
2. Surface Water Database (ALCOM, water resource database)
3. Watershed coverage (ALCOM, water resource database)
4. River coverage (ALCOM, water resource database)
5. Administrative boundaries (FAO/SADC regional remote sensing project)
6. Topographical layers (FAO/SADC regional remote sensing project)
7. Climate surfaces (FAO/SADC regional remote sensing project)
8. Land use information (FAO/SADC regional remote sensing project)
9. Digital elevation model (Geodatec, Grahamstown). The digital elevation model (DEM) incorporated into the atlas was obtained subsequent to the development of the database of freshwater fish. The DEM from Geodatec was used in the atlas instead of the model from the FAO/SADC regional remote sensing project (used to map species distributions from the database of freshwater fish, Chapter 3) for two reasons. Some difficulty was experienced in importing the FAO/SADC layer into *TNTmips*, and the Geodatec layer, of the same resolution, covered the whole of Africa. This DEM would hence be of more value in the atlas of freshwater fish if the scope were ever broadened to include other African countries.

File naming convention

File names of data layers were kept in, or modified to, the format chosen by the regional remote sensing project (RRSP). Each name is defined as XX_YYYYZ.ext where XX is a country code, YYYY is the data type, and .ext is the file format extension (Anon. 1997). The country codes for the SADC nations are shown in Table 4.1., and the data type codes for each layer are listed in Table 4.2.

Table 4.1 Country codes for map files in the atlas of freshwater fish.

Code	Country/Region
AO	Angola
BW	Botswana
LS	Lesotho
MW	Malawi
MZ	Mozambique
NA	Namibia
ZA	South Africa
SZ	Swaziland
TZ	Tanzania
ZM	Zambia
ZW	Zimbabwe
DC	Entire SADC region

Table 4.2 Data type codes for map files in the atlas of freshwater fish.

Administrative file codes	ADM1	national borders
	ADM2	level 1 administrative boundaries (provinces)
	ADM3	level 2 (districts)
	URBN	urban areas as polygons
	FRDB	fish distribution points
Climatological data file codes	PET	normal evapo-transpiration surfaces
	PRE	normal precipitation surfaces
	TAV	normal average temperature surfaces
	TMN	normal minimum temperature surfaces
	TMX	normal maximum temperature surfaces
Hydrological feature codes	NPWAT	non-perennial water polygons
	PWAT	perennial water polygons
	LAKE	lakes (may be split into regions)
	RIV	rivers (may be split into regions)
	SWB	surface water bodies
	WS	watersheds
Land use codes	COVA	wetlands and other land cover areas
	PARK	national parks / nature reserves
	WETL	wetlands, classified by type
	WOOD	production forest, classified by type
Topographical file codes	ELEV	1000m contours
	ELSL	spot elevations
	DEM	digital elevation model
Transport file codes	ROAD	roads
	RAIL	railroads

Capture of data layers

Vector map layers from the RRSP and ALCOM were captured using the process / import-export vector function in *TNTmips*. The format of all vector data layers was ASCII atlas, or *.bna* file format, which is easily imported into the GIS (Table 4.3). The projection of all the map layers is standard geographic, or latitude-longitude.

Table 4.3 Structure of a *.bna* file, the raw data files describing the vector layers that were incorporated into the atlas.

.bna file structure	**(comma delimited)**		
854,"LIMPOPO",10	**KEY**		
29.28874,-21.7693	854	Field ID 1	Unique numerical identification
29.30887,-21.77314	"Limpopo"	Field ID 2	Unique text identification
29.35316,-21.78082	10	Field ID 3	Number of lines of identifying co-ordinates to follow
29.46589,-21.79619			
29.51018,-21.83077			
29.55044,-21.83846			
29.56655,-21.88072			
29.59473,-21.8884			
29.61084,-21.92298			
29.70344,-21.91529			

Appendix D lists the 218 map layers that have been captured into the atlas.

The digital elevation model is raster based and was obtained from Geodatec, Grahamstown, in *TNTmips* format. All the other raster layers were obtained from the RRSP and were converted into ERDAS images in *.lan* format, then imported into *TNTmips* using the process / import-export raster function.

The database of freshwater fish and the surface water database were imported into *TNTmips* using the process / import-export vector function. Both the databases were imported in *.dbf* format (DBASE IV files).

Editing and testing of data layers

The quality of the output of a GIS is directly related to the integrity of the graphic and non–graphic data entered into the system (Antenucci *et al.* 1991b), so all data must be verified (Anon. 1999b).

Each of the vector map layers was checked visually, with comparison of adjacent maps and with reference to projection co-ordinates. Twenty–eight of the data layers were corrupt, with nodes (end points of lines) joined incorrectly, and were edited manually using the Process / edit... function in *TNTmips* to remove errors. The corrupt layers were loaded into the Edit system and changed using some of the following options:

1. Add / select line
2. Add / select node
3. Add / select point
4. Delete line / node / point
5. Draw line / node / point
6. Copy / paste polygon

As an example, part of layer tz_adm1 was corrupt (Figure 4.1) and has been altered using the "load data for edit / select layer / select line / delete active line / save layer" process (Figure 4.2).

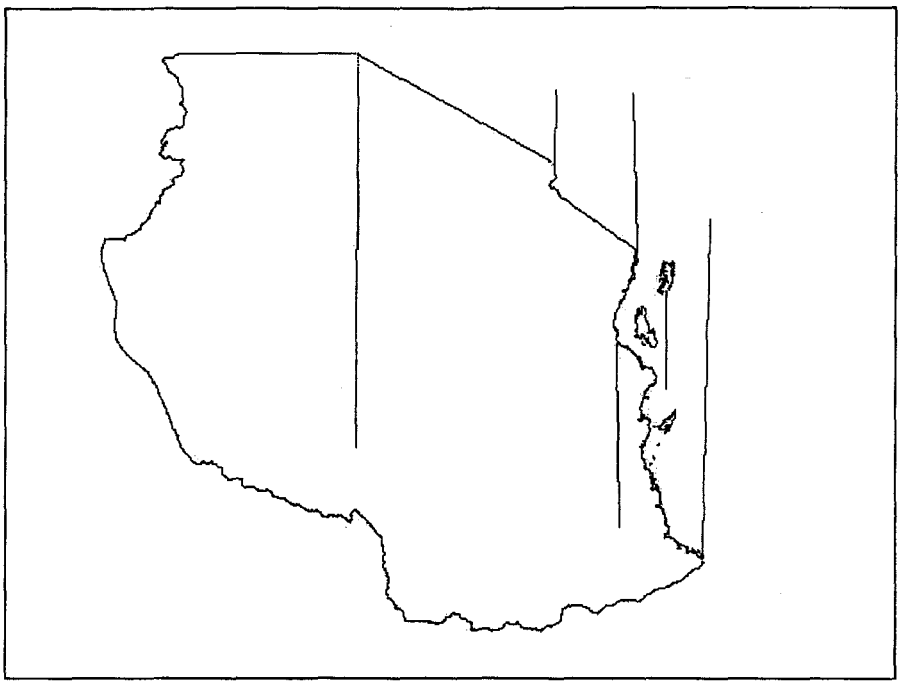


Figure 4.1 Corrupt map layer tz-adm1 (Tanzania, country borders) in the atlas of freshwater fish, before editing.

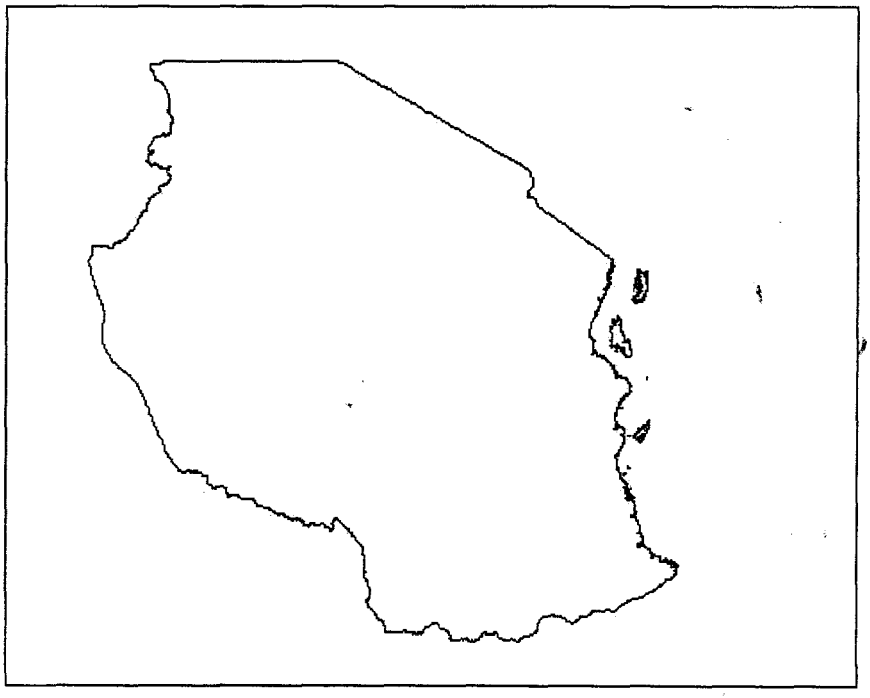


Figure 4.2 Corrupt map layer tz-adm1 (Tanzania, country borders) in the atlas of freshwater fish, after editing.

Map layers that were edited are listed in Table 4.4.

Table 4.4 List of map layers in the atlas of freshwater fish that were corrupt and have been edited in *TNTmips*.

Angola	ao_npwat
Botswana	bw_lake
Malawi	mw_pwat
	mw_lake
Mozambique	mz_lakec
	mz_lakee
	mz_lakew
	mz_pwat
Namibia	na_park
	na_riv
	na_road
Tanzania	tz_adm1
	tz_lakee
	tz_laken
	tz_lakes
	tz_lakew
	tz_rive
	tz_rivn
	tz_rivs
	tz_rivw
South Africa	za_lakee
	za_lakes
	za_lakew
	za_npwat
Zambia	zm_lakec
	zm_pwat
Zimbabwe	zw_lake
	zw_pwat

Each database was checked with reference to projection co-ordinates and associated geographical features (rivers and country borders). Although the errors in map layers were corrected, some of the vector layers (1000 m contour layers especially) were found to be somewhat incomplete. One layer, the normal potential evapo-transpiration surface for March, was missing from the source data files altogether.

These problems will be overcome when more map layers are available for incorporation into the atlas, allowing a greater choice of maps to incorporate into the atlas, and will facilitate the filling of gaps in the existing layers.

Each raster data layer was checked visually with reference to the corrected vector data layers, and with reference to projection co-ordinates. As previously mentioned, the raster images were converted from an ERDAS image format into a *TNTmips* format. Unfortunately, during the conversion process, a problem was identified with the cell values of each pixel in the raster images. Instead of the climate data value linked to each pixel in the ERDAS image being imported into *TNTmips* with the raster, a colour code value was automatically stored in each pixel. These colour codes are used in the creation of raster images on a grey or colour scale, to illustrate the changes in values across the surface with a colour key. The colour codes, however, have no use in the interpretation or analysis of a layer.

This problem was solved when a key table was found with conversion values from original climate data (temperature, rainfall values etc.) to a colour code. All the raster based climate surfaces were transformed automatically using a spatial manipulation language (SML, the programming language of *TNTmips*) programme designed specifically for this purpose by Mr Rob Harris (Geodatec, Grahamstown). The *TNTmips* function used to run the conversion programme was Interpret / SML / run....with the input raster specified as the corrupt map layer, and the output raster being a new, corrected map layer with accurate values.

Results

The GIS atlas of freshwater fish was developed with the objective of a dynamic, powerful system in mind. The atlas has been constructed to allow the import of additional information at any stage; as the database of freshwater fish grows, or as more map layers become available for incorporation. Although some degree of Geographic Information Systems operating expertise is needed to harness the analytical power of the atlas, it has been designed to be as user-friendly as possible.

Structure of the Atlas

The 218 GIS layers of the atlas of freshwater fish are stored in a single computer directory in a simple *TNTmips* file structure. The primary structure is of theme files; a file exists for every type of map layer (administrative boundaries, climate layers etc.) and within each theme file is a subfolder for each country. The file "administrative boundaries", for example, has twelve subfolders (Angola, Botswana etc.) each containing the map layers for the administrative boundary of the particular region.

A file named "groups" has been created to contain twenty-one project files for the rapid mapping of layers with a common theme or from a single region. A project file contains pointers to map layers with a specified theme, allowing the rapid mapping of a number of layers. This is purely a time-saving device, so that each layer does not have to be opened separately. Nine project files were created by theme and are listed in Table 4.5. The watershed layers were grouped with fish distribution points to provide a frame of reference for the points by drainage region. Project file P1, for example, contains directions for the mapping of all administrative boundary layers of all countries in the atlas Twelve project files were created by country / region (Table 4.6) to allow all the available data layers for each country to be accessed rapidly. Project file P10, for example, contains directions for the mapping all the map layers within Angola that are in the atlas of freshwater fish. The function used for group mapping is Display / 2D spatial data / open group.

Table 4.5 Project file numbers and contents (by theme) in the GIS file structure of the atlas of freshwater fish.

Project file number	**File contents**
P1	Administrative boundaries
P2	Urban areas
P3	Crops
P4	Miscellaneous land use layers
P5	Lakes, perennial & non-perennial water
P6	Rivers
P7	Transport
P8	Topography
P9	Watersheds and fish distribution points

Table 4.6 Project file numbers and contents (by region) in the GIS file structure of the atlas of freshwater fish.

Project file number	**Country/Region name**
P10	Angola
P11	Botswana
P12	Lesotho
P13	Malawi
P14	Mozambique
P15	Namibia
P16	Tanzania
P17	Swaziland
P18	South Africa
P19	Zambia
P20	Zimbabwe
P21	SADC region

A file named "Analysis" contains all new data layers created from existing data.

Each category of vector layer was given a unique and distinct appearance (Table 4.7) to increase the contrast of the layers during group display, and to facilitate the use of a key.

Table 4.7 Key to the colours of vector layers in the atlas of freshwater fish.

Vector layer	**Colour**
Administrative boundaries	black
Urban areas	yellow
Crops	pink
Miscellaneous	orange
Contour lines	grey
Lakes, perennial & non-perennial water	light blue
Rivers	dark blue
Surface water bodies	light green
Watersheds	dark green
Roads	red
Railway lines	purple
Fish distribution points	green

Display

Each map layer may be viewed singly or in any combination. An attribute table linked to every map element contains all the non-spatial data and additional information for that element. Appendix E contains a diagram of each of the map layers in the atlas.

Updating the atlas

One of the advantages of the atlas as a finished product is that it is not limited in size to the spatial data layers previously described. The dynamic nature of the atlas will allow it to expand and develop as more information becomes available. New data files would be loaded using the Prepare / import–export function with the appropriate file types and the georeferencing specified.

A new type of data not already in the atlas (eg. vegetation type) would be saved in a new theme file for vegetation, within subfolders for each particular country. If the coverage of the atlas were extended and maps of existing themes (eg. river layers) were added for new countries (eg. Kenya), a "new country" subfolder would merely be created in the theme file of interest in which to save the map layer.

Additional data for an existing file (new fish distribution points, for example) can be imported in the same way. The additional data file would be imported into the GIS and then opened in the Process / Edit.... function along with the existing file. The two files would then be merged to form a single data layer.

Discussion

The literature that is available suggests that no enterprise of this nature, a GIS atlas specifically for freshwater fish, has been undertaken before. An atlas of North American freshwater fishes was published in 1980, but was only distributed as a series of distribution maps in hardcopy (Lee *et al.* 1980). While an important work as far as comparative distributions of fish is concerned, the maps would have dated quickly, and would be of little use in spatial analysis of the nature that is possible with a digital atlas. In a similar way to the Atlas of South African Birds, the atlas of freshwater fish has extended the use of point distribution records by incorporating them into a dynamic, user friendly information system.

The atlas of freshwater fish has been designed with the resources available to be a reliable source of information at present, and to provide a framework for the integration of more data at a later stage. As with the database of freshwater fish, frequent updates of collection information and efficient quality control are essential to maintain the integrity of the atlas. As further fish collections are made available, and more fish are collected, distribution points will be added to the atlas. Besides the addition of further freshwater specimens, the atlas could be incorporated into a larger body of southern African data, with marine fish, for example, or other terrestrial taxa.

Additional data layers, such as comprehensive land use information and surfaces of other environmental variables, as well as complementary data for incomplete layers that are in the atlas at present, will be captured as they become available. The regional scope of the atlas also has potential for expansion, possibly throughout Africa. The size of the Geographic Information System is restricted only by the availability of information and the capacity of the computer processor. At the rate of present technological advances, the latter is not likely to be a limiting factor (Davis *et al.* 1991).

In the following chapters, the atlas will be discussed with respect to the objective quantitative analysis of regional patterns in fish distribution (Chapter 5), the investigation of the effect of environmental factors on species distribution (Chapter 6) as well as some applications in other fields of management and research (Chapter 7).

CHAPTER 5

THE APPLICATION OF THE ATLAS OF FRESHWATER FISH TO THE STUDY OF SPECIES DISTRIBUTION PATTERNS

Introduction

The atlas of southern African freshwater fish is important, both as a resource for species distribution information, and as a tool for biogeographic analysis, the study of biotic distribution in space. As mentioned in previous chapters, the atlas has been designed, produced and checked to ensure the highest possible data quality. A test of the application of the atlas with reference to previous studies is a measure of its integrity. The extent and reliability of the species point distribution data would be determined by this comparison with well-known species distribution patterns.

The distribution of freshwater fish in southern Africa is regulated by countless biotic and abiotic variables (Matthews & Robison 1988). The identification of distinct patterns or geographical arrangements of taxa must take place before the factors regulating these distributions can be investigated and freshwater faunas better understood (Hugueny & Lévêque 1994). Some previous studies of freshwater fish distributions in southern Africa have quantified local patterns of distribution using variations on an index of similarity (Skelton 1994, Hay *et al.* 1999).

In this chapter, an index of similarity was used to compare the degree of faunal similarity between all the major drainage basins in southern Africa. The purpose of this analysis is twofold. Firstly, to test the distribution points in the atlas by comparing results with previous studies that apply the same method to a different source of species distribution information. Secondly, to demonstrate the power of the atlas as a tool in biogeographic research by applying an existing method of faunal comparison on a regional scale to the entire SADC area.

The ichthyofaunal provinces of southern Africa have been described in detail, but a naive, objective analysis of their boundaries has not yet been carried out (Roberts 1975, Matthews 1998). A quantitative analysis of the similarities and differences in fish populations using the atlas would substantiate and possibly modify the geographical boundaries of faunal groups. Similarly, this analysis would have two objectives; to redefine the boundaries of ichthyofaunal regions using an objective method, and to test the integrity of the atlas as far as well-established faunal patterns are concerned.

Methods

All the point distribution records from the atlas of freshwater fish were used in the analysis of species distribution patterns. The objective was to obtain a comprehensive "snapshot" of species distribution patterns as they are recognised today, including introduced and translocated species. The Geographic Information System itself was not used to carry out these calculations as these specialised population analysis functions are more easily conducted using stastistics software. Integrated species population analyses (as discussed in this chapter) are well within the capacity of a GIS, but their development was considered to be beyond the scope of this thesis.

Index of similarity

An index of similarity was used to quantify the degree of similarity of the fish faunas between each of the 39 megabasins in the SADC region (As listed in Appendix C).
A measure of similarity (S.I.) (Skelton 1994, Krebs 1999) was calculated as:

$$\text{S.I.} = \frac{\text{number of species shared by both megabasins}}{\text{total number of species in both basins}}$$

Each of the megabasins was compared with every other to get an objective rating of the percentage similarity between them.

For comparative purposes, similarity indices for the Kunene/Okavango, the Okavango/Upper Zambezi, the Kafue/Upper Zambezi, the Buzi/Save, the Save/Limpopo, the Limpopo/Incomati, and the Limpopo/Orange megabasins were also calculated using freshwater dispersant species alone, to enable comparison of the results with a previous study (Skelton 1994). A Chi-square test was used to test the hypothesis that there were no differences between the similarity index results of this study and the results of Skelton's (1994) work.

A hierarchical tree plot was generated to link related megabasins in an ordered manner that would allow the identification of groups or branches of basins that have a similar freshwater faunal composition at species level. An unweighted pair groups method using arithmetic averages (UPGMA) was employed (Gauch 1982). Only the megabasins with n>5 species samples were used in this analysis to reduce some of the bias associated with poorly sampled regions.

Ichthyofaunal provinces

A 2-means cluster analysis of 36 megabasins was conducted to determine whether the species distributions in the atlas supported the southern African ichthyofaunal provinces of Roberts (1975). Five ichthyofaunal provinces have been identified in the SADC region; the Quanza, the Zambezi, the East Coast, the Cape and the Zaire (Roberts 1975). Point distributions in the atlas of freshwater fish fall mainly into regions that Roberts has assigned to his Cape and Zambezi ichthyofaunal regions. The Balombo megabasin is the only one containing fish distribution points that would fall into Roberts' Quanza province. The Zaire megabasin is the only one containing fish points that would fall into Roberts' Zaire province, and the Ruvuma is the only megabasin with point distribution records from the atlas that would fall into the East Coast province.

Since the greatest majority of megabasins in the atlas that contain point distribution records fall into the two geographical regions that Roberts named the Cape and Zambezi ichthyofaunal provinces, a 2-means cluster analysis was chosen to test the position of the dividing line that was Roberts assigned to divide them, using the atlas of freshwater fish. Thirty-six megabasins (Balombo, Zaire and Ruvuma excluded in this analysis alone) were used in the 2-means cluster analysis, which was carried out at family level due to the exceptionally large amount of data used in the calculation. The analysis of taxa at family level is an acceptable substitute for species analysis in some cases involving large-scale distribution patterns (Matthews 1998).

Results

Figure 5.1 illustrates the results for the index of similarity within a single megabasin, that of the Pungwe in central Mozambique. The freshwater fish community in the Pungwe was found to share the highest similarity with the Buzi (S.I. = 0.478), closely followed by the Save (S.I. = 0.410) and the Middle Zambezi (S.I. = 0.349). These four megabasins are in close geographic proximity and all have a large proportion of sub-tropical freshwater species.

The five megabasins that had the next highest similarity values with the Pungwe are the Incomati, Black Umbuluzi, Upper Zambezi, Maputo and the Limpopo. Despite their relative geographical isolation, they still share a number of common species with the Pungwe. Figure 5.1 indicates that these five megabasins all had between a 0.268 and 0.221 S.I. with the Pungwe. Some species which were shared between all six basins were *Barbus trimaculatus*, *Barbus viviparus* and *Labeo cylindricus*. Between these very similar faunas, the differing species richness values in the basins (36 species –123 species) had some effect on the similarity index values.

The megabasins that had the lowest similarity values with the Pungwe were to the far south, due to the larger proportion of temperate freshwater fish families in those waters. Of the ten megabasins that had a less than 0.020 S.I. value with the Pungwe, all of them shared only one species with the Pungwe. In nine of those cases the species was *Oreochromis mossambicus*. The Gamtoos was the exception, the shared species being *Anguilla bengalensis labiata*.

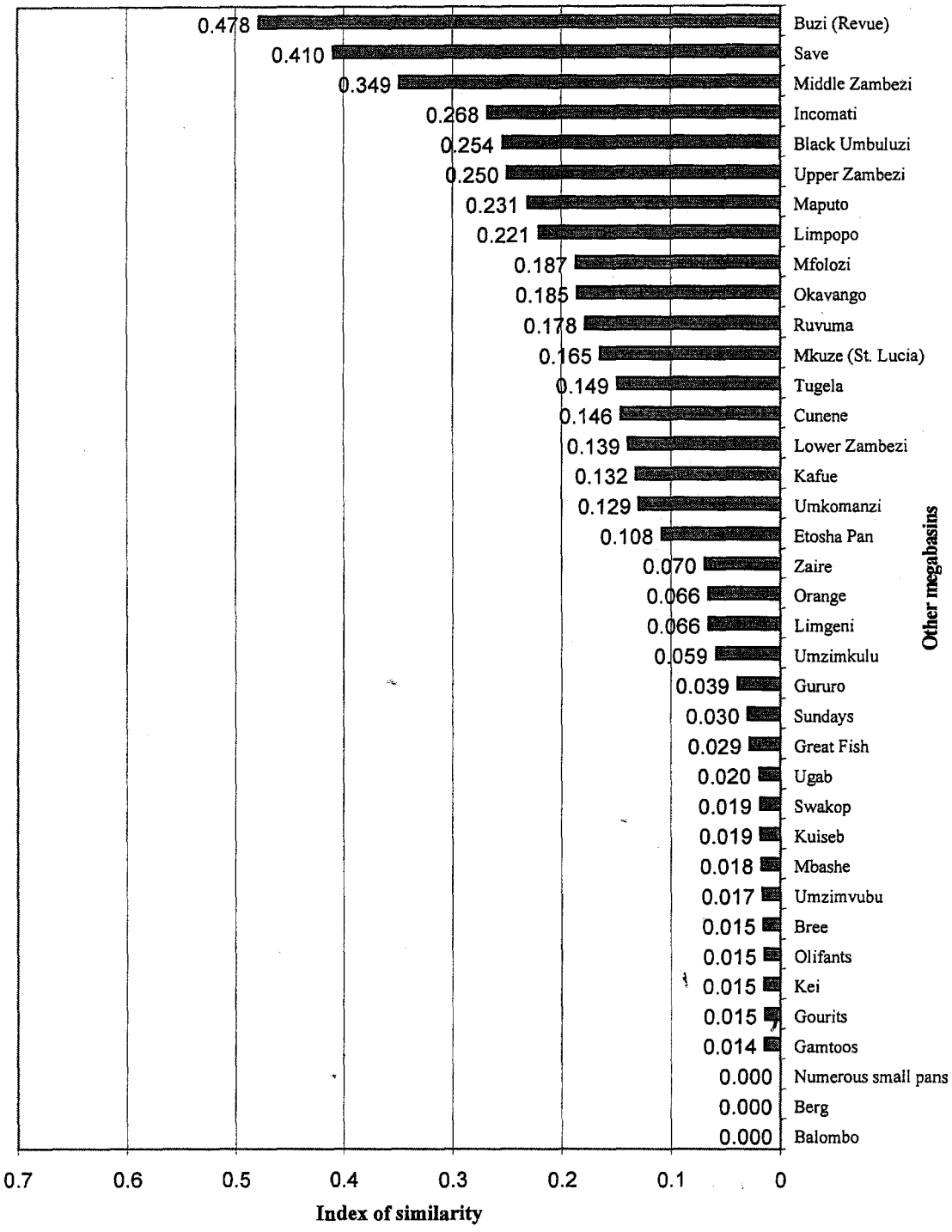


Figure 5.1 Index of similarity (S.I.) of the freshwater fish fauna of the Pungwe megabasin as compared to all the other megabasins in the SADC region, where S.I. = the number of species found in both megabasins / total number of species.

The similarity of the species composition of adjacent or proximal megabasins in the western SADC region is illustrated in Figure 5.2. The values varied greatly, from 0.029 to 0.351. The values incorporating data from the Ugab and Balombo basins were biased by the low sampling effort (two specimens were collected from each of these two basins, the fewest number for any region). The fact that this was not a representative sample must be taken into consideration when comparing the percentage similarity results. The higher similarity between the Cunene and Etosha than between the Swakop and Kuiseb may be due to the larger size of the drainage area, and the greater length of the common watershed divide. Higher species richness values are known to correlate with a positive increase in basin size, due to the greater diversity of aquatic habitats available for colonisation by fish (Hugueny & Lévêque 1994).

Figure 5.3 illustrates the similarity of the species composition of adjacent, or proximal megabasins in the eastern SADC region. The similarity of adjacent faunas from the Pungwe down to the Mkuzi basin (Lake St. Lucia) was relatively high, above 0.4. The similarity between the Mkuzi and the Tugela was, however, only 0.292. This may be due to the higher component of temperate species in the Tugela system (below the subtraction zone of tropical fish species) than in other more northerly basins (Skelton 1994). The Pungwe / Lower Zambezi and the Ruvuma / Lower Zambezi both had relatively low similarity values.

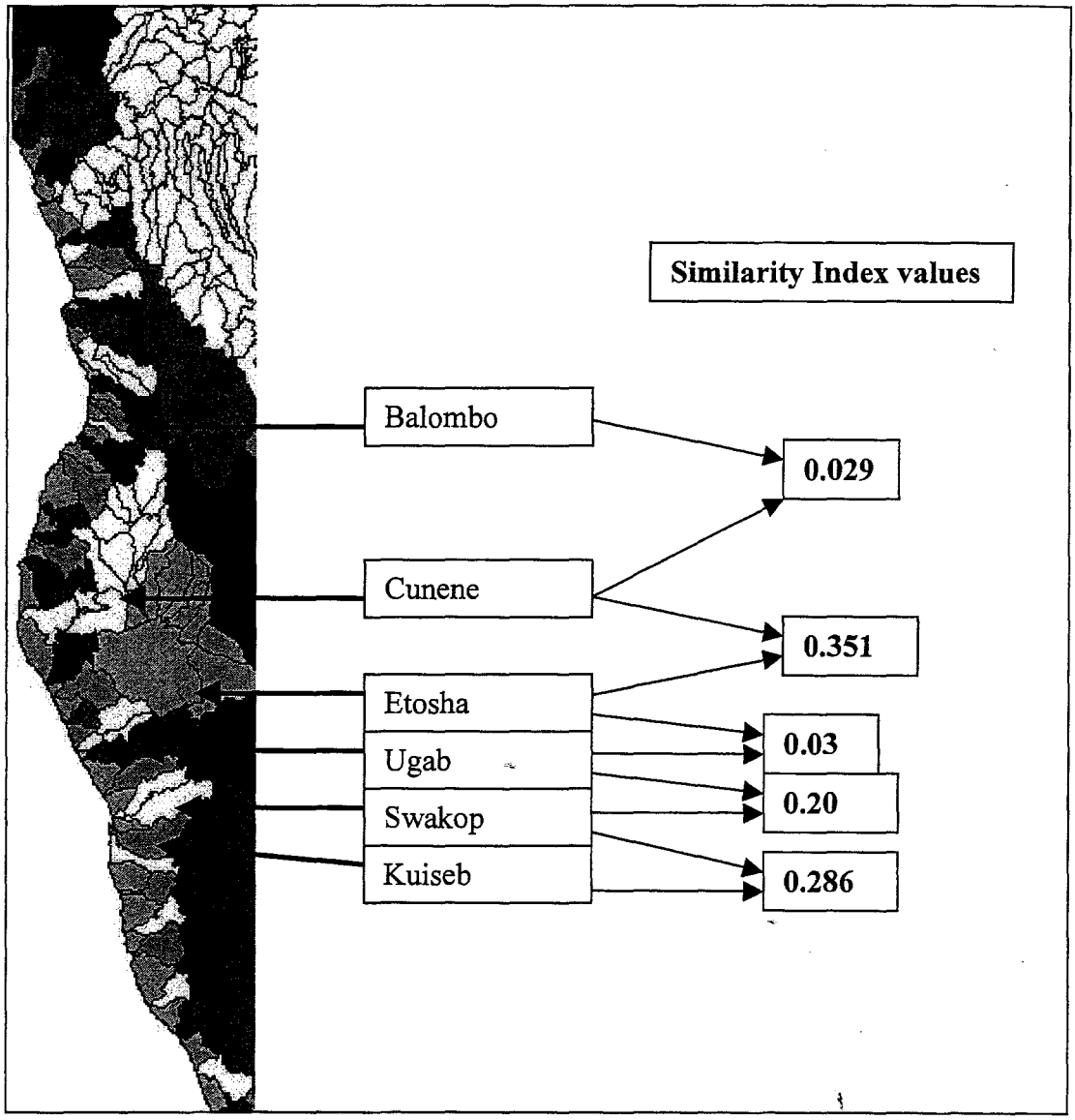


Figure 5.2 Relative positions of megabasins in the western SADC region with percentage similarity index values given for freshwater fish faunas (S.I. = number species shared / total number of species in both megabasins).

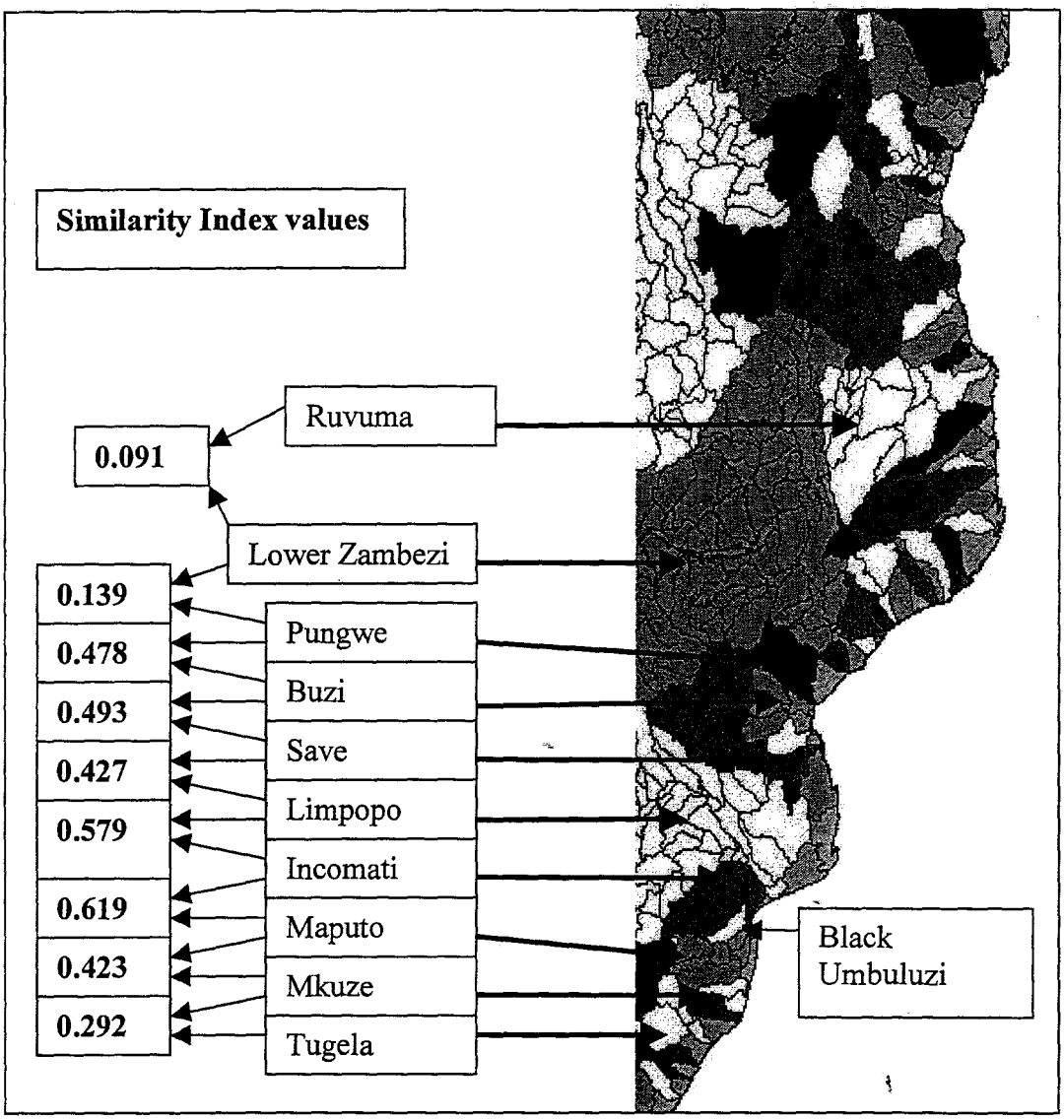


Figure 5.3 Relative positions of megabasins in the eastern SADC region with percentage similarity index values given for freshwater fish faunas (S.I. = number species shared / total number of species in both megabasins).

Figure 5.4 illustrates the similarity of the species composition of adjacent, or proximal megabasins in the southern SADC region. The lowest similarity value is between the Okavango and the Orange systems. The faunal similarity values are higher for all the more southerly megabasins. Introduced species are largely responsible, the Olifants and Berg systems, for example, share six species, three of which are introduced.

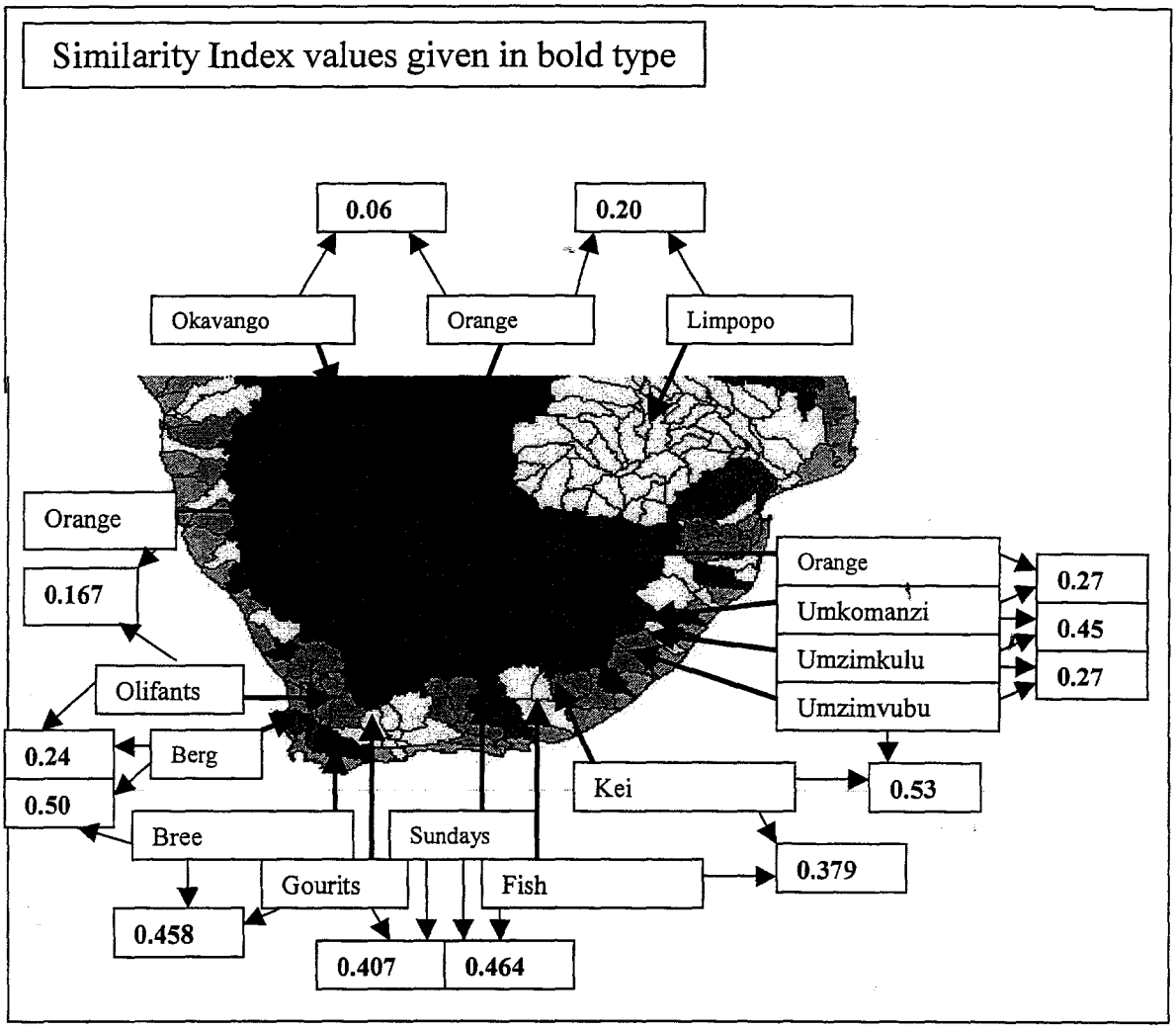


Figure 5.4 Relative positions of megabasins in the southern SADC region with similarity index values given for freshwater fish faunas (S.I. = number species shared / total number of species in both megabasins).

The Olifants system is characterised by a large number of endemic species that may explain its low similarity values with other megabasins. The disparate areas and dissimilar species richness counts of the Orange and Olifants systems may explain why such a low similarity index value was given for their faunas. As an example, the Orange and Olifants, with very different species richness values, were found to share seven species and had a S.I of 0.167 whereas the Olifants and Berg, with more similar species richness values, only shared six species but had a higher S.I. of 0.24.

Similarity index values for freshwater dispersant species alone were compared with some results from a previous study (Skelton 1994) which was based on some collection specimen data and published species distributions. Table 5.1 lists the similarity index results for freshwater dispersant species. The chi-squared test for the two data sets showed that there was no statistical difference between them ($P = 0.99$, $df = 6$, $\chi^2 = 6.71$). The differences in actual values were attributed to the larger base of freshwater fish distribution data available in the atlas that was used in the calculations. Without exception, the list of species for each region was longer in the atlas than was given by Skelton (1994), so a measure of variation in the similarity values was inevitable.

Table 5.1 Similarity indices (S.I.) for freshwater dispersant fish faunas calculated with the atlas of freshwater fish and compared to a previous study, where S.I. = number of species shared by both megabasins / total number species in both megabasins.

Megabasins compared	**Similarity index**	**Result of previous study (Skelton 1994)**
Cunene / Okavango	0.51	0.55
Okavango / Upper Zambezi	0.68	0.80
Upper Zambezi / Kafue	0.41	0.64
Buzi / Save	0.49	0.54
Limpopo / Save	0.43	0.48
Limpopo / Incomati	0.59	0.71
Limpopo / Orange	0.21	0.13

The result of the hierarchical tree analysis is illustrated in Figure 5.5. The closest linkages between megabasins were evident between six groups of megabasins. The Berg/ Breë had a linkage distance of 3 with a similarity index of 0.5 (half of the fish species present in both basins were shared). The shared species included *Sandelia capensis*, and *Barbus andrewi*, and some introduced species such as *Micropterus salmoides, Tilapia sparrmanii* and *Cyprinus carpio,* that were largely responsible for the high degree of similarity. Literature concerned with indigenous species alone has suggested a high degree of faunal separation between these systems (Barnard 1943), so the incorporation of introduced species into the index calculation had a marked effect.

The Olifants basin was the next closest to the Berg/ Breë, with a number of shared fauna, but the Olifants has a high proportion of endemic species (such as *Barbus erubescens* and *Barbus serra*). The Gourits / Gamtoos / Sundays had a linkage distance of <4 and also shared a good proportion of species, both indigenous (such as *Barbus anoplus* and *Labeo umbratus*) and introduced (such as *Cyprinus carpio*). The Umzimvubu/Kei/Mbashe, the Umzimkulu / Umkomanzi / Limgeni / Tugela and the Buzi / Pungwe / Save groups all had linkage distances less than 6.5. The drainage areas within these clusters are large and geographically proximate. The Limpopo/Maputo/Incomati systems had a close linkage that may possibly be explained by historical drainage linkages and several "relict" species that are limited to these waters today. Some examples of common species are *Mesobola brevianalis, Barbus mattozi* and *Ctenopoma multispine* (Gaigher & McPott 1973, Skelton 1994).

The hierarchial tree cluster analysis placed the Zaire and the Zambezi systems as both relatively distinct from other faunal groups as far as linkage distance is concerned. They are both characterised by extensive drainage surface areas and high species richness counts, which is again likely to account for some of the linkage distance. The Zambezi had the highest species richness at n = 375, and the Zaire had the second highest, at n = 275. The Zambezi megabasin in particular is often reduced to a number of smaller sub-drainage areas for the purposes of species analysis, but in this case it was investigated as a single drainage system as there are freshwater links between the Kafue/Upper/ Middle and Lower divisions.

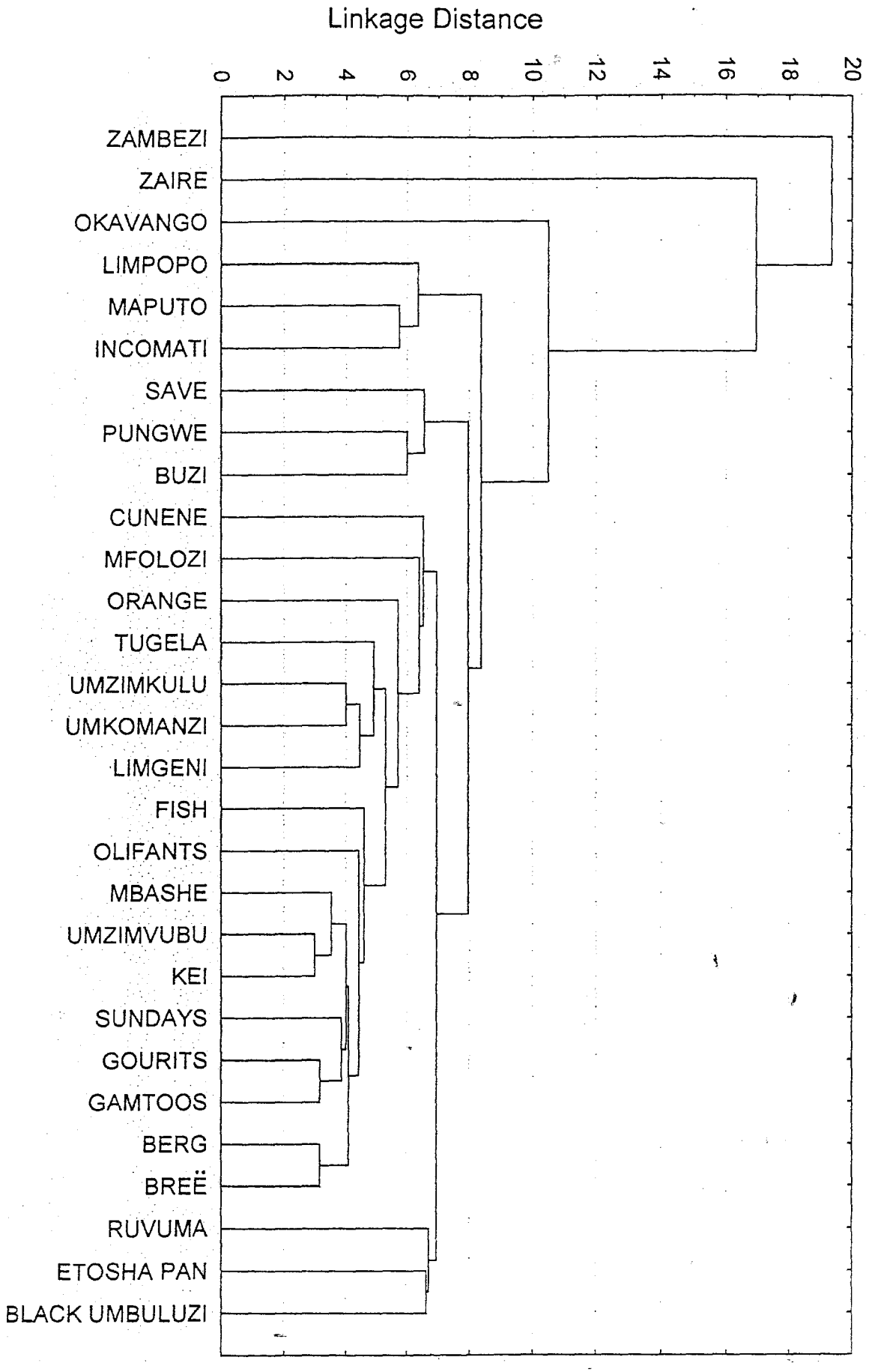


Figure 5.5 Hierarchial tree cluster analysis (unweighted pair-group average; Euclidean distances) of megabasins in the SADC region with respect to their freshwater faunal composition.

The clustering of the Ruvuma, Etosha Pan and Black Umbuluzi appeared to be an unusual group in the hierarchial tree diagram as they are geographically thousands of kilometres apart (Figure 5.5). The linkage distance, however, was noted to be the highest of any of the first nodes for linkage groups, at approximately 6.4. These three basins could therefore be seen rather as relatively dissimilar to any of the other basins as well as to each other, but clustered "together" to fit in with the pattern of the tree diagram.

The results for the megabasin similarity index (S.I.) were consulted to attempt to explain this anomaly. The Ruvuma megabasin had the highest S.I. with the Buzi megabasin (S.I. = 0.371), but the Buzi had far higher S.I. values with the Save (S.I. = 0.493) and Pungwe (S.I. = 0.478), hence the exclusion of the Ruvuma from that cluster. The Black Umbuluzi had the highest S.I. value with the Maputo system (S.I. = 0.426), closely followed by the Incomati and Limpopo systems, but the Maputo was far more similar to the Incomati (S.I. = 0.619) and the Limpopo (S.I. = 0.573), hence the exclusion of the Black Umbuluzi from that group. The Etosha Pan megabasin had by far the highest similarity with the Cunene (S.I. = 0.351), but the Cunene shared a higher similarity with the Okavango (S.I. = 0.486).

The assignment of megabasins to one of two groups in the 2 – means cluster analysis (Table 5.2) resulted in the division of the southern African fauna into two groups (Figure 5.6). The clusters derived objectively from presence- absence of families in megabasins were found to match the subjectively defined ichthyological regions of Roberts. The freshwater fish fauna of Roberts' Zambezi ichthyofaunal province comprises over 160 species, most of which are found in the Zambezi drainage system itself. The fauna is dominated by cyprinids and to a lesser degree by siluroid catfish (Skelton 1994). The Cape ichthyofaunal province coincides with the entire Orange-Vaal drainage system, as well as systems to the south and east (Roberts 1975). This province is characterised by less than 40 indigenous species, most of which are barbine cyprinids (Skelton 1994). It must be noted that the hierarchial tree diagram result does not correspond with the 2-means cluster result as the former was an analysis at species level while the latter was at family level and had a cluster number (n = 2) specified *a priori*.

Table 5.2 Results of the 2-means cluster analysis of 36 megabasins according to the family richness and composition of their freshwater faunas.

Number	Megabasin name	Cluster allocation (result)
1	Berg	Group 1
2	Black Umbuluzi	Group 2
3	Breë	Group 1
4	Buzi	Group 2
5	Etosha Pan	Group 2
6	Cunene	Group 1
7	Gamtoos	Group 1
8	Gourits	Group 1
9	Great Fish	Group 1
10	Gururo	Group 2
11	Incomati	Group 2
12	Kafue	Group 1
13	Kei	Group 1
14	Kuiseb	Group 2
15	Limpopo	Group 1
16	Lower Zambezi	Group 2
17	Maputo	Group 2
18	Mbashe	Group 2
19	Mfolozi	Group 1
20	Middle Zambezi	Group 2
21	Mkuze	Group 2
22	Numerous small pans	Group 2
23	Okavango	Group 1
24	Olifants	Group 2
25	Orange	Group 1
26	Pungwe	Group 1
27	Save	Group 2
28	Sundays	Group 2
29	Swakop	Group 1
30	Tugela	Group 1
31	Ugab	Group 1
32	Umgeni	Group 1
33	Umkomanzi	Group 1
34	Umzimkulu	Group 1
35	Umzimvubu	Group 1
36	Upper Zambezi	Group 2

The position of the division between the groups of megabasins is exactly the same as Roberts' division between the Zambezi and Cape ichthyofaunal provinces. Without exception, all the river systems that fell into group 1 in this analysis were assigned to the Cape ichthyofaunal province subjectively by Roberts (1975), and all those that fell into group 2 were placed into the Zambezi ichthyofaunal province. Despite the larger base of data and advanced methods that are available for the analysis of fish distributions through the atlas, Roberts' ichthyofaunal provinces are still conclusively supported by the distribution of freshwater fish as we know it today.

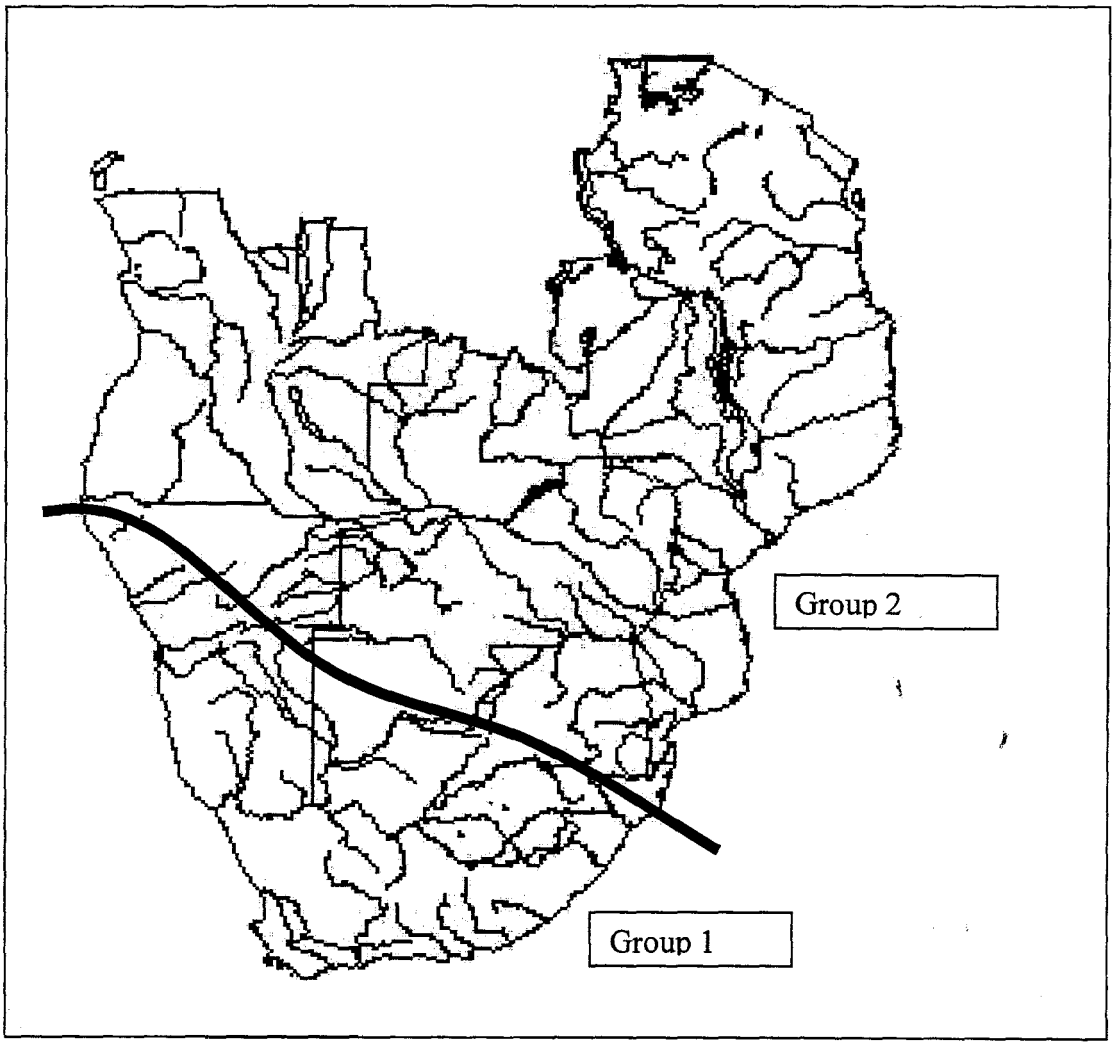


Figure 5.6 Diagrammatic illustration of the continental dividing line between cluster 1 and cluster 2, as given by the results of a 2-means cluster analysis at family level listed in Table 6.2. All the megabasins south of this line fell into Group 1 and those north of this line fell into Group 2.

Discussion

The atlas has been demonstrated as an efficient descriptive tool for the identification and comparison of fish distribution patterns. Similarity indices have been calculated for all the megabasins of the SADC region with respect to each other, and a hierarchical tree clustering analysis has been used to sort the megabasins into clusters to identify groups of greatest freshwater fish faunal similarity. The quality and integrity of the distribution data in the atlas of southern African freshwater fish has been conclusively verified with regard to previous work. The results for megabasin similarity values using the atlas of freshwater fish are the same as those in previous studies based on other freshwater fish data sets and literature accounts (Skelton 1994). The objective clustering of megabasins into two provinces also follows previous ichthyofaunal region analyses (Roberts 1975). This method could, in fact be used throughout Africa, should the data allow, to redefine the boundaries of ichthyofaunal regions throughout the continent.

The biogeographic region analyses that were used to test the atlas of freshwater fish reflect the total faunal assemblages of drainage areas as they are known at present, and some results, for that reason, do not reflect the results of previous basin comparisons using indigenous species alone. This chapter was designed to test the power of the atlas as a tool in biogeographic research, and not to provide answers to complicated long standing biogeographical problems. More specific biogeographic work would make use of subsets of the total species complement of the atlas. Studies of historical drainage patterns using present day freshwater fish distributions, for example, would only make use of indigenous freshwater dispersant species.

Faunal provinces and regions that share low similarity values are, in effect, areas of endemicity (Greenwood 1983, Hugueny & Lévêque 1994, Matthews 1998). Regions with a high proportion of endemic species, the Olifants system for example, share a lower number of species with other regions by definition. The study of fish faunas at a catchment level is an excellent means to identify hotspots of richness and endemism, and to assess the health of fish populations (Minns 1987).

The use of grid based scales for the study of endemism and richness may be simpler to set up as equal areas are used to quantify species numbers. The implementation of management policies at a drainage or catchment level is more practical, however, as grid squares or pixels often encompass more than one aquatic system (Lombard 1995b). Ichthyofaunal provinces or drainage regions with high freshwater fish faunal similarities may be used in the allocation of ecoregions, or ecologically distinct biotopes (Werger 1978, Whittier *et al.* 1988). The Worldwide Fund for Nature, for example, has used freshwater fish species along with other aquatic organisms in conjunction with abiotic variables, in defining ecoregions for the entire African continent (Anon. 1999a).

The distribution of collection effort and the bias of some sampling methods must be taken into consideration when interpreting distribution information (Burgman *et al.* 1995). The atlas has incorporated all the freshwater fish distribution information available to date that is comprehensive for most drainage regions in the south and south-eastern SADC area. With a greater number of collection specimens incorporated, the sampling bias will be reduced even further. Species distribution studies must also take into consideration the taxonomic uncertainty within some groups of freshwater fish, such as the Cichlidae in Lake Malawi (Greenwood 1983, Lévêque 1997).

Once patterns of distribution of freshwater fish have been identified, an interpretation of distribution patterns is necessary to better understand the ecological processes affecting populations as well as to enable the efficient conservation of threatened habitats and rare species (Skelton 1987). The atlas of southern African freshwater fish is discussed in Chapter 7 with reference to its use as a tool in the investigation of the influence that some environmental factors have on the distribution of freshwater fish.

CHAPTER 6

THE USE OF THE ATLAS OF SOUTHERN AFRICAN FRESHWATER FISH AS A TOOL IN THE STUDY OF FACTORS INFLUENCING SPECIES DISTRIBUTION

Introduction

Freshwater fish species exhibit their present day distributions for many reasons. Climatic, geological, physico-chemical and biotic interactions over time and space all have an effect on the structure of aquatic ecosystems as they exist today (Brain & Meester 1964, Brown 1984, Hugueny & Lévêque 1994, Miller 1994a, Whittier *et al.* 1988).

Freshwater fish, in particular, depend entirely on direct links between aquatic habitats in order to facilitate their dispersal (Boulenger 1905). Climatic conditions and biotic interactions further regulate distribution patterns, as they limit the potential distribution of a species by determining whether a particular habitat is suitable for the species' survival and propagation. In many instances, aquatic species are not present in certain areas that meet their ecological requirements because they have never had the opportunity to invade these systems (De Moor 1993). A southern African example is Lake Malawi where many of the Lower Zambezian fish species have been unable to colonise the lake because of the presence of the Kapachira falls on the Shire River (Tweddle *et al.* 1979).

At present, very little quantitative information is available on the relative importance of climatic factors on species distributions in southern Africa. Effective temperature, which takes mean annual temperature and the mean temperature range into consideration, provides a measure of the influence of temperature on species distribution (Stuckenberg 1969, Bowmaker *et al.* 1978). The 16°C effective temperature isotherm, in particular, has been used to describe the division between the tropical Zambezian and southern, more temperate, freshwater fish fauna (Skelton 1994).

In order to investigate biogeographic processes, various modelling approaches have been applied. Biogeographic modelling involves the analysis of spatial information to determine species distribution patterns and to produce maps or models of distributions that can be used for descriptive or predictive purposes (De Moor 1993). Computer integration and analysis of data is the most powerful function of any Geographic Information System, and is what distinguishes a GIS from mapping packages (Brooks 1985), making a GIS the most suitable platform to use in this context. Functions such as mathematical overlaying (the integration of two map layers), measurement (point counts or area measurements) and comparison of data have all been employed in the analysis of freshwater fish species richness.

The atlas of freshwater fish has been developed as a fully functional analytical system for use as a tool in the process of quantifying the effect various factors have on freshwater fish distributions. As this is a preliminary study, a gradient analysis approach was employed. Gradient analysis is the study of the way gradients of species, population and community characteristics change in response to environmental gradients. A number of ecological gradients such as latitude (a measure of temperature and seasonality), elevation (a measure of temperature), and aridity have previously been correlated with species richness (Brown 1984). Regions of southern Africa susceptible to invasion by alien aquatic animals have also been identified using gradients of elevation and median annual rainfall (De Moor 1993).

Methods

A gradient analysis of some factors influencing the distribution of freshwater fish in the SADC region was carried out by correlating species richness to three co-variates (megabasin area, minimum temperature and average precipitation). Minimum temperature and average precipitation were chosen due to the accessibility of comprehensive, reliable digital data sets of these variables as well as previous work that has suggested their influence on the richness of freshwater fish communities. A positive relationship has been established between the species richness of freshwater fishes and drainage basin size (Hugueny & Lévêque 1994). Megabasin area was therefore included to incorporate size variation into the analysis. The objective of this experiment is to determine whether significant correlations exist between the number of species in a megabasin and megabasin area, minimum temperature or average precipitation, and hence to demonstrate the effectiveness of the atlas as a fully functional tool in biogeographic research.

A species list was generated for each megabasin using *TNTmips*. The display / spatial data window was activated, the vector layer of megabasin boundaries and the vector layer of species distribution points were both activated. A species list was then generated for each megabasin from the attribute table of information linked to each species point within the relevant megabasin polygon. A species richness value was obtained for each megabasin from the species lists.

Minimum temperature values for each polygon were generated using *TNTmips*. Two GIS layers were used in this exercise, the vector layer of megabasin boundaries and a raster layer of minimum temperatures for July for the entire SADC region. An average July minimum temperature value was needed for every polygon. The *TNTmips process / vector / attributes / raster properties* function was used to extract these values into a new attribute table. The July minimum temperature layer was used as the input variable, and the megabasin boundary layer was used as the reference layer.

Average precipitation values for each polygon were generated using *TNTmips*. Two GIS layers were used in this exercise, the vector layer of megabasin boundaries and a raster layer of mean precipitation values for the entire SADC region. A single relative mean precipitation value was needed for every polygon. The *TNTmips process / vector / attributes / raster properties* function was used to extract these values into a new attribute table. The mean precipitation layer was used as the input variable, and the megabasin boundary layer was used as the reference layer. The output value for mean precipitation for each polygon was the average of the precipitation values for each grid-square or pixel in the raster layer. The output value is therefore independent of basin size, it is a relative measure of the amount of precipitation per unit area for each megabasin.

The megabasin areas were taken from an attribute table linked to the megabasin vector layer that contain property values of every element in the layer (the elements in the layer were all polygons, so the properties of the polygons corresponded to the megabasin properties).

The four variables for every megabasin (species richness, megabasin area, minimum temperature and average precipitation) were then extracted into *SPLUS* (© Mathsoft) for predictive stepwise multiple linear regression analysis. To ensure that the parametric assumptions of the model were not violated, the species richness and megabasin area values were log-transformed (Figure 6.1). The temperature and precipitation data sets were normally distributed without requiring log transformation. Two regression approaches were used to correlate richness with one or more physical co-variates. Predictive mean regressions were used for each of the co-variates as well as a multiple linear regression. $\varepsilon \sim N(\mu, \sigma^2)$

$$\text{Ln(Richness)} = \ln(\text{Area}) + \text{Temp} + \text{Precip} + \text{interactions (Area, Temp, Precip)} + \varepsilon$$

Where Richness is the number of species in a megabasin, Area is the surface area of each megabasin, Temp. is the mean minimum temperature in a basin, Precip. is the Mean precipitation per unit area of each megabasin, and ε is the residual error.

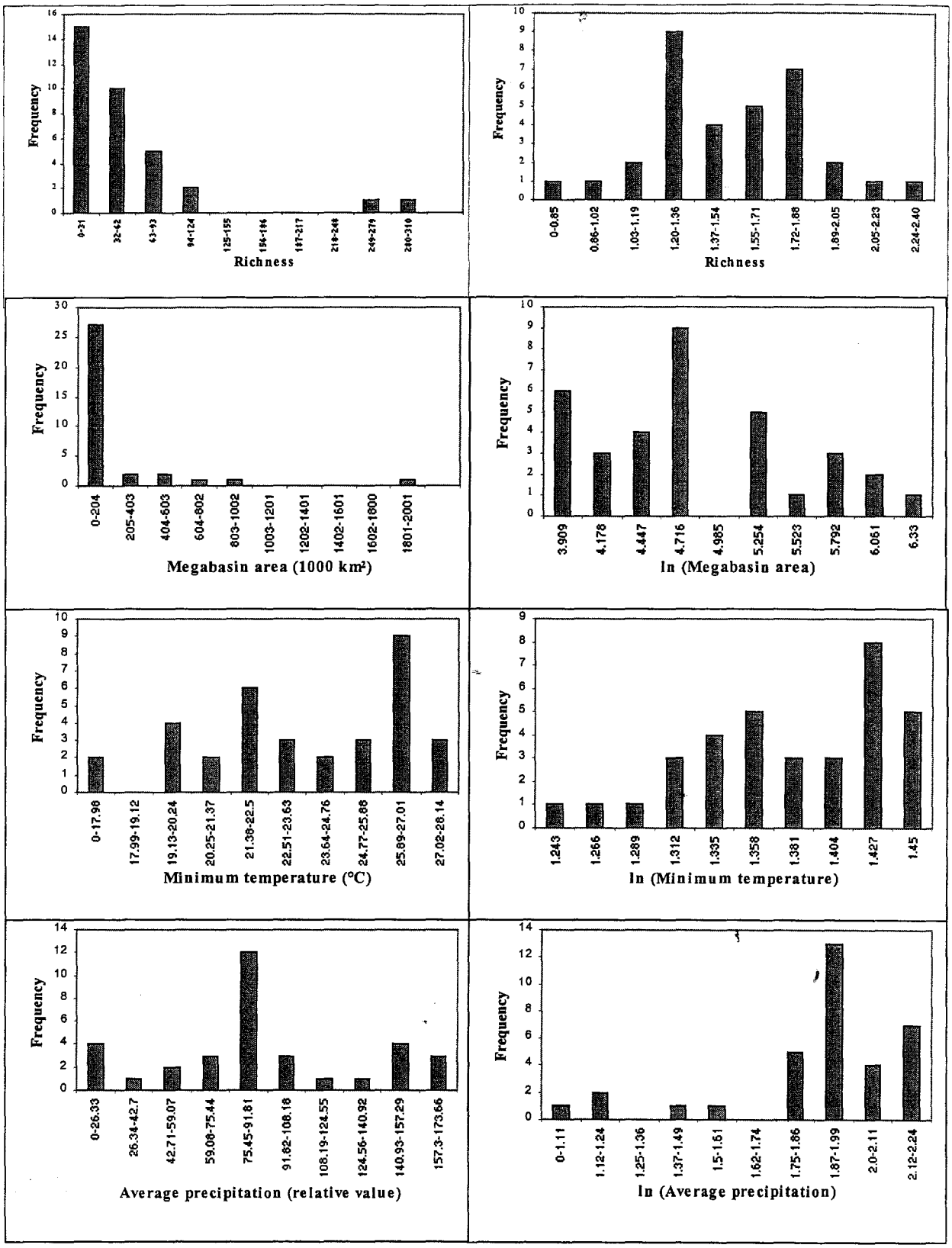


Figure 6.1 Frequency distribution of species richness, temperature, precipitation and megabasin area. The left-hand panels illustrate the data in its raw format, whilst the right-hand panels are natural logarithmic transformations. Only the species richness and megabasin area data were log-transformed in the analysis.

Results

All individual covariates (minimum temperature, mean precipitation and megabasin area) were found to have a significant effect on species richness. Investigation of the residuals using a quartile plot illustrated normality.

The co-efficient of determination, a measure of the variability of the response variable explained by the predictor variable, ranged from 15% in the case of minimum temperature to 45% for basin size. All correlations were positive, indicating that species richness increases with increasing minimum temperature, mean precipitation and megabasin area (Figures 6.2–6.5). The strongest correlation was noticed using the stepwise multiple regression model. All covariates, except their interactions, were found to be significant, explaining 68% of the model variation (Table 6.1).

Table 6.1 Results of three mean linear regression analyses and one multiple linear regression analysis between species richness and three covariates (minimum temperature, mean precipitation and drainage basin area).

Relationship	**R^2**	**F**	**df**	**P-value**
Richness, minimum temperature	0.15	5.664	1, 32	0.023
Richness, mean precipitation	0.40	21.79	1, 32	<0.001
Richness, megabasin area	0.45	27.06	1, 32	<0.001
Richness, minimum temperature + mean precipitation + megabasin area	0.68	21.72	3, 30	<0.001

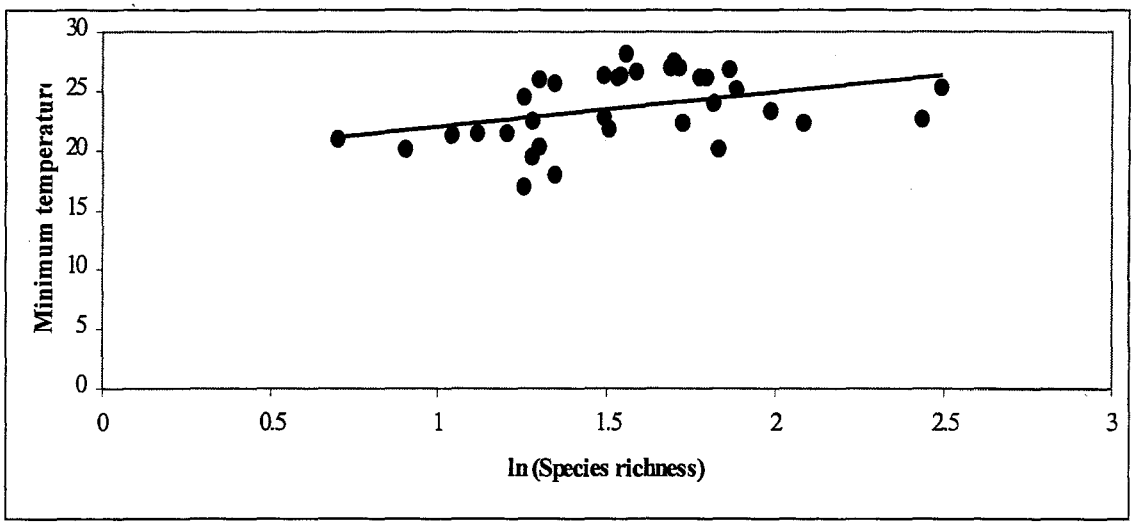


Figure 6.2 Linear regression of species richness counts for each megabasin in the SADC region against the minimum temperature in each megabasin.

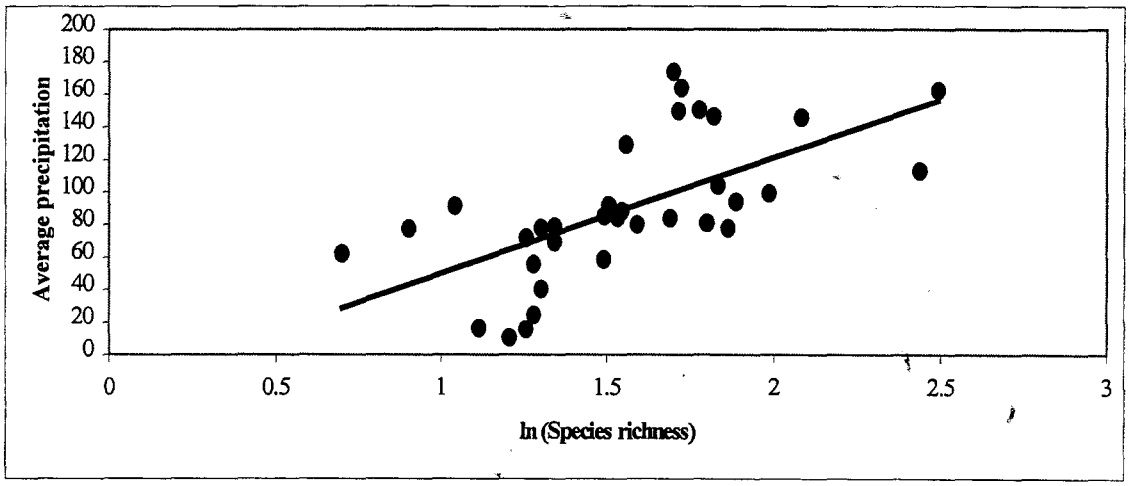


Figure 6.3 Linear regression of species richness counts for each megabasin in the SADC region against the average precipitation in each megabasin.

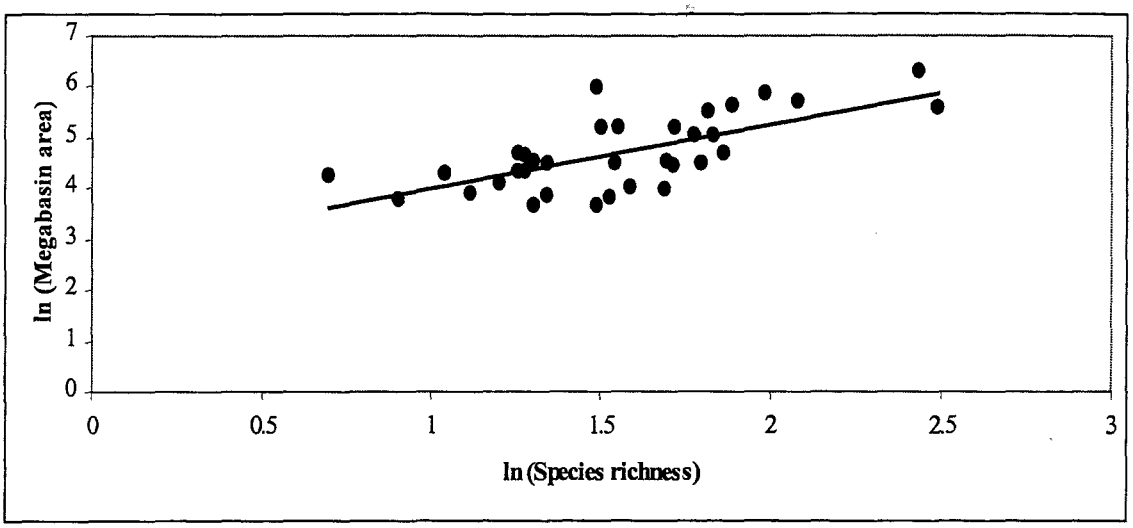


Figure 6.4 Linear regression of species richness counts for each megabasin in the SADC region against the area of each megabasin.

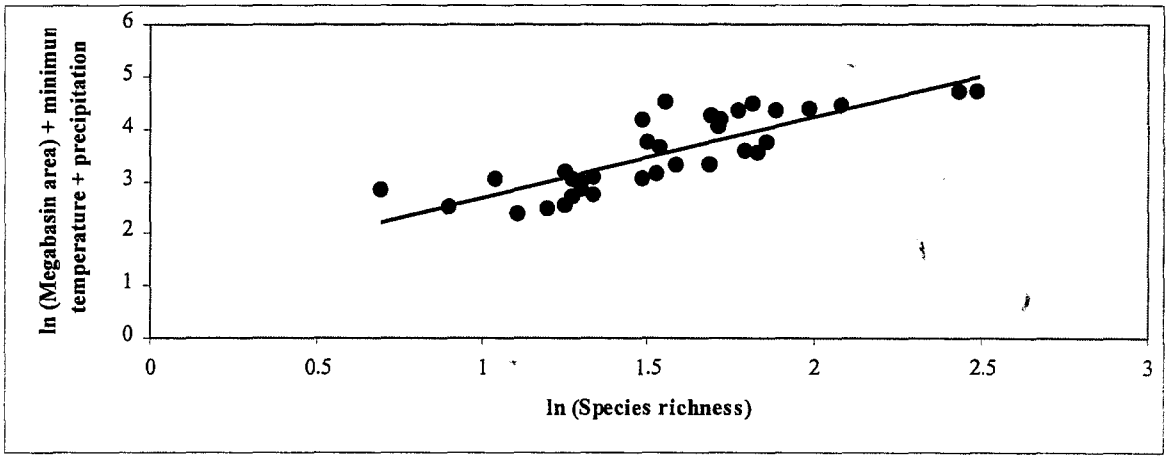


Figure 6.5 Linear regression of species richness counts for each megabasin in the SADC region against all covariates together (minimum temperature, average precipitation and basin size) of each megabasin.

Discussion

The atlas of southern African freshwater fish has been illustrated as a tool to investigate the effects of some environmental gradients on the species richness of megabasins. Documenting these correlations, through exploratory data analysis, is an important initial step in understanding the ecology and biology of a species (Harrison 1991). Hypotheses concerning the mechanisms may be developed from these results and incorporated into future studies with other environmental variables, if necessary, before the effect of environmental influences on the distribution of freshwater fish can be properly understood.

Species richness was found to be higher in larger megabasins, a correlation well substantiated in the literature. This is explained by the greater number and diversity of aquatic habitats available to species in drainage basins that have larger surface areas (Hugueny & Lévêque 1994). Likewise, a higher average precipitation is likely to result in larger bodies of surface water and higher niche diversity available for colonisation by fish. The positive correlation between minimum temperature and species richness may be due to the fact that the more diverse tropical faunas are less tolerant of low winter temperatures, and are thus restricted to warmer climes (Skelton 1994). A lower temperature regime has been found to suggest greater aridity and variability of rain, hence less surface water and habitat available for colonisation by fish (Bowmaker *et al.* 1978).

Increases in minimum temperature, rainfall and basin size, although significantly correlated with species richness, must not be necessarily viewed as causative agents. Faunal composition is determined by countless interacting abiotic and biotic factors, many of which have not yet been quantified or investigated. Other environmental variables that were not incorporated into this analysis cannot be disregarded. For example, species richness may be lower in drainage basins with a lower temperature because they may have been geographically isolated and tropical faunas may not have had the opportunity to invade. Seasonality or day length may be regulating factors, but since these variables always correlate with temperature gradients, their effects are difficult to quantify in natural systems.

Similarly, many ecological variables may have a cumulative or synergistic effect and are thus difficult to quantify. Fish distributions are determined by many poorly understood complex processes, leading to subjective hypotheses of cause and effect being the traditional approaches to explaining these distributions (Gabie 1965). As has been demonstrated in this chapter, advanced analytical tools are increasingly being applied to biogeographical problems, and deductive methods will begin to predominate in the search for meaningful patterns and the underlying causal factors. This study, therefore, presents a framework for assessment and is merely a preliminary approach used to illustrate the potential of the Geographic Information Systems atlas in large-scale population studies.

The importance of accurate data sets cannot be overemphasised to ensure the quality and reliability of the analysis. As with any scientific experiment, the outcome is dependent on the integrity of the raw data, in the case of GIS analysis, the large size of the digital data sets increases the chance of errors being introduced.

The assessment of factors affecting single species distributions is extremely difficult due to cumulative effects, physiological and behavioural responses (such as fish finding thermal refuges as unfavourable temperature extremes) which are not well understood or quantified (De Moor 1993). Biotic interactions such as predation and competitive exclusion further complicate matters.

A study of the changes in abiotic conditions and fish distribution patterns across an area over time is likely to indicate limiting factors on the distribution of a fish species existing within a river system (Bozek & Rahel 1991, Jackson 1962). This has important consequences for threatened species and populations of freshwater fish. Human influences such as habitat degradation, pollution, degree of development, population increase and water abstraction, for example, can be quantified and easily incorporated into a GIS in a number of forms. The various threats to species can thus be compared and quantified with reference to the contribution each has to the status of the freshwater population or aquatic system.

As a result, the more information that becomes available, the more detailed and applied analyses become. At present, data availability limits GIS analysis to multi-species and continental scale correlation analysis, but with the investment of further time and money, these tools can be applied to more specific and relevant problems (Miller 1994a, Rubec *et al.* 1999).

CHAPTER 7

APPLICATION OF THE ATLAS OF FRESHWATER FISH

Introduction

Data mapping, the integration of digital map layers, and spatial analysis, are the primary functions of a Geographic Information System (Brooks 1985, Cowen 1988). Analytical capabilities and modelling add functionality to the information system by providing the capability to structure, analyse and interpret data in relation to specific users' requirements (Chapman & Busby 1994, De Man 1990).

Some functions of a Geographic Information System include reproducing a series of maps to a common scale, expanding or contracting relevant parts of a map for more or less detail, overlaying maps to demonstrate exclusion or similarities, computing areas or volumes of units with specific characteristics, computing zones at distances away from objects (such as a buffer zone around a dam), computing distances to or from points, computing lengths of lines such as streams / polygon perimeters, summarising statistical data, modelling or computing an expression within a cell or linking with simulation models to anticipate natural changes or those associated with development (Giles & Nielsen 1992). The atlas of freshwater fish has been designed to facilitate all of these applications by taking the potential of geographically referenced point distributions of specimens beyond the mapping of species.

The atlas is a vast resource of fish point distribution information. In addition to its primary use as a visualisation tool and reference database, its enormous scope for exploratory data analysis and hypothesis driven modelling have been demonstrated. In this chapter, some additional applications that may arise from the atlas of freshwater fish are discussed.

Applications

Digital mapping is rapid and efficient. Mapping known localities for a species throughout its range generates a standardised and comprehensive record of its geographical distribution. The mapping end product is often considered to be an end in itself, although species maps may contribute as a resource to further elucidate species ecological relationships and morphological trends (Hall 1994, Miller 1994a, Paw 1994). Appendix F contains a point distribution map of each species of freshwater fish included in the atlas.

The atlas of freshwater fish has been developed so that each distribution point is actively linked to all the additional information associated with that specimen. If any species point is activated, all the attribute information is automatically displayed in a table in a window within the GIS. A simple query function in the atlas also allows the display of categories of specimens. For example, points can be displayed by a specific species, by collector, by date, by location or by source (Figure 7.1). The attribute table is always linked to the information that is displayed in map form, so the results of a query can also be viewed numerically in the attribute table with additional information (Lombard *et al.* 1992).

As information is stored in co-ordinate format, species maps can be produced at any scale, for dams, catchments (Figure 7.2) or megabasins as required. Any additional spatial data may be included within these maps.

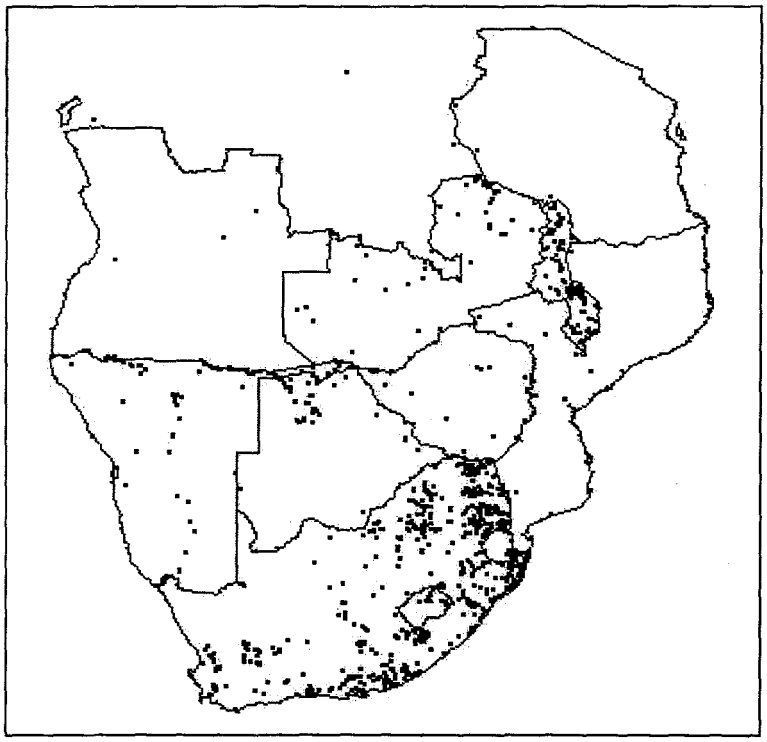


Figure 7.1 Theme selection of all freshwater fish in the atlas sourced at the JLB Smith Institute of Ichthyology, mapped as points (13 909 records).

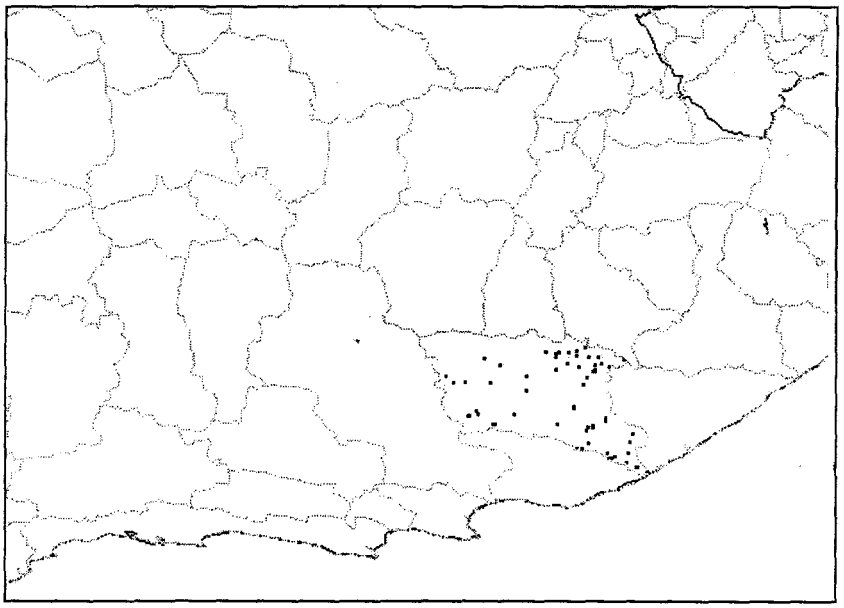


Figure 7.2 All species points in the atlas of freshwater fish found in catchment number 1135, Fish River system, Eastern Cape, South Africa. Country border and watershed layers are illustrated as a frame of reference.

The distribution of fish collections can be mapped at any scale. Figure 7.3 illustrates the catchments in which collections have been made for the atlas, highlighting the poorly sampled regions in Botswana, Angola and in particular, Namibia. This facility is significant to the planning of future collections, so that gaps in the knowledge of fish fauna can be filled in the most cost effective manner possible by concentrating efforts in the least sampled areas. Collaborative efforts between institutions can also be facilitated to promote the sharing of data rather than the duplication of effort.

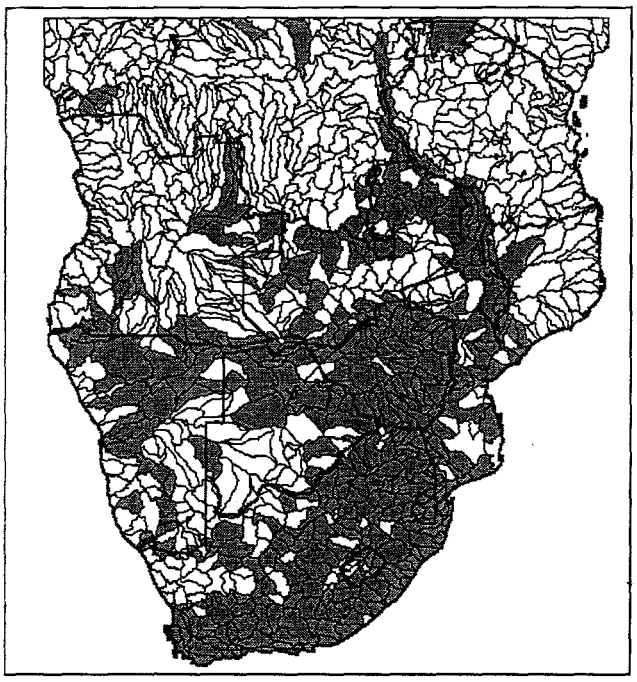


Figure 7.3 Grey catchments indicate the presence of freshwater fish specimen records in the atlas. White catchments have no recorded data points in the atlas at present.

The atlas of freshwater fish will be available as a tool for interactive use by fieldworkers. A digital basemap and portable computer would be needed to facilitate this. Existing point distribution data are present on the basemap, and new point collections made can be directly entered into the GIS at the appropriate co-ordinates. The attribute data can be entered into the electronic form that is attached to the new point on the basemap. The collection information would thus be immediately available for use, subject to verification after the expedition and once the specimen or sample had been accessioned.

Mapping of fish distribution points at different time intervals can illustrate temporal change in an area, as long as collections have been made intensively and consistently throughout the region over a sufficent period of time (Skelton *et al.* 1995). This facility would be extremely useful in the event of the development of an area, to see the impacts of change on the freshwater fish populations.

The atlas of freshwater fish can be used as a reference for rural fishery work, to identify edible fish species present in dams and rivers. ALCOM has already incorporated freshwater fish species data into a water resource database CD-ROM with this goal. The atlas is a more powerful tool as lists are generated for a region of any size (other spatial data can be incorporated into any analysis), and new distribution information included in the GIS is immediately reflected in the mapping or analytical output.

The atlas will contribute to systematic studies as the availability of specimens of a particular taxon can be rapidly identified for comparison (Skelton & Verheust 1998). The drawings and diagrams linked to species names will make it easier to prevent misidentifications. The synonym information available for each species also assists in clarifying its taxonomic status.

The distribution of alien species (both introduced and translocated species) can be monitored at any scale, using a query function (Figure 7.4). A temporal aspect can be incorporated into the query for species distribution. This facilitates the study of changes in the range of the species, which could be useful for the efficient management and control of alien species.

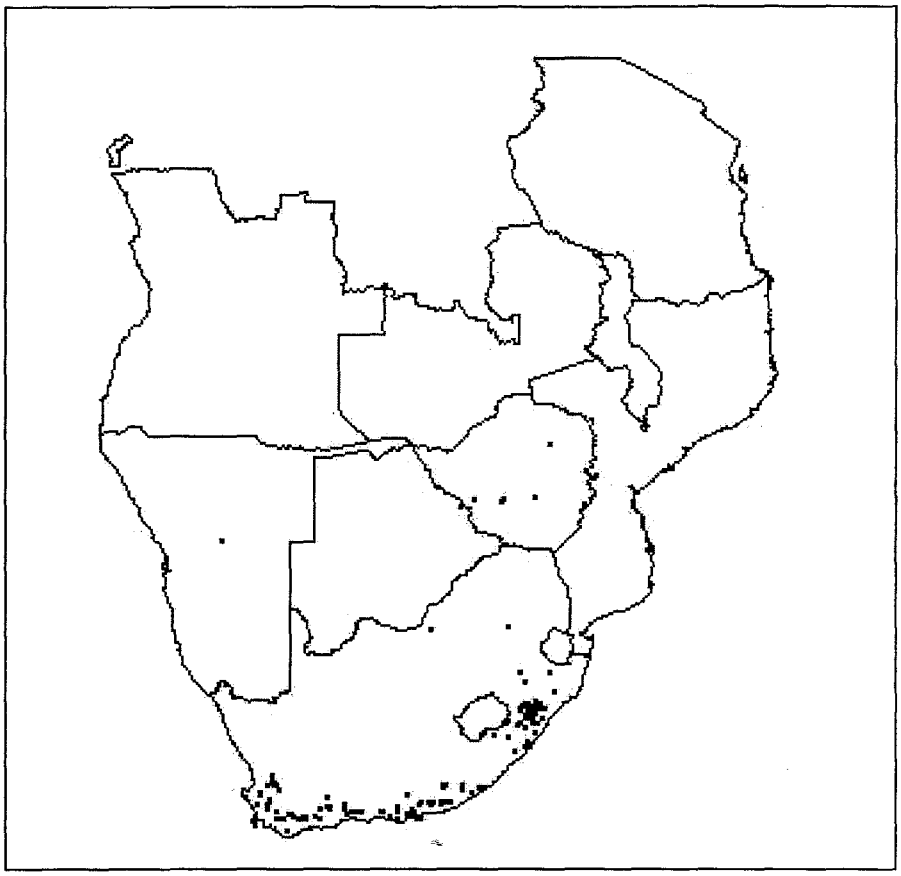


Figure 7.4 Point distribution of an introduced species, largemouth bass, *Micropterus salmoides*, mapped using the atlas of freshwater fish.

Spatial search and overlay are unique functions of Geographic Information Systems (Cowen 1988). GIS is a powerful tool for aquaculture or reserve site selection as a number of factors must be integrated before a feasible area is identified. A number of layers of spatial data (existing infrastructure, species presence) can be incorporated into a decision support system. Figure 7.5, for example, illustrates a simple query for water bodies within 1km of a national road.

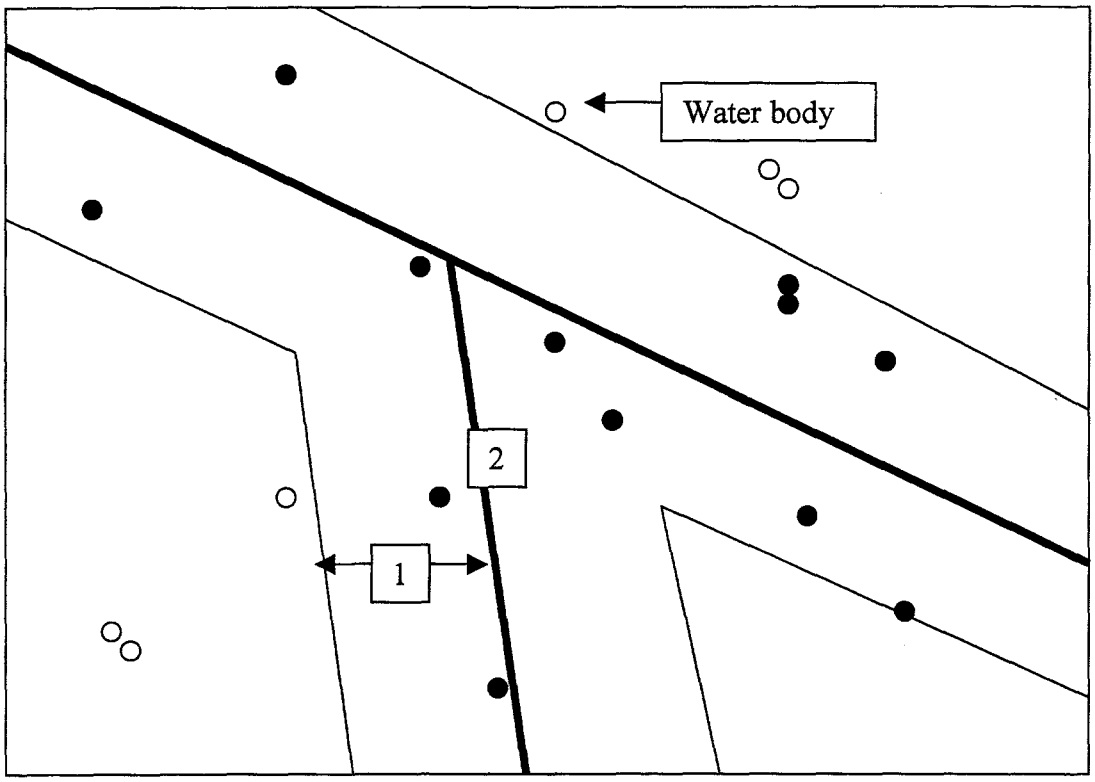


Figure 7.5 Illustration of the process of a query for water bodies within 1km of a national road, using the atlas. A 1km wide buffer zone region (1) is created around each length of road (2) and the query identifies water bodies that fall within the required zone.

The atlas may be used as a predictive tool in the building of dams, weirs and other obstructions to water flow. For example, a 10m high wall can be planned across a stretch of river, and predictions made about the extent of the resultant water body. Since the freshwater fish species composition of the river system is known, the species composition of the dam can also be hypothesised (Verheust 1997). A map of existing dams overlaid with land use zones and human population distribution can be used to identify areas with the greatest need for water (Verheust 1999).

The efficient management of natural systems, and the conservation of aquatic biodiversity is aided by the development of aquatic atlases. Although hotspots of species richness and endemism have traditionally been carried out using a grid system (Humphries *et al.* 1999, Lombard 1993, McAllister *et al.* 1994, Miller 1994b) the atlas as constructed in this study is capable of hotspot identification both at a grid level and at a catchment level. The identification of hotspots of species richness and diversity together with vulnerable populations and areas with aquatic conservation priority are relevant to conservation planners (Harrison 1991, Lombard 1995b). The distribution of human activities that impact on the environment can be easily identified with data stored in a GIS, which is useful in prioritising areas for protection, predicting impacts of pending threats and planning preventative or remedial conservation activities (Miller 1994a).

The presence of some stenotopic indigenous species may be used as a good indication of the status of aquatic environments, and any obvious depletion in numbers, or local population extinctions, may be good indicators of system deterioration. Studies evaluating changes in fish communities and the instream flow requirements of fishes are now being made in order to determine the conservation requirement of rivers (Hughes *et al.* 1990, Karr 1990, Le Cren 1990, Lowe-McConnell 1990).

Discussion

The presentation of digital data is usually through graphical user interfaces (digital menus and windows), people compatible output (screen display, hardcopy maps, tables and graphs), computer compatible output (diskette, tape) or electronic data transmission (network or telephone) (Wijers 1993). The atlas of freshwater fish is presently accessible only at one computer terminal due purely to time constraints of developing usable copies, and the need to restrict access to the master copy.

A hard copy publication similar to the Atlas of Southern African Birds is due for publication in 2000. It will have many possible applications, for amateur naturalists and researchers as a reference of freshwater fish distributions as they are known today.

A digital atlas of freshwater fish will be released at the same time and will have additional value as an analytical tool as well as a reference for species distributions. Internet access in the future will greatly increase the user base, and with appropriate regulation and copyright agreement, will maximise its availability.

CHAPTER EIGHT

GENERAL DISCUSSION

The Geographic Information Systems atlas of southern African freshwater fish is the first of its kind for this region. The integration of spatial data layers with the database of freshwater fish has provided a valuable new resource of information from existing data. The development of this GIS atlas harnessed the latest computing technology for the mapping and analytical requirements of both research and management concerns.

The production of any digital atlas in a developing nation is likely to face more obstacles than would be the case in a developed one (Pettit 1999). Financial limitations are a significant problem, especially when working with expensive hardware and software. The lack of skilled workers and unsuitable working environments in some African countries may prove to hinder production, and the poor availability of digital data would slow any study as paper maps or field notes are digitised and typed into spreadsheets (Adenyini 1985). Without any regulating body to set standards for the quality and type of digital data in southern Africa, the accuracy and compatibility of data sets is often of concern. Map layers are often needed in various file formats for specific types of GIS software by different end users, and digitised layers may on occasion be very difficult to get into the correct format. Any physical change to a map layer potentially introduces errors, so further checks are needed if the accuracy is not to be compromised. The cost of detailed digital map layers has promoted the sharing of data between individuals and larger concerns, which does reduce the duplication of a lot of effort and the costs of digitising. The accuracy of map layers obtained from unknown sources are, however, sometimes difficult to establish, and so require extensive error checks.

Without an accurate database and sound, consistent nomenclature, even the most rigorous biogeographic analysis will lack credibility (Greenwood 1983). The studies that were carried out using the atlas of southern African freshwater fish were, however, only preliminary analysis used to illustrate the power of the atlas as a tool in biogeographic research, and not to provide definitive answers to long-standing biogeographical problems.

The database of freshwater fish was assumed to be accurate for incorporation into the atlas of southern African freshwater fish, although this is not known to be a fact. Despite the many manual and automatic checks that the data has been exposed to, it is practically impossible to ensure that a database of this magnitude is completely error free (Antenucci *et al.* 1991b). The priority was hence considered to be in establishing the database for immediate use, as the demands for this type of information far outweigh any drawbacks that the more subtle inconsistencies in the system may present. If unidentified errors still exist in the database, they will only be detected with a very time consuming review of field notes and the re-identification of every specimen. With 35180 specimen records from five collections around southern Africa to work with, this was considered to be impractical until further resources are made available.

The fact that an electronic tool for data storage and manipulation is now available in no way detracts from the importance of natural history collections. These collections have possibly become even more valuable to science now that some of their information has been copied into database systems for more efficient reference. Besides their aforementioned purpose to validate all the biological data in the database and atlas of freshwater fish, collection specimens store vastly more morphological and genetic information than we have presently been able to extract. The utilisation of this additional information on a large scale may only be possible in many years to come, so the preservation of specimens is an investment in future knowledge. Besides the historical aspect of natural history collections, each specimen has a temporal aspect, one which will become very important when the database is large enough to study species changes over time.

In recent years, with the automation of biological databases worldwide, public attention has increasingly been brought to their potential contribution to biodiversity studies and conservation efforts (Ahearn *et al.* 1990). The Atlas Florae Europaeae (AFE), for example, has recently been digitised with WORLDMAP software that facilitates biodiversity analysis. Species richness and range size calculations of plant species in Britain have been demonstrated for the use of reserve planners and other conservationists (Humphries *et al.* 1999).

The atlas of freshwater fish can be put to similar use in southern Africa where many indigenous freshwater fish species are threatened or endangered due to habitat loss and degradation. The application of electronic biological databases has been recognised more locally, in South Africa, and their value in identifying areas of conservation priority has been discussed at length in the 1995 issue of the South African Journal of Zoology (volume 30). The development of the database of freshwater fish and its integration with other spatial data into an atlas has created a framework for the future harnessing of information stored in fish collections and other data regarding freshwater fish in this region. The potential for application of a digital tool such as the atlas of freshwater fish cannot be overemphasised in the quantification of biodiversity, conservation planning and biogeographical studies.

FISHWATCH is a marine project developed at the JLB Smith Institute of Ichthyology that is concerned with the recording of sightings or specimens of marine fish by scientific divers along the South African coast. Recorded sightings of fish by any individual can be incorporated into the FISHWATCH database on condition of verification by an ichthyologist (J.L.B. Smith Institute of Ichthyology, Heemstra pers. comm.). This increases the volume of data in the FISHWATCH database, but possibly at the expense of the accuracy of the information if new records are not screened properly. Unless physical evidence is preserved of a species record, no future verification of the database can be carried out should a query be raised about a distribution record. The FISHWATCH database is to be published on the internet for online use, which will make it easily accessible to subscribers, without the need for the physical distribution of a copy of the database. Another advantage of internet distribution that has been considered with respect to the atlas of freshwater fish, is the awareness of important aquatic and environmental issues that can be generated with an online atlas. Communication channels between scientists working on southern African freshwater fish can be set up between interested parties at a international scale. This would be of significant benefit to the expansion of the atlas and for the co-ordination of collection effort in this region. In the past, many organisations or research projects have undertaken similar studies without being aware of any overlap. Better avenues of communication will minimise the duplication of effort in the field and encourage data sharing, a benefit to all (Bassole 1998).

FISHBASE is a global resource of information, published in book form and on CD-ROM, that aims to provide data on all aspects of distribution, ecology, anatomy, taxonomy, aquaculture, genetics and fisheries management of all species of fish worldwide. The database is extensive at present, extremely informative in some fields, but its goal, to co-ordinate all existing knowledge on fish, is ambitious. FISHBASE has many varied sources of data, not all of which are verified by professionals, although a distinction is made between submitted sources of data, and data which have been checked after submission (Electronic citation 4). At some stage in the future, if all the distribution records are verified, FISHBASE may be useful for the type of biogeographic research that the atlas of freshwater fish was used to demonstrate. FISHBASE was, however, designed with a different objective, that of compiling vast amounts of data and separate databases into a single source of information, much like an encyclopedia. The essential distinctions that can be made between the atlas of freshwater fish and FISHBASE, are that the atlas was established with objectives of quality before quantity, with limited geographical scope whereas FISHBASE has prioritised the quantity of information gathered at a global scale. Although the two information systems have different objectives and applications, they are not mutually exclusive. The information in the atlas of freshwater fish would be a valuable addition to the FISHBASE data set, and FISHBASE could be a valuable source of information on natural history collections that may be of use for incorporation into the atlas.

The development of an extensive database of freshwater fish was a significant part of the construction of the atlas. As a specialised subset of the GIS, the database is designed to operate as an entity on its own. The database is presently far more accessible for general use than the atlas as it is structured on commercially available database software. Although compiled in *Approach*, the records in the database files, excluding the approach file template or mapping links, can be used with any other database software programme (*Access*, for example), or imported into any programme that recognises database format (*.dbf*) files. The atlas, on the other hand, although a more powerful tool as far as analysis capability is concerned, is more limited in its user base.

A Geographic Information System like *TNTmips* requires the expertise of a skilled operator, and the use of the atlas as it stands is restricted to the system in which it was designed. The components of the atlas can be converted to a format recognised by another Geographic Information System, but this is time consuming and the structure of the atlas would have to be reworked.

Geographic Information Systems have, however, become increasingly user friendly and integrated in their design over the past few decades (Chrisman 1999). The *TNTmips* software in particular is a good example of a system that incorporates edit, analysis and display modules in a single package as opposed to other GISs that work with components that are sold separately (Electronic citation 3). SML, or spatial manipulation language, is the programming language of *TNTmips* that can be used to design custom processes such as file conversions or data analyses that are not standard menu options (Ghormley 1997).

In the future, aside from internal processing becoming more streamlined and simple to use, a greater variety of analytical tools will be available as menu options for use by less skilled people who lack a comprehensive knowledge of programming language. This, together with the present rate of increase in computer literacy (especially among younger scholars and students) in southern Africa, will result in Geographic Information Systems becoming more mainstream and incorporated into most analyses with a spatial component, in much the same way that computer software has taken over from typewriters for word processing. Anticipating this trend, the atlas was designed using the best suited tools and data available at present, and will develop with further advances in Geographic Information Systems design and as data are made available. The database of freshwater fish is considered dynamic as it will reflect freshwater fish specimens continually collected over both space and time. No definable goal of completion can be set as far as number of specimens is concerned, because even if every aquatic region is comprehensively sampled at some future point, additional specimen records will still be of value in studies of temporal change. The database (together with the atlas) will continue to expand naturally with an increase in distribution records over time.

Efficient database management is essential to the maintenance of database integrity. The standards for the database and the atlas of freshwater fish which have been set during their development must be continued by a proficient user if any of the new information incorporated into these information systems is not to compromise the quality of the existing data. The digital nature of the data makes the updating of both the database and the atlas easy to accomplish, and the major concern is that the additional data are of a sufficient standard. Copies of the database and the atlas must be archived at regular intervals to insure against data loss, and a master copy of each should have limited access to a single administrator.

The atlas should be made available to all potential users in order to fulfil its purpose as a tool. The maintenance of data standards and the protection of the copyright of contributors are, however, factors to consider when releasing digital information of this type. The release of hardcopy publications is simple to manage as the units that are released are kept intact. Information on CD-ROM, in contrast, is very easy to duplicate and redistribute for other purposes. While this is undoubtedly an advantage to data sharing by legitimate users, it makes the distribution of all data, including a digital end product, practically impossible to regulate.

The requirements of biological databases and digital atlases have been clearly outlined, the applications of established biological atlases have been discussed and the standards for future work of this nature have been set. The atlas of southern African freshwater fish has been created from verified biological and spatial data sources and demonstrated as a dynamic and useful tool in the aquatic sciences. One of its major strengths is that biogeographic analysis, as demonstrated with the atlas, has not previously been possible with traditional subjective approaches. A number of other applications are presently possible, and their potential will only increase as the scope of Geographic Information Systems expand and databases improve.

The atlas of southern African freshwater fish has been developed, tested and demonstrated as a dynamic multidisciplinary tool for both research and management objectives in the aquatic sciences. It meets all the systems requirements of a functional GIS as a system for the capture, storage, management, analysis and display of spatial data. The atlas has begun, and will continue to serve as an essential tool in the study of aquatic habitats and freshwater fishes in southern Africa.

LIST OF ABBREVIATIONS

ALCOM - Aquatic Resources Management for Local Community Development Programme

CAD - Computer aided drawing

DCW - Digital Chart of the World

DEM - Digital elevation model

FAO - Food and Agricultural Organisation

GIS - Geographic Information System

MB - Megabytes

RAM - Random access memory

RRSP - Regional Remote Sensing Project

SADC - Southern African Development Community

SML - Spatial manipulation language

TIN - Triangulated irregular network

USGS - United States Geological Survey

WWF - World Wide Fund for Nature

GLOSSARY

Anadromous – fish ascending rivers and streams from the sea to spawn in fresh waters; opposite of catadromous

Catadromous – fish descending rivers and streams from fresh water to spawn in the sea; opposite of anadromous

Cline – a cline is a geographic gradient in a characteristic of a natural population that reflects evolutionary processes such as selection, gene flow, secondary contact and recent range extensions.

DEM – a digital elevation model is a raster GIS layer with an elevation value stored within each pixel. A colour key is used to display the layer with a relief effect.

MB – a megabyte is 1 000 000 bytes, a byte being the unit of storage in a computing system

Pixel – a pixel is the smallest unit of a GIS raster layer, it is one cell containing a single value

RAM – random access memory is the memory used by a computer to run processes within the system.

Topology – defines the spatial relationships between elements (points, lines, polygons, in a vector map layer)

REFERENCES

Adenyini, P. O. (1985). Remote Sensing, Resource Development, and Education in Africa. *Education and Training in Contemporary Cartography.* (Taylor, D. R. F., Eds), London: Wiley & Sons.

Ahearn, S. C., Smith, J. L. D. & Wee, C. (1990). Framework for a geographically referenced conservation database: case study Nepal. *Photogrammetric Engineering and Remote Sensing* **56,** 1477-1481.

Anon. (1984). *Reader's Digest Atlas of Southern Africa*: Reader's Digest Association of South Africa.

Anon. (1987). *The Times Atlas of the World.* London: Times Books Limited.

Anon. (1993). *Understanding GIS: The ARC/INFO Method.* Environmental Science Research Institute. London: Longman Scientific Publishers.

Anon. (1996). *The American Heritage Dictionary of the English Language.* Third Edition. United States of America: Houghton Mifflin Company.

Anon. (1997). The Database of the SADC regional remote sensing project. Version 0.9a. Working Paper No.6. Harare: SADC Regional Remote Sensing Project.

Anon. (1999a). *Freshwater ecoregions of Africa.* Conservation Science Program. Washington: World Wildlife Fund

Anon. (1999b). Map Issues Fact Sheet. Honours coursework information. Geography Department. Rhodes University, Grahamstown.

Antenucci, J. C., Brown, K., Croswell P. L. and Kevany, M. J. (1991a). Data Base Concepts. *Geographic Information Systems: A guide to the technology.* In: Antenucci, J. C., Brown, K., Croswell P. L. and Kevany, M. J. (Eds), pp.85-110. New York: Van Nostrand Rheinhold.

Antenucci, J. C., Brown, K., Croswell P. L. and Kevany, M. J. (1991b). Geographic Information System software. *Geographic Information Systems: A guide to the technology*. In: Antenucci, J. C., Brown, K., Croswell P. L. and Kevany, M. J. (Eds), pp.161-183. New York: Van Nostrand Rheinhold.

Asante, K. & Maidment, D. (1998). The building blocks of GIS. *Geoinformation Africa* 22-24.

Balon, E. K. (1974). Fishes from the edge of Victoria Falls, Africa: demise of a physical barrier for downstream invasions. *Copeia* **3,** 643-660.

Barnard, K. H. (1943). Revision of the indigenous freshwater fishes of the S.W. Cape Region. *Annals of the South African Museum.* **36,** 101-262.

Bassole, A. (1998). African answers to a global question. *Geoinformation Africa* 18-19.

Bell-Cross, G. (1965). Physical barriers separating the fishes of the Kafue and Middle Zambezi River systems. *Fisheries Research Bulletin of Zambia* **4,** 97-101.

Boulenger, G. A. (1905). The distribution of African fresh-water fishes. *British Association for the Advancement of Science.* Annual Report, 412-432.

Bowmaker, A. P., Jackson, P. B. N. & Jubb, R. A. (1978). Freshwater fishes. *Biogeography and Ecology of Southern Africa.* (Werger, M. J. A., Eds), pp.1181-1231. The Hague: Dr W. Junk Publishers.

Bozek, M. A. & Rahel, F. J. (1991). Assessing habitat requirements of young Colorado River cutthroat trout by use of macrohabitat and microhabitat analyses. *Transactions of the American Fisheries Society* **120,** 571-581.

Brain, C. K. & Meester, J. (1964). Past climatic changes as biological isolating mechanisms in southern Africa. *Ecological Studies in Southern Africa.* (Davis, D. H. S., Eds), pp.333-240. The Hague: Dr. W. Junk Publishers.

Brooks, K. M. (1985). Determination of Geographic Information System database characteristics: An application of the information integration theory.

Brown, J. H. (1984). On the relationship between abundance and distribution of species. *The American Naturalist* **124,** 255-279.

Burgman, M. A., Grimson, R. C. & Ferson, S. (1995). Inferring threat from scientific collections. *Conservation Biology* **9,** 923-928.

Butterfield, B. R., Csuti, B. & Scott, M. (1994). Modelling vertebrate distributions for GAP analysis. *Mapping the Diversity of Nature.* (Miller, R. I., Eds), pp.53-68. London: Chapman & Hall.

Chapman, A. D. & Busby, J. R. (1994). Linking plant species information to continental biodiversity inventory, climate modelling and environmental monitoring. *Mapping the Diversity of Nature.* (Miller, R. I., Eds), pp.179-195. London: Chapman & Hall.

Chrisman, N. (1999). *Exploring Geographic Information Systems.* New York: John Wiley & Sons.

Cotterill, F.P.D. (1997). The second Alexandrian tragedy, and the fundamental relationship between biological collections and scientific knowledge. *The Value and Valuation of Natural Science Collections.* (Nudds, J. R. & Pettitt, C. W., Eds), London: Geological Society.

Cowen, D. J. (1988). GID versus CAD versus DBMS : What are the differences? *Photogrammetric Engineering and Remote Sensing* **54,** 1551-1555.

Crass, R. S. (1962). Physical barriers and the dispersion of freshwater fish with particular reference to Natal. *Annals of the Cape Provincial Museum* **2,** 229-232.

Daget, J., Gosse, J. P. & Thys van den Audenaerde, D. F. E. (1984). *Check-list of the freshwater fishes of Africa.* Paris: ORSTOM.

Dangermond, J. (1990). A classification of software components commonly used in Geographic Information Systems. *Introductory Readings in GIS.* (Pequet, D.J. and Marble, D.F., Eds), pp.30-51. New York: Taylor and Francis.

Darlington, P. J. (1957). Fresh-water fishes. *Zoogeography: The geographical distribution of animals.* (Darlington, P. J., Eds), pp.39-127. New York: John Wiley & Sons, Inc.

Davis, F. W., Quattrochi, D. A., Ridd, M. K., Lam, N. S. N., Walsh, S. J., Michaelsen, J. C., Franklin, J., Stow, D. A., Johannsen, C. J. & Johnston, C. A. (1991). Environmental analysis using integrated GIS and remotely sensed data : some research needs and priorities. *Photogrammetric Engineering and Remote Sensing* **57,** 689-697.

Davis, J. R., Whigham, P. & Grant, I. W. (1990). Representing and applying knowledge about spatial processes in environmental management. *Introductory Readings in GIS.* (Pequet D.J. and Marble, D.F. Eds), New York: Taylor and Francis.

De Man, W. H. E. (1990). Establishing a geographical information system in relation to its use: a process of strategic choices. *Introductiory Readings in GIS.* (Pequet D.J. and Marble, D.F. Eds), pp.324-340. New York: Taylor and Francis.

De Mers, M.N. (1999). *Fundamentals of Geographic Information Systems.* New York: John Wiley & Sons Inc.

De Moor, F. C. (1996). The importance of voucher specimens. *South African Journal of Aquatic Science* **22,** 117-118.

De Moor, I. J. (1993). Methods for assessing the susceptibility of freshwater ecosystems in southern Africa to invasion by alien aquatic animals. Masters Thesis. Rhodes University, Grahamstown.

Eekhout, S., King, J. M. & Wackernagel, A. (1997). Classification of South African Rivers. volume 1. Report. Department of Environmental Affairs and Tourism.

Eschmeyer, W. N. (1998). *Catalog of Fishes.* San Francisco: California Academy of Sciences.

Freitag, S., Nicholls, A. O. & Van Jaarsveld, A. S. (1998). Dealing with established reserve networks and incomplete distribution data sets in conservation planning. *South African Journal of Science* **94,** 79-86.

Gabie, V. (1965). Problems associated with the distribution of freshwater fishes in Southern Africa. *South African Journal of Science* **61,** 383-391.

Gaigher, I. G., Hamman, K. C. D. & Thorne, S. C. (1980). The distribution, conservation status and factors affecting the survival of indigenous freshwater fishes in the Cape Province. *Koedoe* **23,** 57-88.

Gaigher, I. G. & McPott, R. (1973). Distribution of fishes in Southern Africa. *South African Journal of Science* **69,** 25-27.

Gatrell, A. C. (1991). Concepts of space and geographical data. *Geographical Information Systems : Principles and Applications.* (Maguire, D.J., Goodchild, M.F., Rhind, D.W., Eds), pp.119-133. London: Longman.

Gauch, H. G. Jr. (1982). *Multivariate analysis in community ecology.* Cambridge: Cambridge University Press.

Ghormley, K. (1997). Spatial manipulation language. *Getting Started Booklets.* Nebraska: MicroImages.

Giles, R. H. J. & Nielsen, L. A. (1992). The uses of Geographic Information Systems in fisheries. *American Fisheries Society Symposium* **13,** 81-94.

Goodchild, M. F. (1994). Integrating GIS and remote sensing for vegetation analysis and modeling: methodological issues. *Journal of Vegetation Science* **5,** 615-626.

Greenwood, P. H. (1983). The zoogeography of African freshwater fishes: bioaccountancy or biogeography? *Evolution, time and space: The emergence of the biosphere.* (Sims, R. W., Price, J. H. & Whalley, P. E. S., Eds), pp.179-199. New York: Academic Press.

Hall, J. B. (1994). Mapping for monographs : baselines for resource development. *Mapping the Diversity of Nature.* (Miller, R. I., Eds), pp.21-35. London: Chapman & Hall.

Harrison, J. A. (1989). Atlassing as a tool in conservation, with special reference to the Southern African Bird Atlas Project. *Biotic Diversity in Southern Africa, Concepts and Conservation.* pp.157-169.

Harrison, J. A. (1991). A bird in the hand. *Conserva* 10-13.

Harrison, J. A., Underhill, L. G., Herremans, M., Tree, A. J., Parker, V., Brown, C. J. & Allan, D. G. (1997). *The Atlas of Southern African Birds.* Johannesburg: BirdLife South Africa.

Hawkes, C. L., Miller, D. L. & Layher, W. G. (1986). Fish ecoregions of Kansas : stream fish assemblage patterns and associated environmental correlates. *Environmental Biology of Fishes* **17,** 267-279.

Hay, C. J., Van Zyl, B. J., Van der Bank, F. H., Ferreira, J. T. & Steyn, G. J. (1999). The distribution of freshwater fish in Namibia. *Cimbebasia* **15,** 41-63.

Hughes, R. M., Rexstad, E. & Bond, C. E. (1987). The relationship of aquatic ecoregions, river basins and physiographic provinces to the ichthyographic regions of Oregon. *Copeia* **2,** 423-432.

Hughes, R. M., Whittier, T. R. & Rohm, C. M. (1990). A regional framework for establishing recovery criteria. *Environmental Management* **14,** 673-683.

Hugueny, B. & Lévêque, C. (1994). Freshwater fish zoogeography in west Africa: faunal similarities between river basins. *Environmental Biology of Fish* **39,** 365-380.

Humphries, C., Araujo, M., Williams, P., Lampinen, R., Lahti, T. & Uotila, P. (1999). Plant diversity in Europe: Atlas Florae Europaeae and WORLDMAP. *Acta Botanica Fennica* **162,** 11-21.

Jackson, P. B. N. (1962). Ecological factors affecting the distribution of freshwater fishes in tropical Southern Africa. *Annals of the Cape Provincial Museum* **2,** 223-228.

Jackson, P. B. N. (1986). Fish of the Zambezi System. *The Ecology of River Systems.* (Davies, B. R. & Walker, K. F., Eds), pp.269-288. Dordrecht: Dr W. Junk Publishers.

Jubb, R. A. (1953). Some notes on freshwater fish in Southern Rhodesia. *Rhodesia Agricultural Journal* **50,** 292-293.

Jubb, R. A. (1964). Freshwater fishes and drainage basins in Southern Africa. *South African Journal of Science* 17-21.

Jubb, R. A. & Farquarson, F. L. (1965). The fresh water fishes of the Orange River drainage basin. *South African Journal of Science* **61,** 118-125.

Karr, J. R. (1990). Biological integrity and the goal of environmental legislation: lessons for conservation biology. *Conservation Biology* **4,** 244-250.

Krebs, C. J. (1999). The nature of the community. *Ecology: The experimental analysis of distribution and abundance.* (Krebs, C. J., Eds), pp.385-407. New York: Harper & Row.

Lawes, M. J. & Piper, S. E. (1998). There is less to binary maps than meets the eye: the use of species distribution data in the southern African sub - region. *South African Journal of Science* **94,** 207-210.

Le Cren, E. D. (1990). Rare fishes and their conservation: a brief introduction to the symposium. *Journal of Fish Biology* **37,** 1-3.

Lee, D. S., Gilbert, C. R., Hocutt, C. H., Jenkins, R. E., McAllister, D. E. & Stauffer, J. R. (1980). *Atlas of North American Freshwater Fishes.* United States of America: North Carolina State Museum of Natural History.

Leth-Nissen, S. (1993). How to run a database for fish farming extension. *ALCOM News* **9,** 10-11.

Lévêque, C. (1997). *Biodiversity dynamics and conservation : The freshwater fish of tropical Africa*. Cambridge: Cambridge University Press.

Lombard, A. T. (1993). Multi-species conservation, advanced computer architecture and GIS : where are we today? *South African Journal of Science* **89,** 415-418.

Lombard, A. T. (1995a). Introduction to an evaluation of the protection status of South Africa's vertebrates. *South African Journal of Zoology* **30,** 63-70.

Lombard, A.T. (1995b). The problems with multi-species conservation: do hotspots, ideal reserves and existing reserves coincide? *South African Journal of Zoology* **30,** 145-163.

Lombard, A. T., August, P. V. & Siegfried, W. R. (1992). A Proposed Geographic Information System for assessing the optimal dispersion of protected areas in South Africa. *South African Journal of Science* **88,** 136-140.

Lowe-McConnell, R. H. (1990). Summary address: rare fish, problems, progress and prospects for conservation. *Journal of Fish Biology* **37,** 263-269.

MacDougall, M. (1996). GIS - tegnologie vir omwegingsbestuur. *Conserva* **11,** 18-19.

Matambanadzo, P. (1998). Strategies for spatial data. *Geoinformation Africa* 16-18.

Matthews, W. J. (1998). Influences of global to regional zoogeography on local fish assemblages. *Patterns in Freshwater Fish Ecology.* (Matthews, W. J., Eds), pp.191-263. United States of America: Chapman and Hall.

Matthews, W. J. & Robison, H. W. (1988). The distribution of the fishes of Arkansas : A multivariate analysis. *Copeia* **2,** 358-374.

McAllister, D. E., Schueler, F. W., Roberts, C. M. & Hawkins, J. P. (1994). Mapping and GIS analysis of the global distribution of coral reef fishes on an equal-area grid. *Mapping the Diversity of Nature.* (Miller, R. I., Eds), pp.157-175. London: Chapman & Hall.

Michelmore, F. (1994). Keeping elephants on the map: Case studies of the application of GIS for conservation. *Mapping the Diversity of Nature.* (Miller, R. I., Eds), pp.107-125. London: Chapman & Hall.

Miller, R. I. (1994a). Possibilities for the future. *Mapping the Diversity of Nature.* (Miller, R. I., Eds), pp.199-205. London: Chapman & Hall.

Miller, R. I. (1994b). Setting the scene. *Mapping the Diversity of Nature.* (Miller, R. I., Eds), pp.3-17. London: Chapman & Hall.

Miller, R. I. & Allen, J. H. (1994). Mapping the elements of biodiversity : The rare species of Madagascar. *Mapping the Diversity of Nature.* (Miller, R. I., Eds), pp.37-51. London: Chapman & Hall.

Minns, C. K. (1987). A method of ranking species and sites for conservation using presence - absence data and its application to native freshwater fish in New Zealand. *New Zealand Journal of Zoology* **14,** 43-49.

Myers, G. S. (1937). Fresh-water fishes and West Indian Zoogeography. *Annual Report of the Smithsonian Institution* 339-364.

Nico, L. G. & Fuller, P. L. (1999). Spatial and temporal patterns of nonindigenous fish introductions in the United States. *Fisheries* **24,** 16-27.

Paw, J. N. (1994). Mapping point data in Geographic Information Systems. *Naga (The ICLARM quarterly)* **17,** 21

Pettit, L. M. (1999). An appraisal of the production and utility of digital atlases in Africa : A case study of Swaziland. Masters Thesis. Rhodes University. Grahamstown.

Roberts, T. R. (1975). Geographical distribution of African freshwater fishes. *Zoological Journal of the Linnean Society* **57,** 249-319.

Ross, L. G. (1995). Environmental modelling and management of complex datasets for aquaculture: progress in using GIS. *Aquaculture news* 21-24.

Rubec, P. J., Bexley, J. C. W., Norris, H., Coyne, M. S., Monaco, M. E., Smith, S. G. & Ault, J. S. (1999). Suitability modeling to delineate habitat essential to sustainable fisheries. American Fisheries Society Symposium **22**, 108-133.

Skelton, P. H. (1986). Distribution patterns and biogeography of non-tropical southern African freshwater fishes. *Proceedings of the Southern African Society for Quaternary Research* **17**, 211-230.

Skelton, P. H. (1987). *South African Red Data Book - Fishes*. South African National Scientific Programmes Report . Pretoria. No.137

Skelton, P. H. (1990). The conservation and status of threatened fishes in southern Africa. *Journal of Fish Biology* **37**, 87-95.

Skelton, P. H. (1993). *A Complete Guide to the Freshwater Fishes of Southern Africa.* Halfway House: Southern Book Publishers.

Skelton, P. H. (1994). Diversity and distribution of freshwater fishes in East and Southern Africa. *Musee Royal de l'Afrique Centrale Tervuren Belgique Annales serie IN-8 Sciences Zoologiques.* Biological Diversity in African Fresh and Brackish Water Fishes Symposium. Vol. 275, 95-131.

Skelton, P. H., Cambray, J. A., Lombard, A. T. & Benn, G. A. (1995). Patterns of distribution and conservation status of freshwater fishes in South Africa. *South African Journal of Zoology* **30**, 71-81.

Skelton, P. H. & Verheust, L. (1998). A collection based GIS Atlas of fish distribution in southern Africa. *Conference?*

Skrdla, M.P. (1997). Pin Mapping. *Getting Started Booklets*. Nebraska: MicroImages.

Stuckenberg, B. R. (1969). Effective temperature as an ecological factor in southern Africa. *Zoologica Africana* **4**, 145-197.

Tweddle, D., Lewis, D. S. C. & Willoughby N. G. (1979). The nature of the barrier separating the Lake Malawi and Zambezi fish faunas. Bulletin 39. Grahamstown: J.L.B. Smith Institute of Ichthyology.

Van Jaarsveld, A. S., Gaston, K. J., Chown, S. L. & Freitag, S. (1998). Throwing biodiversity out with binary data? *South African Journal of Science* **94,** 210-214.

Van Jaarsveld, A. S. & Lombard, A. T. (1995). Towards the establishment of a national environmental network. *South African Journal of Science* **91,** 10-10

Van Viegen, T. R. (1996). ENPAT - An environmental management decision support system. *Conserva* **11,** 18-19.

Verheust, L. (1997). The SADC database of small water bodies, more than just a list of dams. *ALCOM News* **1,** 3-6.

Verheust, L. (1999). ALCOM's Water Resource database for SADC, more than just a list of dams, lakes and swamps. Draft paper, ALCOM.

Verheust, L. & Johnson, G. (1998a). The SADC Water Resource Database : contents, data structure and user interface. Working paper **14**

Verheust, L. & Johnson, G. (1998b). The watershed database for sub-equatorial Africa, structure and user interface. Working paper **16**

Verheust, L. & Johnson, G. (1999). Fish species distribution mapping in southern Africa. *ALCOM News* **26,** 2

Verheust, L., Skelton, P. H. & Johnson, G. (1998). Use of a water resource GIS for fisheries management, conservation and biogeography in Southern Africa, adding a third dimension. Proceedings of the PARADI/FISA conference, Grahamstown.

Werger, M. J. A. (1978). Biogeographical division of southern Africa. *Biogeography and Ecology of Southern Africa.* (Werger, M. J. A., Eds), pp.145-170. The Hague: Dr W. Junk Publishers.

Whittier, T. R., Hughes, R. M. & Larsen, D. P. (1988). Correspondence between ecoregions and spatial patterns in stream systems in Oregon. *Canadian Journal of Fisheries and Aquatic Sciences* **45,** 1264-1278.

Wijers, B. E. W. (1993). The application of GIS in integrated water resource management. Proceedings of the 6th South African National Hydrological Symposium. Volume 1. University of Natal. Pietermaritzburg. 403-409.

Electronic citations

Electronic citation 1. National Imagery and Mapping Agency.
Source: http://164.214.2.59/gns/html/index.html

Electronic citation 2. Windisp
Source: http://ag.arizona.edu/~epfirman/windisp3.html

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THE DEVELOPMENT OF A GEOGRAPHIC INFORMATION SYSTEMS BASED ATLAS OF SOUTHERN AFRICAN FRESHWATER FISH, AND ITS APPLICATION TO BIOGEOGRAPHIC ANALYSIS

A thesis submitted in fulfilment of the
requirements for the degree of

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of

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by

LUCY ELIZABETH POWELL SCOTT

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VOLUME II - APPENDICES

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Table A.1 Maps and charts used in the assignment of geographical co-ordinates from locality descriptions of fish distribution points.

Map Title	Map Scale	Date	Map Sheet	EAF no.	Publisher
Maun	1: 250 000	**1984**	sheet 6		Department of
Tsodilo	1: 250 000	**1989**	sheet 1		Surveys and Lands
Okavango Delta	1: 350 000	**1987**			Government Printer
Botswana	1: 1 500 000	**1991**			Gaborone, Botswana
Nokaneng	1: 250 000	**1988**	sheet 5		
Lake Victoria	1: 1 000 000	**1943**	SA36/SA35	**1448**	
Bulawayo	1: 1 000 000	**1943**	SF35		
Lusambo	1: 1 000 000	**1942**	SB34		
Inongo	1: 1 000 000	**1944**	SA34		
Mombasa-Nairobi	1: 1 000 000	**1943**	SA37/SA38		
Chinde	1: 1 000 000	**1942**	SE37		Directorate of
Livingstone	1: 1 000 000	**1943**	SE35		Colonial
Ondangua	1: 1 000 000	**1942**	SE33		Surveys, British
Mozambique	1: 1 000 000	**1943**	SD37		Government.
Lusaka	1: 1 000 000	**1944**	SD35		
Cassamba	1: 1 000 000	**1944**	SD34		
Benguela	1: 1 000 000	**1944**	SD33		
Lindi	1: 1 000 000	**1946**	SC37	**1630**	
Dilolo	1: 1 000 000	**1944**	SC34		
Loanda	1: 1 000 000	**1944**	SC33		
Dar es Salaam	1: 1 000 000	**1942**	SB37	**729**	
Elisabethville	1: 1 000 000	**1942**	SC35		
Tabora	1: 1 000 000	**1919**	SB36		
Albertville	1: 1 000 000	**1944**	SB35/SB36		
Lake Nyasa	1: 1 000 000	**1954**	SC36/SC35		
Blantyre	1: 1 000 000	**1942**	SD36	**1175**	
Okavango	1: 1 000 000	**1943**	SE34		

APPENDIX B

LIST OF SPECIES OF FRESHWATER FISH IN THE ATLAS

Table B.1 Species in the atlas of southern African freshwater fish arranged alphabetically by genus and species (Daget *et al.* 1984, Eschmeyer 1998).

Acanthopagrus berda
Acapoeta tanganicae
Aethiomastacembelus albomaculatus
Aethiomastacembelus cunningtoni
Aethiomastacembelus ellipsifer
Aethiomastacembelus flavidus
Aethiomastacembelus frenatus
Aethiomastacembelus micropectus
Aethiomastacembelus moorii
Aethiomastacembelus ophidium
Aethiomastacembelus plagiostomus
Aethiomastacembelus platysoma
Aethiomastacembelus shiranus
Aethiomastacembelus signatus
Aethiomastacembelus tanganicae
Aethiomastacembelus vanderwaali
Alestes grandisquamis
Alestes macropthalmus
Alticorpus macroleithrum
Alticorpus mentale
Alticorpus pectinatum
Altolamprologus calvus
Altolamprologus compressiceps
Amarginops hildae
Ambassis natalensis
Ambassis productus
Amphilius cryptobullatus
Amphilius jacksonii
Amphilius kivuensis
Amphilius natalensis
Amphilius uranoscopus
Amphilius zairensis
Anguilla bengalensis labiata
Anguilla bicolor bicolor
Anguilla marmorata
Anguilla mossambica
Aplocheilichthys hutereaui
Aplocheilichthys johnstoni
Aplocheilichthys katangae
Aplocheilichthys macrurus
Cyrtocara ornatus
Cyrtocara orthognathus
Cyrtocara pictus
Cyrtocara placodon
Cyrtocara polystigma
Cyrtocara rostratus
Cyrtocara virgatus
Cyrtocara woodi
Dimidiochromis dimidiatus
Dimidiochromis kiwinge
Dinotopterus cunningtoni
Diplotaxodon argenteus
Diplotaxodon greenwoodi
Distichodus maculatus
Distichodus mossambicus
Distichodus schenga
Docimodus evelynae
Docimodus johnstoni
Doumea alula
Dules rupestris
Ectodus descampsi
Eleotris fusca
Eleotris melanosoma
Enantiopus melanogenys
Engraulicypris sardella
Eretmodus cyanostictus
Euchilichthys guentheri
Euchilichthys royauxi
Eutropiellus longifilis
Exochochromis anagenys
Galaxias zebratus
Gambusia affinis
Genyochromis mento
Gerres acinaces
Gerres rappi
Gilchristella aestuaria
Glossogobius callidus
Glossogobius giuris
Gnathochromis permaxillaris
Gnathochromis pfefferi
Nimbochromis fuscotaeniatus
Nimbochromis linni
Nimbochromis livingstonii
Nimbochromis polystigma
Nimbochromis venustus
Nothobranchius furzeri
Nothobranchius kirki
Nothobranchius kuhntae
Nothobranchius orthonotus
Nothobranchius rachovii
Nyassachromis breviceps
Nyassachromis leuciscus
Nyassachromis nigritaeniatus
Odaxothrissa vittata
Oncorhynchus mykiss
Ophthalmotilapia nasuta
Ophthalmotilapia ventralis
Opsaridium microcephalus
Opsaridium microlepis
Opsaridium peringueyi
Opsaridium tweddleorum
Opsaridium zambezense
Opthalmochromis ventralis
Oreochromis andersonii
Oreochromis macrochir
Oreochromis mortimeri
Oreochromis mossambicus
Oreochromis niloticus
Oreochromis placidus
Oreochromis saka
Oreochromis shiranus
Oreochromis squamipinnis
Oreochromis tanganyicae
Otopharynx argyrosoma
Otopharynx auromarginatus
Otopharynx brooksi
Otopharynx decorus
Otopharynx heterodon
Otopharynx speciosus
Otopharynx tetraspilus

Aplocheilichthys moeruensis
Aplocheilichthys myaposae
Aplocheilichthys pumilus
Aristochromis christyi
Asprotilapia leptura
Astatotilapia burtoni
Astatotilapia calliptera
Astatotilapia tweddlei
Astyanax orthodus
Atherina breviceps
Auchenoglanis occidentalis
Aulonocara guentheri
Aulonocara macrochir
Aulonocara nyassae
Aulonocara rostratum
Aulonocranus dewindti
Austroglanis barnardi
Austroglanis gilli
Austroglanis sclateri
Awaous aeneofuscus
Bagrus meridionalis
Baileychromis centropomoides
Barbus acuticeps
Barbus aeneus
Barbus afrohamiltoni
Barbus afrovernayi
Barbus amatolicus
Barbus andrewi
Barbus annectens
Barbus anoplus
Barbus apleurogramma
Barbus arcislongae
Barbus argenteus
Barbus atkinsoni
Barbus barnardi
Barbus barotseensis
Barbus bellcrossi
Barbus bifrenatus
Barbus brevicauda
Barbus breviceps
Barbus brevidorsalis
Barbus brevipinnis
Barbus calidus
Barbus capensis
Grammatotria lemairii
Greenwoodochromis bellcrossi
Haplochromis acutidens
Haplochromis argyrosoma
Haplochromis burtoni
Haplochromis caeruleus
Haplochromis chrysonotus
Haplochromis cinereus
Haplochromis compressiceps
Haplochromis horei
Haplochromis inornatus
Haplochromis intermedius
Haplochromis kirkii
Haplochromis lacrimosus
Haplochromis loweae
Haplochromis moorii
Haplochromis nototaenia
Haplochromis prodromus
Haplochromis riponiarus
Haplochromis rostratus
Haplochromis sauvagei
Haplochromis selenurus
Haplochromis triaenodon
Haplotaxodon microlepis
Hemibates stenosoma
Hemichromis elongatus
Hemigrammocharax machadoi
Hemigrammocharax multifasciatus
Hemigrammopetersius barnardi
Hemitaeniochromis urotaenia
Hemitilapia oxyrhyncha
Hepsetus odoe
Heterobranchus boulengeri
Heterobranchus longifilis
Hippichthys heptagonus
Hippopotamyrus ansorgii
Hippopotamyrus discorhynchus
Hoplotilapia retrodens
Hydrocynus vittatus
Hypophthalmichthys molitrix
Hyporhamphus capensis
Hyporhamphus delagoae
Hyporhamphus knysnaensis
Hypseleotris dayi
Paracyprichromis brieni
Paracyprichromis nigripinnis
Parakneria fortuita
Parakneria mossambica
Parauchenoglanis ngamensis
Parauchenoglanis occidentalis
Pareutropius longifilis
Perca fluviatilis
Perissodus lecqui
Perissodus microlepis
Perissodus multidentatus
Perissodus paradoxus
Perissodus straeleni
Petrocephalus catostoma
Petrocephalus simus
Petrochromis ephippium
Petrochromis famula
Petrochromis fasciolatus
Petrochromis macrognathus
Petrochromis orthognathus
Petrochromis polyodon
Petrochromis trewavasae
Petrotilapia genalutea
Petrotilapia nigra
Petrotilapia tridentiger
Phalloceros caudimaculatus
Pharyngochromis acuticeps
Phractura lindica
Phyllonemus typus
Placidochromis longimanus
Placidochromis macrognathus
Placidochromis subocularis
Platyallabes tihoni
Platycephalus indicus
Platygnathochromis melanonotus
Plotosus anguillaris
Poecilia reticulata
Pollimyrus castelnaui
Polypterus endlicheri
Pomatomus saltator
Potamothrissa obtusi rostris
Protomelas annectens
Protomelas kirkii
Protomelas labridens

Barbus choloensis
Barbus codringtonii
Barbus dorsolineatus
Barbus erubescens
Barbus eurystomus
Barbus eutaenia
Barbus fasciolatus
Barbus gurneyi
Barbus haasianus
Barbus hospes
Barbus innocens
Barbus johnstonii
Barbus kerstenii
Barbus kessleri
Barbus kimberleyensis
Barbus lineomaculatus
Barbus litamba
Barbus lornae
Barbus macrotaenia
Barbus manicensis
Barbus marequensis
Barbus mattozi
Barbus miolepis
Barbus motebensis
Barbus multilineatus
Barbus natalensis
Barbus neefi
Barbus owenae
Barbus pallidus
Barbus paludinosus
Barbus pellegrini
Barbus permistus
Barbus poechii
Barbus polylepis
Barbus radiatus
Barbus serra
Barbus tetrastigma
Barbus thamalakanensis
Barbus toppini
Barbus trachypterus
Barbus treurensis
Barbus trevelyani
Barbus trimaculatus
Barbus tropidolepis
Julidochromis dickfeldi
Julidochromis marlieri
Julidochromis ornatus
Julidochromis regani
Julidochromis transcriptus
Kneria auriculata
Kneria maydelli
Kneria paucisquamata
Kneria polli
Kneria wittei
Kuhlia rupestris
Kyphosus cinerascens
Labeo altivelis
Labeo ansorgii
Labeo capensis
Labeo congoro
Labeo cylindricus
Labeo lunatus
Labeo mesops
Labeo molybdinus
Labeo nasus
Labeo rosae
Labeo rubromaculatus
Labeo ruddi
Labeo seeberi
Labeo umbratus
Labeotropheus fuelleborni
Labeotropheus trewavasre
Labidochromis caeruleus
Labidochromis chisumulae
Labidochromis flavigulis
Labidochromis freibergi
Labidochromis gigas
Labidochromis heterodon
Labidochromis ianthinus
Labidochromis maculicauda
Labidochromis mbenjii
Labidochromis pallidus
Labidochromis shiranus
Labidochromis strigatus
Labidochromis vellicans
Lamprichthys tanganicanus
Lamprologus callipterus
Lamprologus kungweensis
Protomelas marginatus
Protomelas similis
Protomelas spilopterus
Protomelas taeniolatus
Protomelas triaenodon
Protopterus aethiopicus
Protopterus annectens
Protopterus annectens brieni
Psammogobius knysnaensis
Pseudobarbus afer
Pseudobarbus asper
Pseudobarbus burchelli
Pseudobarbus burgi
Pseudobarbus phlegethon
Pseudobarbus quathlambae
Pseudobarbus tenuis
Pseudocrenilabrus philander
Pseudosimochromis curvifrons
Pseudotropheus auratus
Pseudotropheus aurora
Pseudotropheus elegans
Pseudotropheus elongatus
Pseudotropheus gracilior
Pseudotropheus johanni
Pseudotropheus livingstonii
Pseudotropheus lombardai
Pseudotropheus lucerna
Pseudotropheus microstoma
Pseudotropheus minutus
Pseudotropheus tropheops
Pseudotropheus williamsi
Pseudotropheus zebra
Pterois volitans
Ptyochromis annectens
Redigobius dewaali
Reganochromis calliurus
Rhabdalestes maunensis
Rhabdalestes rhodesiensis
Rhabdosargus holubi
Rhamphochromis esox
Rhamphochromis longiceps
Rhamphochromis macrophthalmus
Rhamphochromis sox
Rheoglanis dendrophorus

Barbus unitaeniatus
Barbus variabilis
Barbus viviparus
Barbus zanzibaricus
Bathybagrus teranema
Bathyclarias filicibarbis
Bathyclarias foveolatus
Bathyclarias gigas
Bathyclarias longibarbis
Bathyclarias loweae
Bathyclarias meridionalis
Bathyclarias nyasensis
Bathyclarias rotundifrons
Bathyclarias worthingtoni
Benthochromis melanoides
Benthochromis tricoti
Boulengerochromis microlepis
Brachydanio albolineatus
Brycinus imberi
Brycinus lateralis
Bryconaethiops boulengeri
Buccochromis heterotaenia
Buccochromis lepturus
Buccochromis nototaenia
Buccochromis spectabilis
Caffrogobius multifasciatus
Cafrogobius caffer
Callochromis macrops
Callochromis pleurospilus
Campylomormyrus cassaicus
Campylomormyrus elephas
Caprichromis orthognathus
Caranx equula
Caranx fasciatus
Caranx hippos
Caranx ignobilis
Caranx sexfasciatus
Carassius auratus
Chalinochromis brichardi
Champsochromis caerulea
Champsochromis spilorhynchus
Channa punctata
Chanos chanos
Chelaethiops minutus
Lamprologus laparogramma
Lamprologus lemairei
Lamprologus moorei
Lamprologus ornatipinnis
Lamprologus signatus
Lamprologus werneri
Lates augustifrons
Lates mariae
Leiognathus equula
Lepidiolamprologus attenuatus
Lepidiolamprologus cunningtoni
Lepidiolamprologus elongatus
Lepidiolamprologus kendalli
Lepidiolamprologus profundico
Lepomis macrochirus
Leptoglanis cf. dorae
Leptoglanis lacustris
Leptoglanis rotundiceps
Lethrinops albus
Lethrinops altus
Lethrinops argentea
Lethrinops aurita
Lethrinops brevis
Lethrinops christyi
Lethrinops furcifer
Lethrinops gossei
Lethrinops lethrinus
Lethrinops longimanus
Lethrinops longipinnis
Lethrinops macracanthus
Lethrinops macrochir
Lethrinops macropthalmus
Lethrinops micrentodon
Lethrinops microdon
Lethrinops mylodon
Lethrinops parvidens
Lethrinops polli
Lethrinops praeorbitalis
Lethrinops stridei
Lichnochromis acutileps
Limnochromis abeelei
Limnochromis auritus
Limnochromis pfefferi
Limnothrissa miodon
Salmo trutta
Salvelinus fontinalis
Sandelia bainsii
Sandelia capensis
Sargochromis carlottae
Sargochromis codringtonii
Sargochromis coulteri
Sargochromis giardi
Sargochromis gracilis
Sargochromis greenwoodi
Sargochromis mellandi
Schilbe banguelensis
Schilbe intermedius
Schilbe nasalis
Schilbe yangambianus
Schwetzochromis luongoensis
Schwetzochromis machadoi
Sciaenochromis ahli
Sciaenochromis gracilis
Sciaenochromis spiloticus
Serranochromis altus
Serranochromis angusticeps
Serranochromis longimanus
Serranochromis macrocephalus
Serranochromis meridianus
Serranochromis robustus
Serranochromis robustus jallae
Serranochromis robustus robustus
Serranochromis stappersi
Serranochromis thumbergi
Silhouettea sibayi
Sillago sihama
Simochromis diagramma
Simochromis loocki
Simochromis margaretae
Simochromis marginatus
Simochromis pleurospilus
Solea bleekeri
Stenogobius kenyae
Stigmatochromis modestus
Stigmatochromis pholidophorus
Stigmatochromis woodi
Stolothrissa tanganicae
Strongylura leiura

Chetia brevis
Chetia flaviventris
Chetia mola
Chiloglanis anoterus
Chiloglanis bifurcus
Chiloglanis carnosus
Chiloglanis deckenii
Chiloglanis elizabethianus
Chiloglanis emarginatus
Chiloglanis fasciatus
Chiloglanis macropterus
Chiloglanis neumanni
Chiloglanis nilotinus
Chiloglanis paratus
Chiloglanis pretoriae
Chiloglanis swierstrai
Chilotilapia rhoadesii
Chrysichthys brachynema
Chrysichthys grandis
Chrysichthys platycephalus
Chrysichthys sianenna
Chrysichthys stappersi
Clariallabes platyprosopos
Clarias buthupogon
Clarias cavernicola
Clarias gariepinus
Clarias liocephalus
Clarias ngamensis
Clarias stappersii
Clarias theodorae
Clinid sp.
Clypeobarbus pseudognathon
Copadichromis azureus
Copadichromis chrysonotus
Copadichromis eucinostomus
Copadichromis jacksoni
Copadichromis mloto
Copadichromis pleurostigma
Copadichromis prostoma
Copadichromis quadrimaculatus
Copadichromis trimaculatus
Copadichromis virginalis
Coptostomabarbus bellcrossi
Coptostomabarbus wittei
Limnotilapia dardeni
Liza macrolepis
Liza richardsonii
Liza tricuspidens
Lobochilotes labiatus
Lophiobagrus brevispinnis
Lophiobagrus cyclurus
Lutjanus argentimaculatus
Lycodontis punctatus
Malapterurus electricus
Maravichromis anaphyrus
Maravichromis formosus
Maravichromis guentheri
Maravichromis incola
Maravichromis labidon
Maravichromis mollis
Maravichromis semipalatus
Maravichromis sphaerodon
Marcusenius livingstonii
Marcusenius macrolepidotus
Mastacembelus apteryx
Megalops cyprinoides
Melanochromis auratus
Melanochromis brevis
Melanochromis chipokne
Melanochromis joanjohnsonae
Melanochromis melanopterus
Melanochromis parallelus
Melanochromis vermivorus
Mesobola brevianalis
Micralestes acutidens
Micralestes sardina
Micralestes stormsi
Microctenopoma intermedium
Microdontochromis tenuidentata
Microphis brachyurus
Microphis fluviatilis
Micropterus dolomieu
Micropterus punctulatus
Micropterus salmoides
Monodactylus argenteus
Monodactylus falciformis
Mormyrops anguilloides
Mormyrops deliciosus
Syngnathus cyanospilus
Synodontis acanthomias
Synodontis dhonti
Synodontis eurystomus
Synodontis greshoffi
Synodontis katangae
Synodontis leopardinus
Synodontis macrostigma
Synodontis macrostoma
Synodontis multipunctatus
Synodontis nebulosus
Synodontis nigromaculatus
Synodontis nyassae
Synodontis ornatipinnis
Synodontis petricola
Synodontis thamalakanensis
Synodontis vanderwaali
Synodontis woosnami
Synodontis zambezensis
Taeniochromis holotaenia
Taeniolethrinops laticeps
Taeniolethrinops praeorbitalis
Taenoides esquivel
Tanganikallabes mortiauxi
Telmatochromis burgeoni
Telmatochromis dhoti
Telmatochromis temporalis
Telmatochromis vittatus
Telogramma gracile
Thoracochromis albolabris
Thoracochromis buysi
Tilapia baloni
Tilapia guinasana
Tilapia rendalli
Tilapia rendalli rendalli
Tilapia rendalli swierstrae
Tilapia ruweti
Tilapia shirana chilwae
Tilapia sparrmanii
Tilapia swierstrae
Tilapia tanganicae
Tinca tinca
Tramitichromis liturus
Tramitichromis variabilis

Corematodus shiranus
Corematodus taeniatus
Croilia mossambica
Ctenochromis benthicola
Ctenochromis horei
Ctenopharyngodon idella
Ctenopharynx intermedius
Ctenopharynx nitidus
Ctenopoma multispine
Cunningtonia longiventralis
Cyathochromis obliquidens
Cyathopharynx furcifer
Cynotilapia afra
Cynotilapia frontosa
Cyprichromis leptosoma
Cyprichromis pavo
Cyprinus carpio
Cyrtocara anaphyrmus
Cyrtocara compressiceps
Cyrtocara euchilus
Cyrtocara eucinostomus
Cyrtocara fenestratus
Cyrtocara intermedia
Cyrtocara johnstonii
Cyrtocara kiwinge
Cyrtocara lepteris
Cyrtocara livingstonii
Cyrtocara mola
Cyrtocara moorii
Mormyrus lacerda
Mormyrus longirostris
Mugil cephalus
Mugilogobius inhacae
Myxus capensis
Naevochromis chrysogaster
Nannocharax gracilis
Nannocharax macropterus
Neolamprologus bifasciatus
Neolamprologus brevis
Neolamprologus brichardi
Neolamprologus buescheri
Neolamprologus calliurus
Neolamprologus caudopunctatus
Neolamprologus christyi
Neolamprologus fasciatus
Neolamprologus furcifer
Neolamprologus hecqui
Neolamprologus kiritvaitha
Neolamprologus mondabu
Neolamprologus moorei
Neolamprologus multifasciatus
Neolamprologus mustax
Neolamprologus obscurus
Neolamprologus prochilus
Neolamprologus savoryi
Neolamprologus sexfasciatus
Neolamprologus tetracanthus
Neolamprologus toae
Trematocara macrostoma
Trematocranus jacobfreibergi
Trematocranus placodon
Trichogaster trichopterus
Triglachromis otostigma
Tropheus moorei
Tylochromis bangwelensis
Tylochromis polylepis
Tyrannochromis macrostoma
Tyrannochromis nigriventer
Valamugil cunnesius
Varicorhinus dimidiatus
Varicorhinus nasutus
Varicorhinus nelspruitensis
Varicorhinus nyasensis
Varicorhinus pungweensis
Varicorhinus tanganicae
Varicorhinus tyrocheilus
Varicorhinus xyrocheilus
Xenotilapia bathyphila
Xenotilapia caudofasciata
Xenotilapia flavipinnis
Xenotilapia ochragenys
Xenotilapia papillio
Xenotilapia sima
Xenotilapia spiloptera
Xiphophorus helleri
Xiphophorus maculatus
Zaireichthys chobensis

APPENDIX C

LIST OF MEGABASINS IN THE ATLAS

Table C.1 Megabasins of the SADC countries in the atlas of southern African freshwater fish

1	Balombo
2	Berg
3	Black Umbuluzi
4	Breë
5	Buzi (Revue)
6	Cunene
7	Etosha Pan
8	Gamtoos
9	Gourits
10	Great Fish
11	Gururo
12	Incomati
13	Kafue
14	Kei
15	Kuiseb
16	Limpopo
17	Lower Zambezi
18	Maputo
19	Mbashe
20	Mfolozi
21	Middle Zambezi
22	Mkuze (St. Lucia)
23	Numerous small pans
24	Okavango
25	Olifants
26	Orange
27	Pungwe
28	Ruvuma
29	Save
30	Sundays
31	Swakop
32	Tugela
33	Ugab
34	Umgeni
35	Umkomanzi
36	Umzimkulu
37	Umzimvubu
38	Upper Zambezi
39	Zaire

APPENDIX D

LIST OF DIGITAL MAP LAYERS IN THE ATLAS

Table D.1 List of digital map layers in the atlas of southern African freshwater fish

File name	Country	Description	Data source	Layer type
ao_adm1	Angola	national borders	RRSP	vector
ao_adm2	Angola	province borders	RRSP	vector
ao_adm3	Angola	district borders	RRSP	vector
ao_urbn	Angola	urbanised areas as polygons	RRSP	vector
ao_cova	Angola	wetlands and other land cover areas	RRSP	vector
ao_park	Angola	national parks	RRSP	vector
ao_wetl	Angola	wetlands, classified by type	RRSP	vector
ao_laken	Angola	lakes (one subdivision)	RRSP	vector
ao_lakes	Angola	lakes (one subdivision)	RRSP	vector
ao_lakec	Angola	lakes (one subdivision)	RRSP	vector
ao_npwat	Angola	non-perrenial water polygons	RRSP	vector
ao_pwat	Angola	perrenial water polygons	RRSP	vector
ao_rivc	Angola	rivers (one subdivision)	RRSP	vector
ao_rivn	Angola	rivers (one subdivision)	RRSP	vector
ao_rivs	Angola	rivers (one subdivision)	RRSP	vector
ao_elev	Angola	1000m contours	RRSP	vector
ao_rail	Angola	railroads	RRSP	vector
ao_road	Angola	roads	RRSP	vector
bw_adm1	Botswana	national borders	RRSP	vector
bw_adm2	Botswana	province borders	RRSP	vector
bw_adm3	Botswana	district borders	RRSP	vector
bw_cova	Botswana	wetlands and other land cover areas	RRSP	vector
bw_wetl	Botswana	wetlands, classified by type	RRSP	vector
bw_park	Botswana	national parks	RRSP	vector
bw_lake	Botswana	lakes	RRSP	vector
bw_pwat	Botswana	perrenial water polygons	RRSP	vector
bw_riv	Botswana	rivers	RRSP	vector
bw_elev	Botswana	1000m contours	RRSP	vector
bw_rail	Botswana	railroads	RRSP	vector
bw_road	Botswana	roads	RRSP	vector
ls_adm1	Lesotho	national borders	RRSP	vector
ls_adm2	Lesotho	province borders	RRSP	vector
ls_park	Lesotho	national parks	RRSP	vector
ls_wetl	Lesotho	wetlands, classified by type	RRSP	vector
ls_lake	Lesotho	lakes	RRSP	vector
ls_pwat	Lesotho	perrenial water polygons	RRSP	vector
ls_riv	Lesotho	rivers	RRSP	vector
ls_elev	Lesotho	1000m contours	RRSP	vector
ls_road	Lesotho	roads	RRSP	vector
mw_adm1	Malawi	national borders	RRSP	vector
mw_adm2	Malawi	province borders	RRSP	vector
mw_adm3	Malawi	district borders	RRSP	vector
mw_urbn	Malawi	urbanised areas as polygons	RRSP	vector
mw_cova	Malawi	wetlands and other land cover areas	RRSP	vector
mw_park	Malawi	national parks	RRSP	vector

mw_pwat	Malawi	perrenial water polygons	RRSP	vector
mw_lake	Malawi	lakes	RRSP	vector
mw_riv	Malawi	rivers	RRSP	vector
mw_elev	Malawi	1000m contours	RRSP	vector
mw_rail	Malawi	railroads	RRSP	vector
mw_road	Malawi	roads	RRSP	vector
mz_adm1	Mozambique	national borders	RRSP	vector
mz_adm2	Mozambique	province borders	RRSP	vector
mz_urbn	Mozambique	urbanised areas as polygons	RRSP	vector
mz_cova	Mozambique	wetlands and other land cover areas	RRSP	vector
mz_park	Mozambique	national parks	RRSP	vector
mz_wetl	Mozambique	wetlands, classified by type	RRSP	vector
mz_lakec	Mozambique	lakes (one subdivision)	RRSP	vector
mz_lakee	Mozambique	lakes (one subdivision)	RRSP	vector
mz_lakes	Mozambique	lakes (one subdivision)	RRSP	vector
mz_lakew	Mozambique	lakes (one subdivision)	RRSP	vector
mz_pwat	Mozambique	perrenial water polygons	RRSP	vector
mz_rivc	Mozambique	rivers (one subdivision)	RRSP	vector
mz_rive	Mozambique	rivers (one subdivision)	RRSP	vector
mz_rivs	Mozambique	rivers (one subdivision)	RRSP	vector
mz_rivw	Mozambique	rivers (one subdivision)	RRSP	vector
mz_elev	Mozambique	1000m contours	RRSP	vector
mz_rail	Mozambique	railroads	RRSP	vector
mz_road	Mozambique	roads	RRSP	vector
na_adm1	Namibia	national borders	RRSP	vector
na_adm2	Namibia	province borders	RRSP	vector
na_park	Namibia	national parks	RRSP	vector
na_riv	Namibia	rivers	RRSP	vector
na_npwat	Namibia	non-perrenial water polygons	RRSP	vector
na_elev	Namibia	1000m contours	RRSP	vector
na_road	Namibia	roads	RRSP	vector
na_rail	Namibia	railroads	RRSP	vector
sz_adm1	Swaziland	national borders	RRSP	vector
sz_adm2	Swaziland	province borders	RRSP	vector
sz_park	Swaziland	national parks	RRSP	vector
sz_wood	Swaziland	production forest, classified by type	RRSP	vector
sz_wetl	Swaziland	wetlands, classified by type	RRSP	vector
sz_lake	Swaziland	lakes	RRSP	vector
sz_pwat	Swaziland	non-perrenial water polygons	RRSP	vector
sz_riv	Swaziland	rivers	RRSP	vector
sz_elev	Swaziland	1000m contours	RRSP	vector
sz_road	Swaziland	roads	RRSP	vector
sz_rail	Swaziland	railroads	RRSP	vector
tz_adm1	Tanzania	national borders	RRSP	vector
tz_adm2	Tanzania	province borders	RRSP	vector
tz_urbn	Tanzania	urbanised areas as polygons	RRSP	vector
tz_lakee	Tanzania	lakes (one subdivision)	RRSP	vector
tz_laken	Tanzania	lakes (one subdivision)	RRSP	vector
tz_lakes	Tanzania	lakes (one subdivision)	RRSP	vector
tz_lakew	Tanzania	lakes (one subdivision)	RRSP	vector

tz_npwat	Tanzania	non-perrenial water polygons	RRSP	vector
tz_rive	Tanzania	rivers (one subdivision)	RRSP	vector
tz_rivn	Tanzania	rivers (one subdivision)	RRSP	vector
tz_rivs	Tanzania	rivers (one subdivision)	RRSP	vector
tz_rivw	Tanzania	rivers (one subdivision)	RRSP	vector
tz_elsl	Tanzania	1000m contours	RRSP	vector
tz_rail	Tanzania	railroads	RRSP	vector
za_adm1	South Africa	national borders	RRSP	vector
za_adm2	South Africa	province borders	RRSP	vector
za_adm3	South Africa	district borders	RRSP	vector
za_urbn	South Africa	urbanised areas as polygons	RRSP	vector
za_wetl	South Africa	wetlands, classified by type	RRSP	vector
za_lakee	South Africa	lakes (one subdivision)	RRSP	vector
za_laken	South Africa	lakes (one subdivision)	RRSP	vector
za_lakes	South Africa	lakes (one subdivision)	RRSP	vector
za_lakew	South Africa	lakes (one subdivision)	RRSP	vector
za_lakex	South Africa	lakes (one subdivision)	RRSP	vector
za_npwat	South Africa	non-perrenial water polygons	RRSP	vector
za_rive	South Africa	rivers (one subdivision)	RRSP	vector
za_rivn	South Africa	rivers (one subdivision)	RRSP	vector
za_rivs	South Africa	rivers (one subdivision)	RRSP	vector
za_rivw	South Africa	rivers (one subdivision)	RRSP	vector
za_rivx	South Africa	rivers (one subdivision)	RRSP	vector
za_elev	South Africa	1000m contours	RRSP	vector
za_road	South Africa	roads	RRSP	vector
za_rail	South Africa	railroads	RRSP	vector
zm_adm1	Zambia	national borders	RRSP	vector
zm_adm2	Zambia	province borders	RRSP	vector
zm_adm3	Zambia	district borders	RRSP	vector
zm_urbn	Zambia	urbanised areas as polygons	RRSP	vector
zm_cova	Zambia	wetlands and other land cover areas	RRSP	vector
zm_park	Zambia	national parks	RRSP	vector
zm_wood	Zambia	production forest, classified by type	RRSP	vector
zm_lakec	Zambia	lakes (one subdivision)	RRSP	vector
zm_lakee	Zambia	lakes (one subdivision)	RRSP	vector
zm_lakew	Zambia	lakes (one subdivision)	RRSP	vector
zm_npwat	Zambia	non-perrenial water polygons	RRSP	vector
zm_pwat	Zambia	perrenial water polygons	RRSP	vector
zm_rivc	Zambia	rivers (one subdivision)	RRSP	vector
zm_rive	Zambia	rivers (one subdivision)	RRSP	vector
zm_rivw	Zambia	rivers (one subdivision)	RRSP	vector
zm_elev	Zambia	1000m contours	RRSP	vector
zm_rail	Zambia	railroads	RRSP	vector
zw_adm1	Zimbabwe	national borders	RRSP	vector
zw_adm2	Zimbabwe	province borders	RRSP	vector
zw_adm3	Zimbabwe	district borders	RRSP	vector
zw_cova	Zimbabwe	wetlands and other land cover areas	RRSP	vector
zw_park	Zimbabwe	national parks	RRSP	vector
zw_wetl	Zimbabwe	wetlands, classified by type	RRSP	vector
zw_wood	Zimbabwe	production forest, classified by type	RRSP	vector

zw_lake	Zimbabwe	lakes	RRSP	vector
zw_npwat	Zimbabwe	non-perrenial water polygons	RRSP	vector
zw_pwat	Zimbabwe	perrenial water polygons	RRSP	vector
zw_riv	Zimbabwe	rivers	RRSP	vector
zw_elev	Zimbabwe	1000m contours	RRSP	vector
zw_rail	Zimbabwe	railroads	RRSP	vector
dc_adm1	SADC region	national borders	RRSP	vector
dc_adm2	SADC region	province borders	RRSP	vector
dc_roads	SADC region	roads	RRSP	vector
dc_swb	SADC region	surface water bodies	ALCOM	vector
dc_ws	SADC region	watersheds	ALCOM	vector
dc_frdb	SADC region	fish record points	chapter 3	vector
DEM	SADC region	digital elevation model	GEODATEC	raster
pet_jan	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pet_feb	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pet_mar	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pet_apr	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pet_may	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pet_jun	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pet_jul	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pet_aug	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pet_sep	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pet_oct	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pet_nov	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pet_dec	SADC region	normal evapo-transpiration surfaces	RRSP	raster
pre_jan	SADC region	normal precipitation surfaces	RRSP	raster
pre_feb	SADC region	normal precipitation surfaces	RRSP	raster
pre_mar	SADC region	normal precipitation surfaces	RRSP	raster
pre_apr	SADC region	normal precipitation surfaces	RRSP	raster
pre_may	SADC region	normal precipitation surfaces	RRSP	raster
pre_jun	SADC region	normal precipitation surfaces	RRSP	raster
pre_jul	SADC region	normal precipitation surfaces	RRSP	raster
pre_aug	SADC region	normal precipitation surfaces	RRSP	raster
pre_sep	SADC region	normal precipitation surfaces	RRSP	raster
pre_oct	SADC region	normal precipitation surfaces	RRSP	raster
pre_nov	SADC region	normal precipitation surfaces	RRSP	raster
pre_dec	SADC region	normal precipitation surfaces	RRSP	raster
tav_jan	SADC region	normal average temperature surfaces	RRSP	raster
tav_feb	SADC region	normal average temperature surfaces	RRSP	raster
tav_mar	SADC region	normal average temperature surfaces	RRSP	raster
tav_apr	SADC region	normal average temperature surfaces	RRSP	raster
tav_may	SADC region	normal average temperature surfaces	RRSP	raster
tav_jun	SADC region	normal average temperature surfaces	RRSP	raster
tav_jul	SADC region	normal average temperature surfaces	RRSP	raster
tav_aug	SADC region	normal average temperature surfaces	RRSP	raster
tav_sep	SADC region	normal average temperature surfaces	RRSP	raster
tav_oct	SADC region	normal average temperature surfaces	RRSP	raster
tav_nov	SADC region	normal average temperature surfaces	RRSP	raster
tav_dec	SADC region	normal average temperature surfaces	RRSP	raster
tmn_jan	SADC region	normal minimum temp. surfaces	RRSP	raster

tmn_feb	SADC region	normal minimum temp. surfaces	RRSP	raster
tmn_mar	SADC region	normal minimum temp. surfaces	RRSP	raster
tmn_apr	SADC region	normal minimum temp. surfaces	RRSP	raster
tmn_may	SADC region	normal minimum temp. surfaces	RRSP	raster
tmn_jun	SADC region	normal minimum temp. surfaces	RRSP	raster
tmn_jul	SADC region	normal minimum temp. surfaces	RRSP	raster
tmn_aug	SADC region	normal minimum temp. surfaces	RRSP	raster
tmn_sep	SADC region	normal minimum temp. surfaces	RRSP	raster
tmn_oct	SADC region	normal minimum temp. surfaces	RRSP	raster
tmn_nov	SADC region	normal minimum temp. surfaces	RRSP	raster
tmn_dec	SADC region	normal minimum temp. surfaces	RRSP	raster
tmx_jan	SADC region	normal maximum temp. surfaces	RRSP	raster
tmx_feb	SADC region	normal maximum temp. surfaces	RRSP	raster
tmx_mar	SADC region	normal maximum temp. surfaces	RRSP	raster
tmx_apr	SADC region	normal maximum temp. surfaces	RRSP	raster
tmx_may	SADC region	normal maximum temp. surfaces	RRSP	raster
tmx_jun	SADC region	normal maximum temp. surfaces	RRSP	raster
tmx_jul	SADC region	normal maximum temp. surfaces	RRSP	raster
tmx_aug	SADC region	normal maximum temp. surfaces	RRSP	raster
tmx_sep	SADC region	normal maximum temp. surfaces	RRSP	raster
tmx_oct	SADC region	normal maximum temp. surfaces	RRSP	raster
tmx_nov	SADC region	normal maximum temp. surfaces	RRSP	raster
tmx_dec	SADC region	normal maximum temp. surfaces	RRSP	raster

APPENDIX E

FIGURES ILLUSTRATING THE MAP LAYERS IN THE ATLAS

The national borders of respective countries are included in each figure to give a frame of reference to the digital map layers.

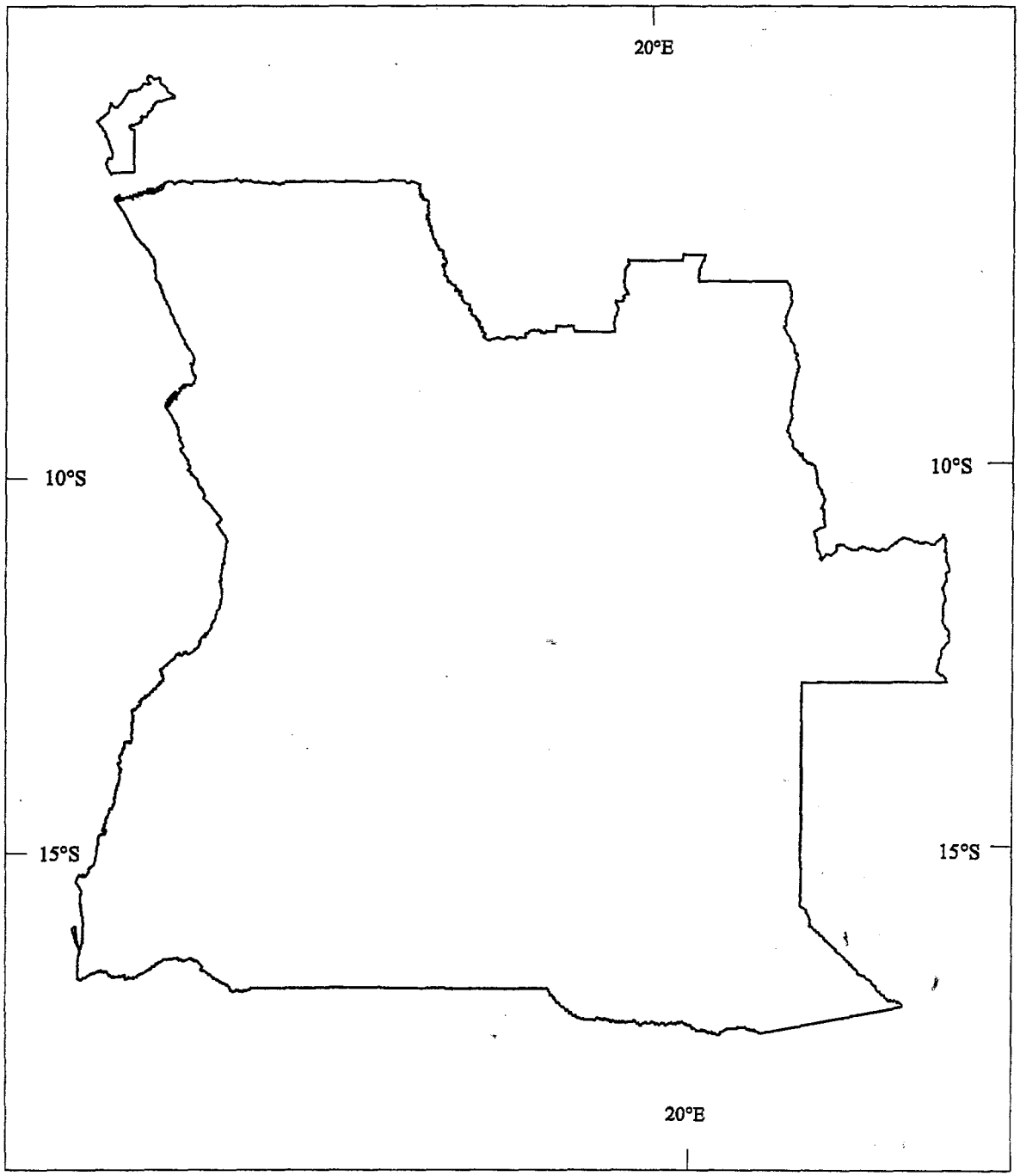


Figure E.1. Digital map layer **ao_adm1** (Angola, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

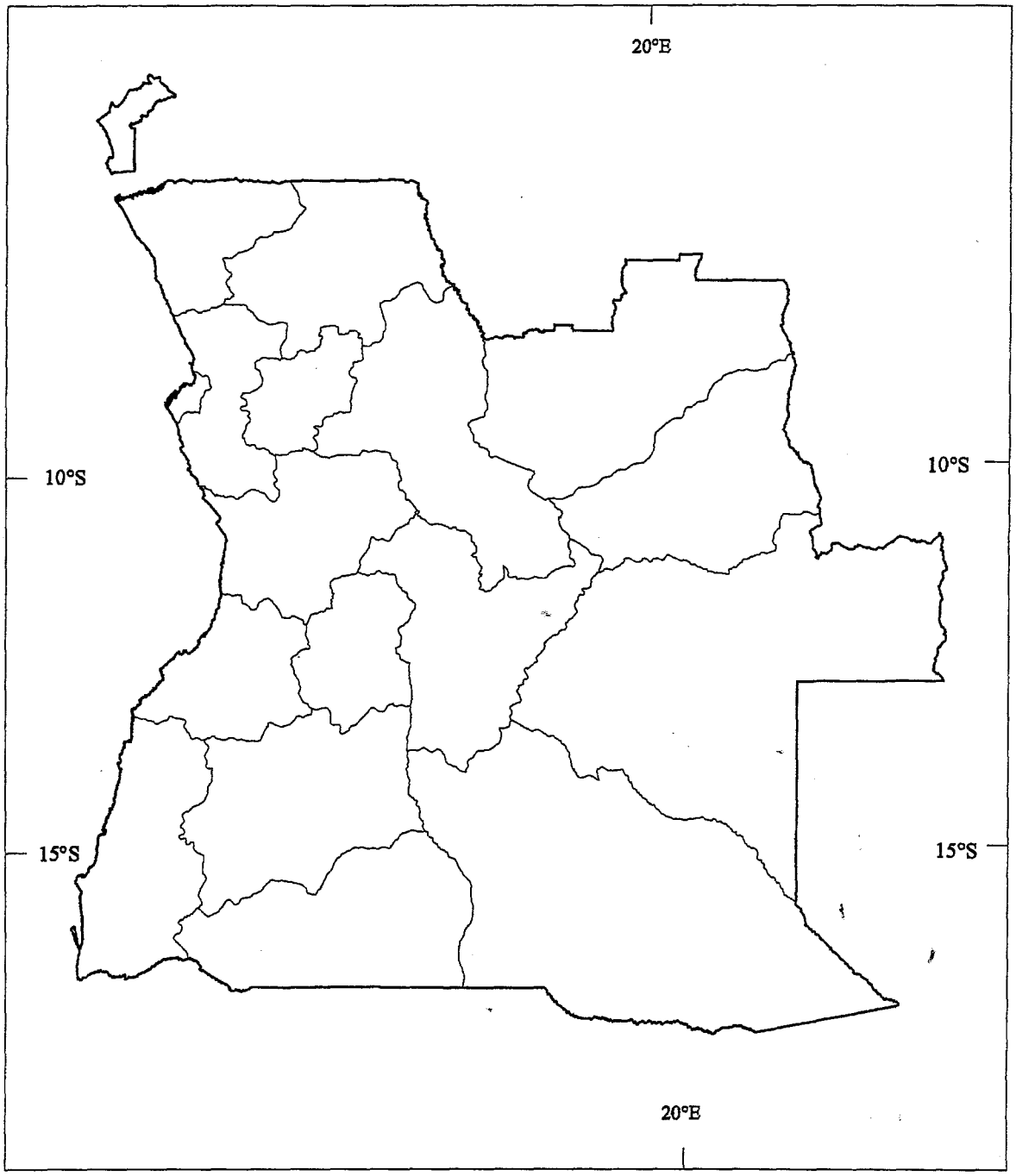


Figure E.2. Digital map layer **ao_adm2** (Angola, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

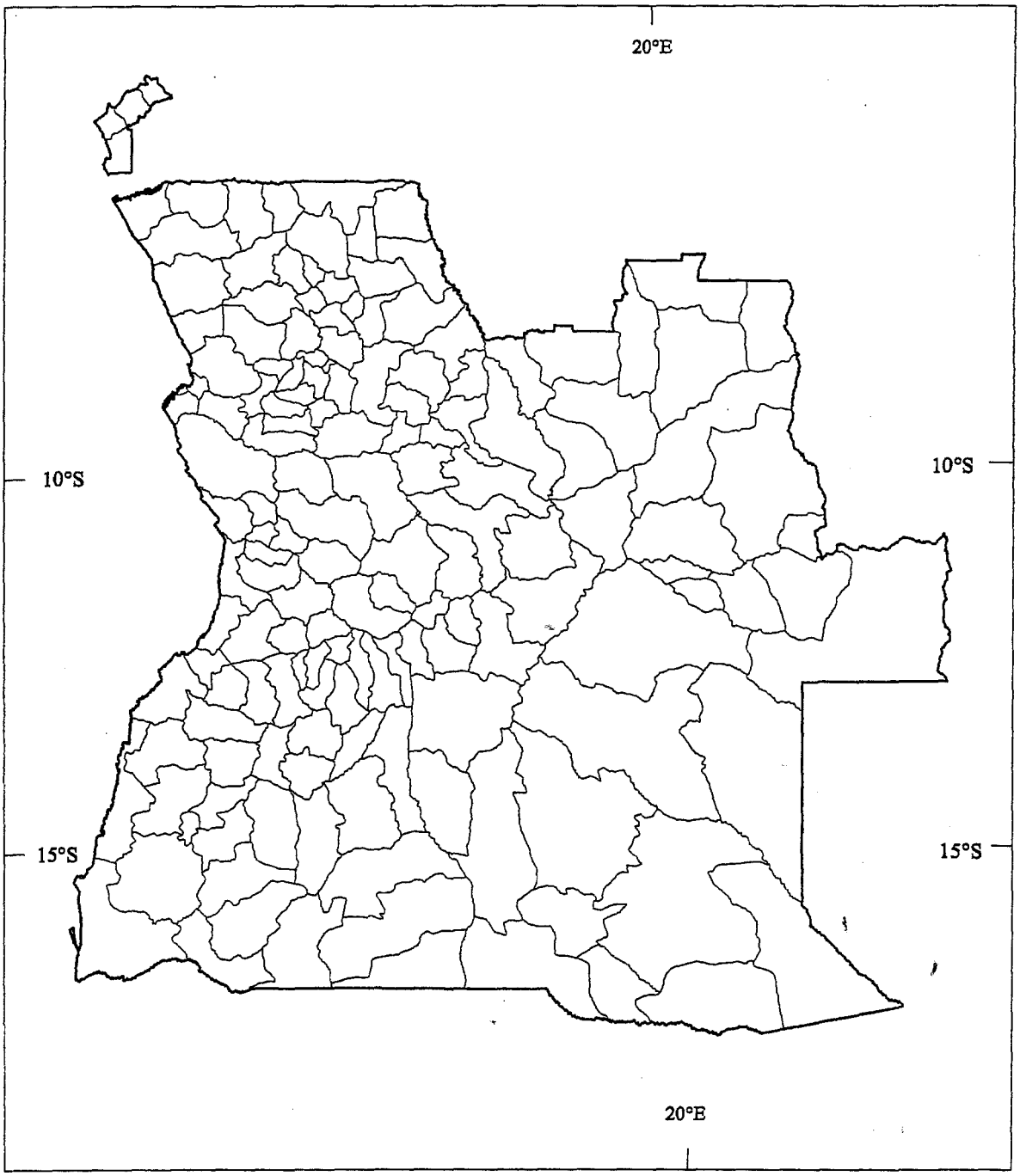


Figure E.3. Digital map layer **ao_adm3** (Angola, district borders) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

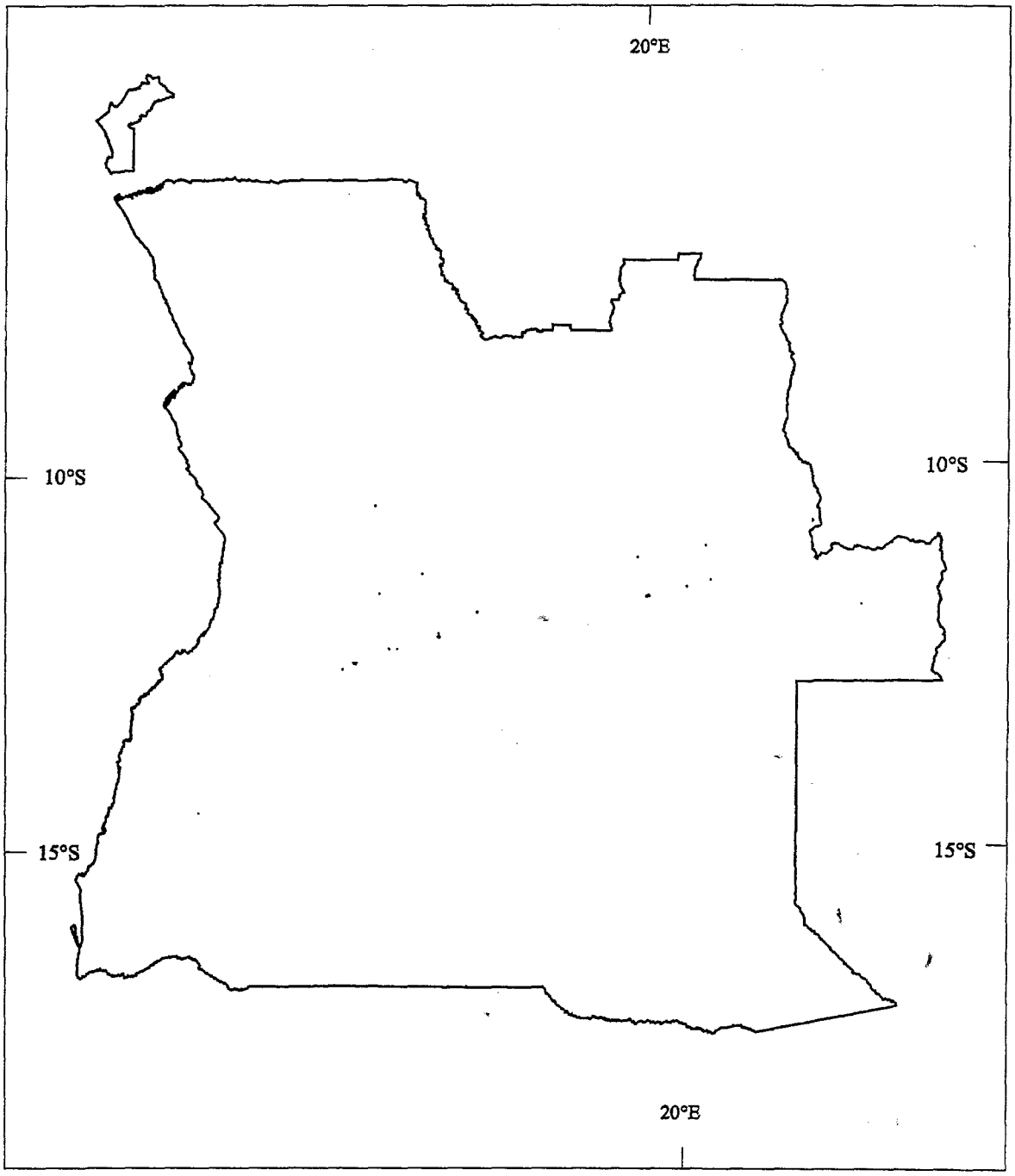


Figure E.4. Digital map layer **ao_urbn** (Angola, urbanised areas as polygons) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

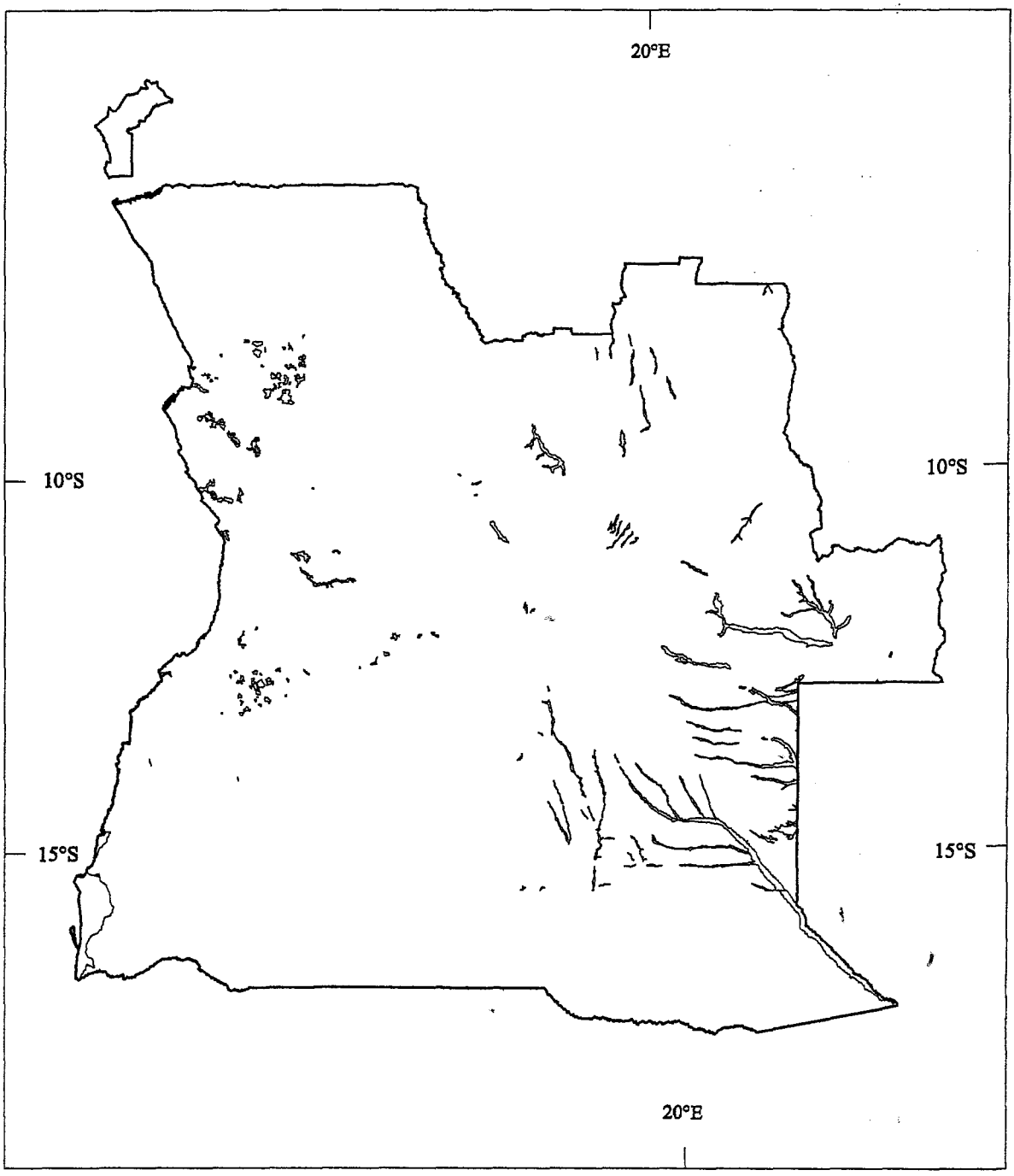


Figure E.5. Digital map layer **ao_cova** (Angola, wetlands and other land cover areas) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

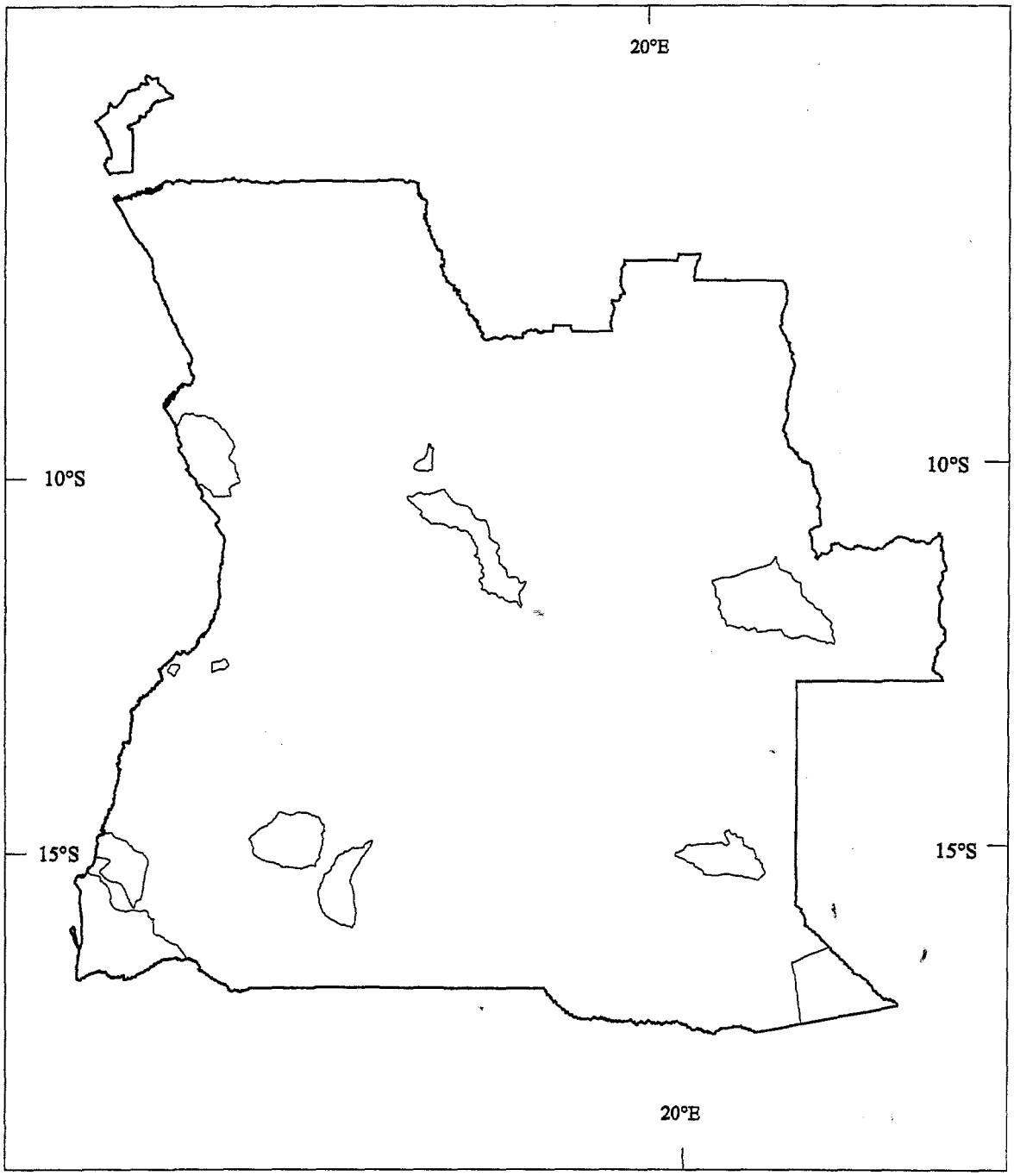


Figure E.6. Digital map layer **ao_park** (Angola, national parks) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

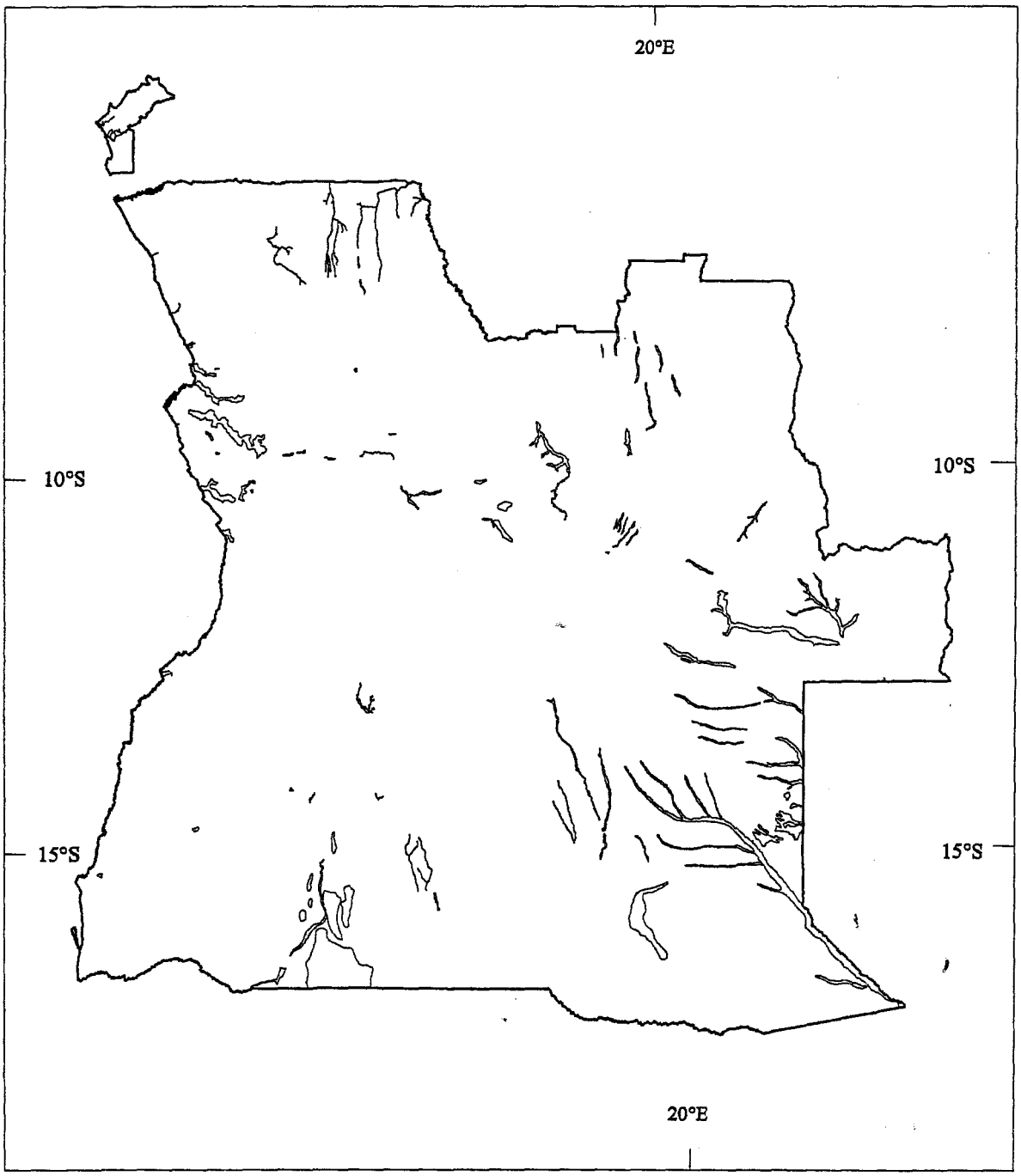


Figure E.7. Digital map layer **ao_wetl** (Angola, wetlands, classified by type) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

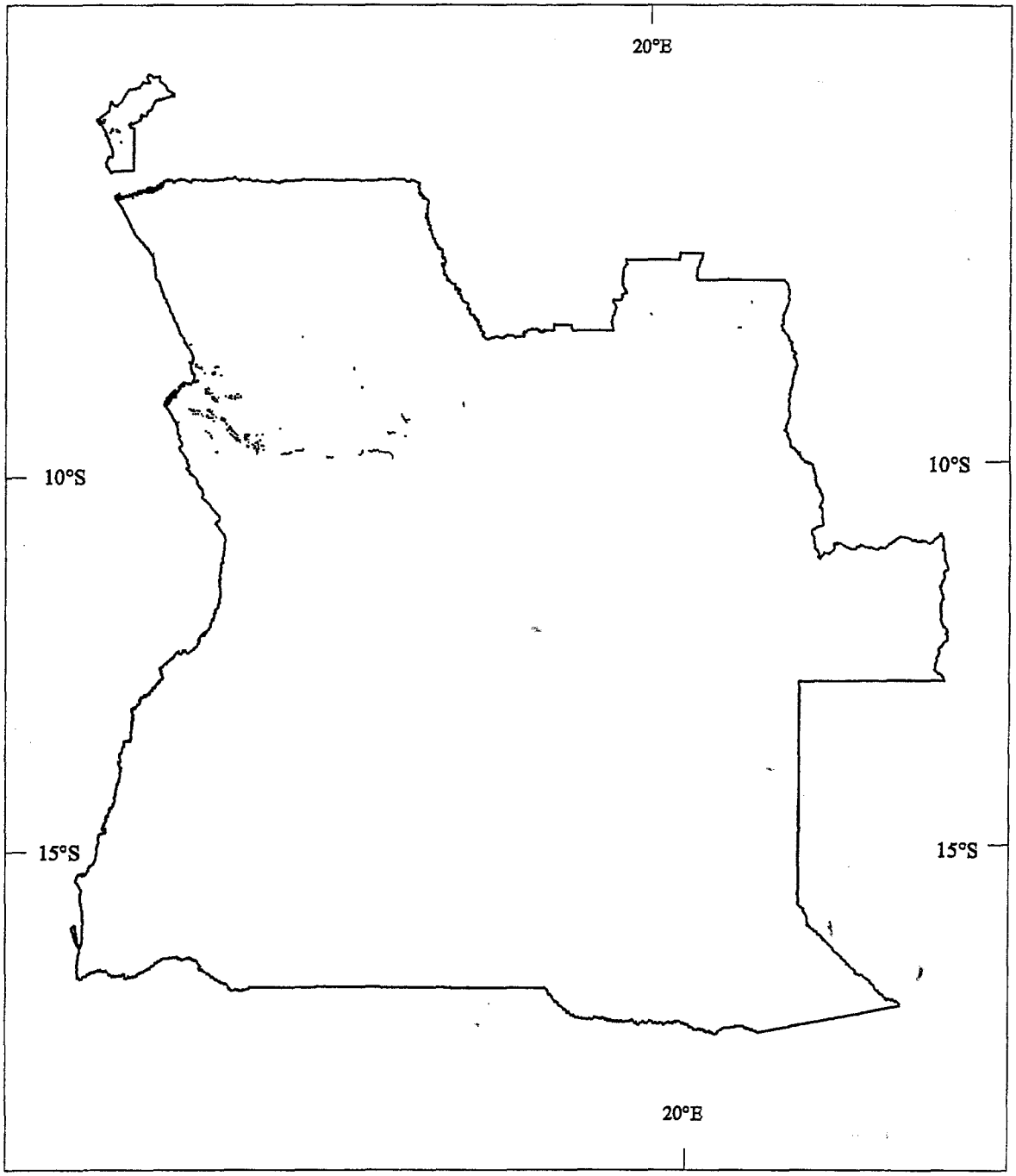


Figure E.8. Digital map layer **ao_laken** (Angola, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

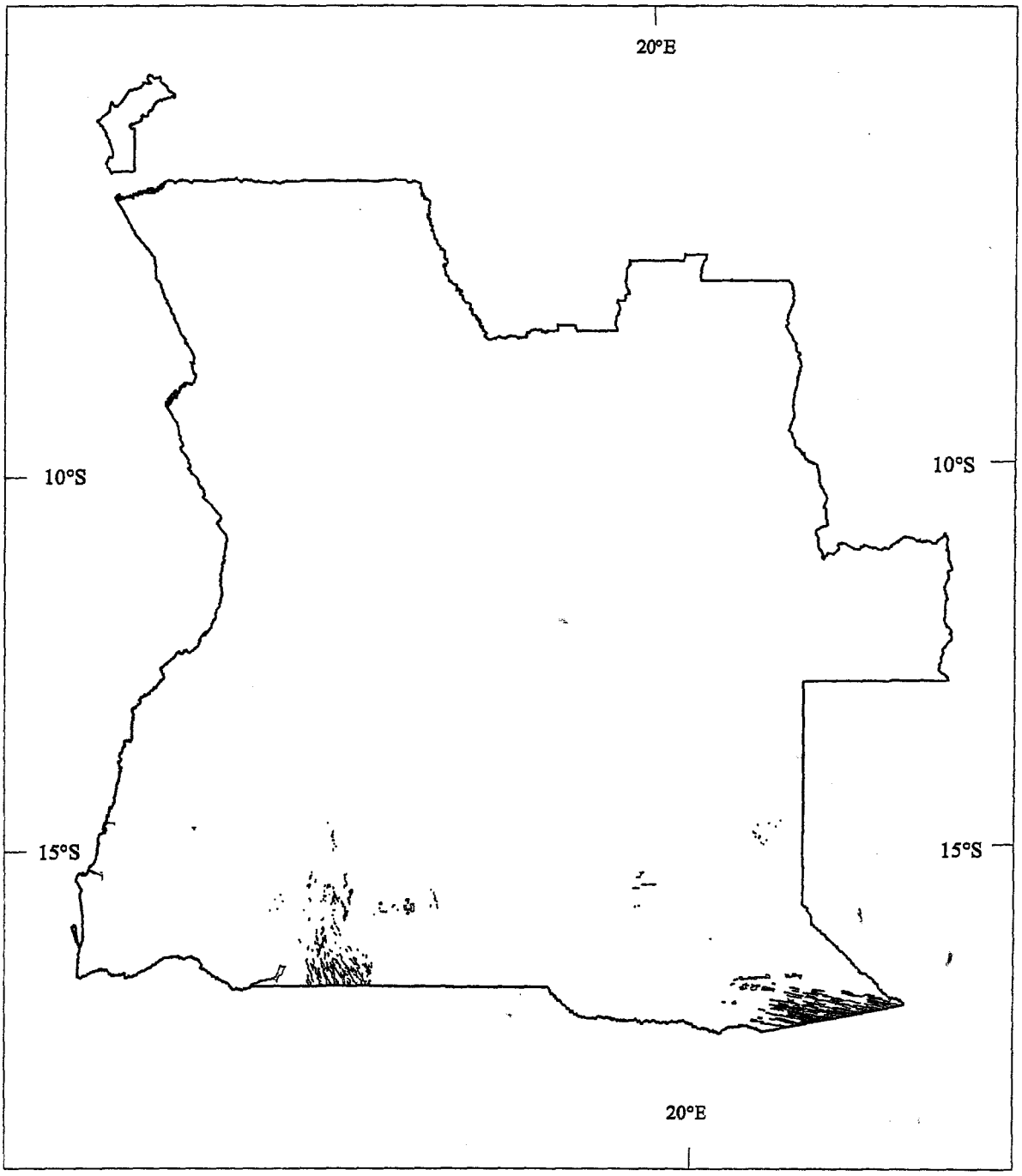


Figure E.9. Digital map layer **ao_lakes** (Angola, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

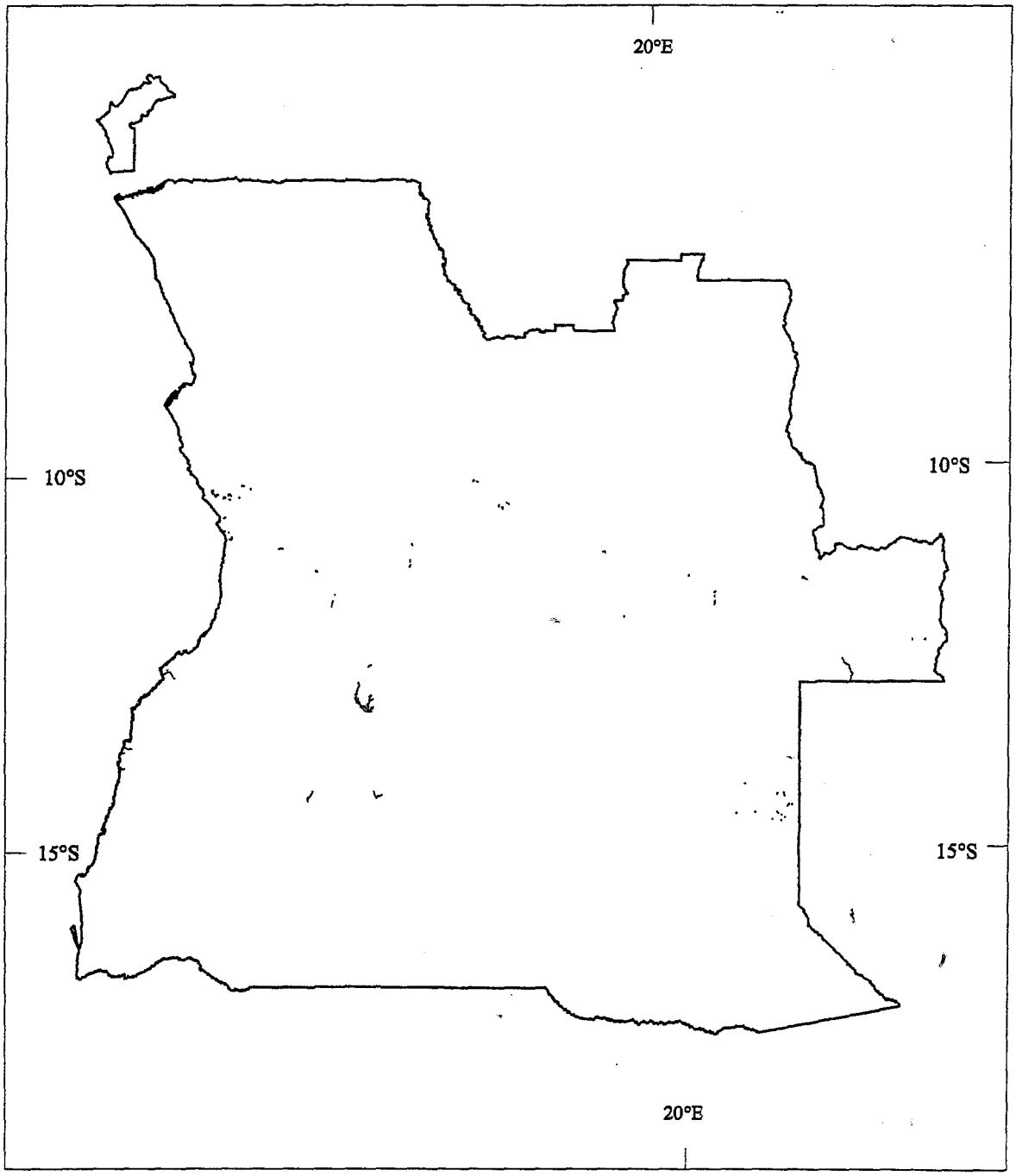


Figure E.10. Digital map layer **ao_lakec** (Angola, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

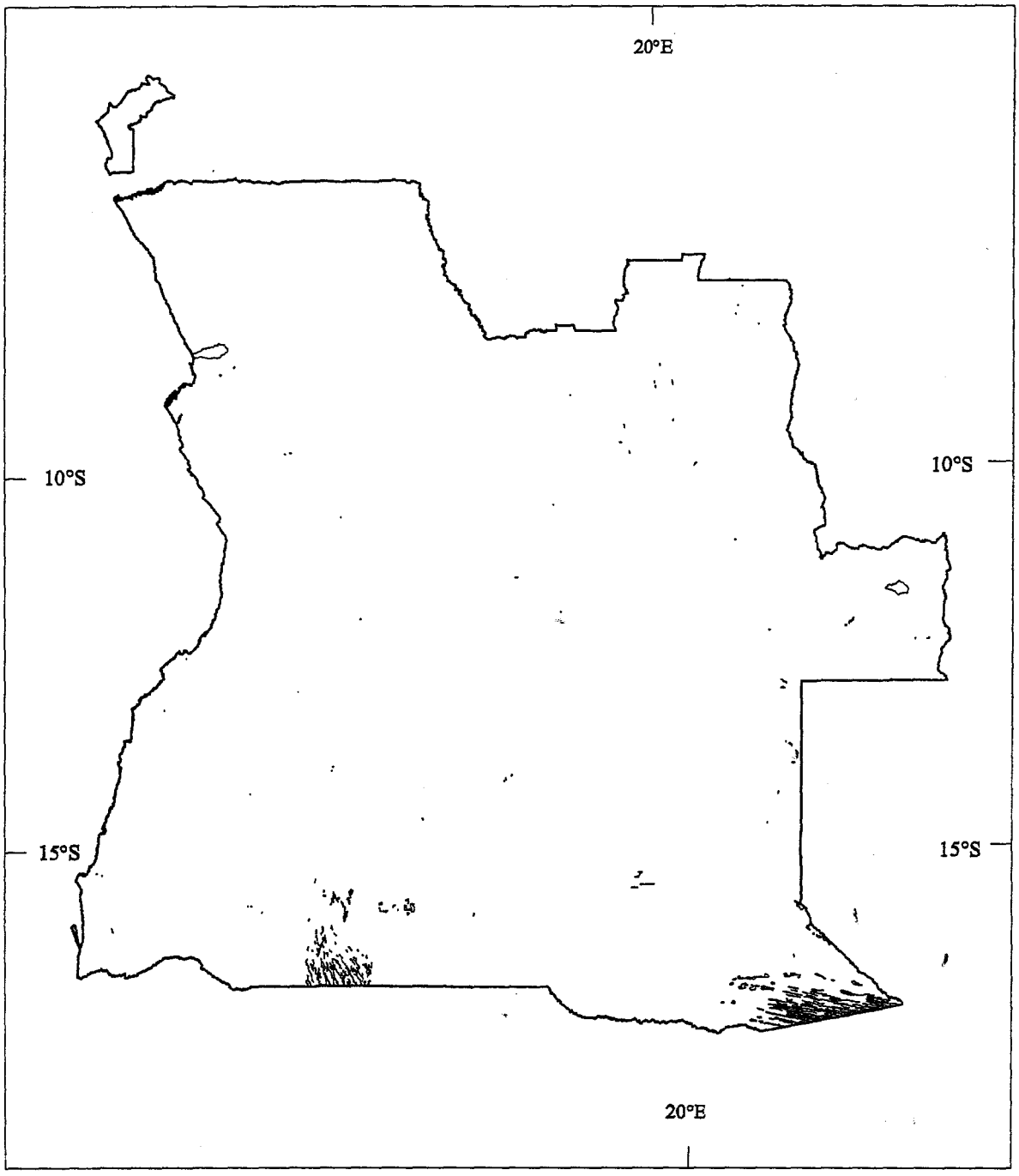


Figure E.11. Digital map layer **ao_npwat** (Angola, non-perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

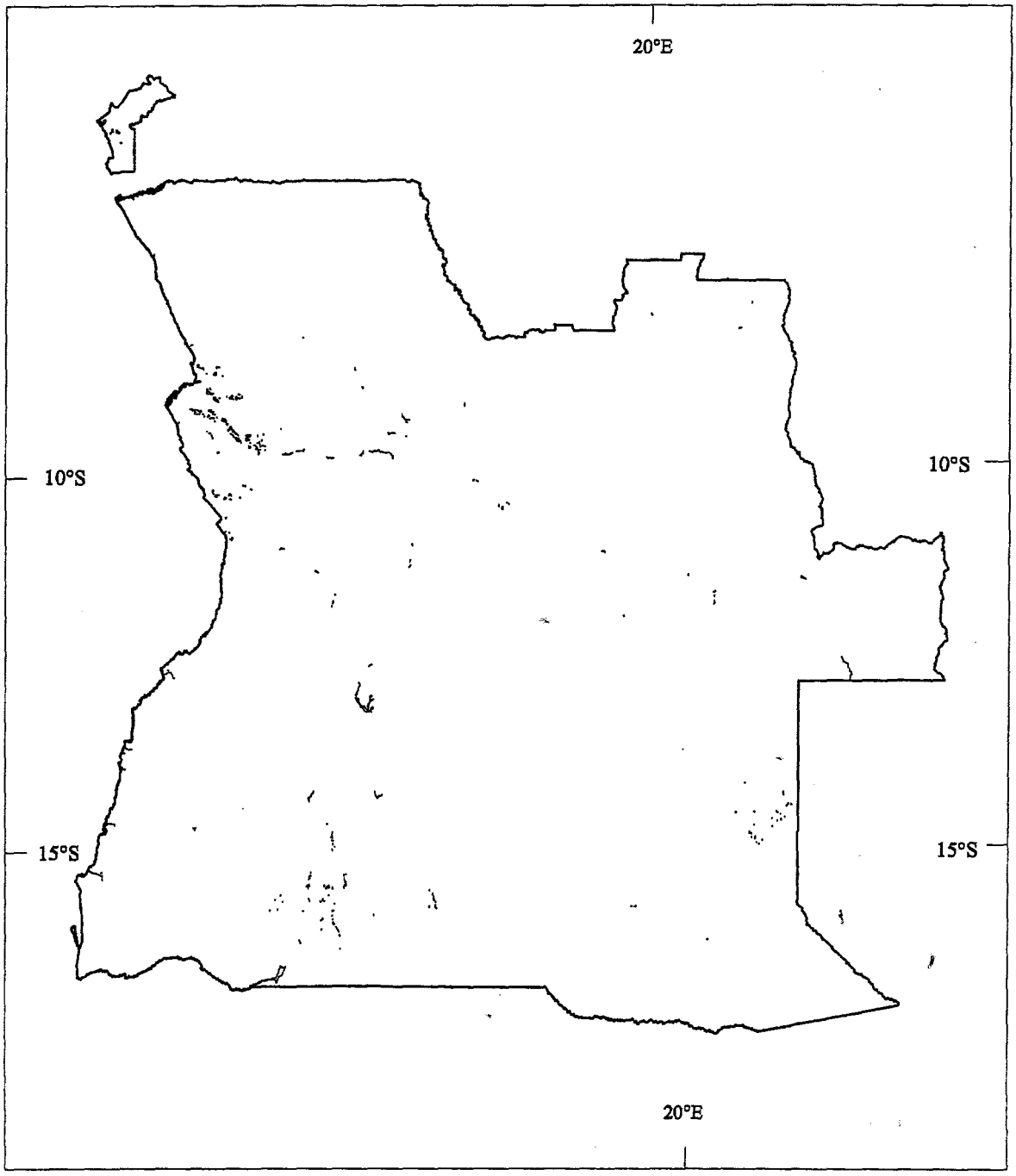


Figure E.12. Digital map layer **ao_pwat** (Angola, perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

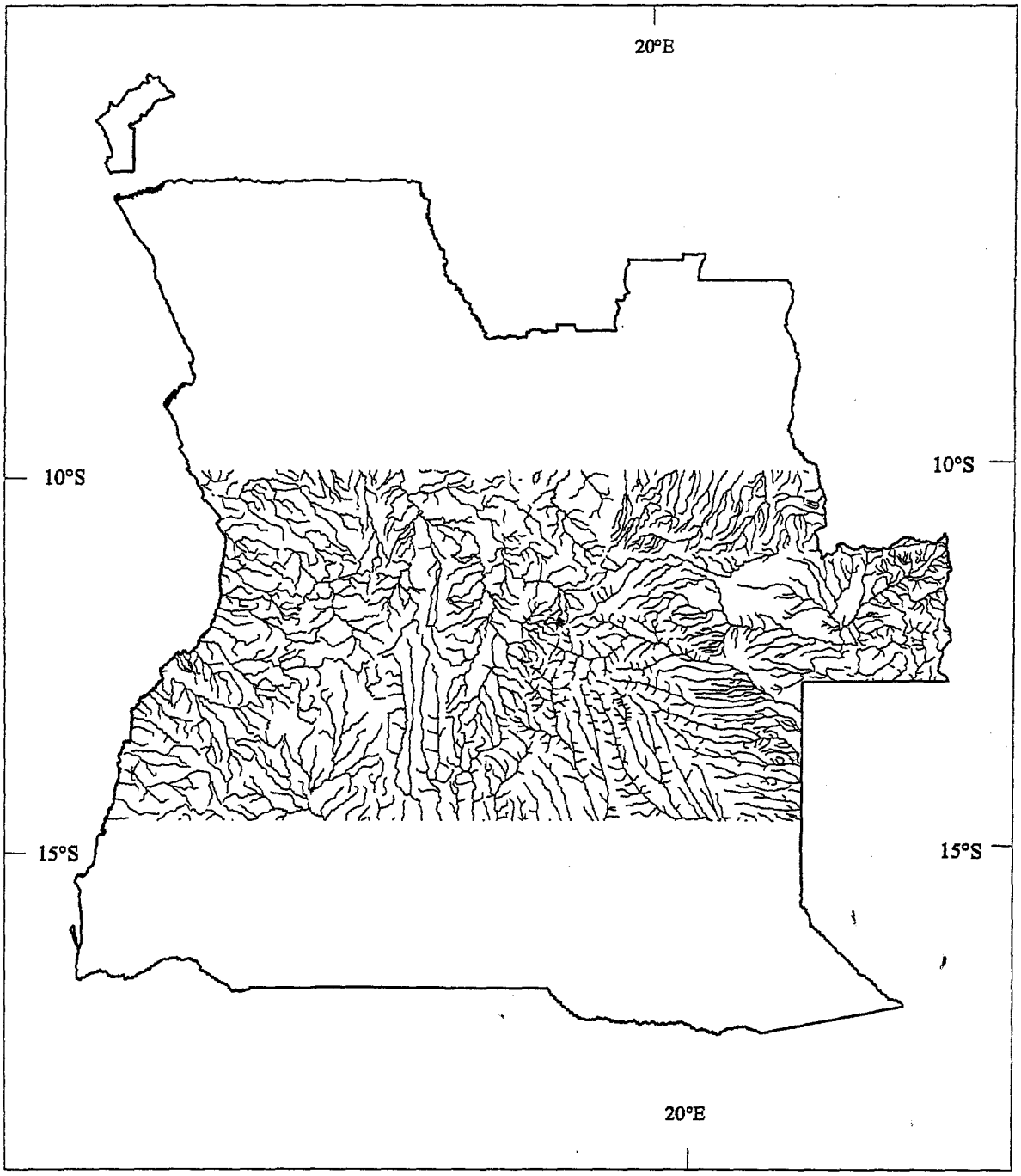


Figure E.13. Digital map layer **ao_rivc** (Angola, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

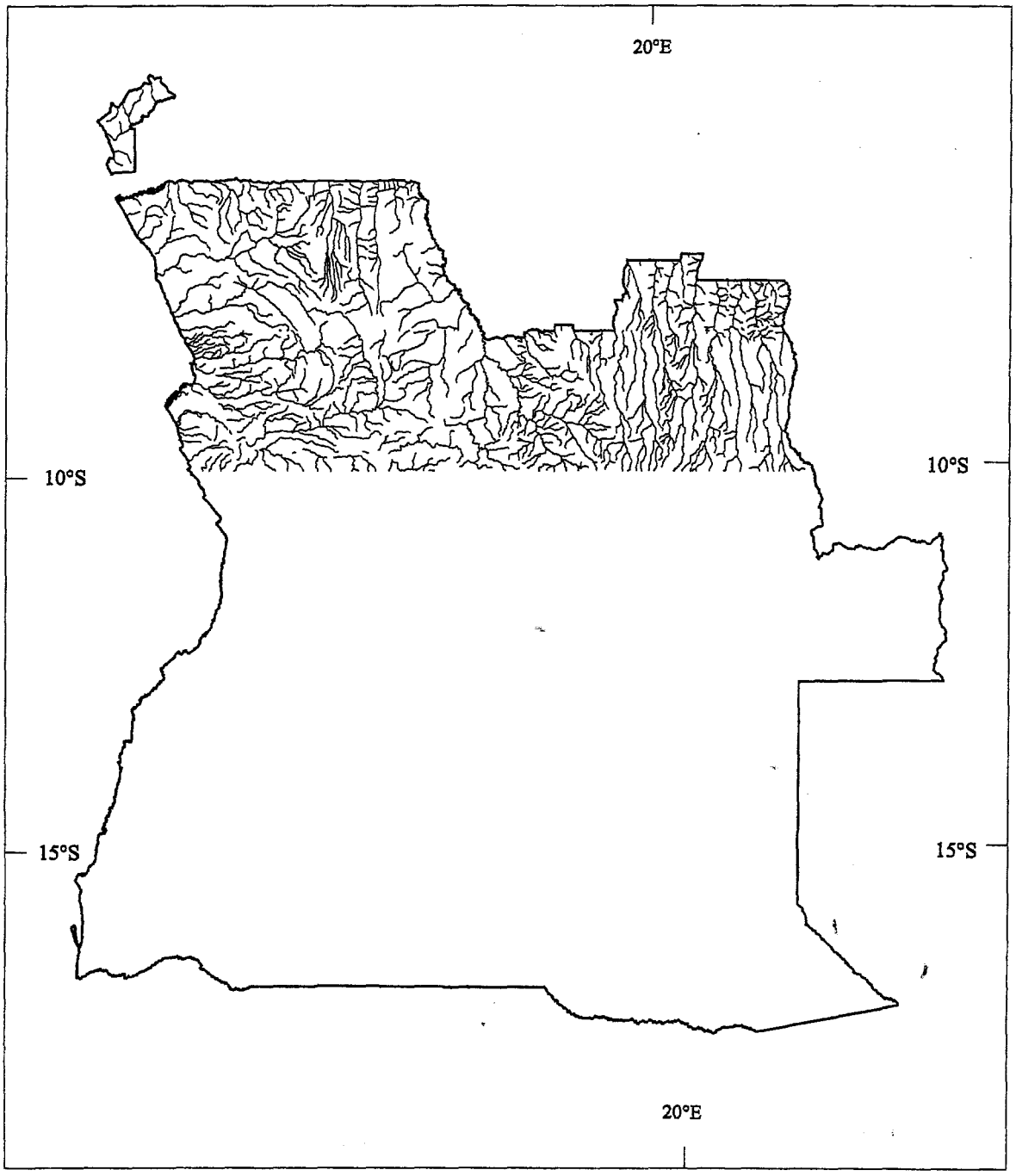


Figure E.14. Digital map layer **ao_rivn** (Angola, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

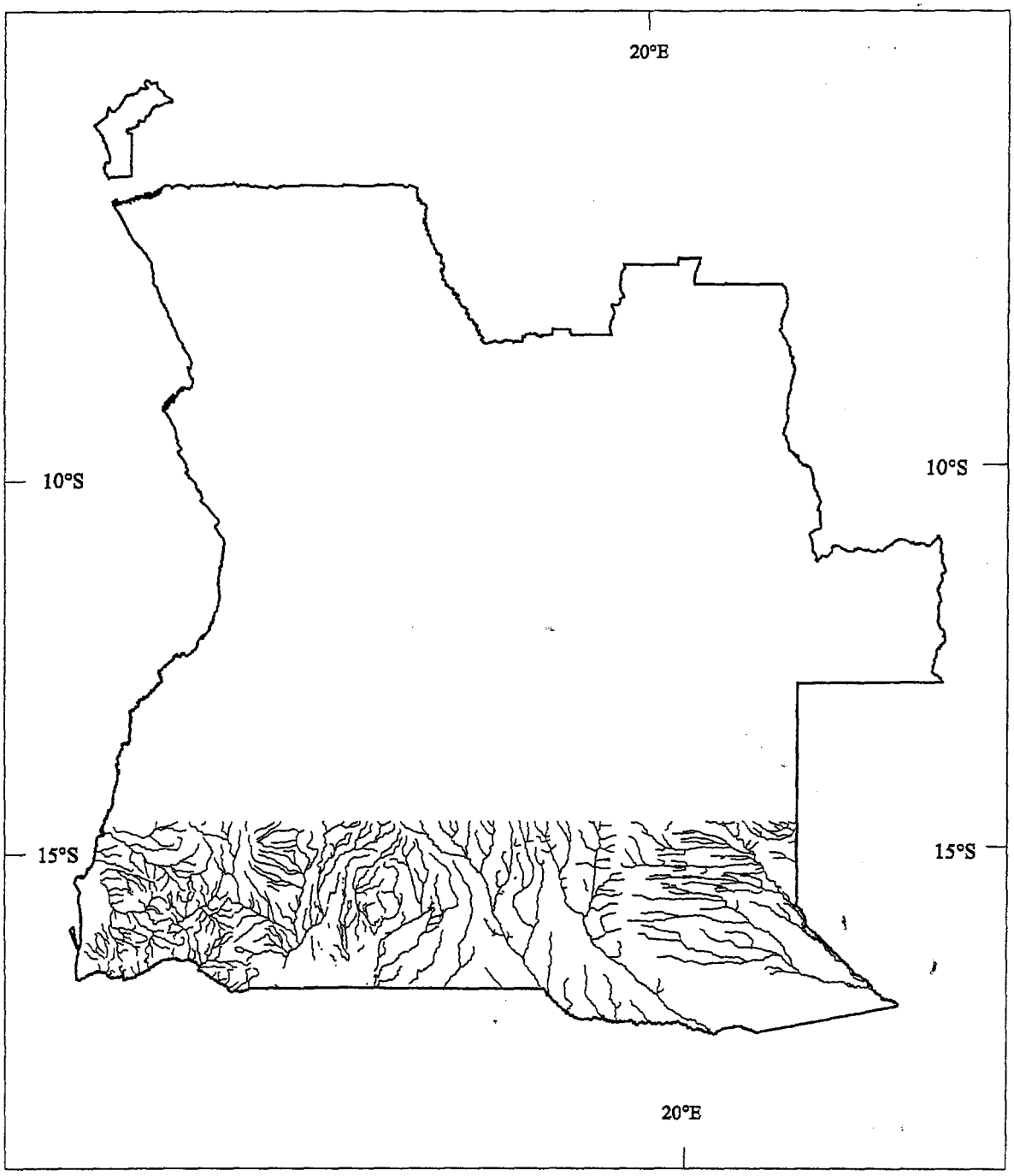


Figure E.15. Digital map layer **ao_rivs** (Angola, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

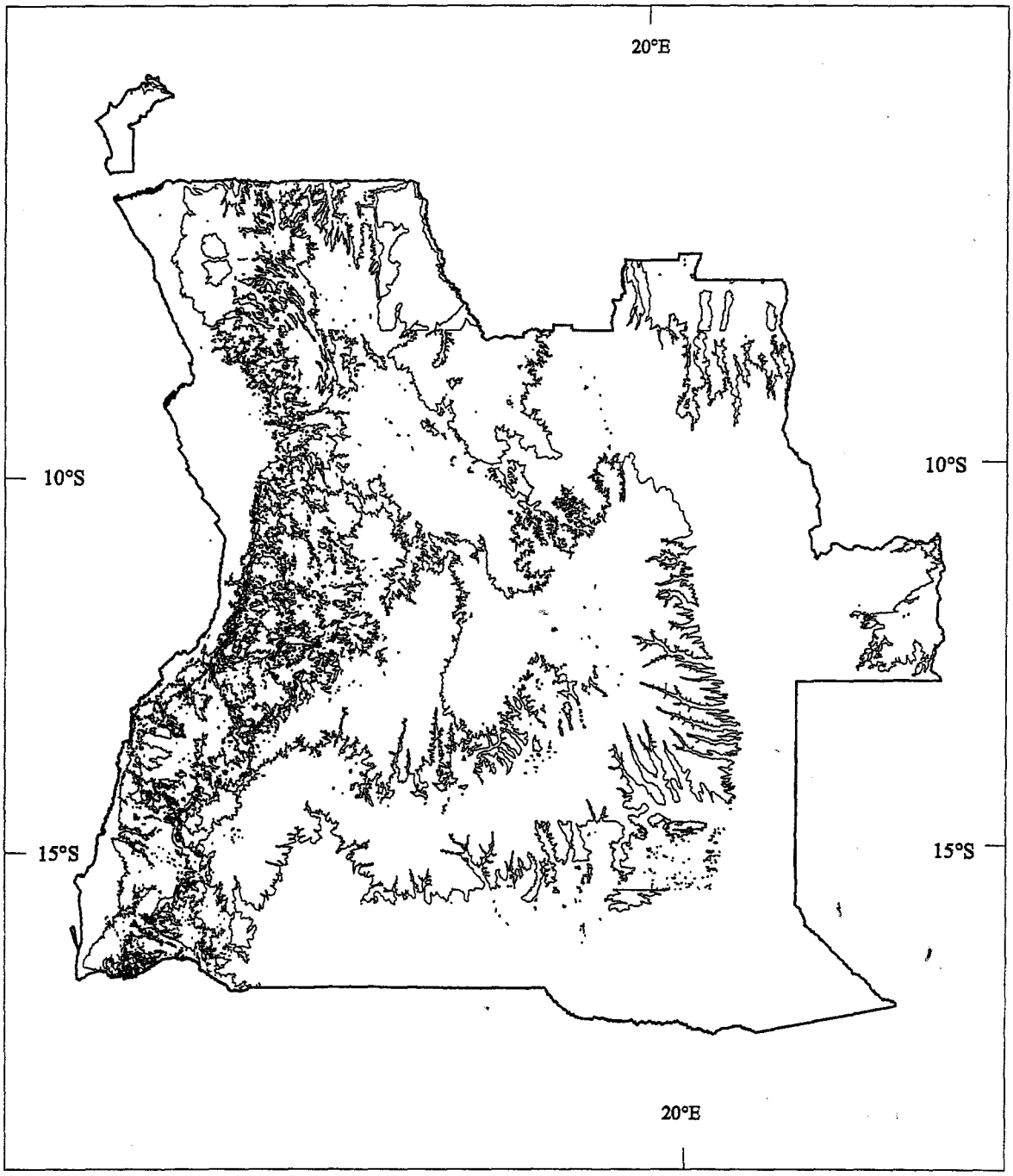


Figure E.16. Digital map layer **ao_elev** (Angola, 1000m contours) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

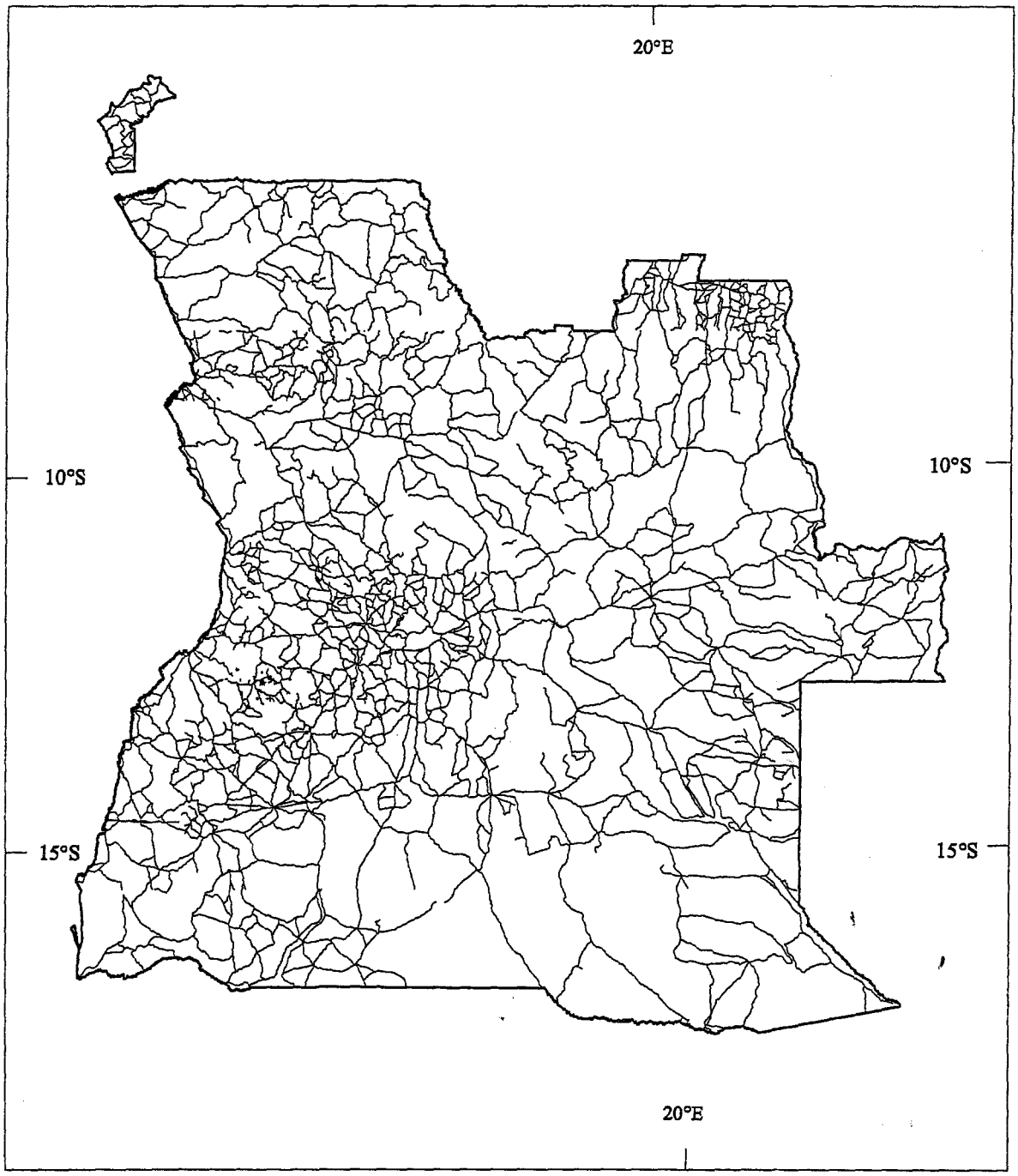


Figure E.17. Digital map layer **ao_rail** (Angola, railroads) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

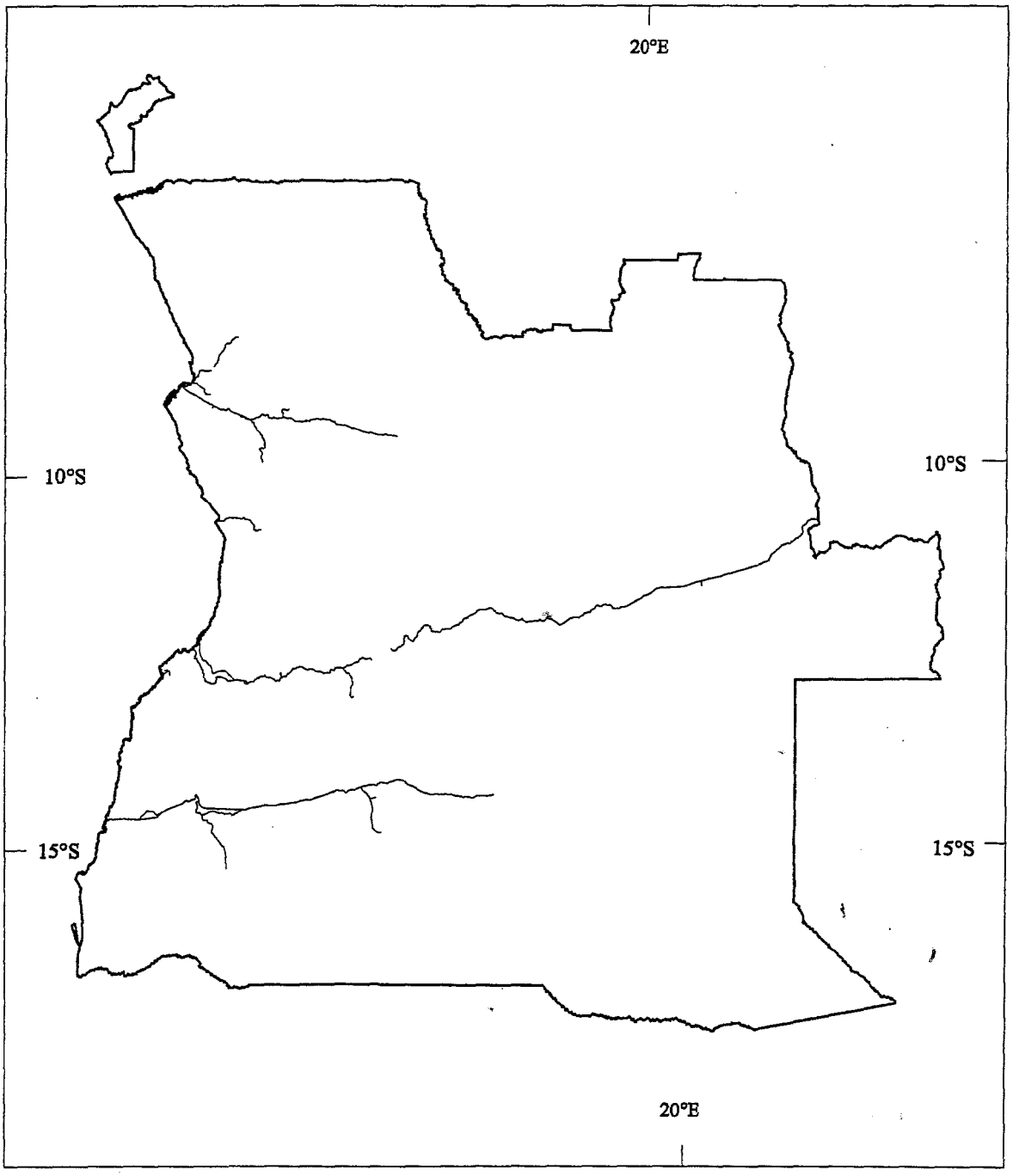


Figure E.18. Digital map layer **ao_road** (Angola, roads) from the atlas of southern African freshwater fish. Scale approximately 1:10 300 000

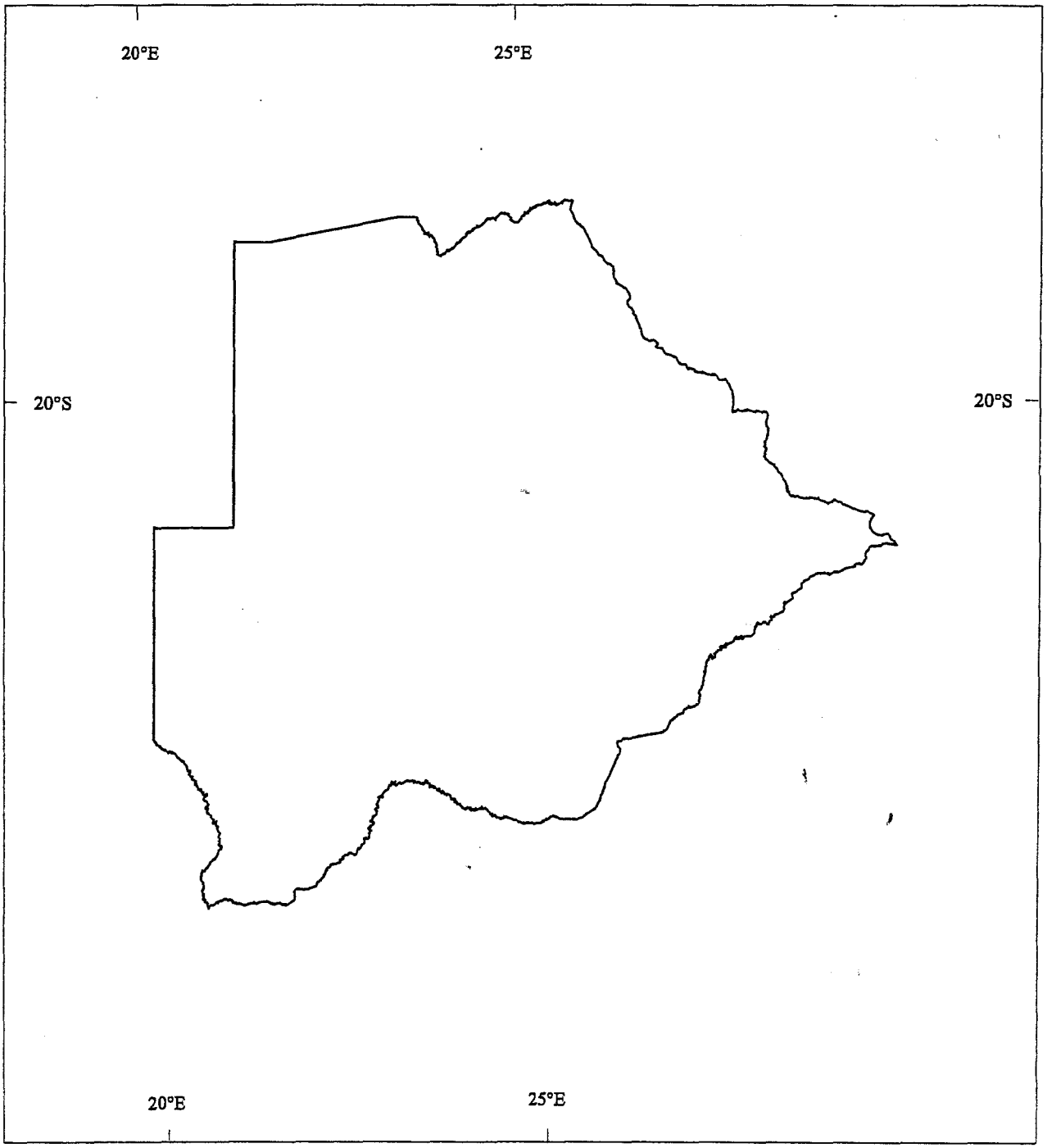


Figure E.19. Digital map layer **bw_adm1** (Botswana, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

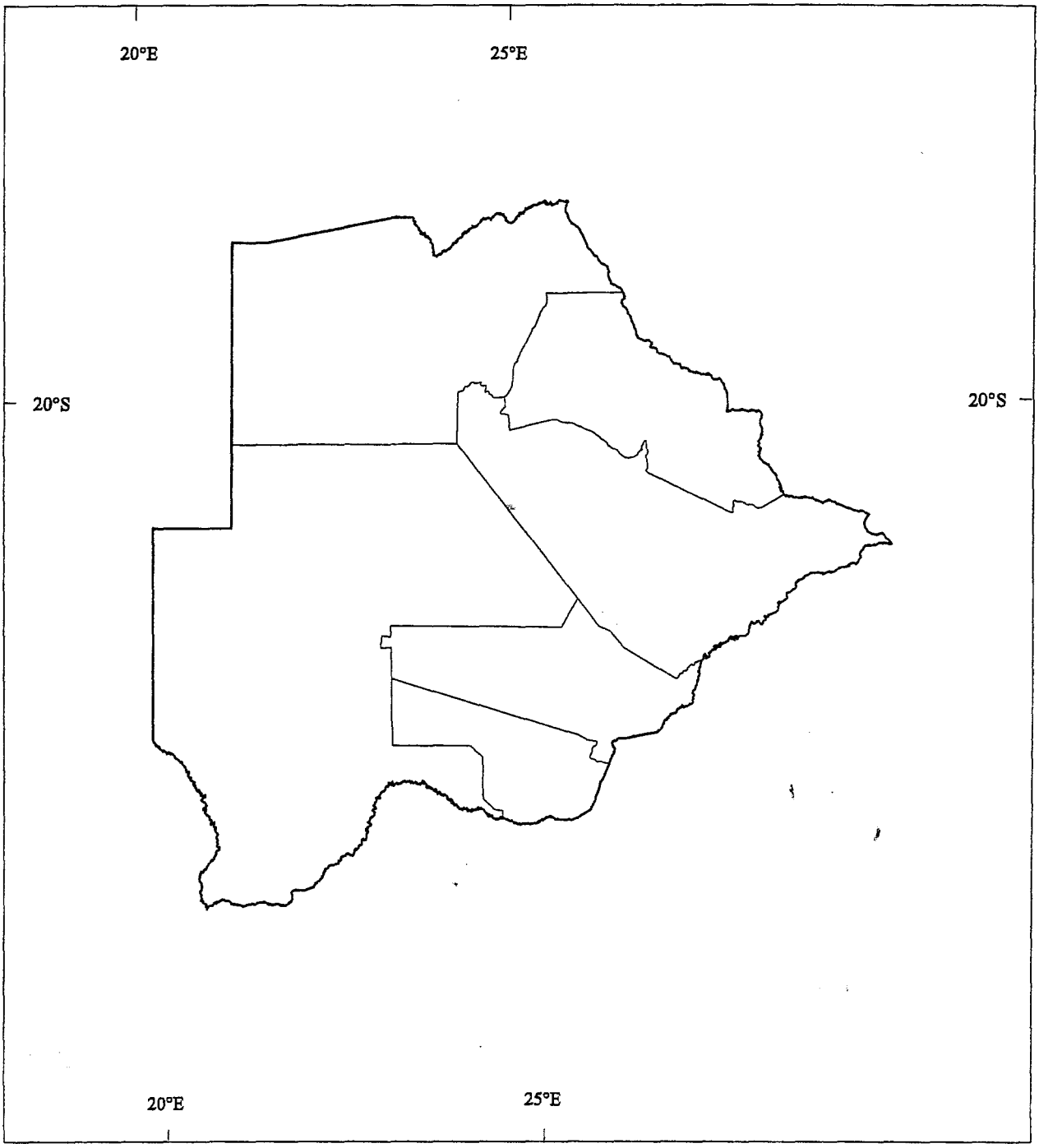


Figure E.20. Digital map layer **bw_adm2** (Botswana, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

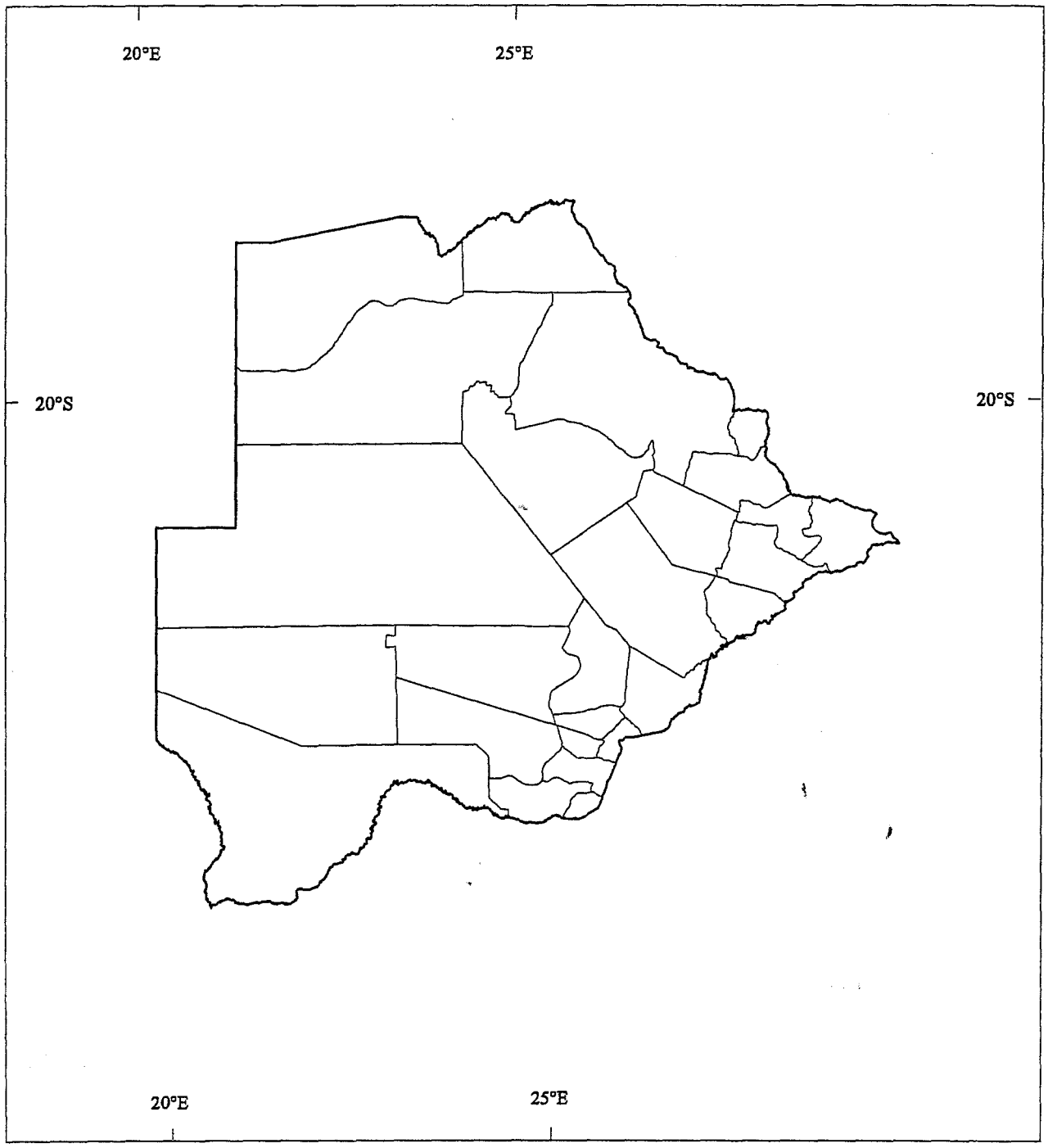


Figure E.21. Digital map layer **bw_adm3** (Botswana, district borders) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

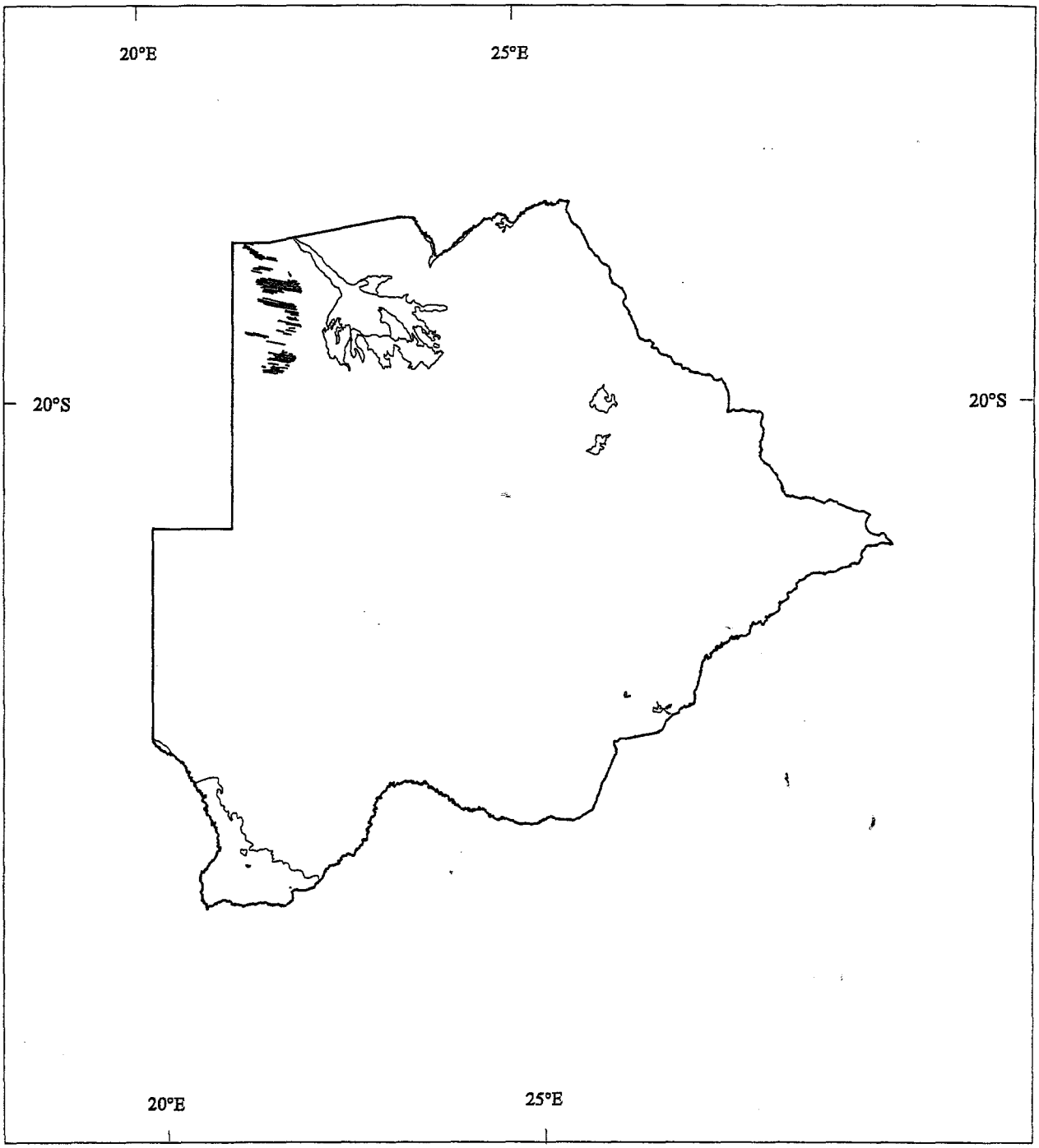


Figure E.22. Digital map layer **bw_cova** (Botswana, wetlands and other land cover areas) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

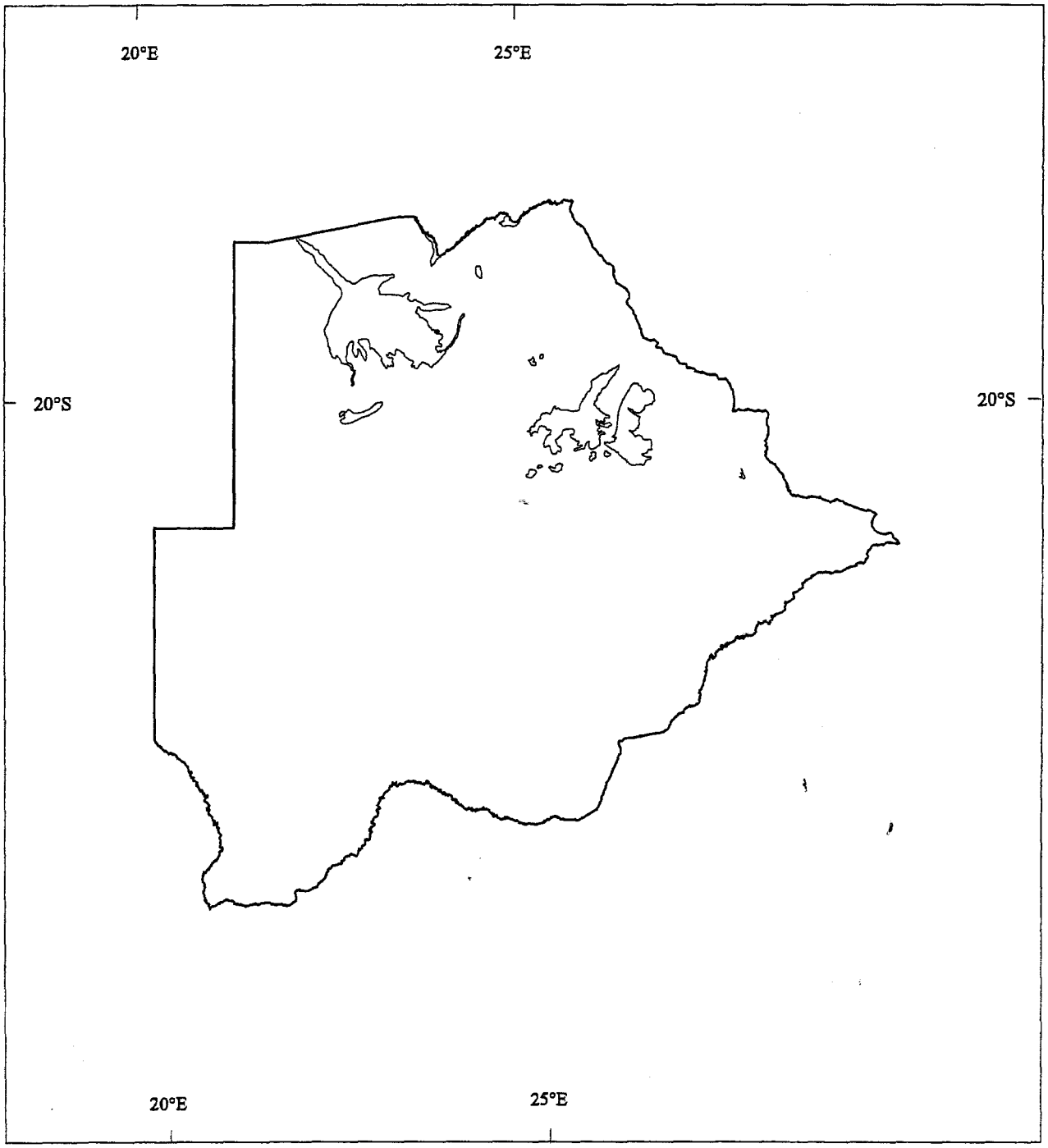


Figure E.23. Digital map layer **bw_wetl** (Botswana, wetlands, classified by type) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

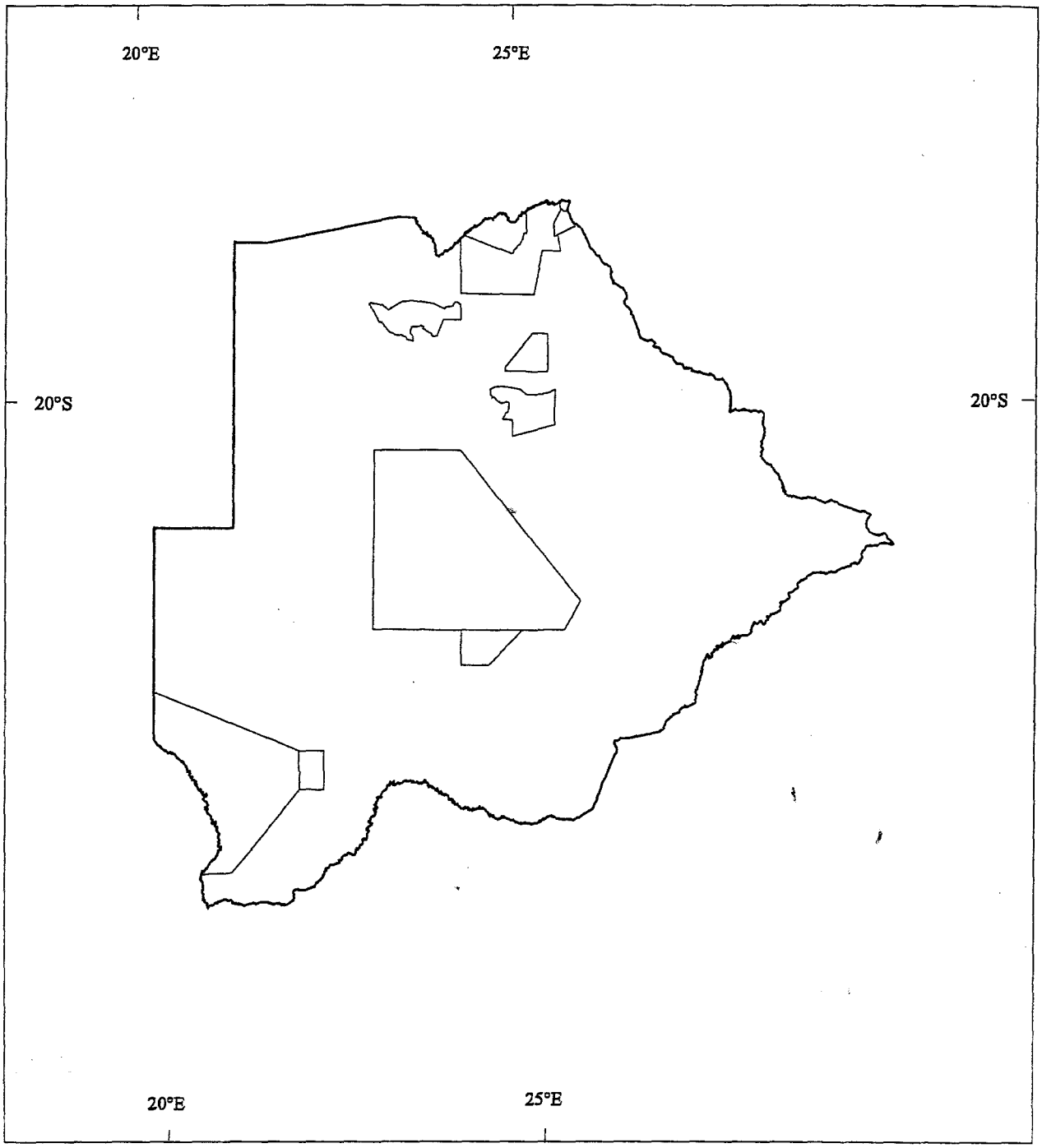


Figure E.24. Digital map layer **bw_park** (Botswana, national parks) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

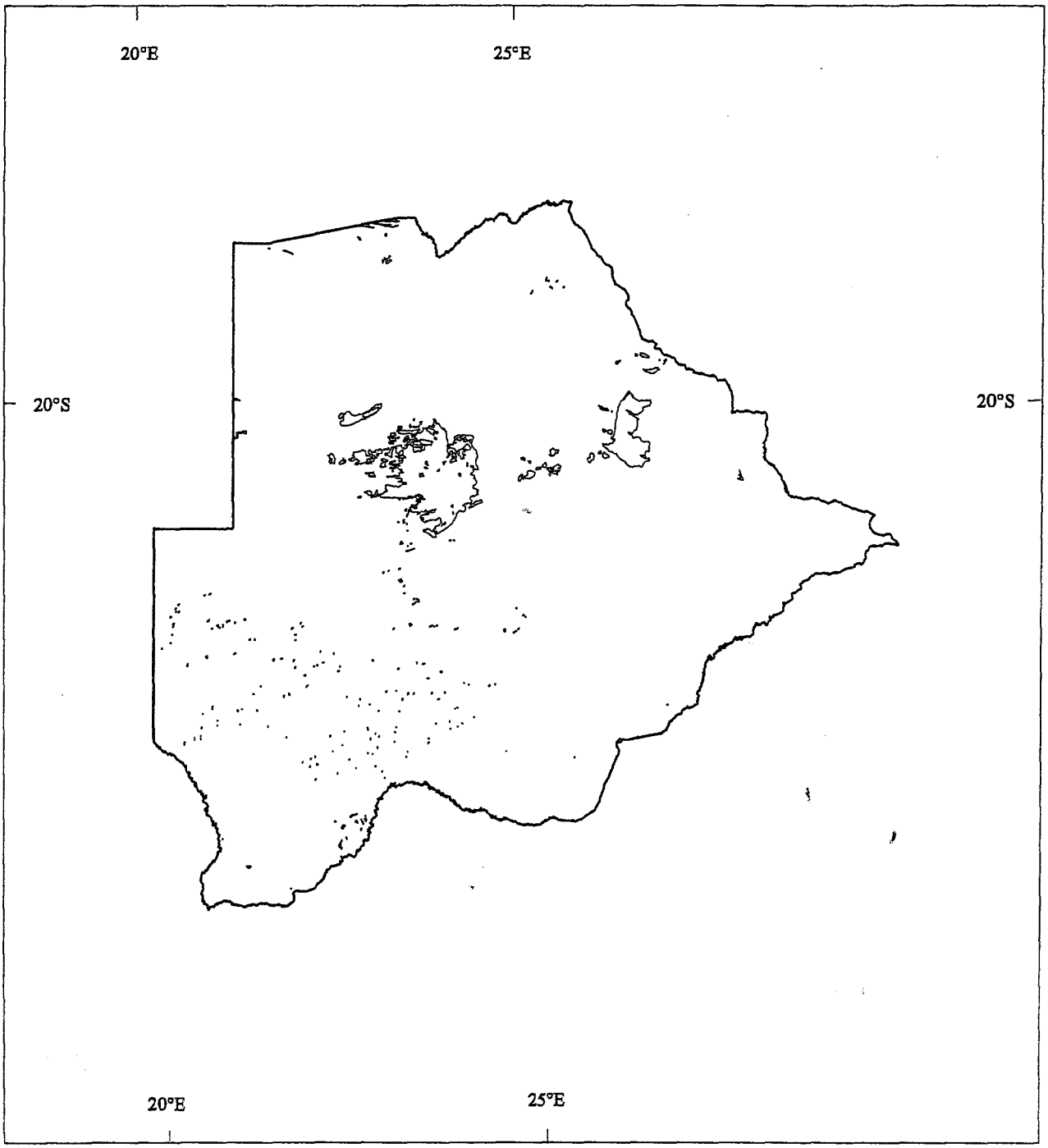


Figure E.25. Digital map layer **bw_lake** (Botswana, lakes) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

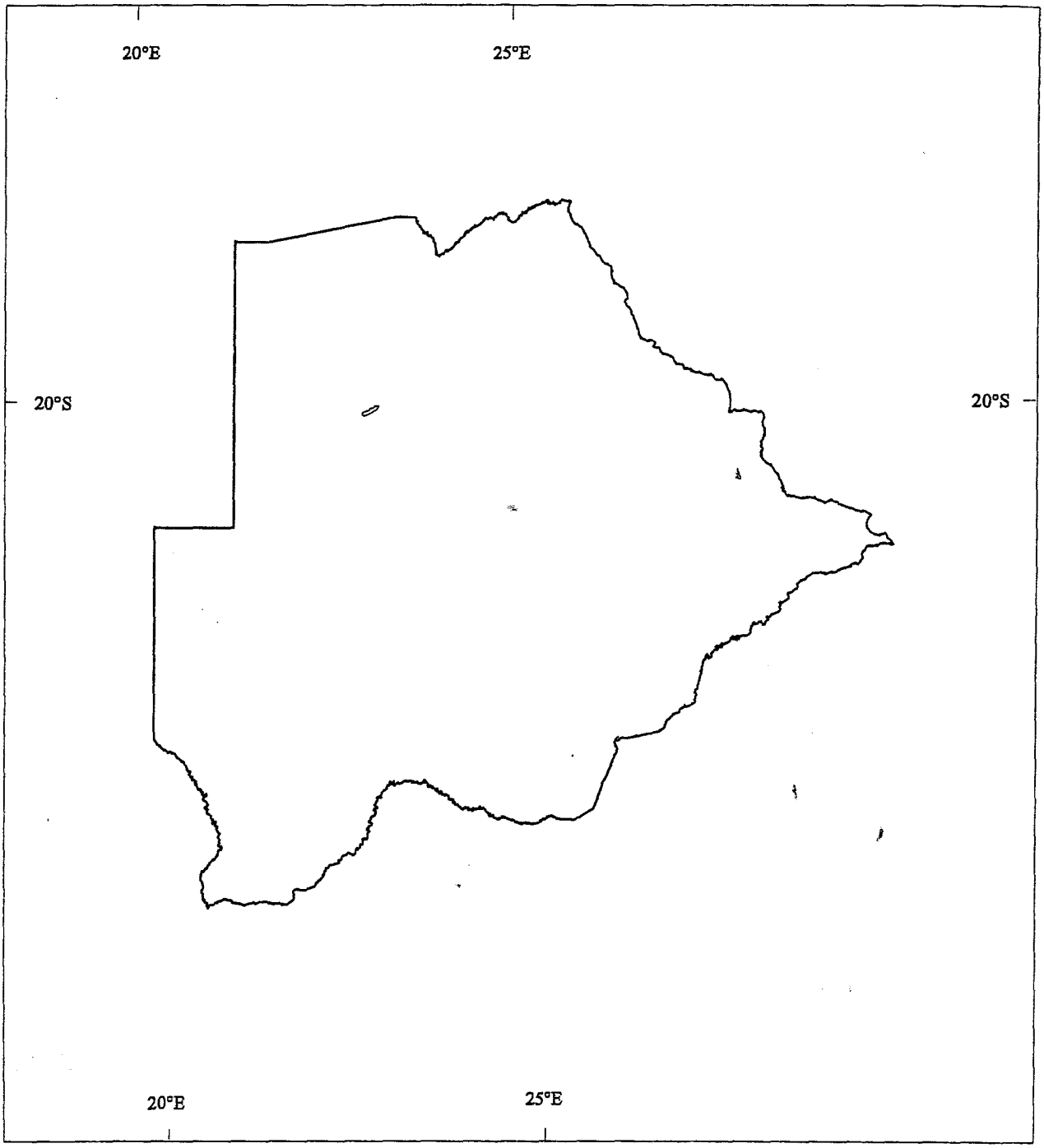


Figure E.26. Digital map layer **bw_pwat** (Botswana, perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

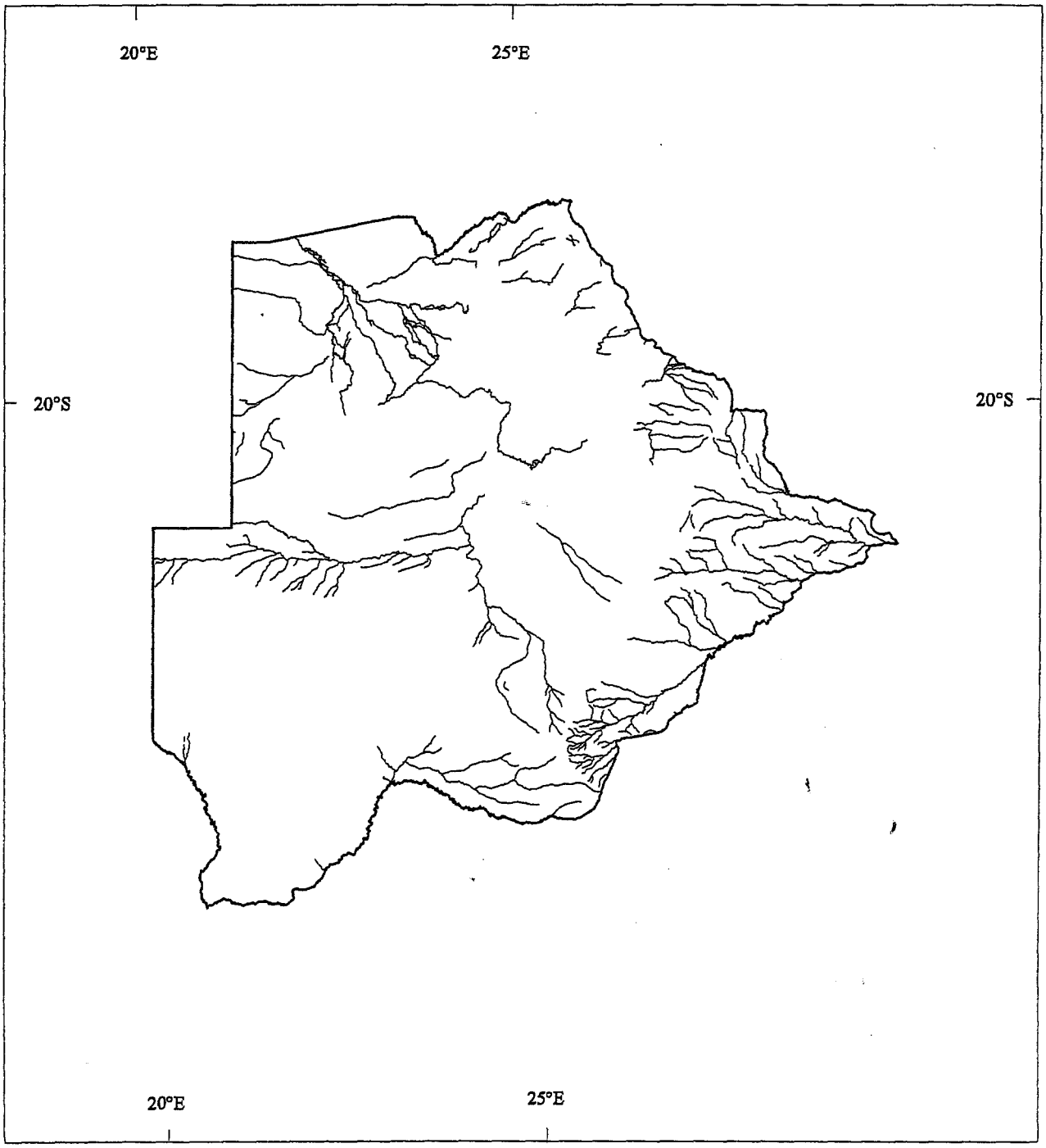


Figure E.27. Digital map layer **bw_riv** (Botswana, rivers) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

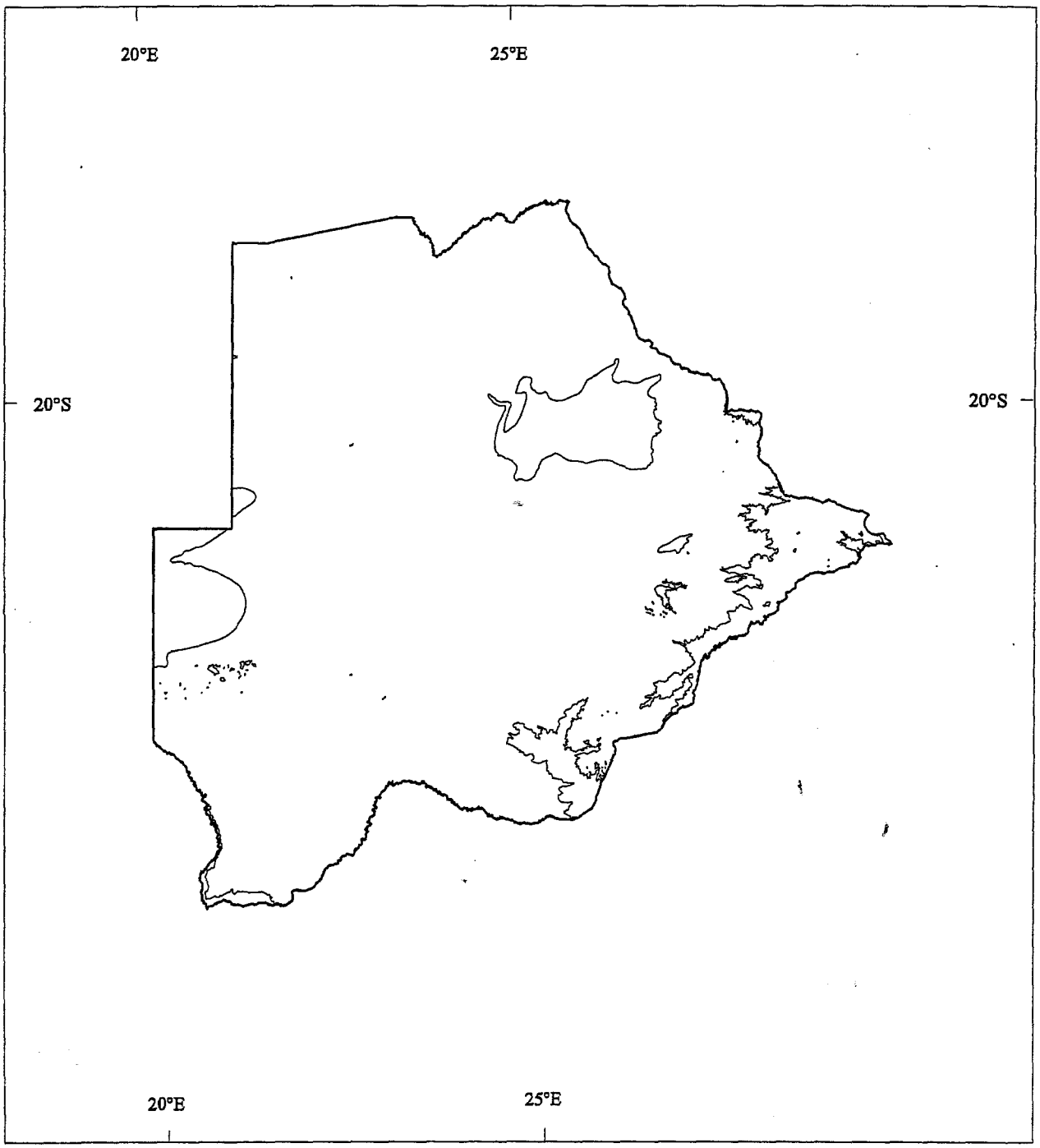


Figure E.28. Digital map layer **bw_elev** (Botswana, 1000m contours) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

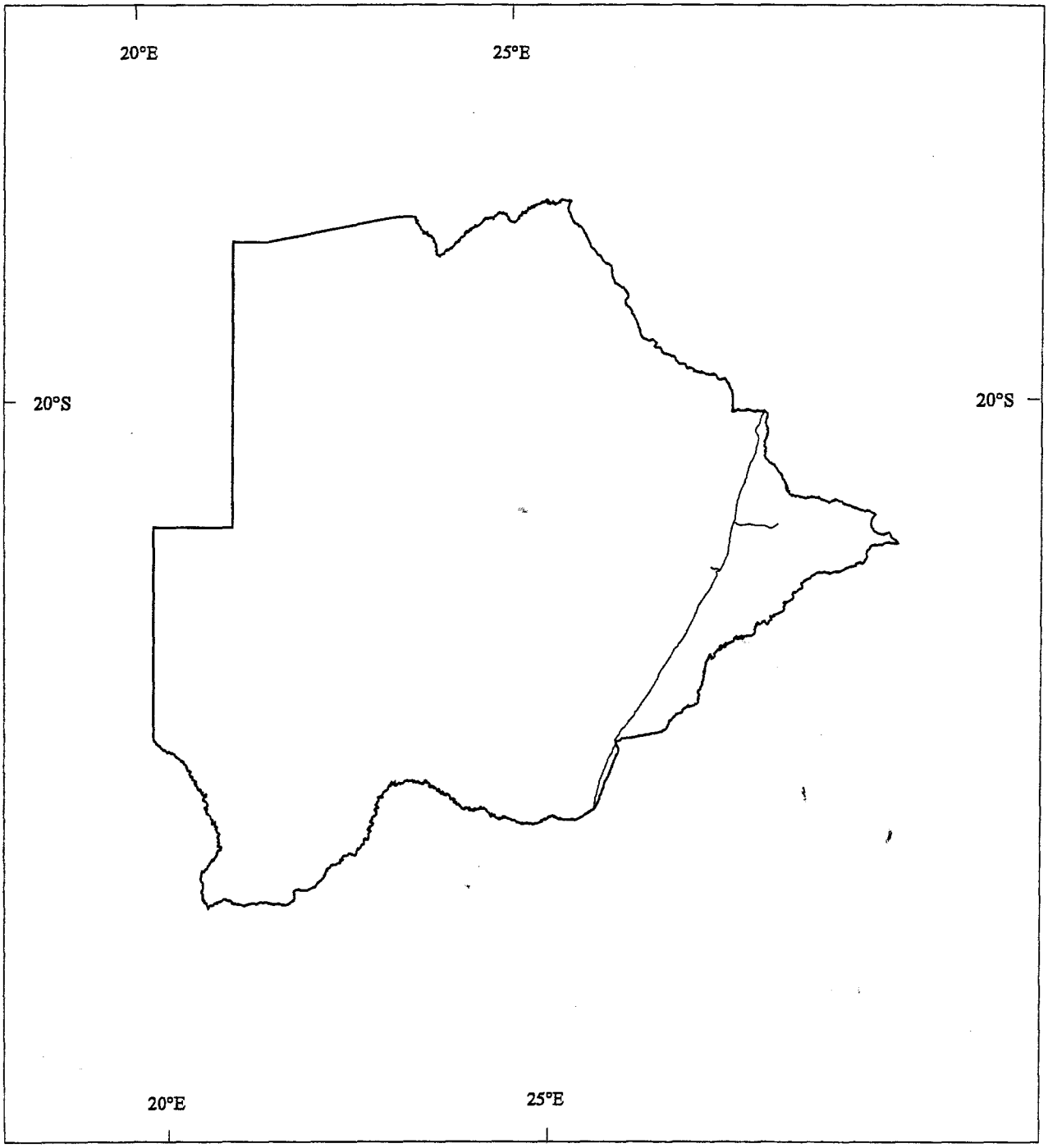


Figure E.29. Digital map layer **bw_rail** (Botswana, railroads) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

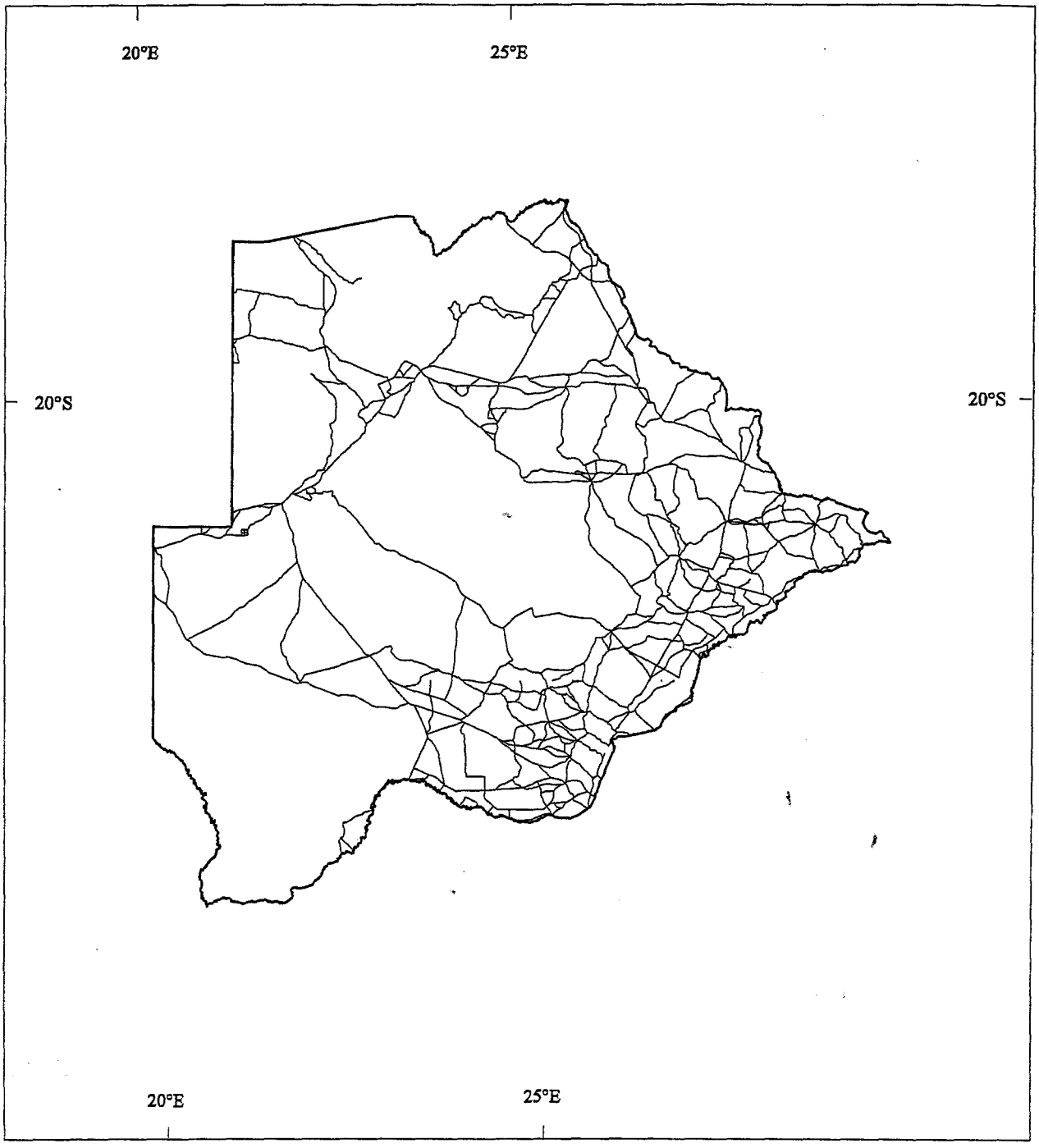


Figure E.30. Digital map layer **bw_road** (Botswana, roads) from the atlas of southern African freshwater fish. Scale approximately 1:8 800 000

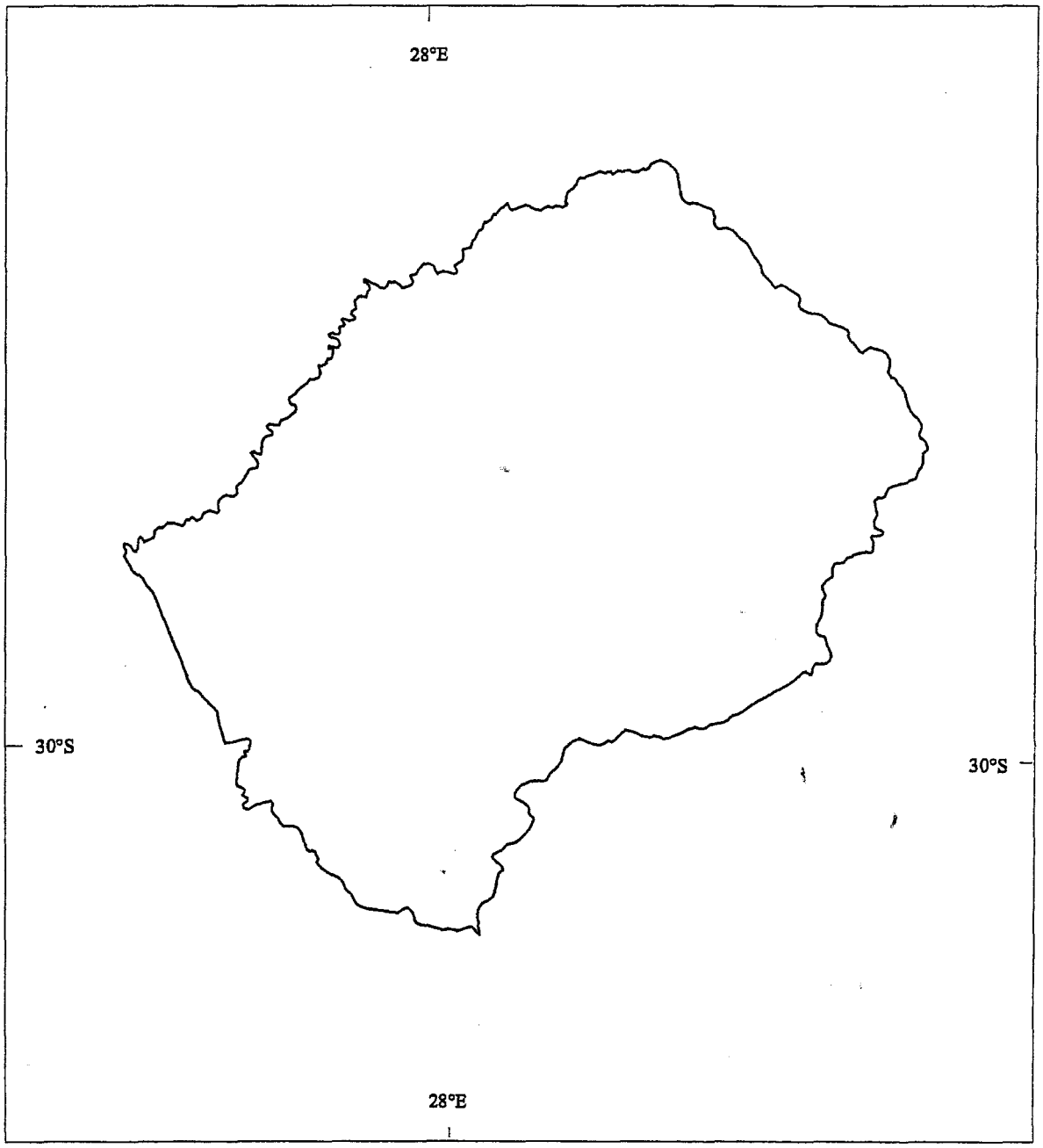


Figure E.31. Digital map layer **ls_adm1** (Lesotho, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:1 900 000

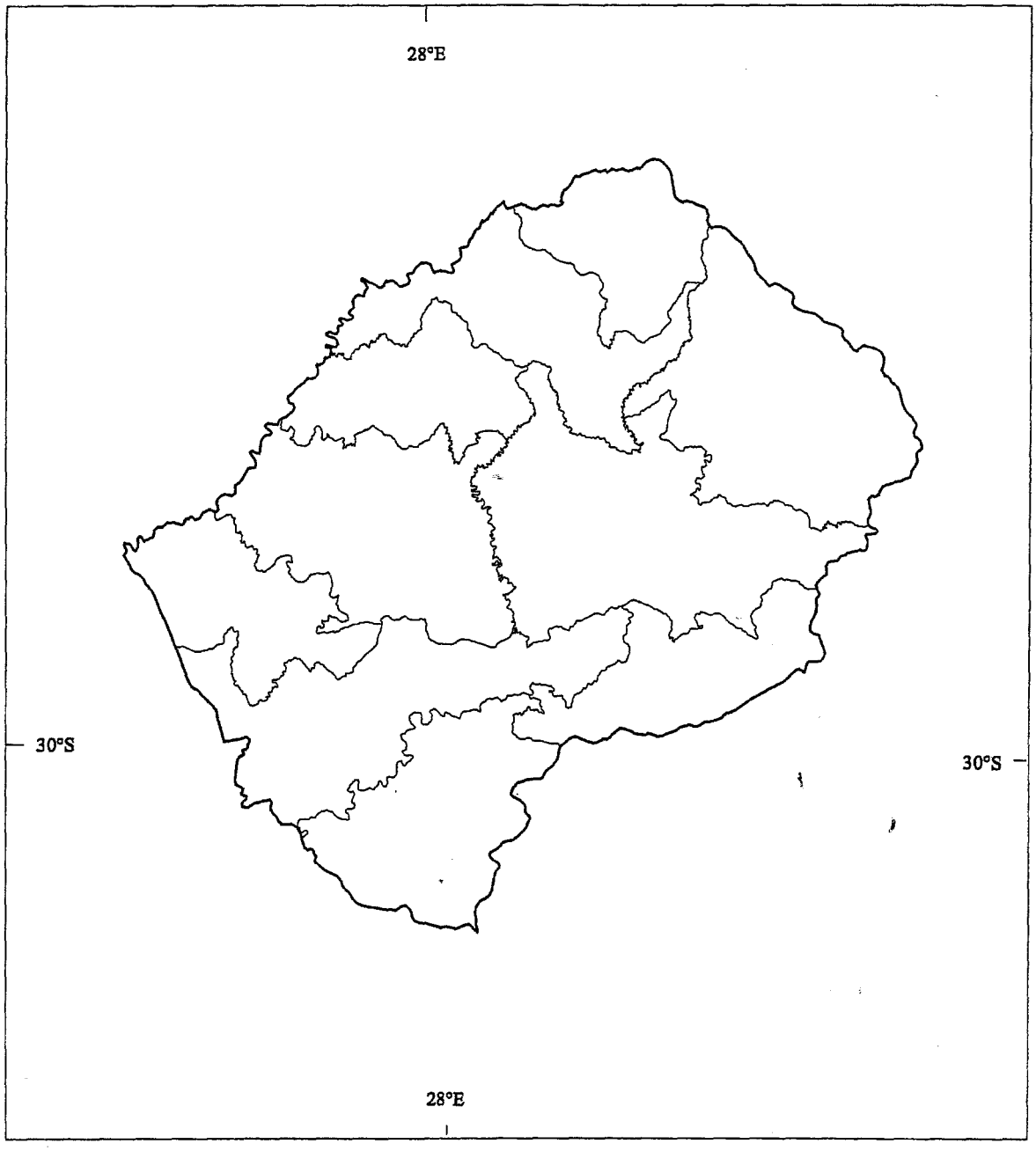


Figure E.32. Digital map layer **ls_adm2** (Lesotho, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:1 900 000

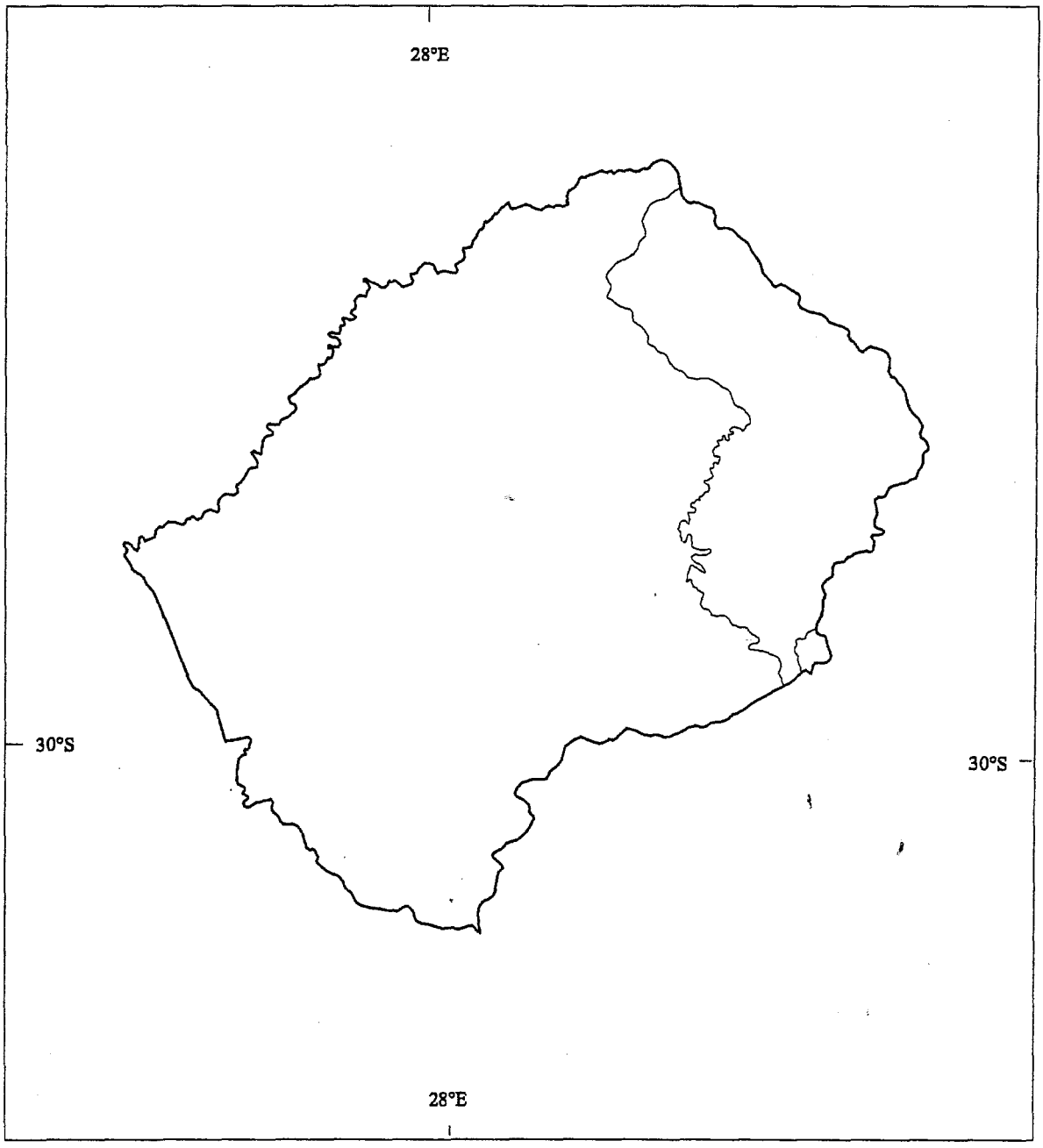


Figure E.33. Digital map layer **ls_park** (Lesotho, national parks) from the atlas of southern African freshwater fish. Scale approximately 1:1 900 000

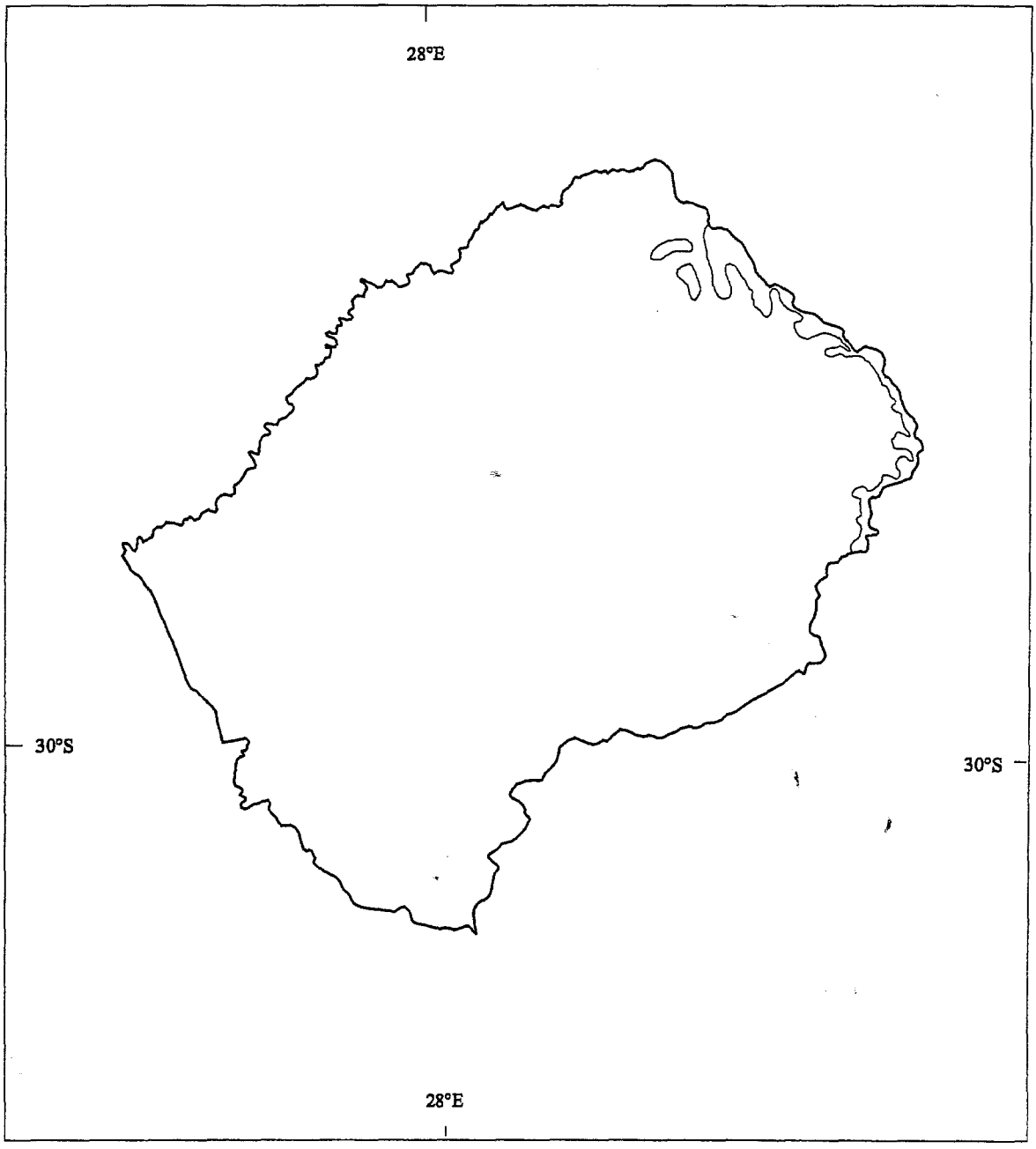


Figure E.34. Digital map layer **ls_wetl** (Lesotho, wetlands, classified by type) from the atlas of southern African freshwater fish. Scale approximately 1:1 900 000

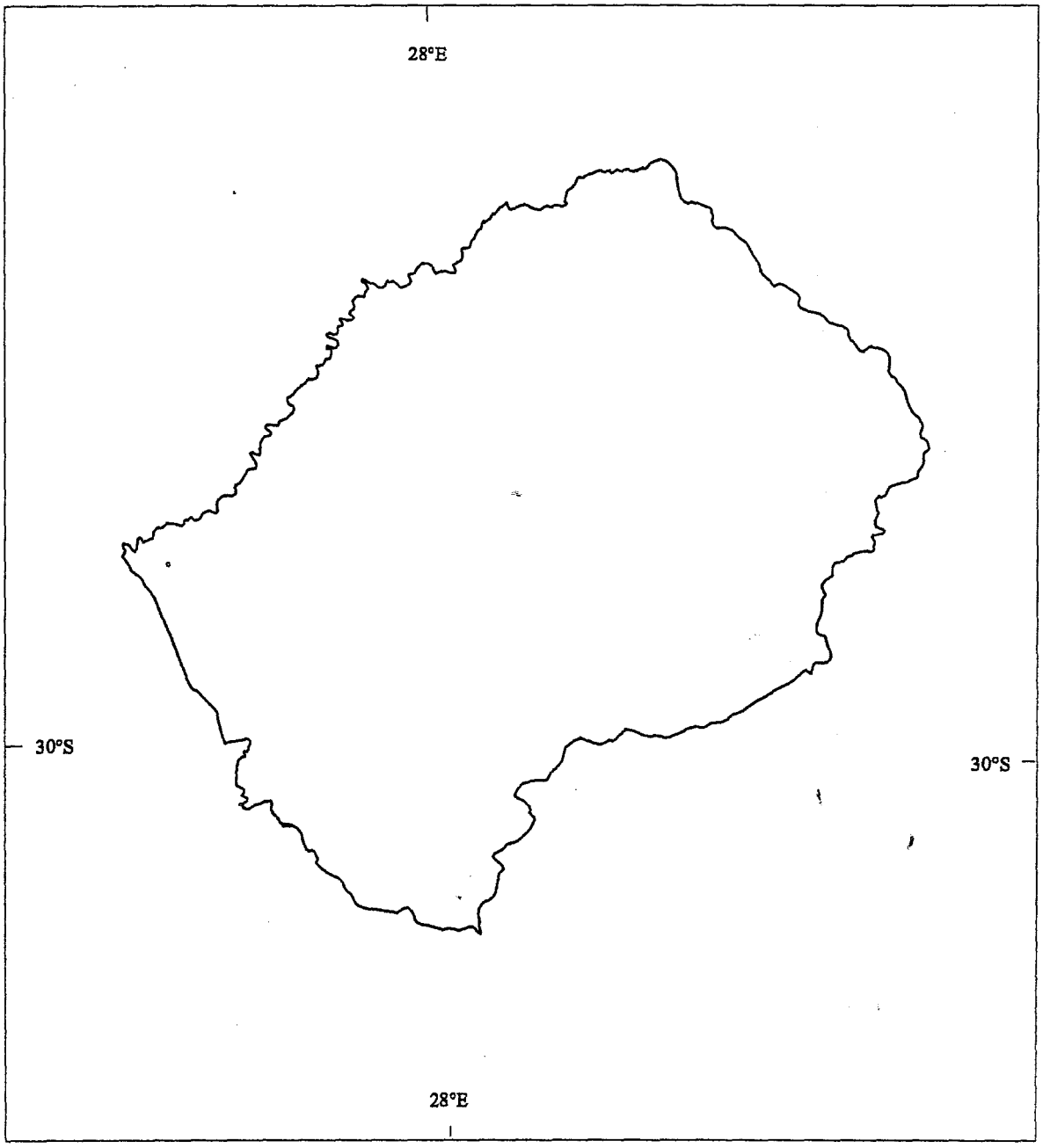


Figure E.35. Digital map layer **ls_lake** (Lesotho, lakes) from the atlas of southern African freshwater fish. Scale approximately 1:1 900 000

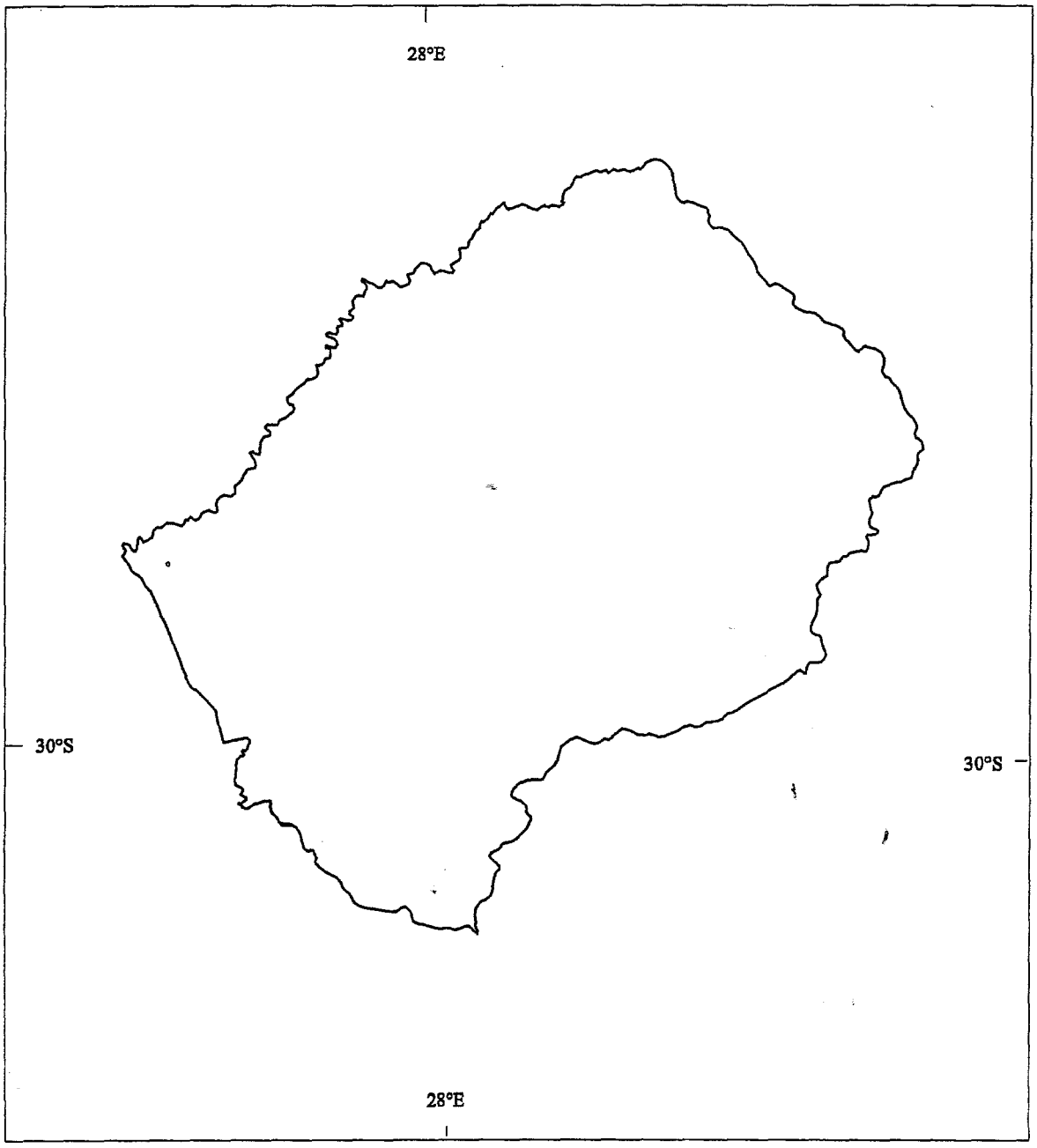


Figure E.36. Digital map layer **ls_pwat** (Lesotho, perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:1 900 000

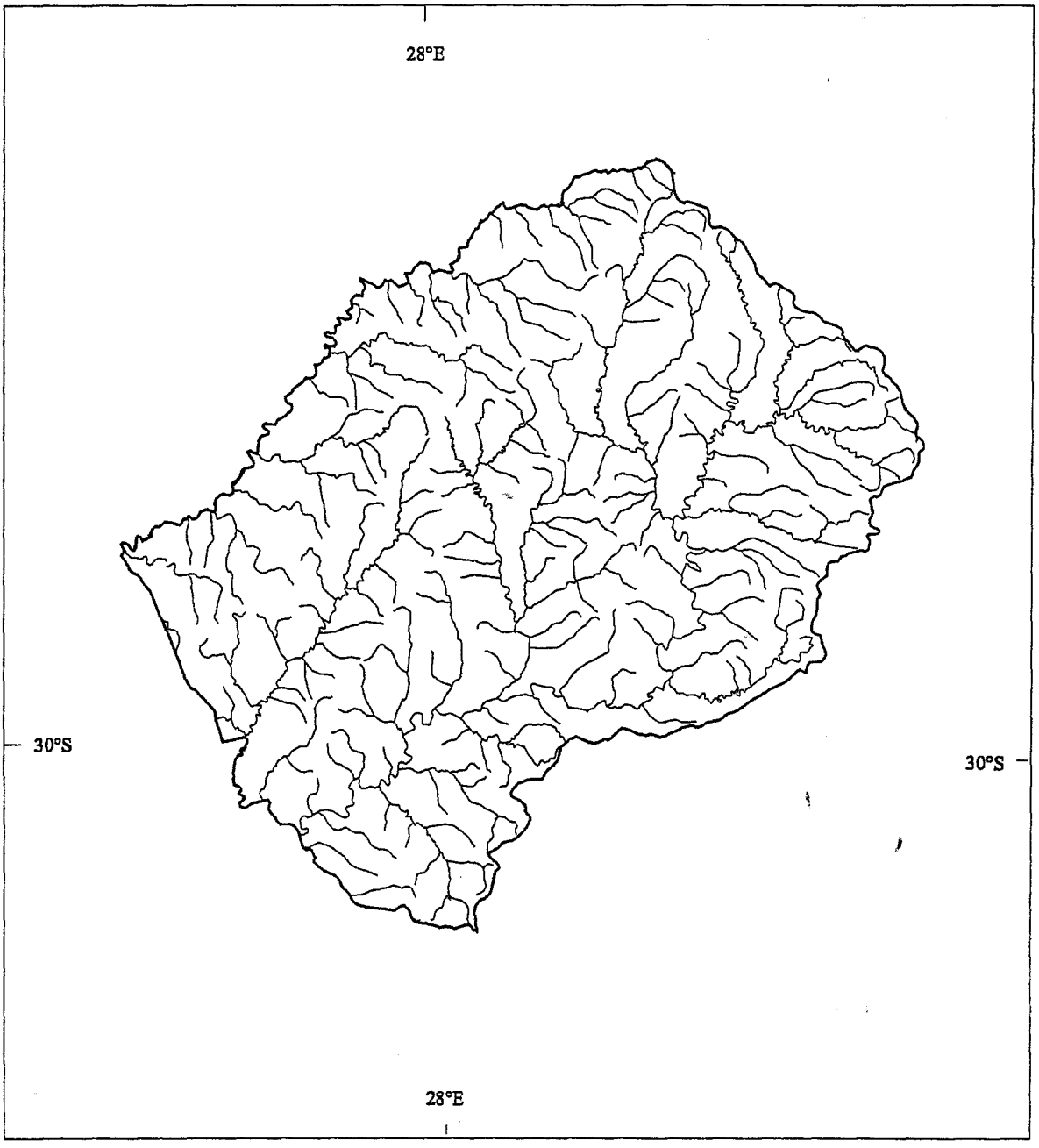


Figure E.37. Digital map layer **ls_riv** (Lesotho, rivers) from the atlas of southern African freshwater fish. Scale approximately 1:1 900 000

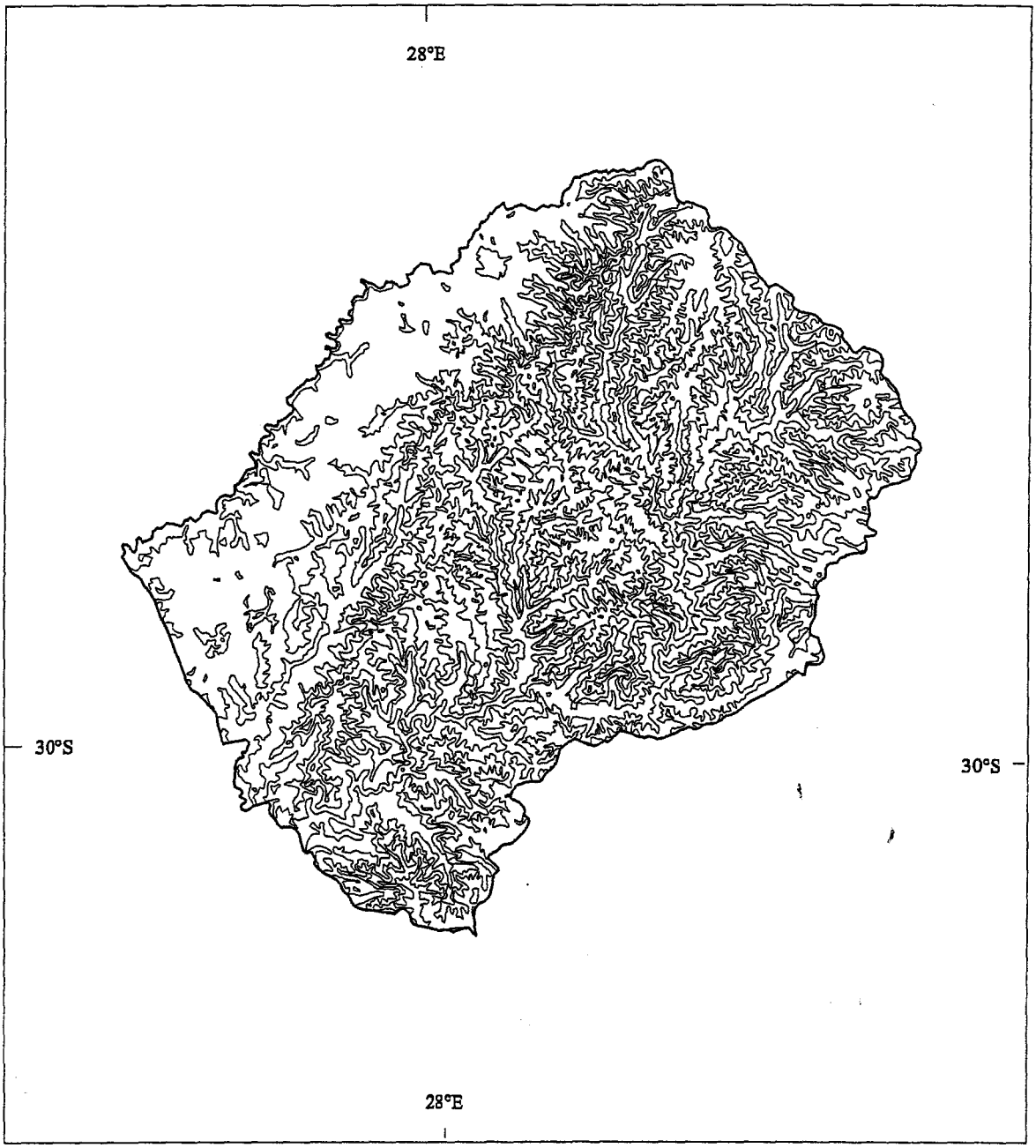


Figure E.38. Digital map layer **ls_elev** (Lesotho, 1000m contours) from the atlas of southern African freshwater fish. Scale approximately 1:1 900 000

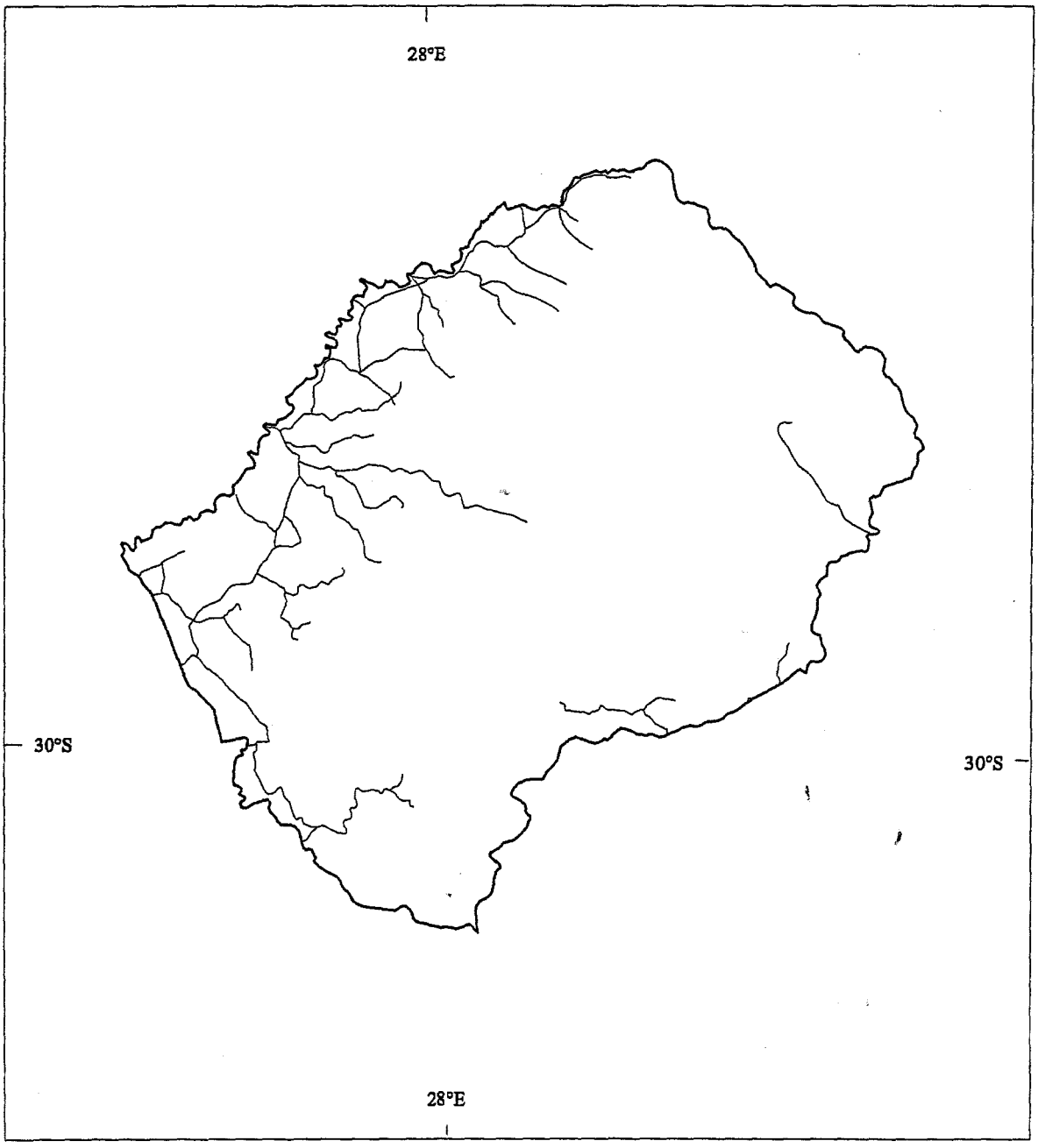


Figure E.39. Digital map layer **ls_road** (Lesotho, roads) from the atlas of southern African freshwater fish. Scale approximately 1:1 900 000

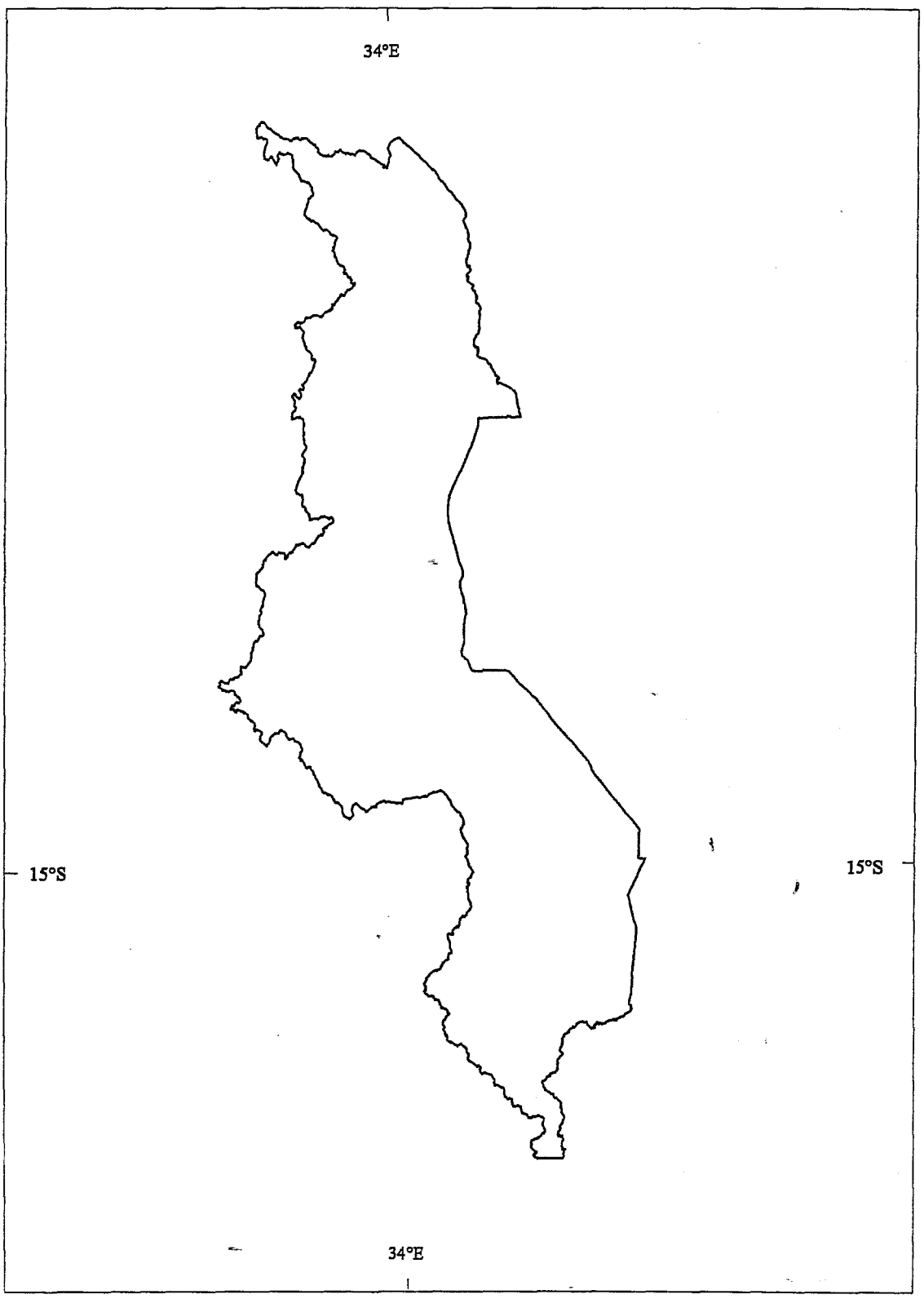


Figure E.40. Digital map layer **mw_adm1** (Malawi, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

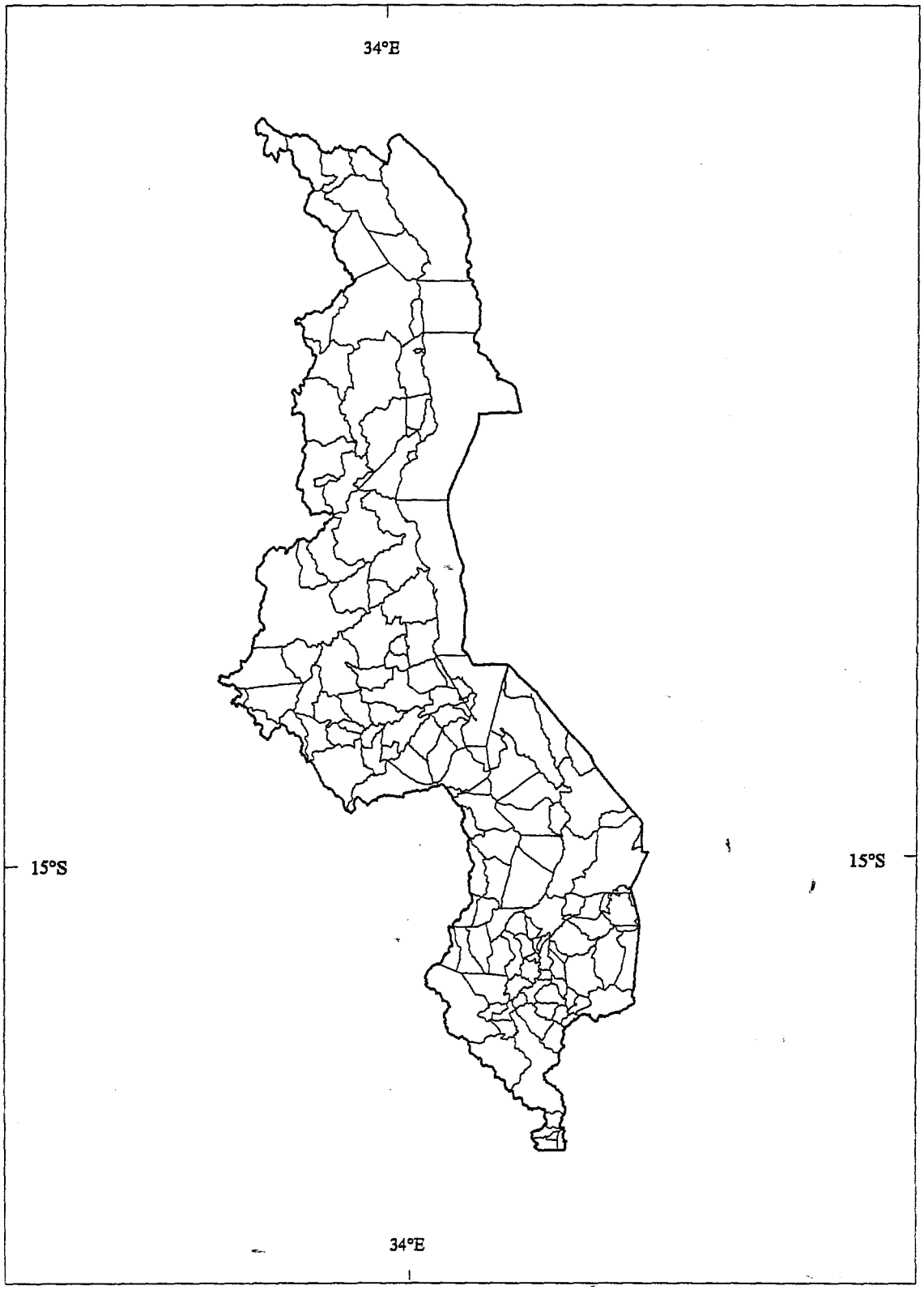


Figure E.41. Digital map layer **mw_adm2** (Malawi, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

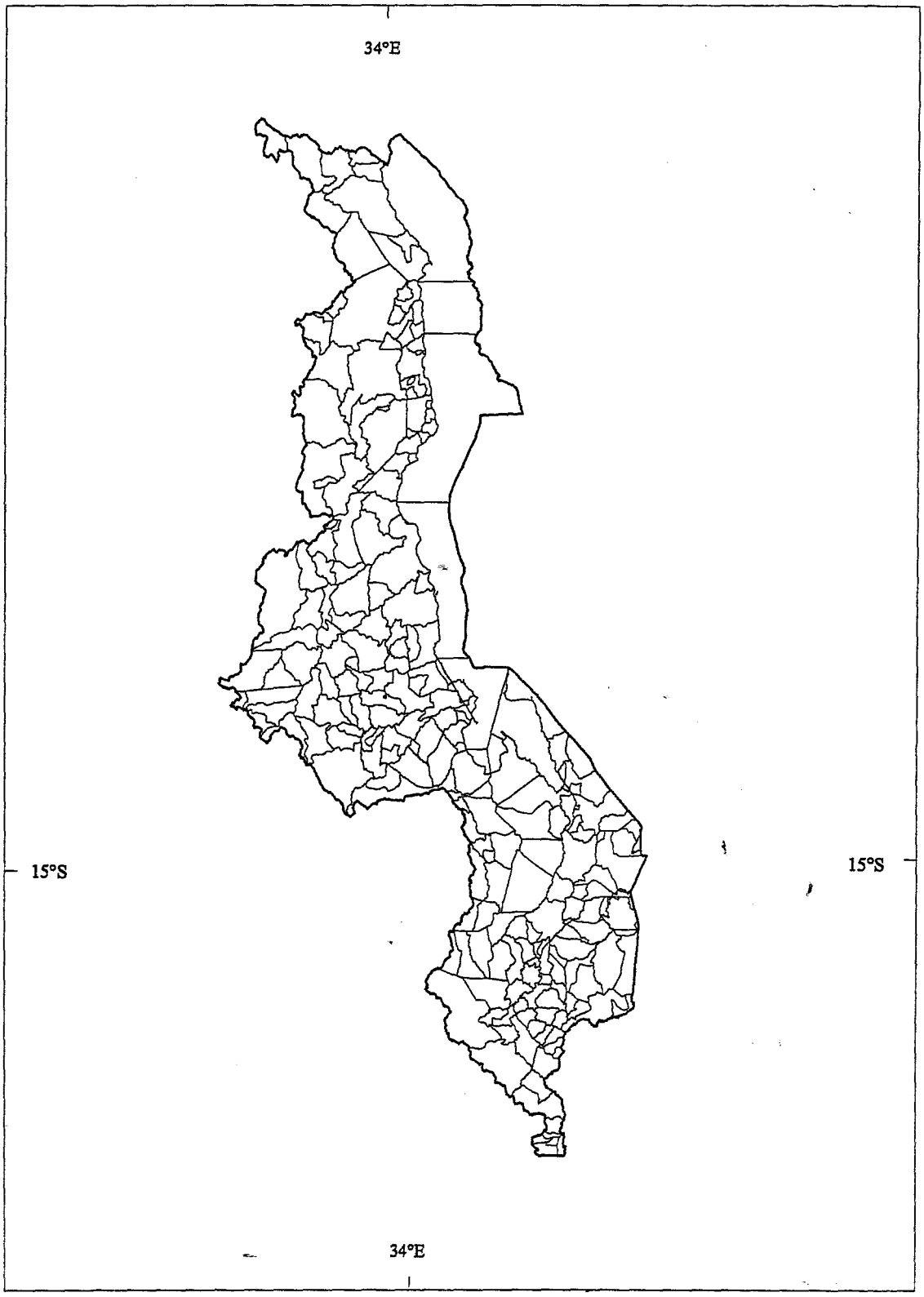


Figure E.42. Digital map layer **mw_adm3** (Malawi, district borders) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

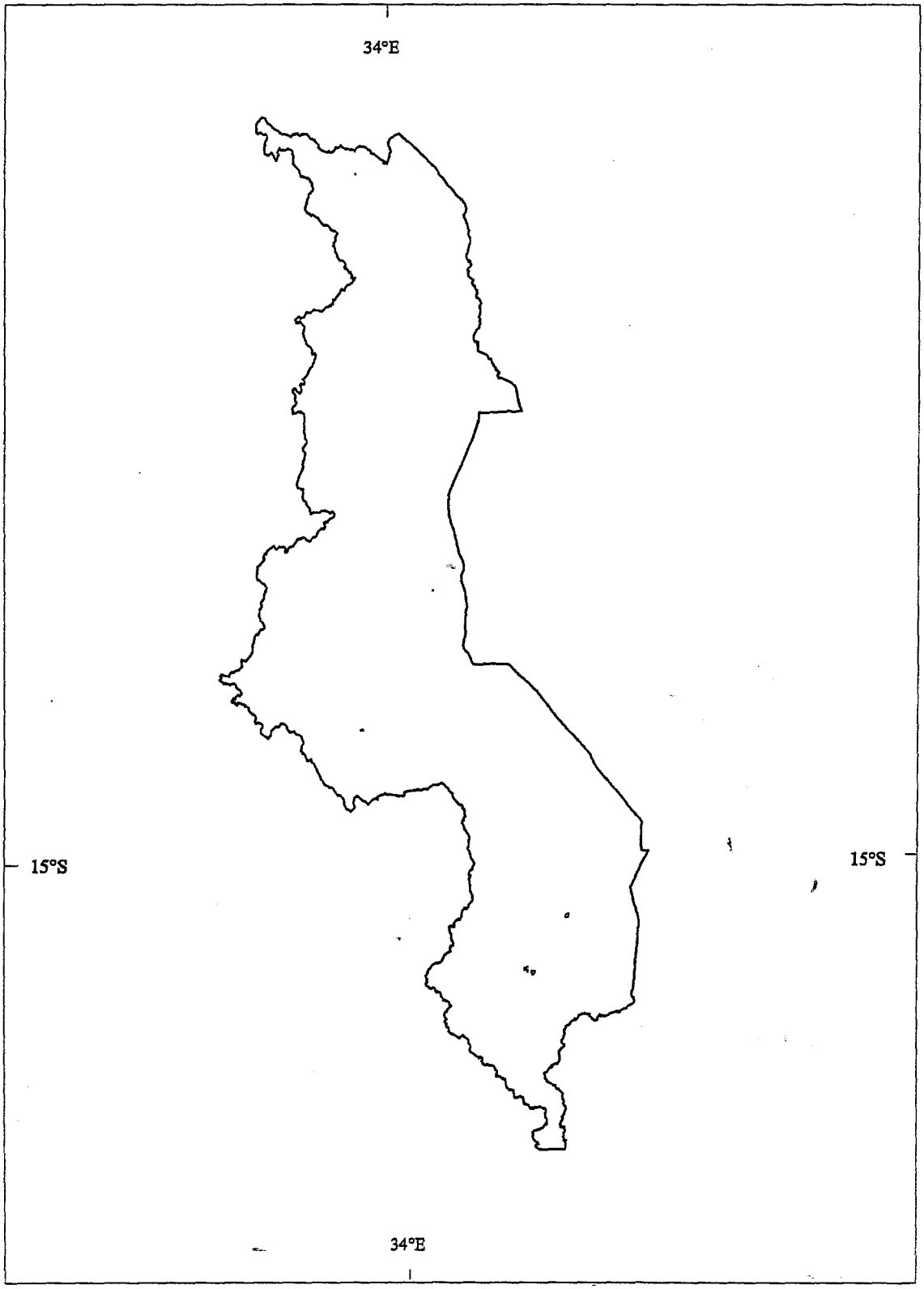


Figure E.43. Digital map layer **mw_urbn** (Malawi, urbanised areas as polygons) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

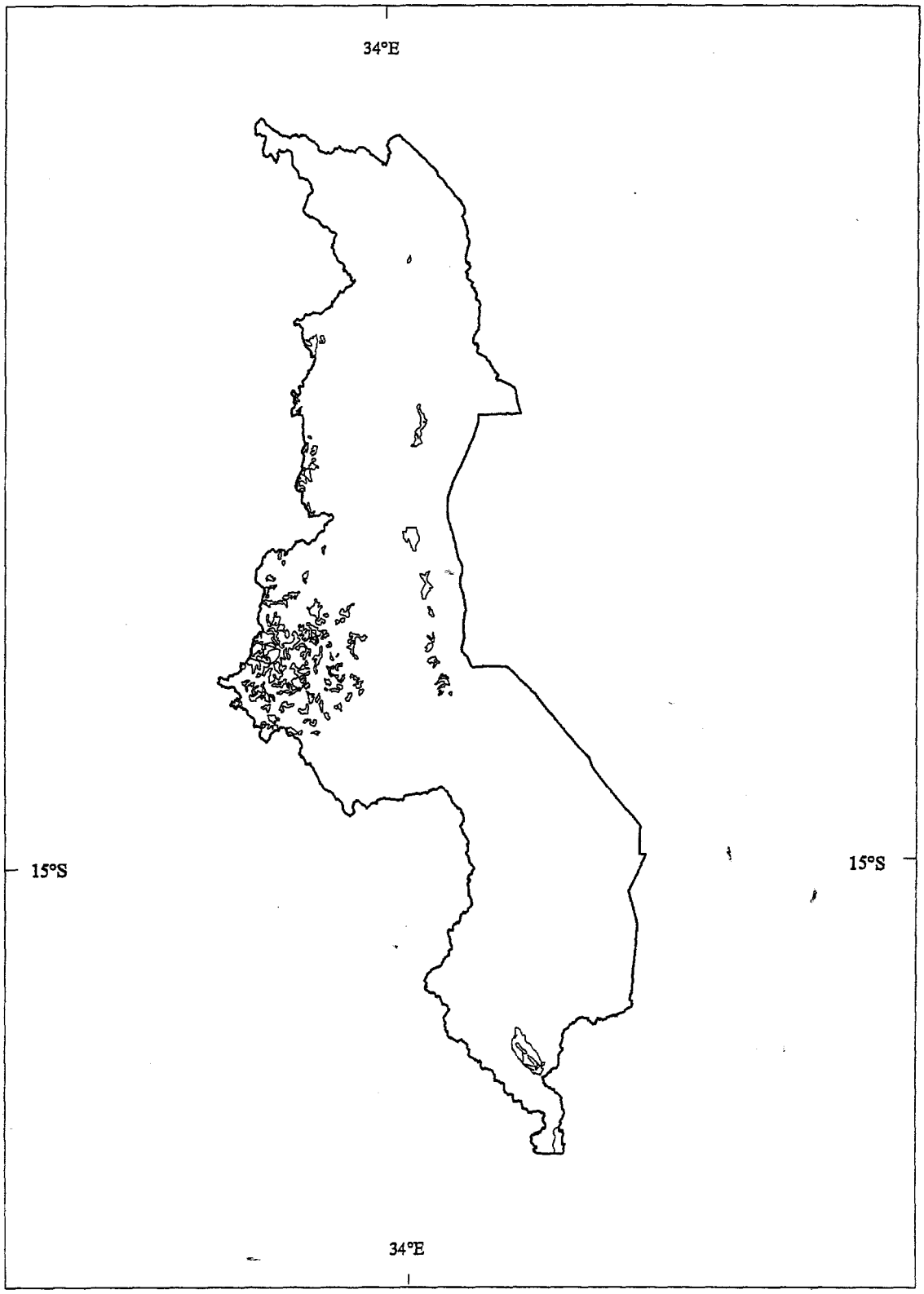


Figure E.44. Digital map layer **mw_cova** (Malawi, wetlands and other land cover areas) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

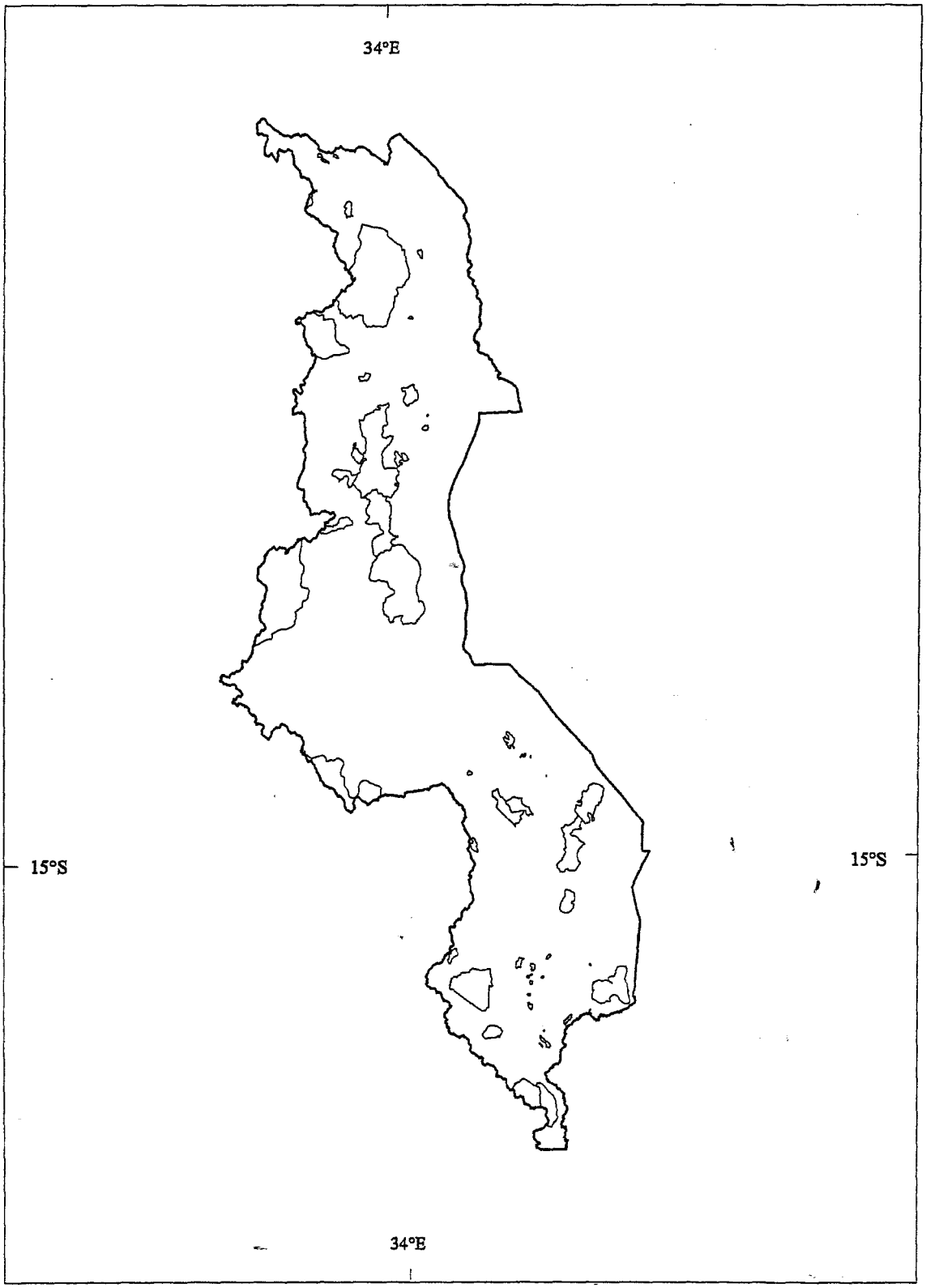


Figure E.45. Digital map layer **mw_park** (Malawi, national parks) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

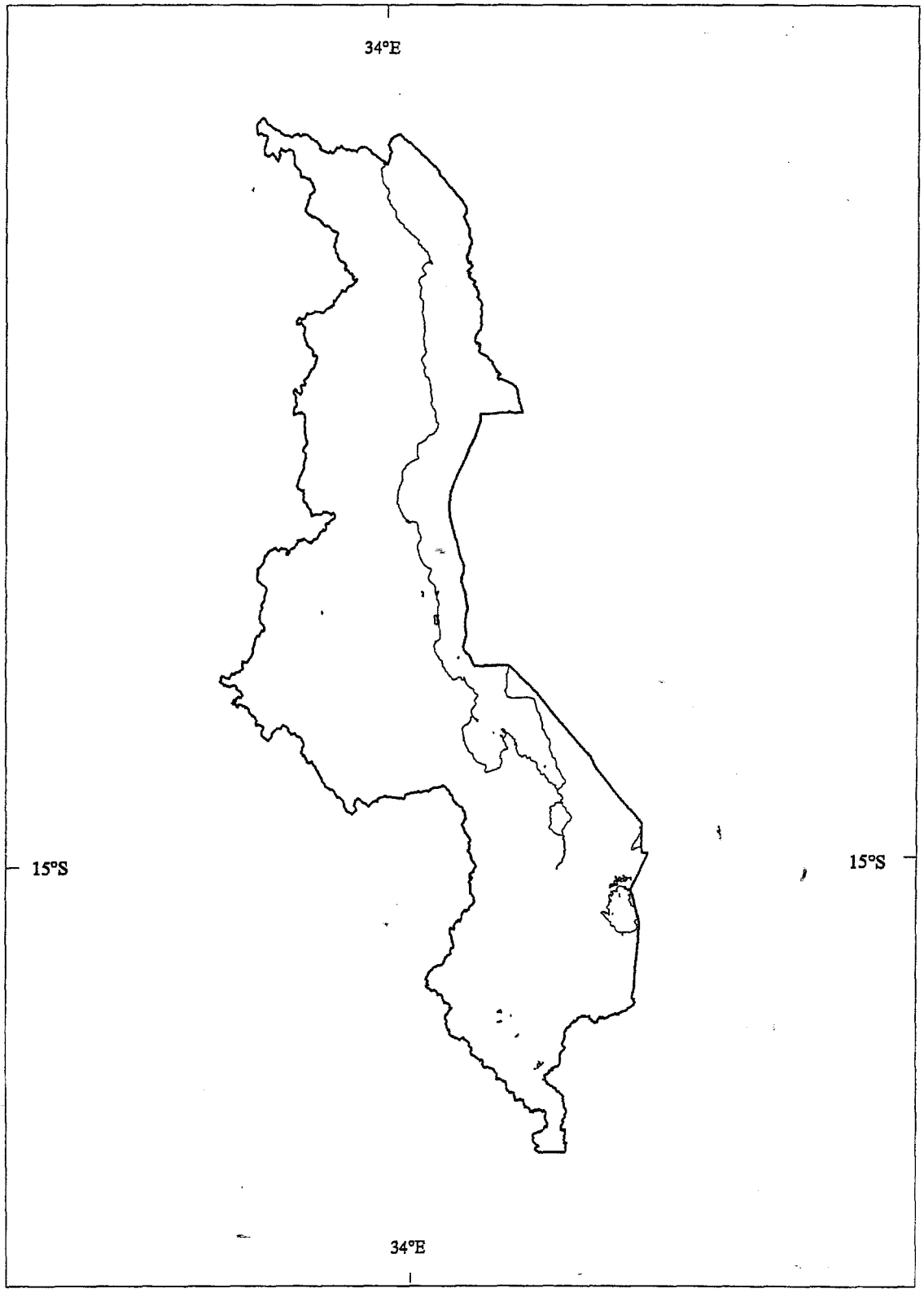


Figure E.46. Digital map layer **mw_pwat** (Malawi, perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

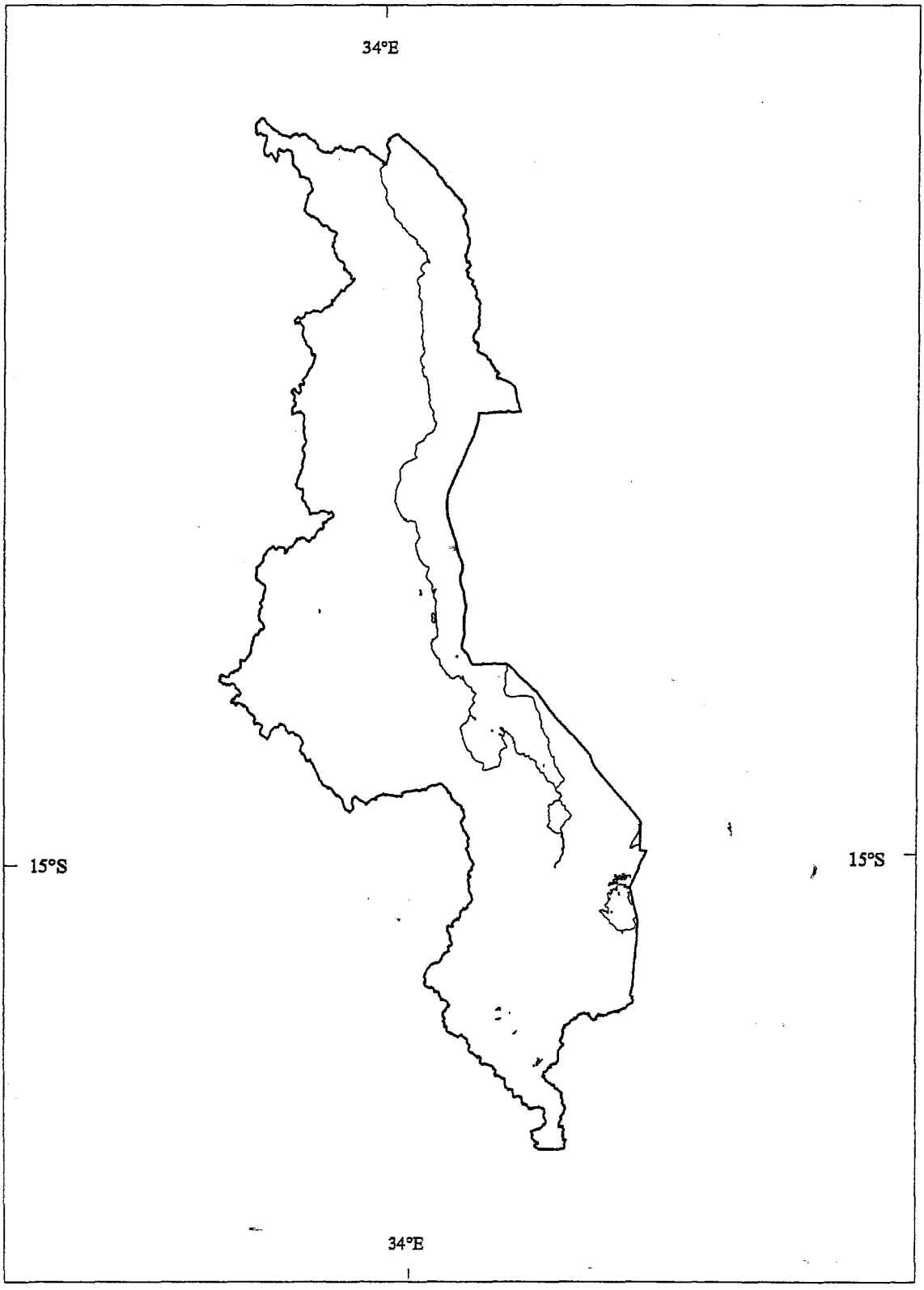


Figure E.47. Digital map layer **mw_lake** (Malawi, lakes) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

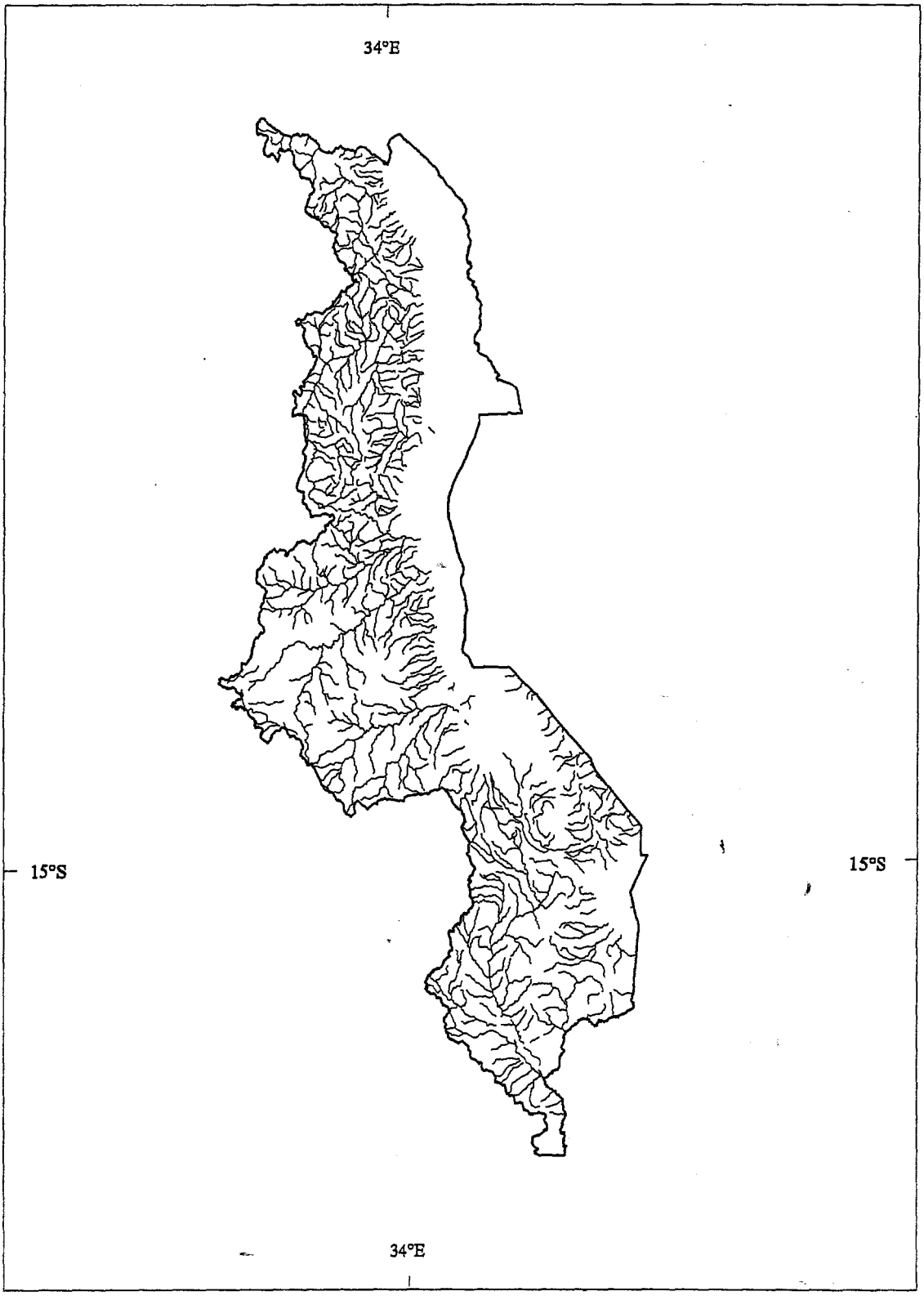


Figure E.48. Digital map layer **mw_riv** (Malawi, rivers) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

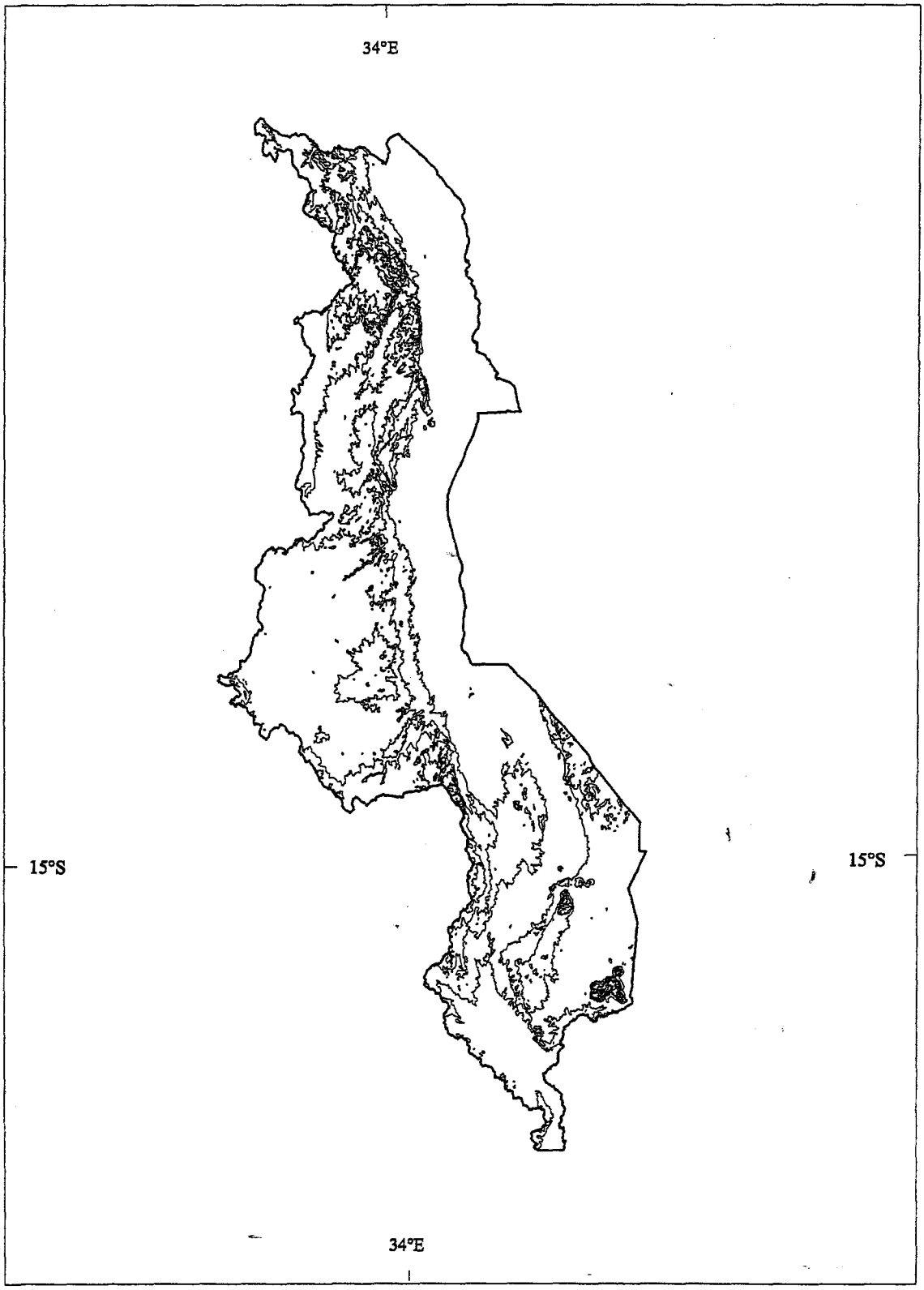


Figure E.49. Digital map layer **mw_elev** (Malawi, 1000m contours) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

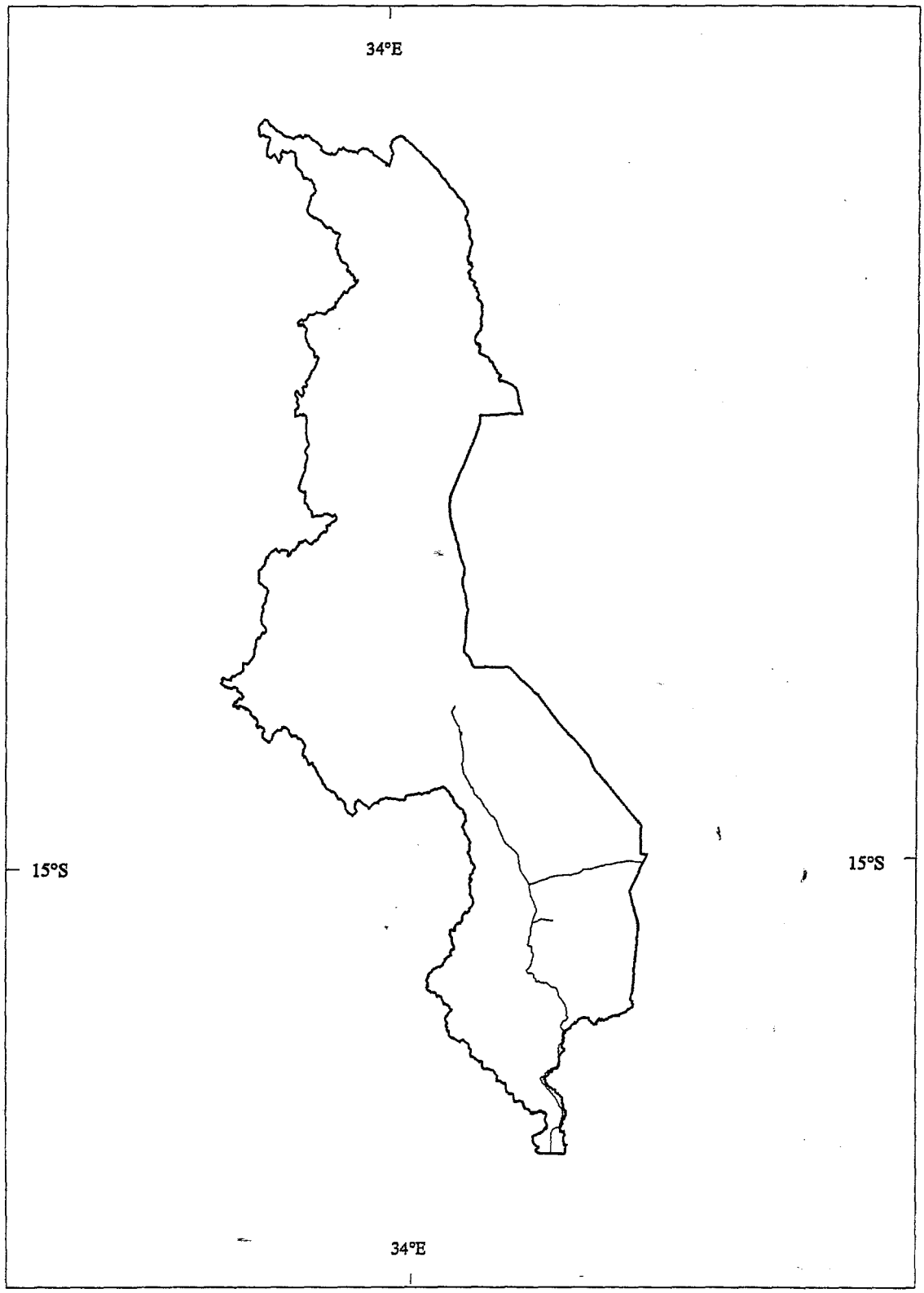


Figure E.50. Digital map layer **mw_rail** (Malawi, railroads) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

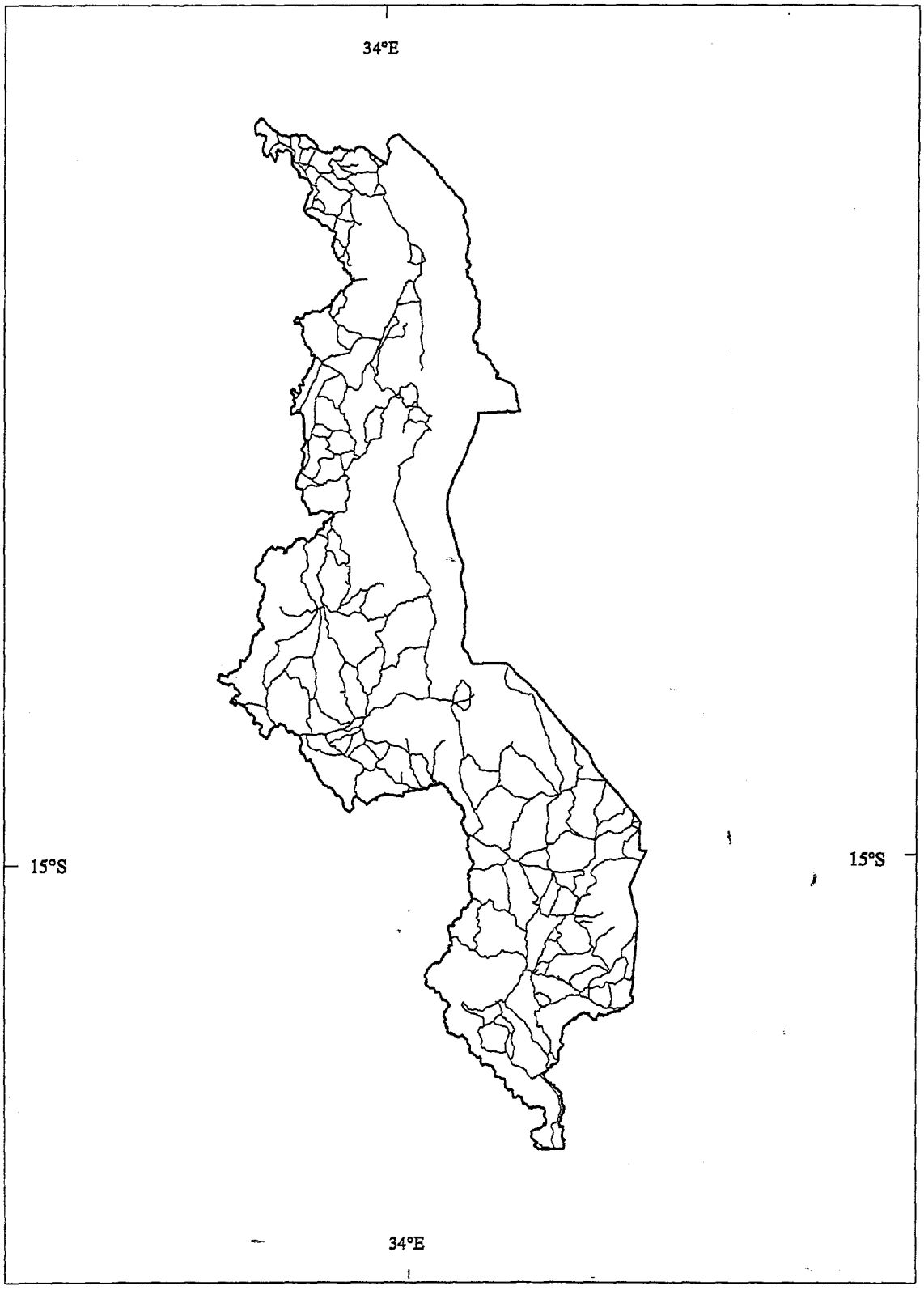


Figure E.51. Digital map layer **mw_road** (Malawi, roads) from the atlas of southern African freshwater fish. Scale approximately 1:5 200 000

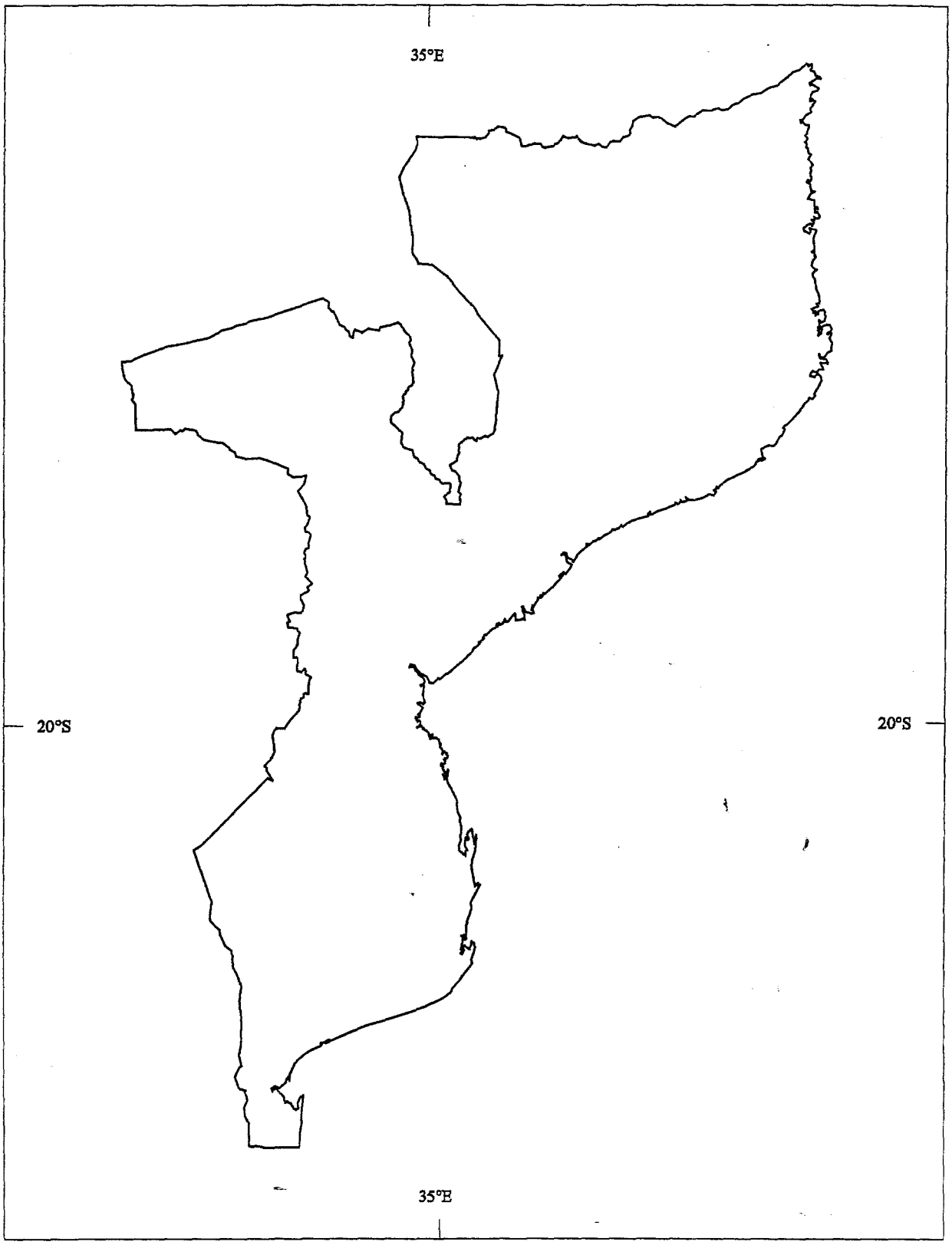


Figure E.52. Digital map layer **mz_adm1** (Mozambique, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

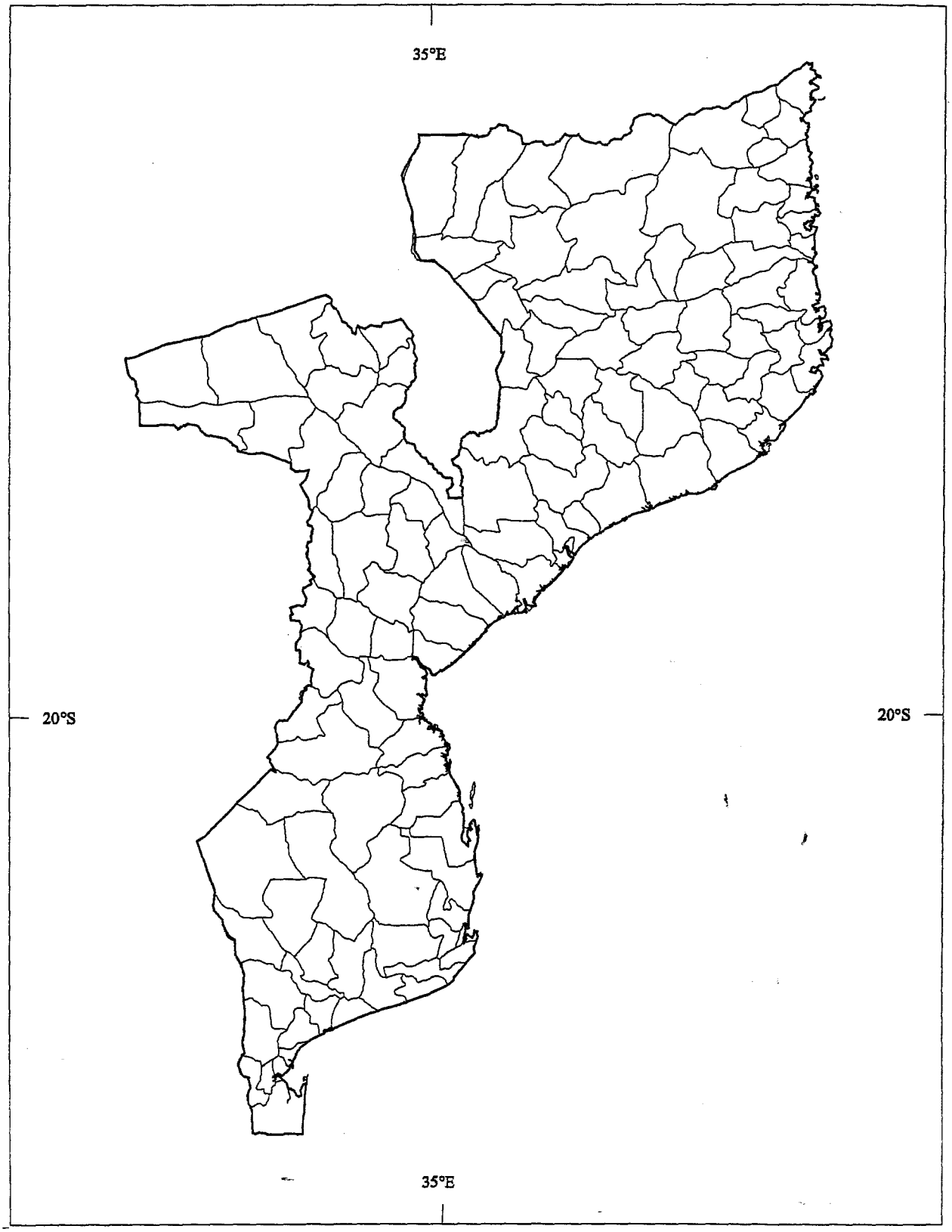


Figure E.53. Digital map layer **mz_adm2** (Mozambique, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

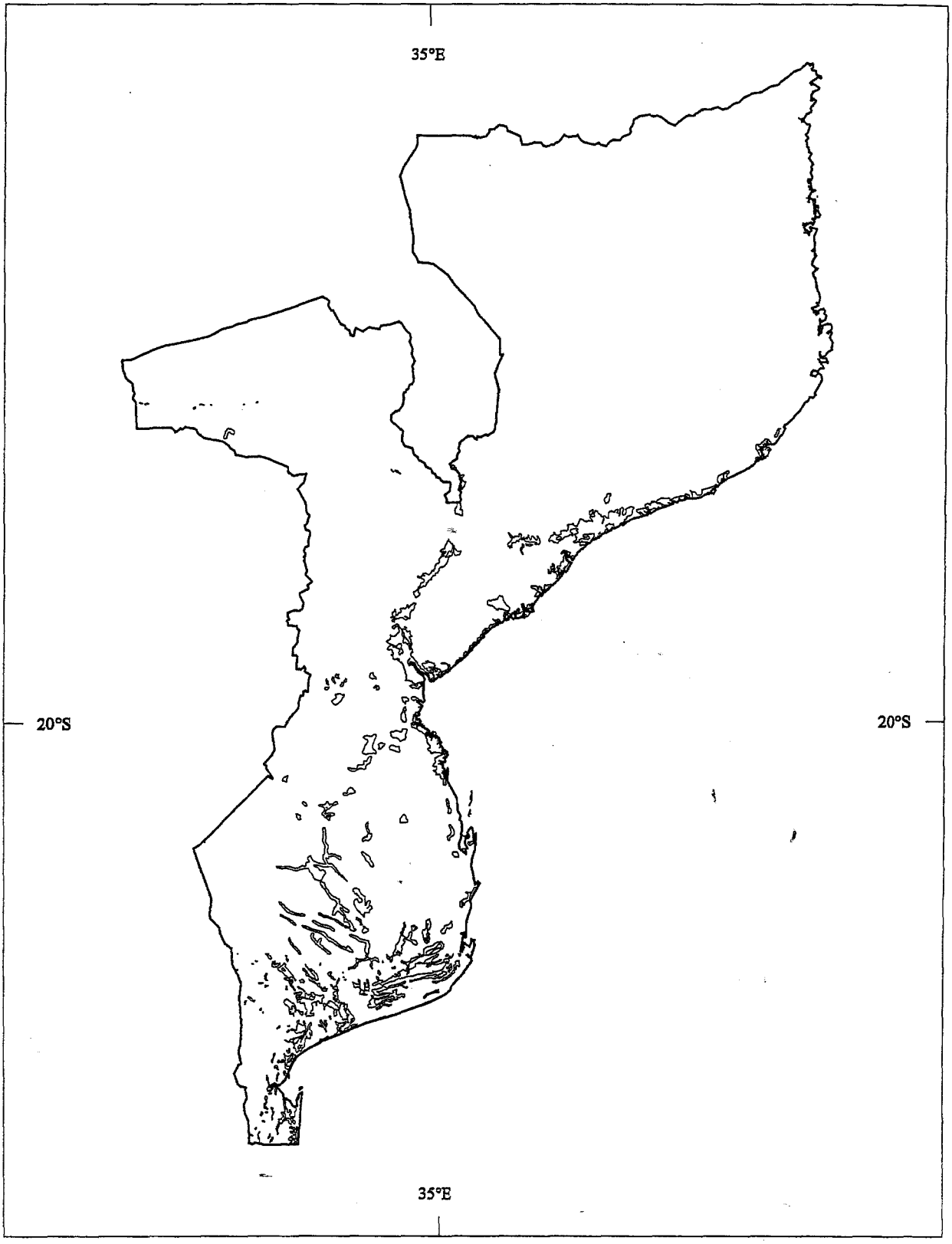


Figure E.54. Digital map layer **mz_cova** (Mozambique, wetlands and other land cover areas) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

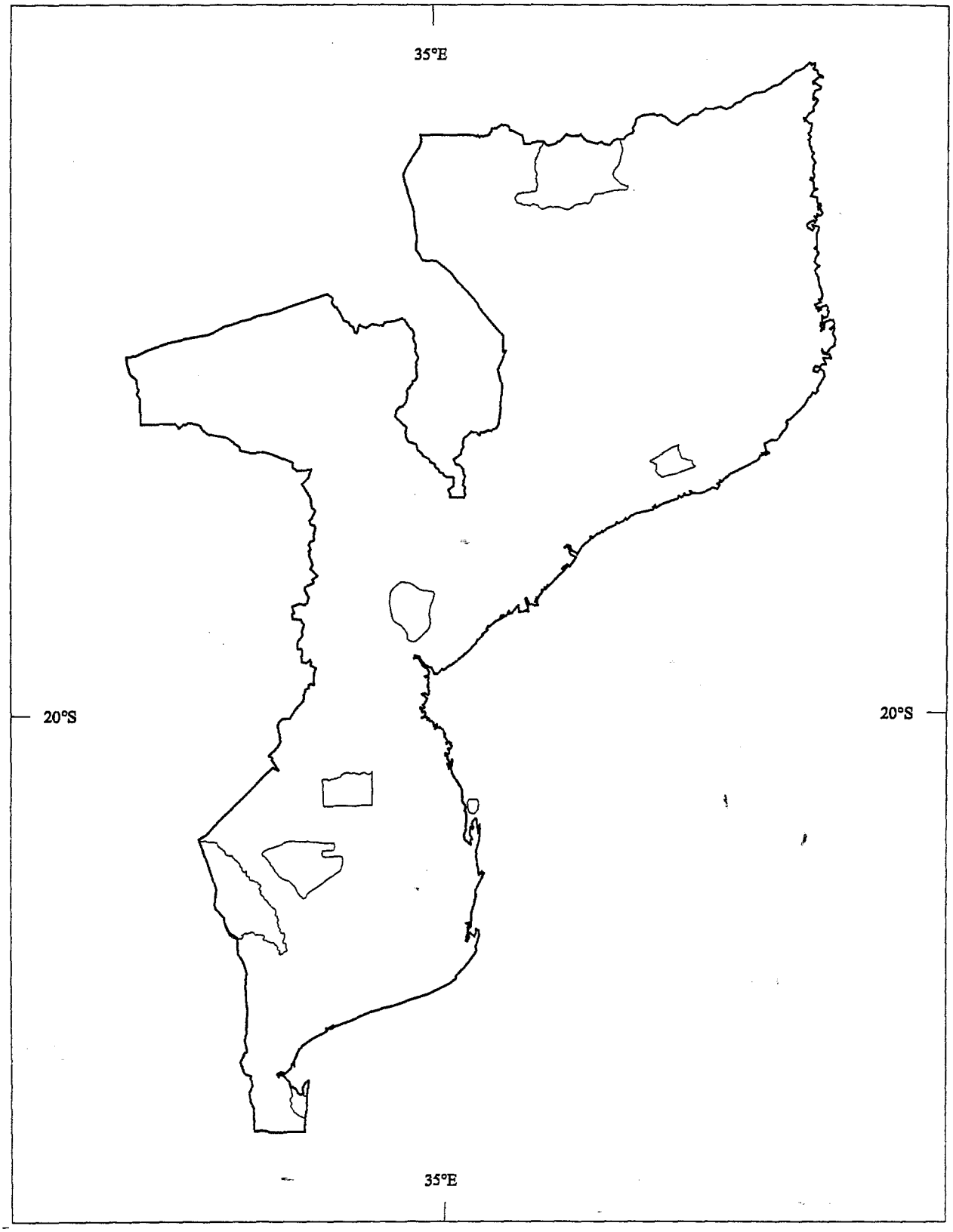


Figure E.55. Digital map layer **mz_park** (Mozambique, national parks) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

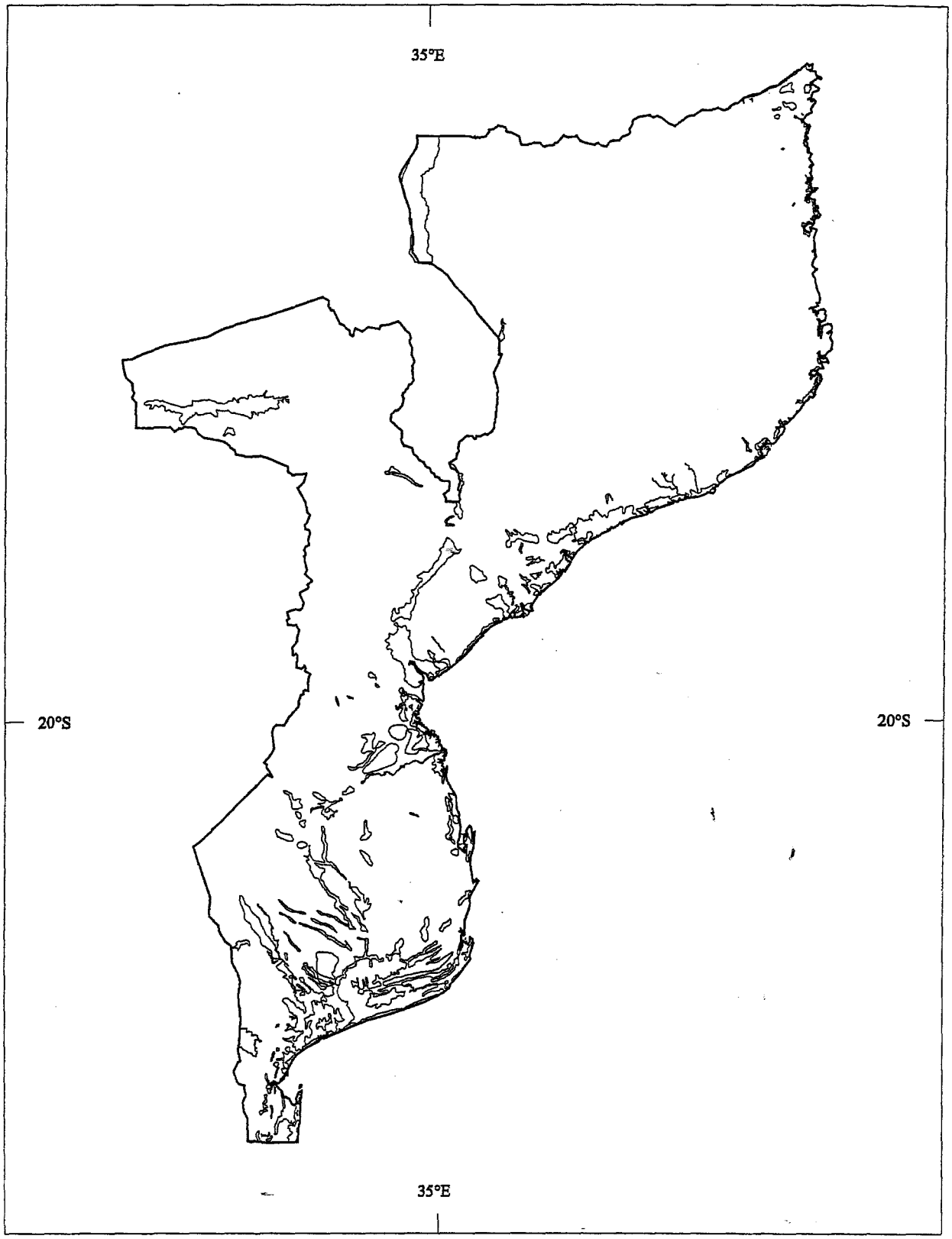


Figure E.56. Digital map layer **mz_wetl** (Mozambique, wetlands, classified by type) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

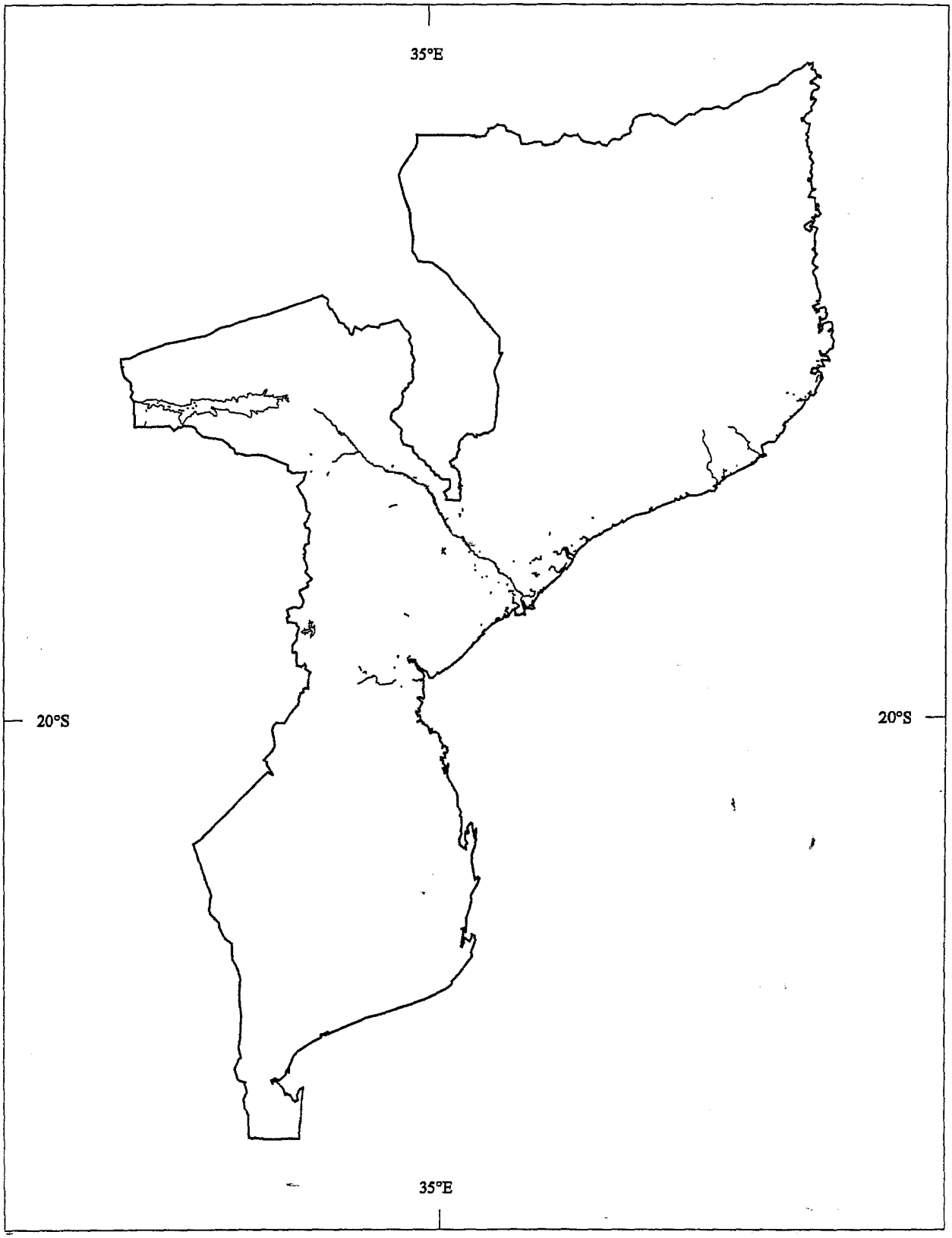


Figure E.57. Digital map layer **mz_lakec** (Mozambique, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

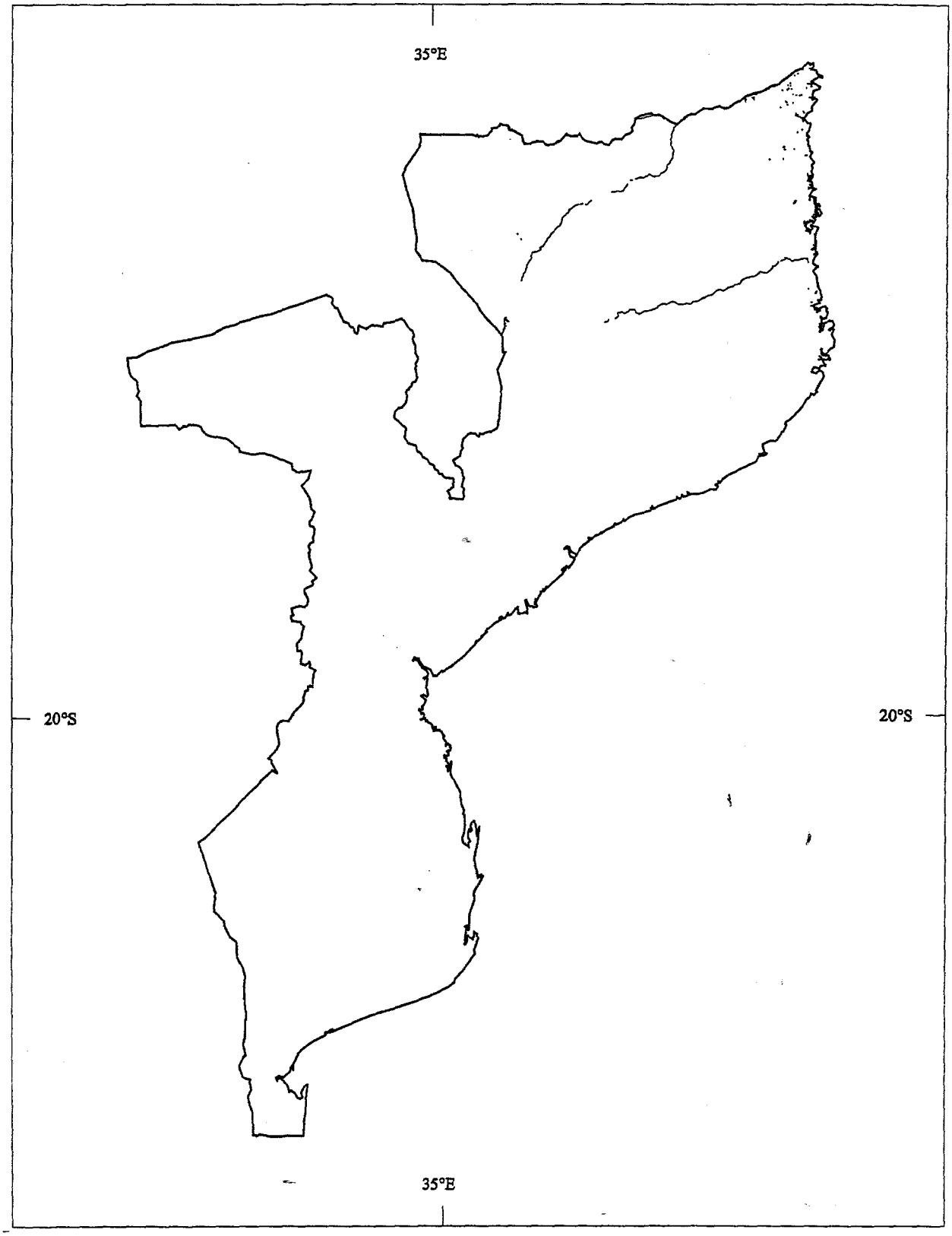


Figure E.58. Digital map layer **mz_lakee** (Mozambique, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

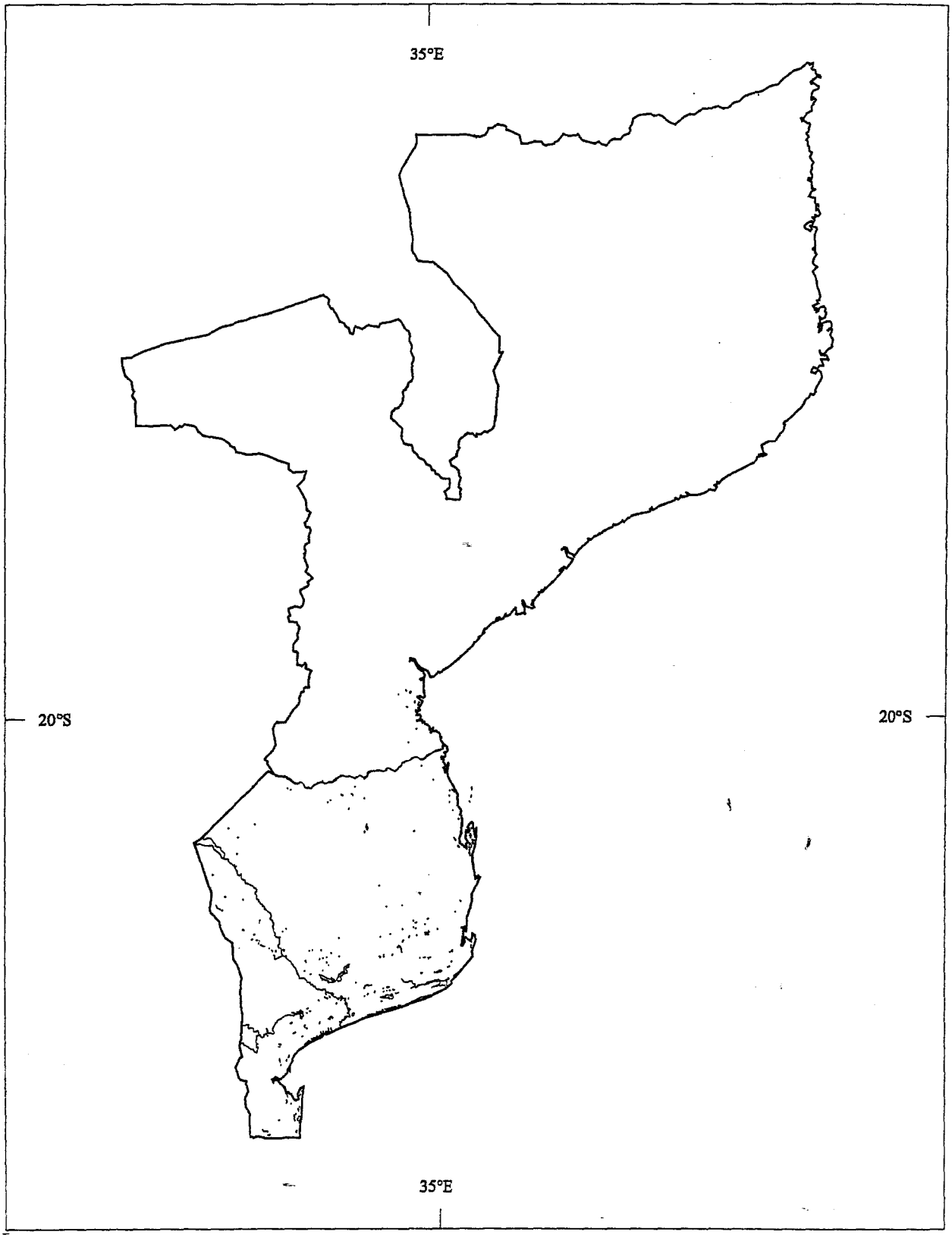


Figure E.59. Digital map layer **mz_lakes** (Mozambique, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

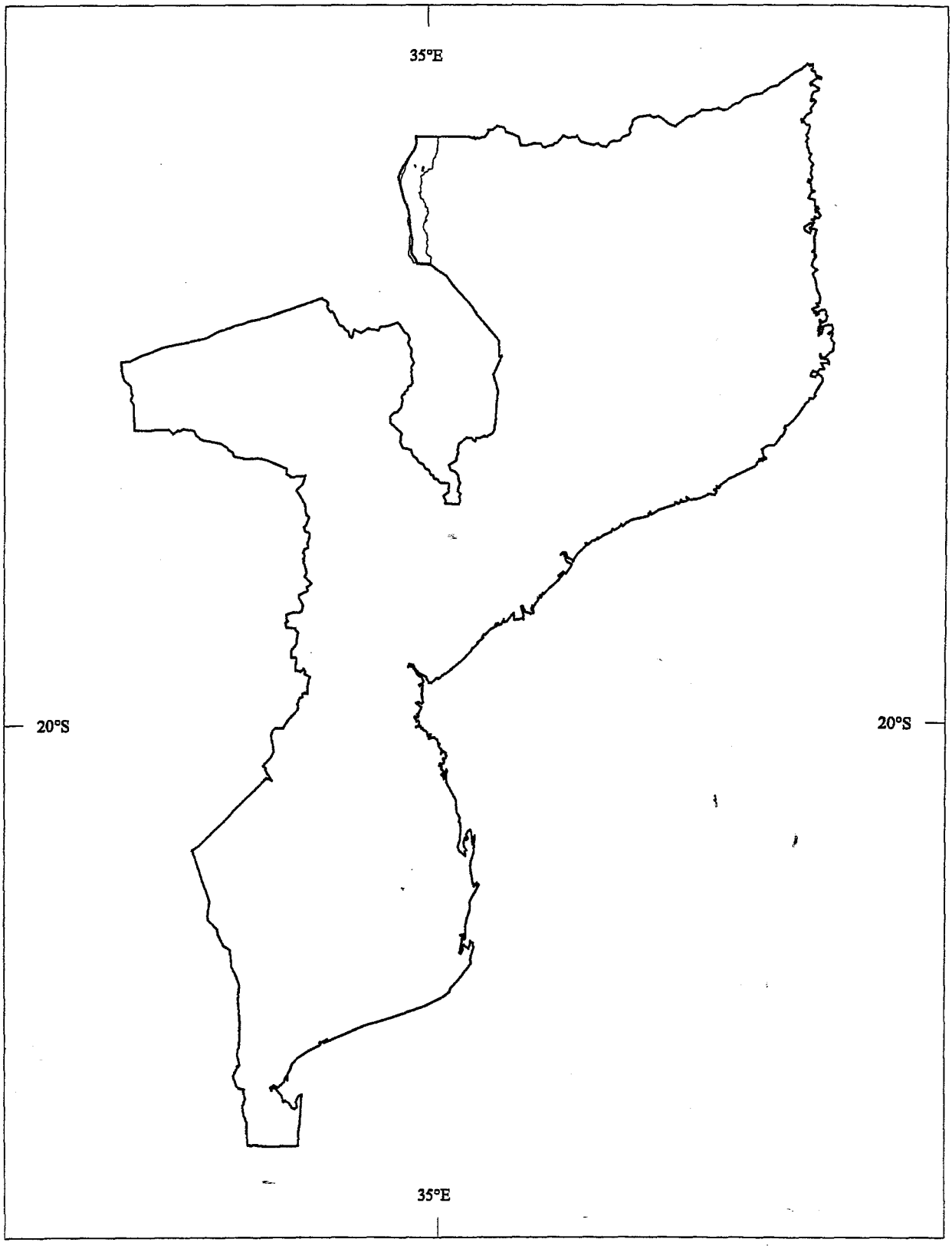


Figure E.60. Digital map layer **mz_lakew** (Mozambique, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

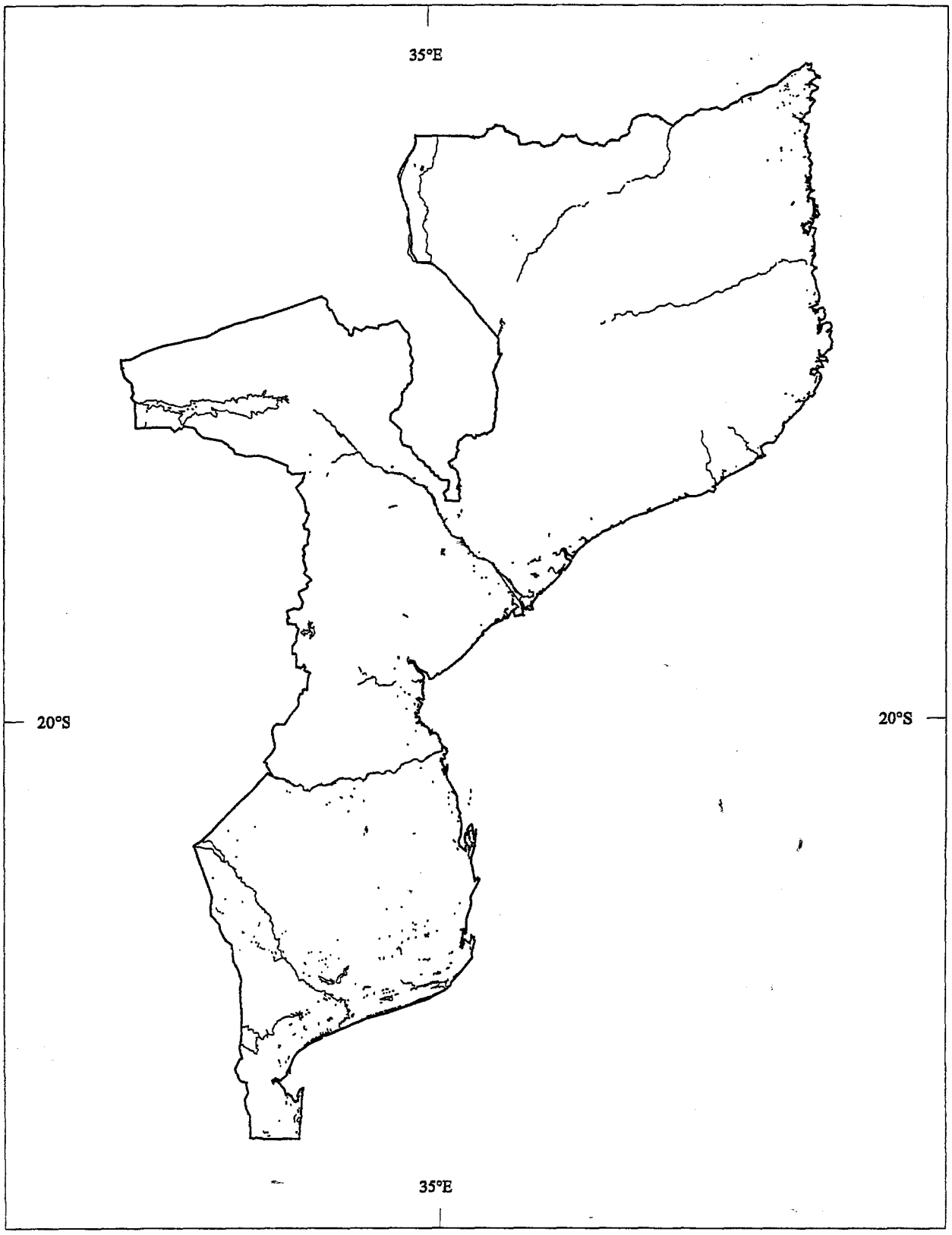


Figure E.61. Digital map layer **mz_pwat** (Mozambique, perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

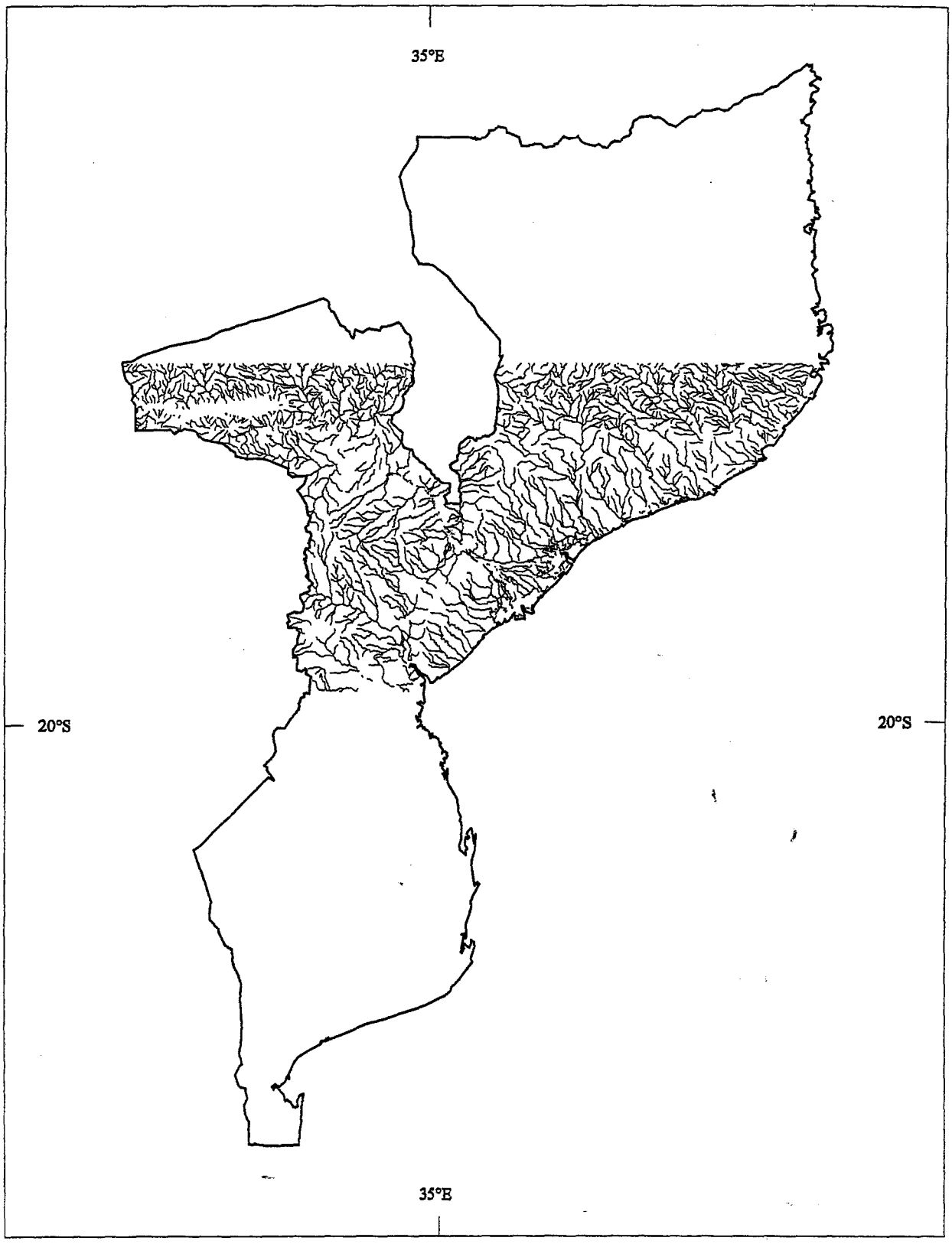


Figure E.62. Digital map layer **mz_rivc** (Mozambique, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

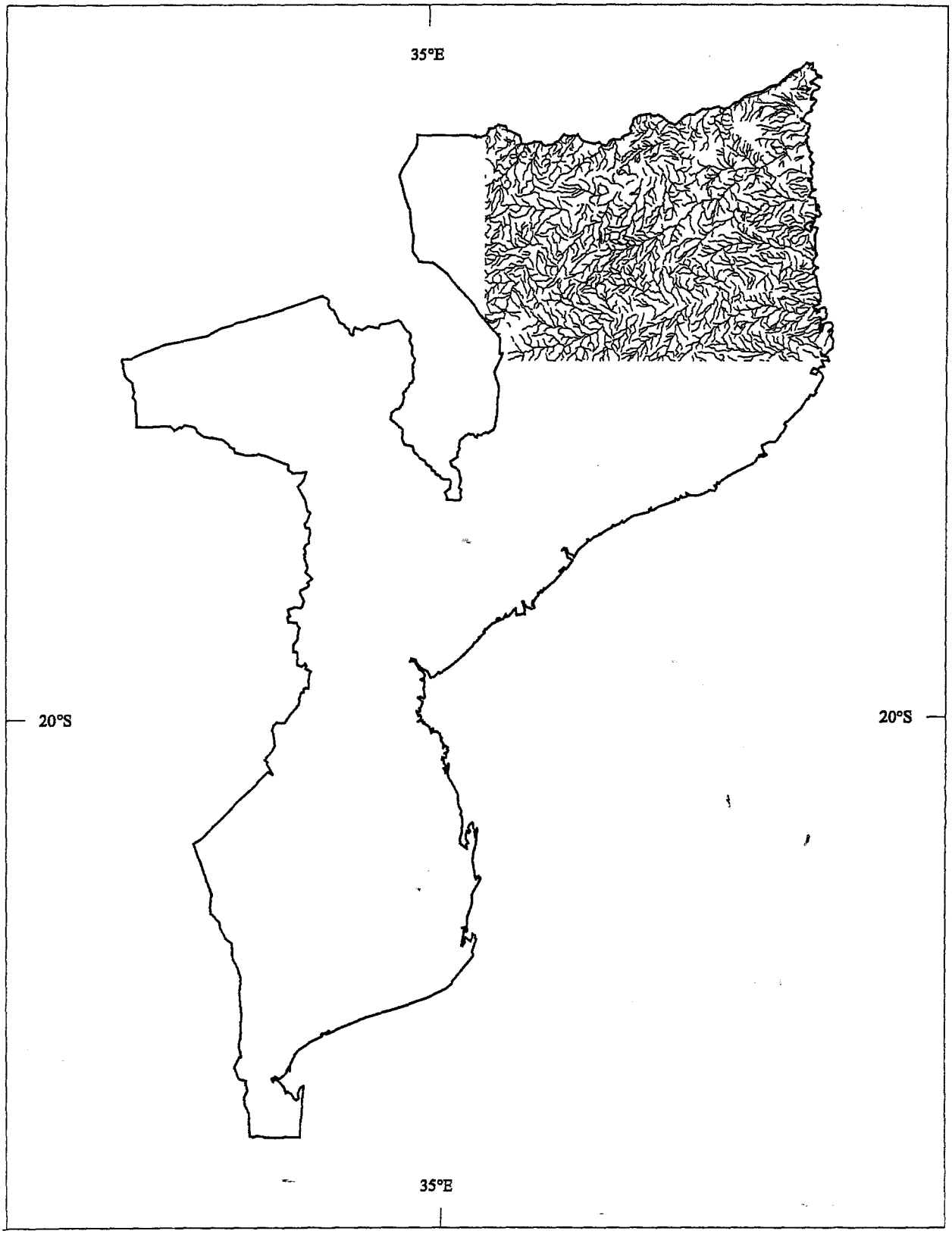


Figure E.63. Digital map layer **mz_rive** (Mozambique, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000



Figure E.64. Digital map layer **mz_rivs** (Mozambique, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

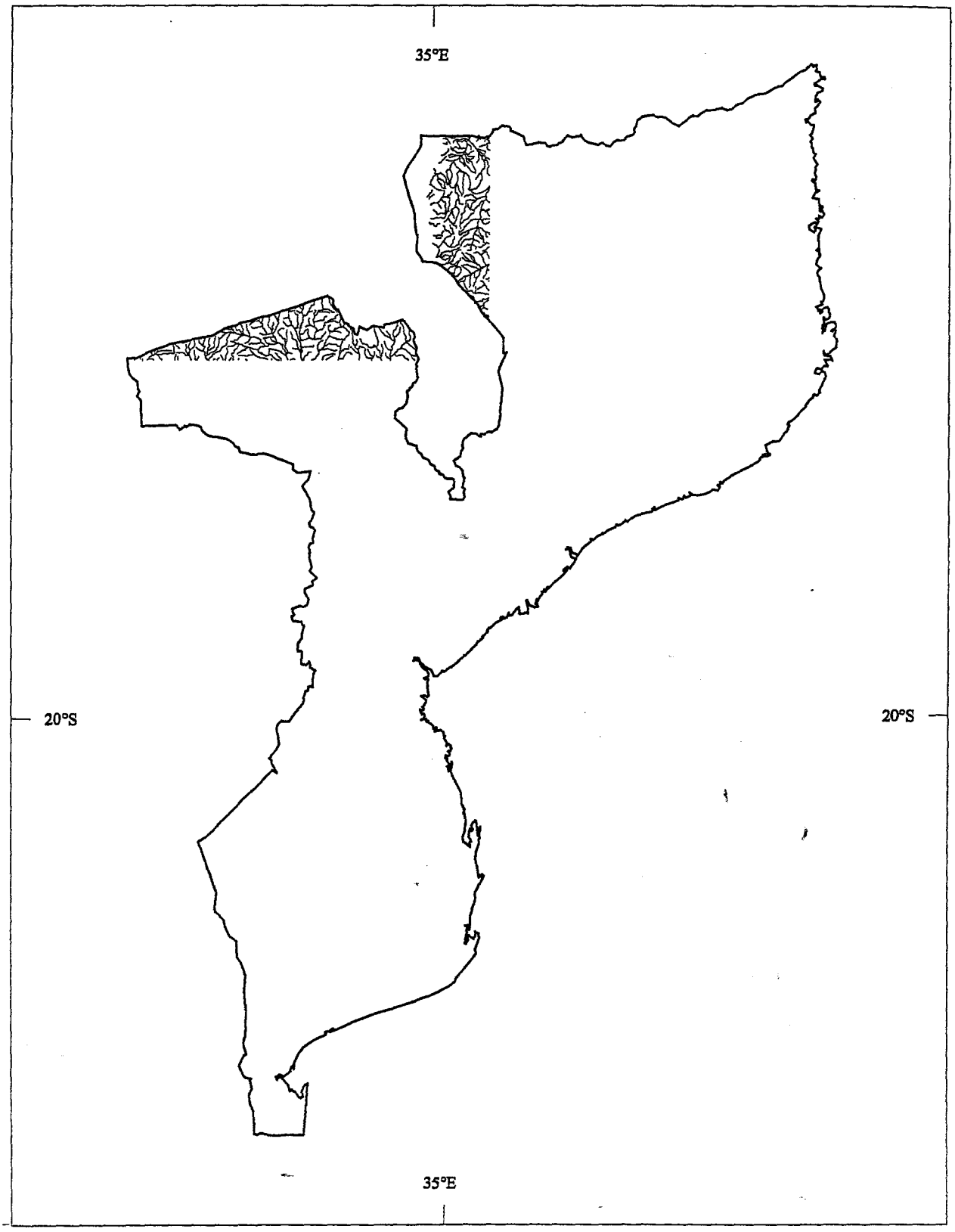


Figure E.65. Digital map layer **mz_rivw** (Mozambique, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

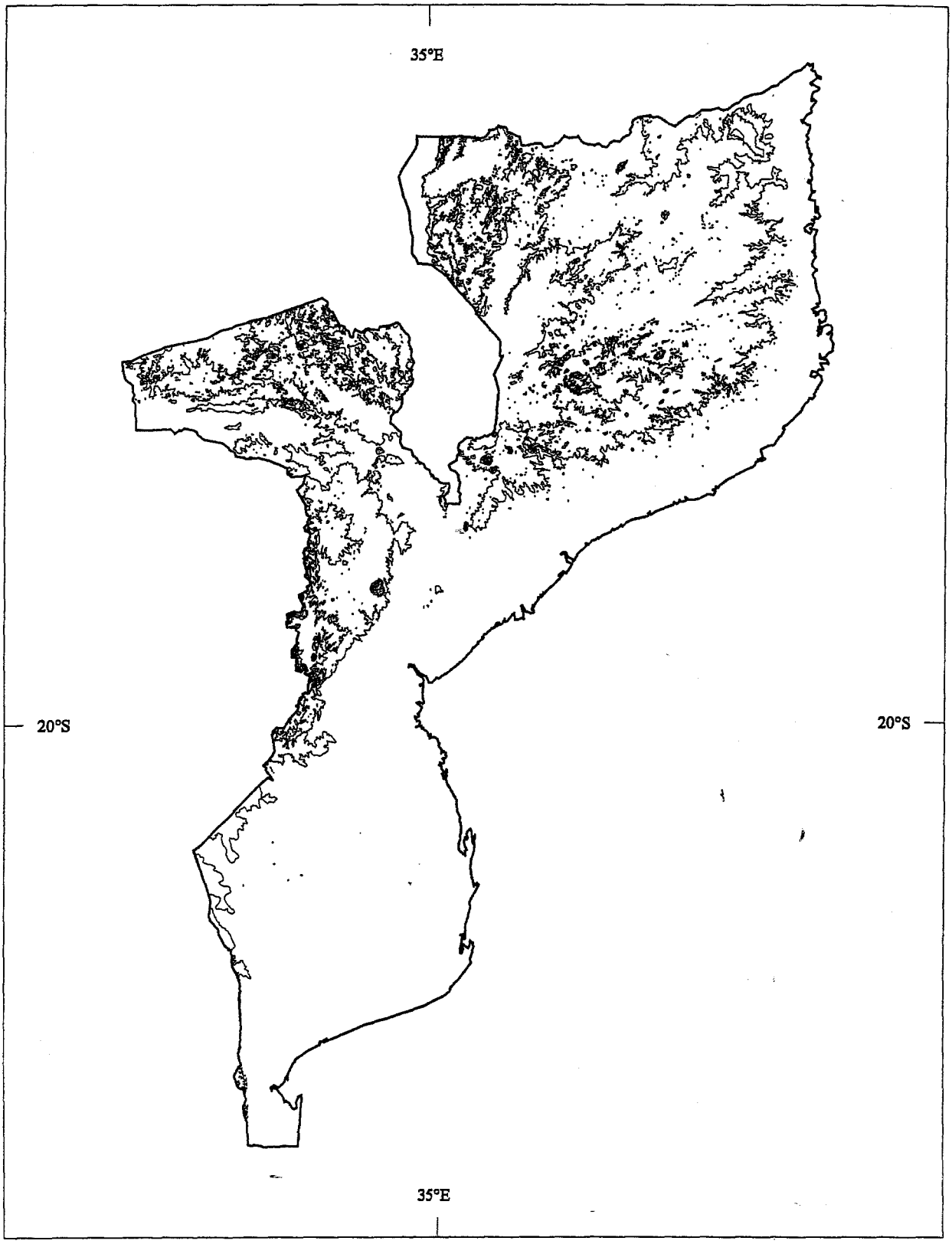


Figure E.66. Digital map layer **mz_elev** (Mozambique, 1000m contours) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

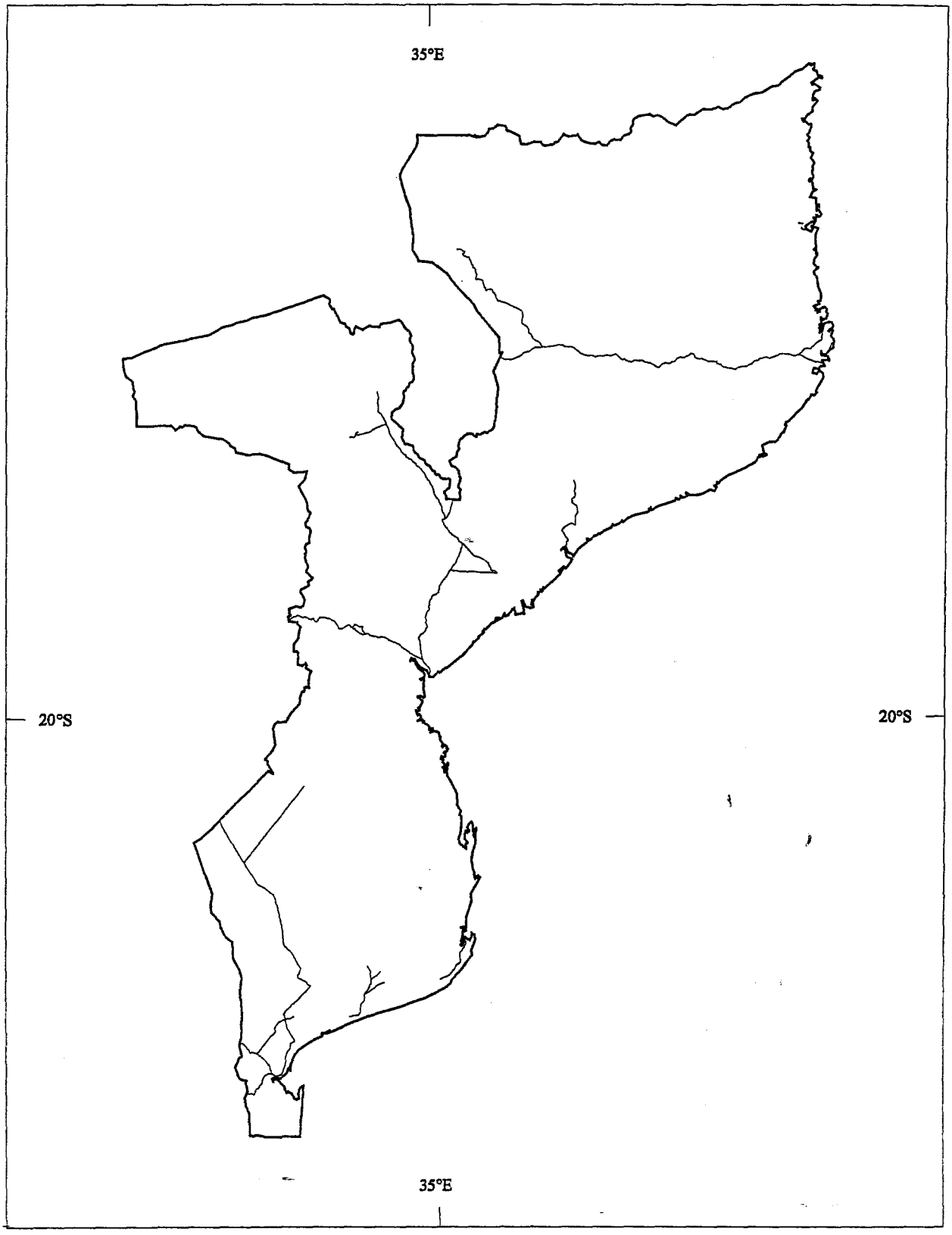


Figure E.67. Digital map layer **mz_rail** (Mozambique, railroads) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

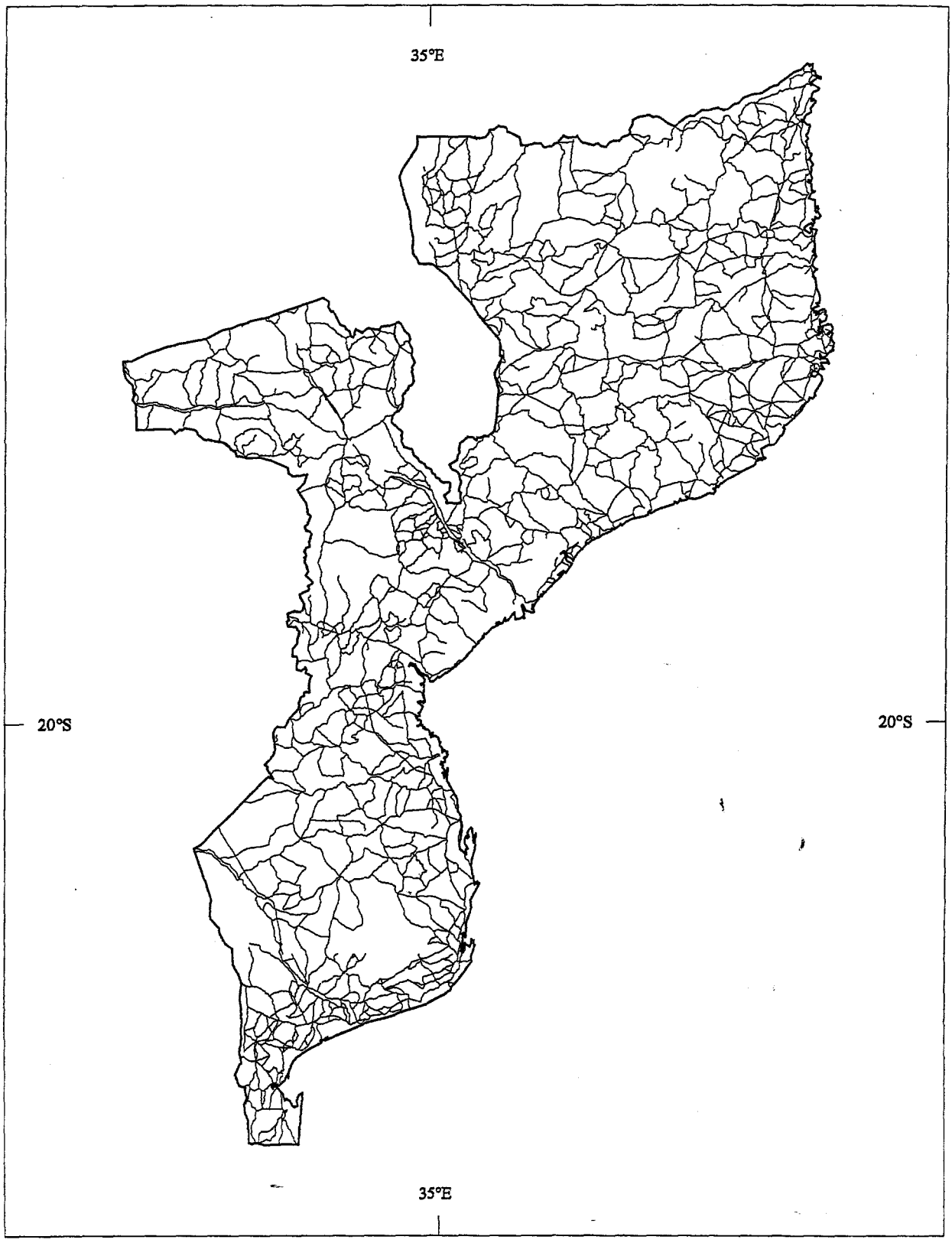


Figure E.68. Digital map layer **mz_road** (Mozambique, roads) from the atlas of southern African freshwater fish. Scale approximately 1:9 400 000

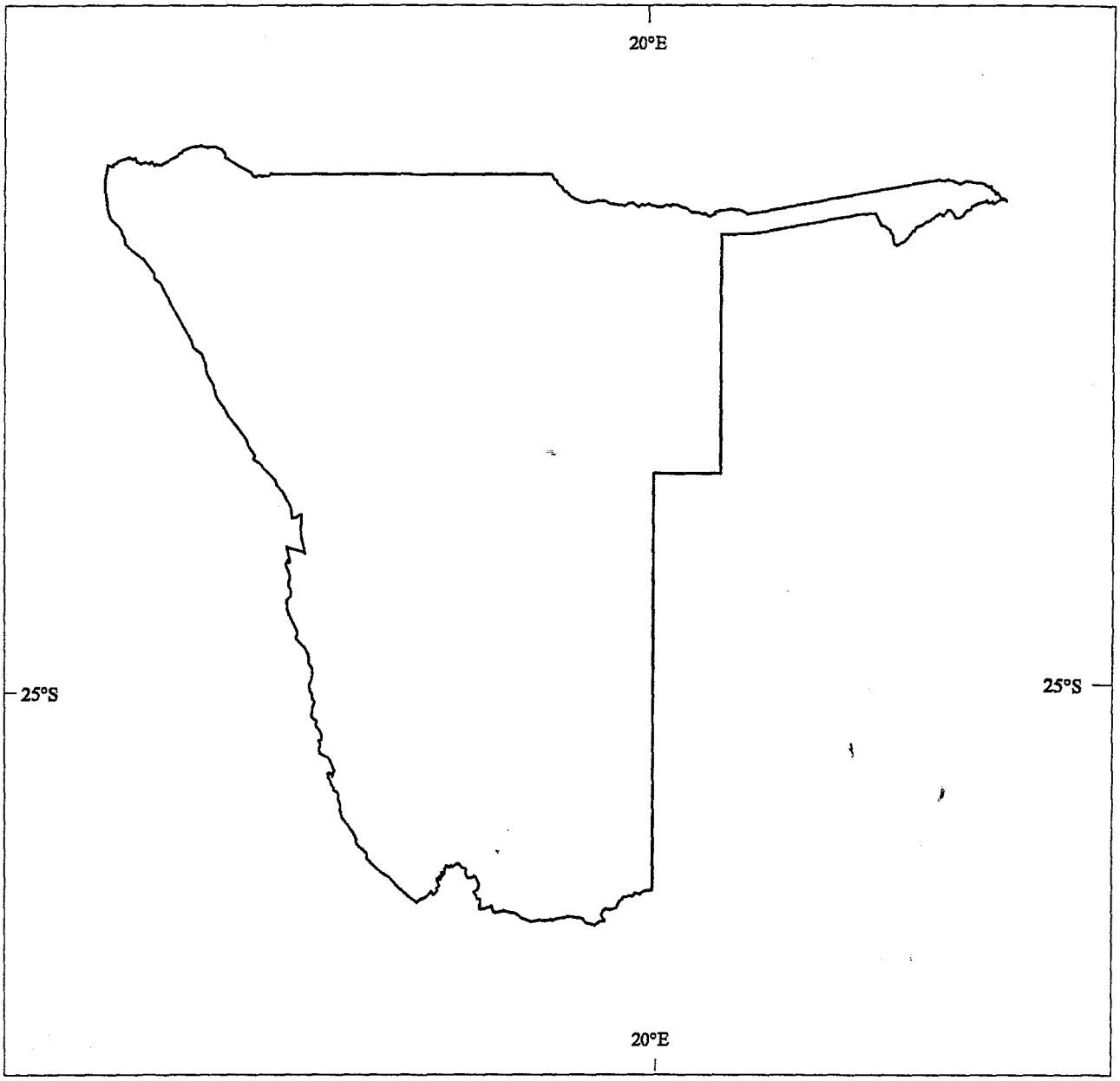


Figure E.69. Digital map layer **na_adm1** (Namibia, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:11 100 000

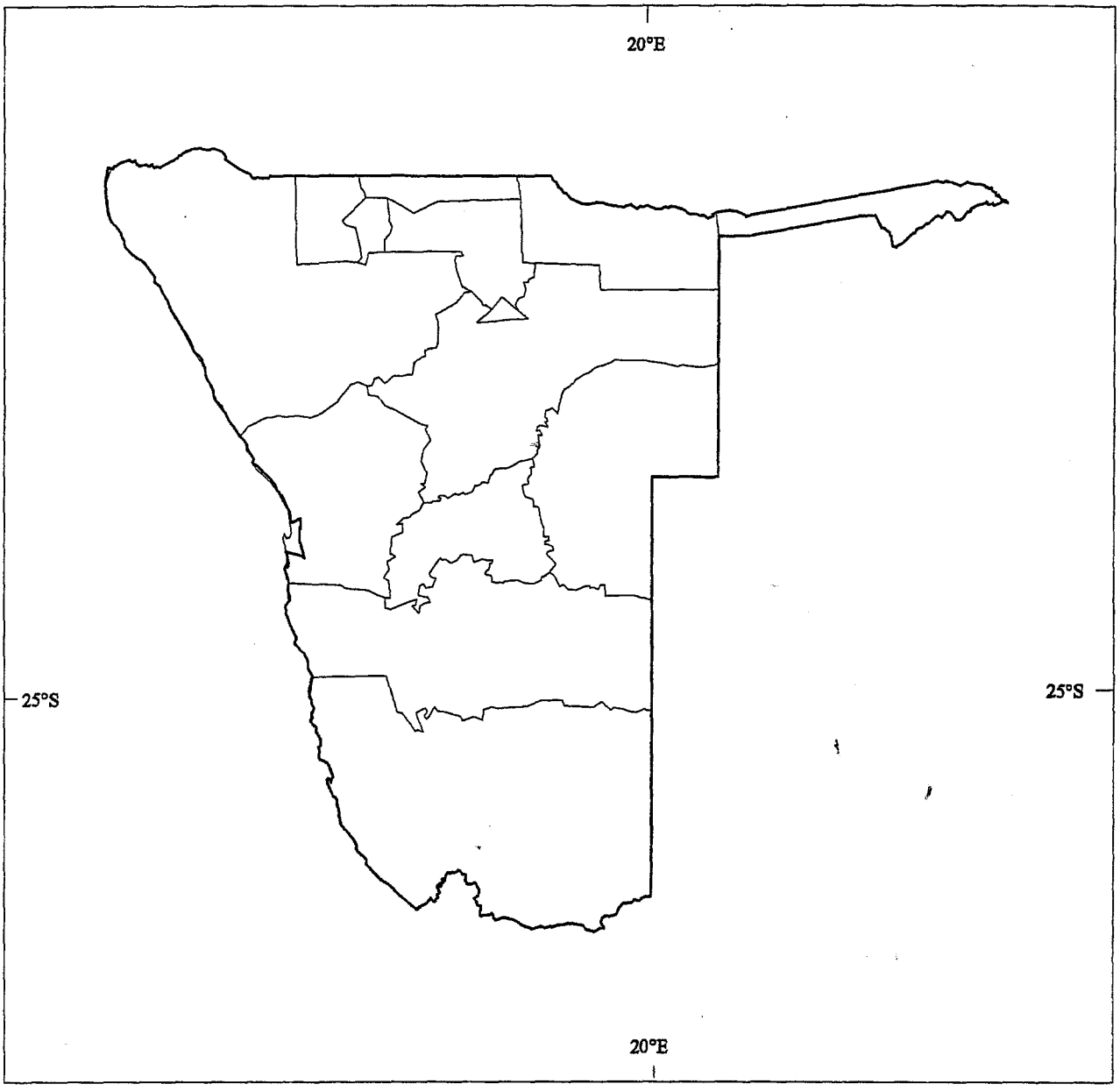


Figure E.70. Digital map layer **na_adm2** (Namibia, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:11 100 000

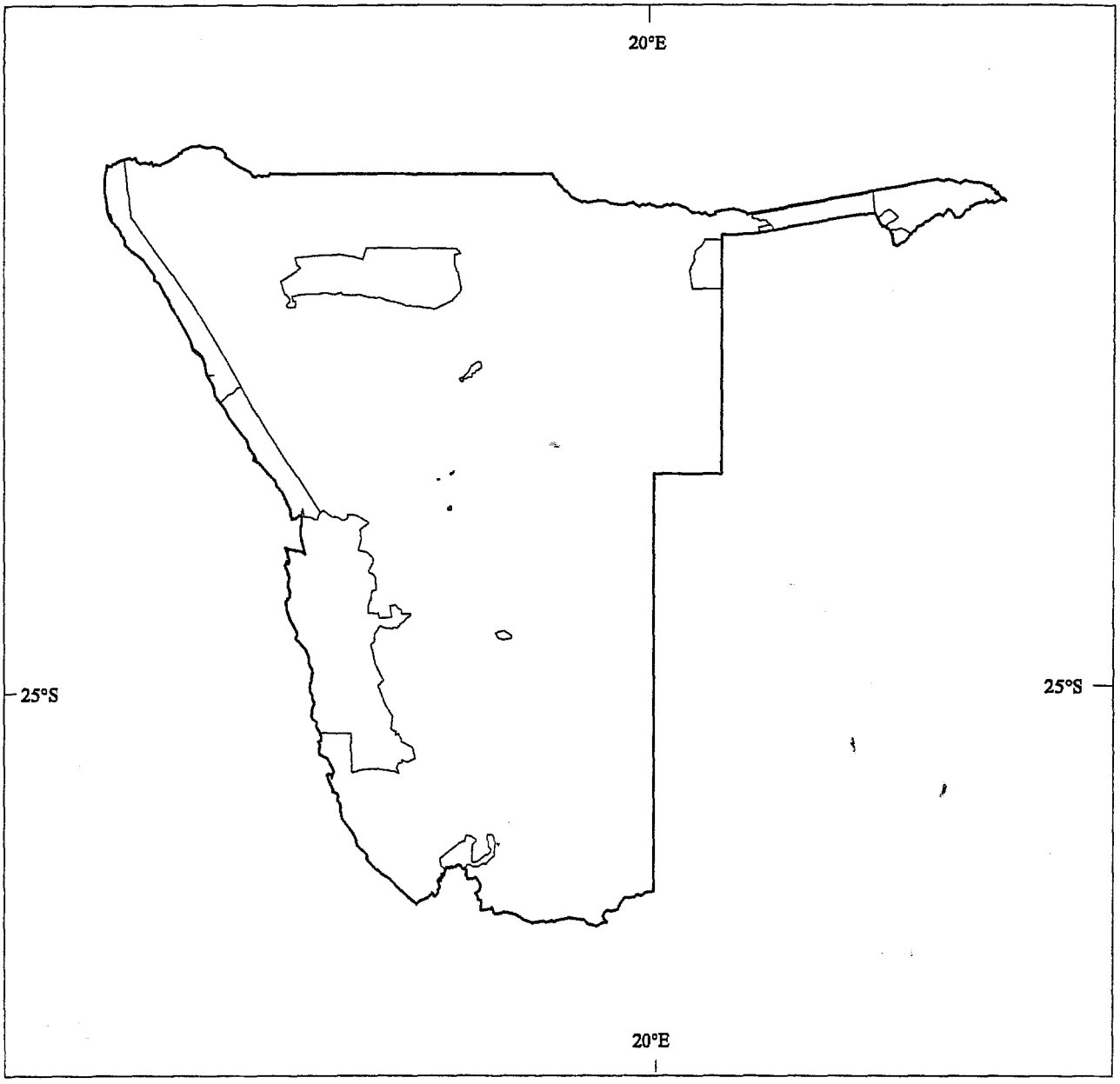


Figure E.71. Digital map layer **na_park** (Namibia, national parks) from the atlas of southern African freshwater fish. Scale approximately 1:11 100 000

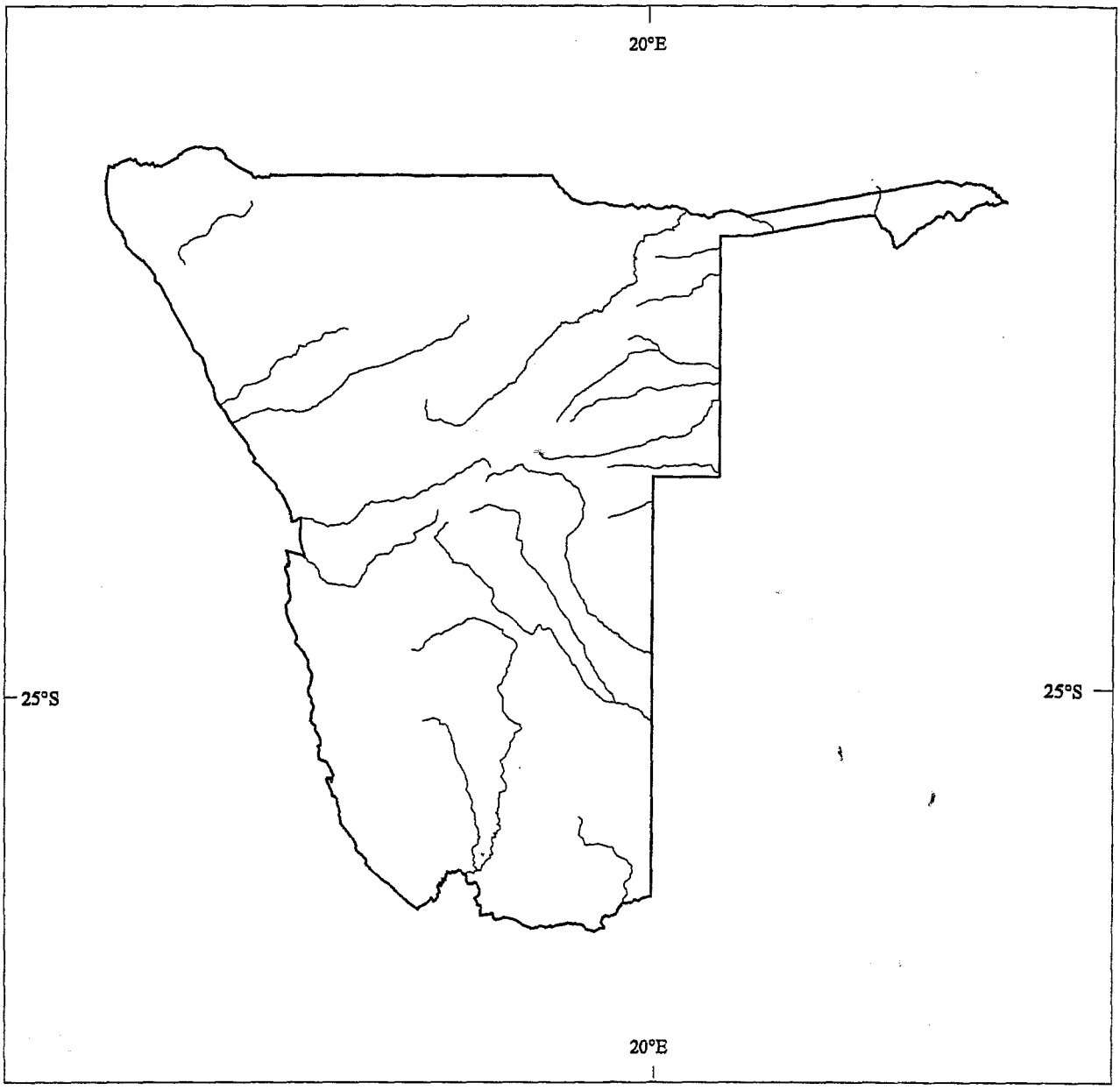


Figure E.72. Digital map layer **na_riv** (Namibia, rivers) from the atlas of southern African freshwater fish. Scale approximately 1:11 100 000

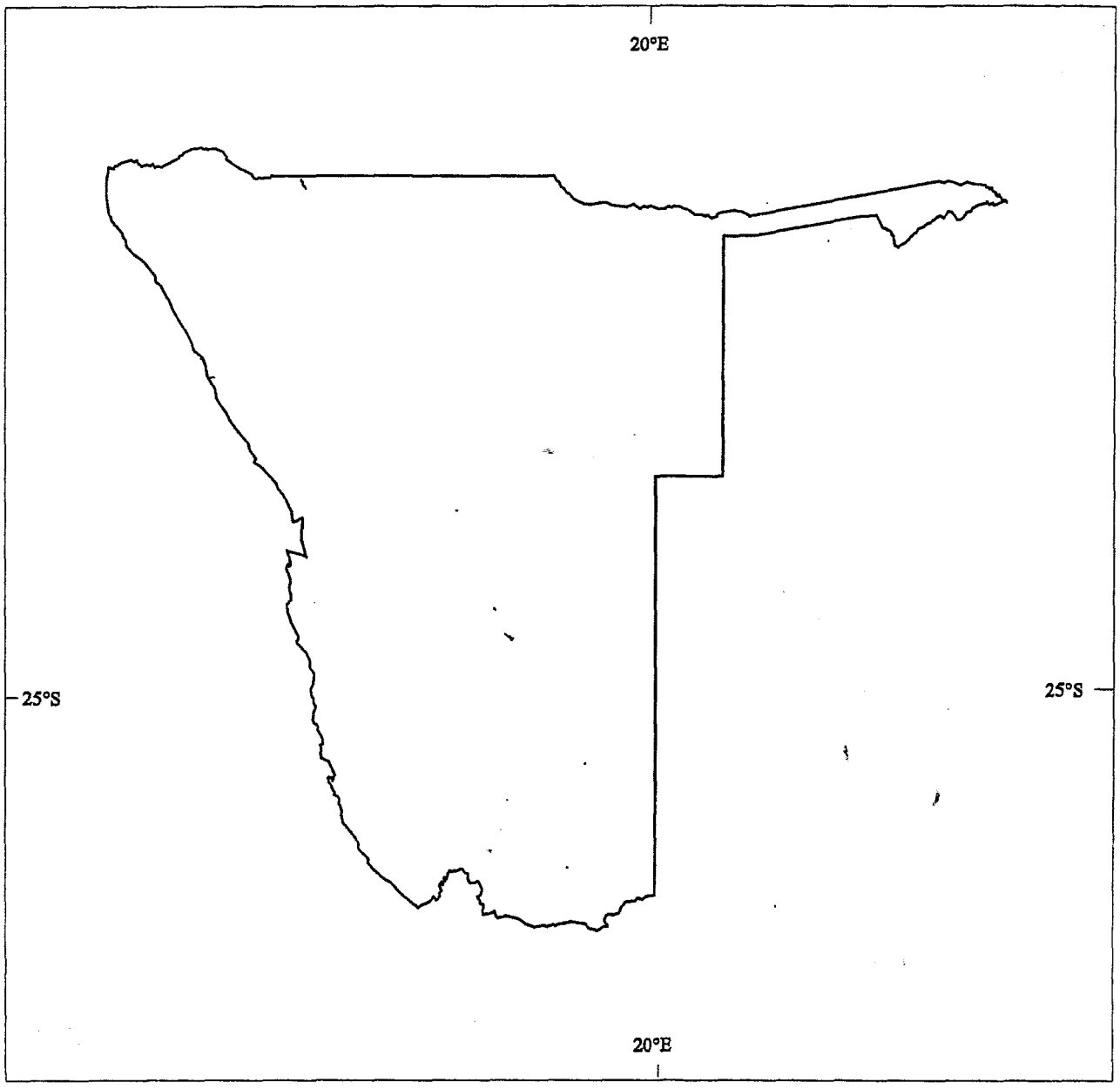


Figure E.73. Digital map layer **na_pwat** (Namibia, non-perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:11 100 000

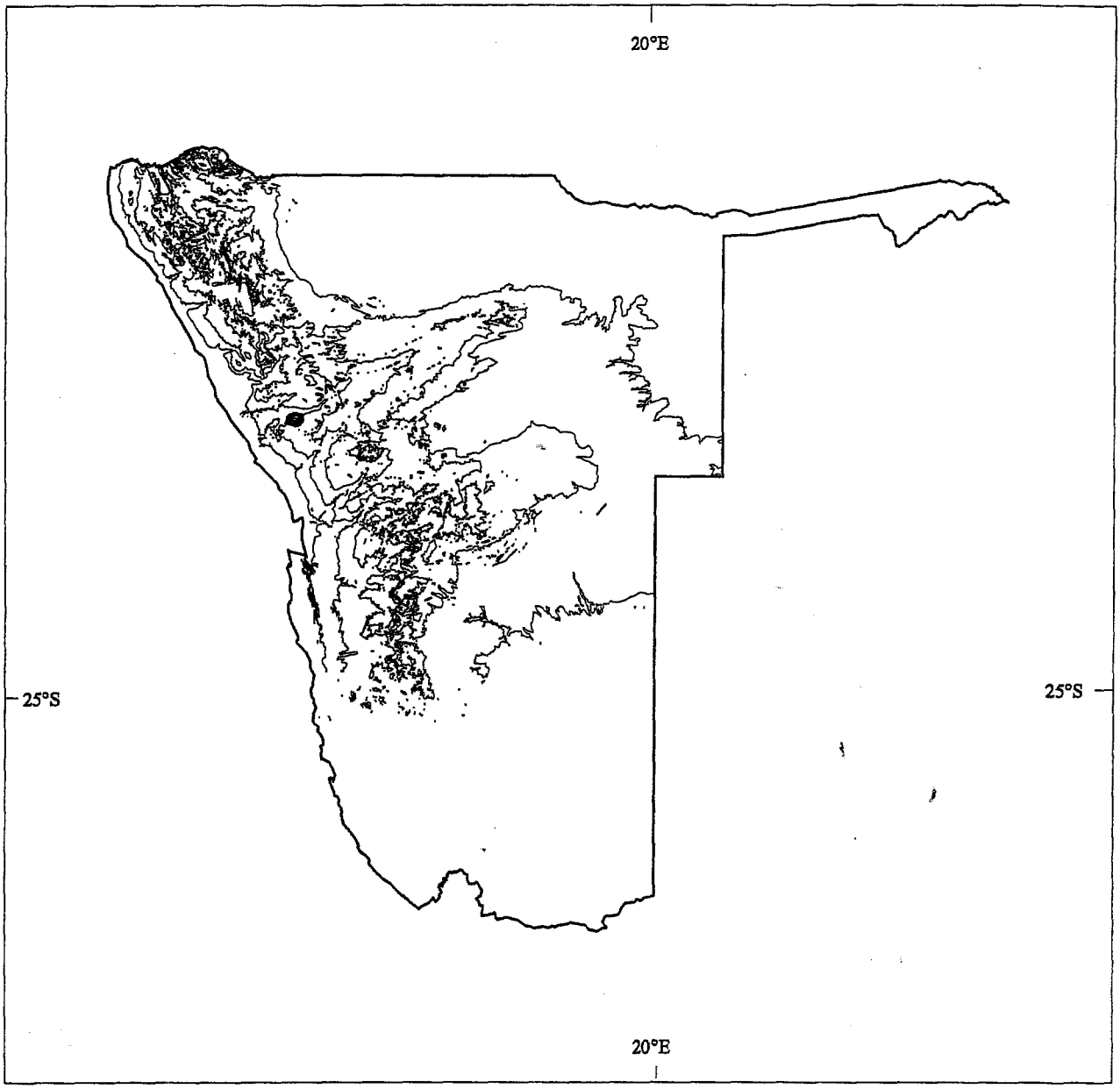


Figure E.74. Digital map layer **na_elev** (Namibia, 1000m contours) from the atlas of southern African freshwater fish. Scale approximately 1:11 100 000

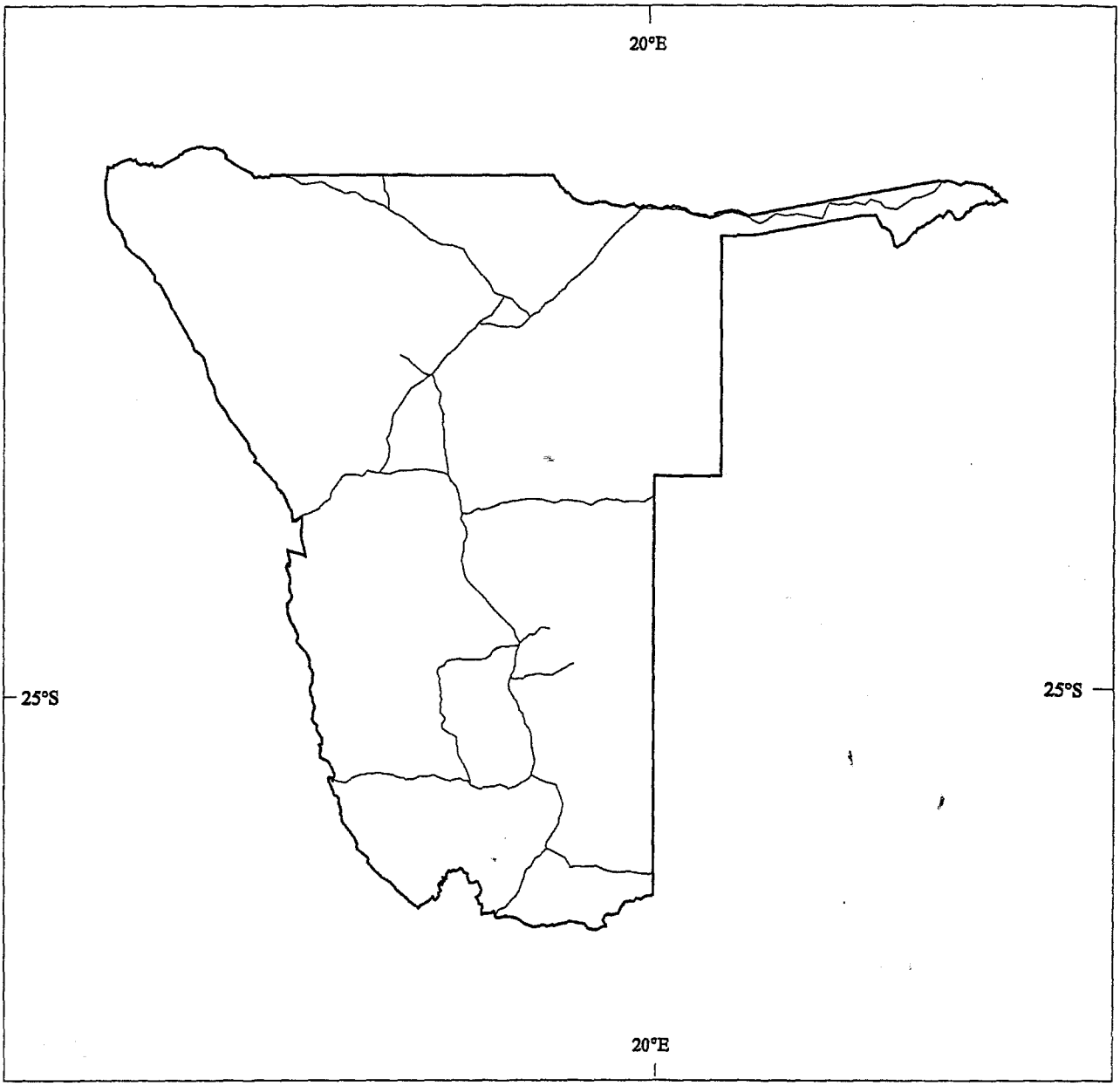


Figure E.75. Digital map layer **na_road** (Namibia, roads) from the atlas of southern African freshwater fish. Scale approximately 1:11 100 000

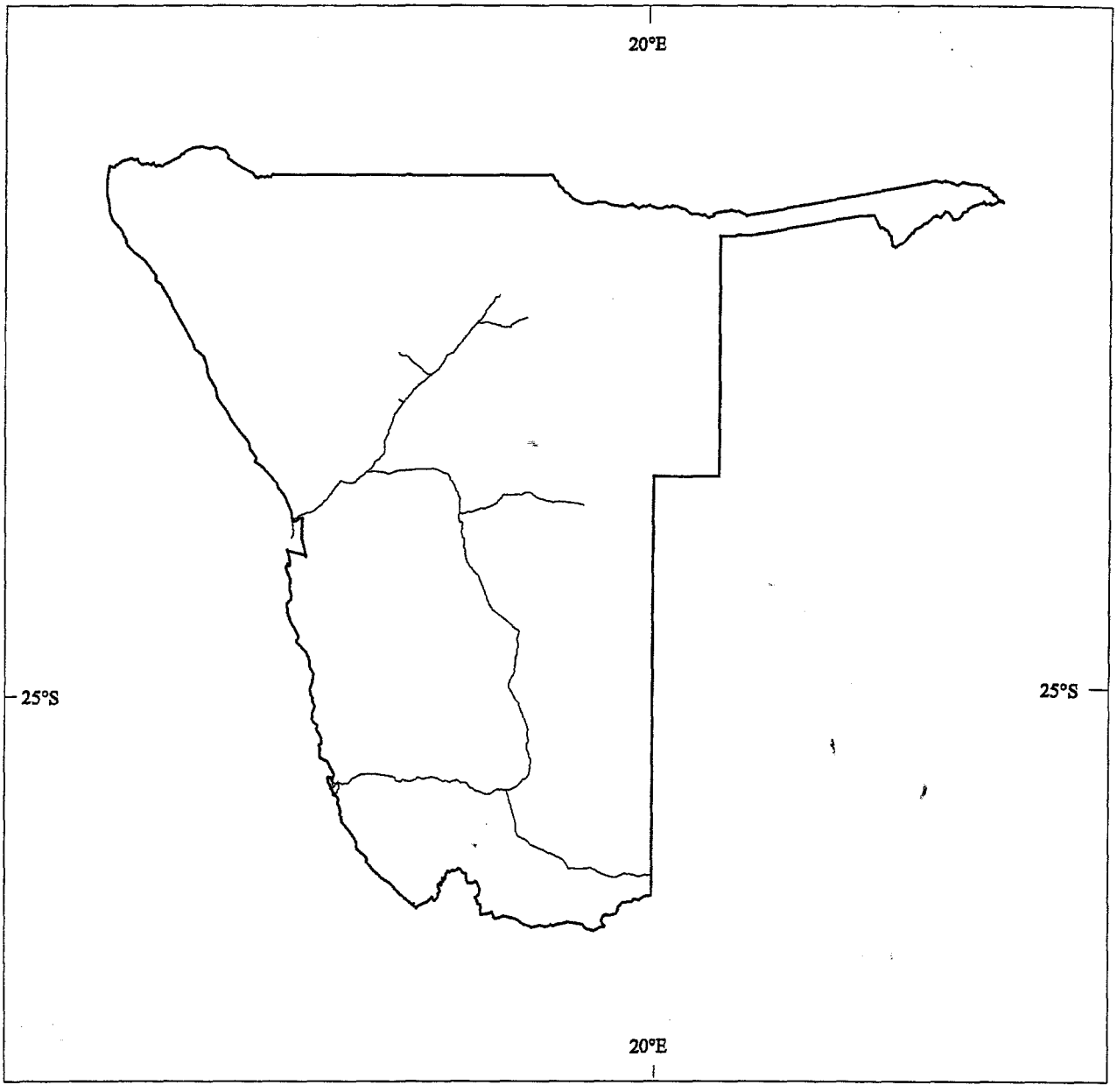


Figure E.76. Digital map layer **na_rail** (Namibia, railroads) from the atlas of southern African freshwater fish. Scale approximately 1:11 100 000

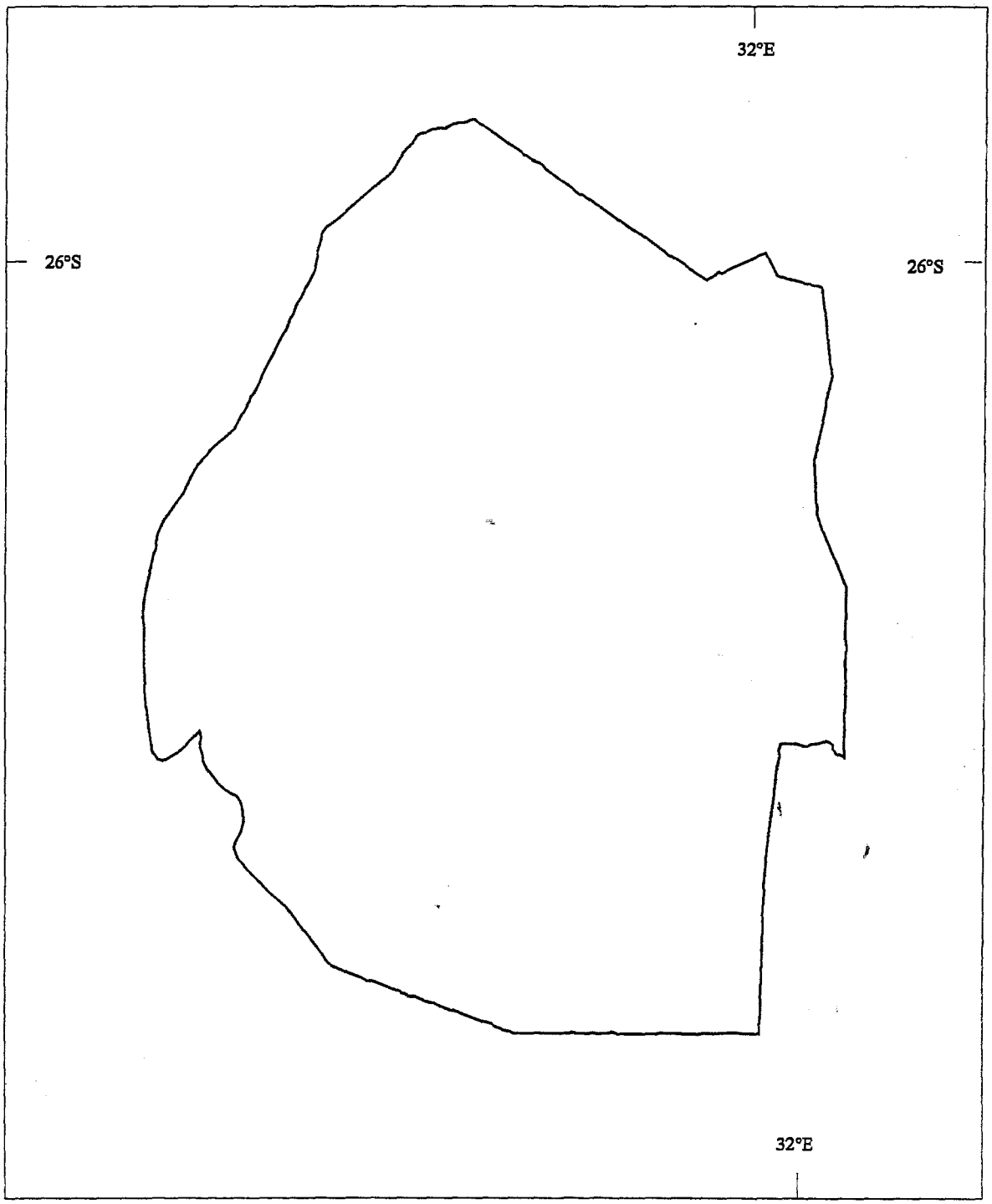


Figure E.77. Digital map layer **sz_adm1** (Swaziland, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:1 300 000

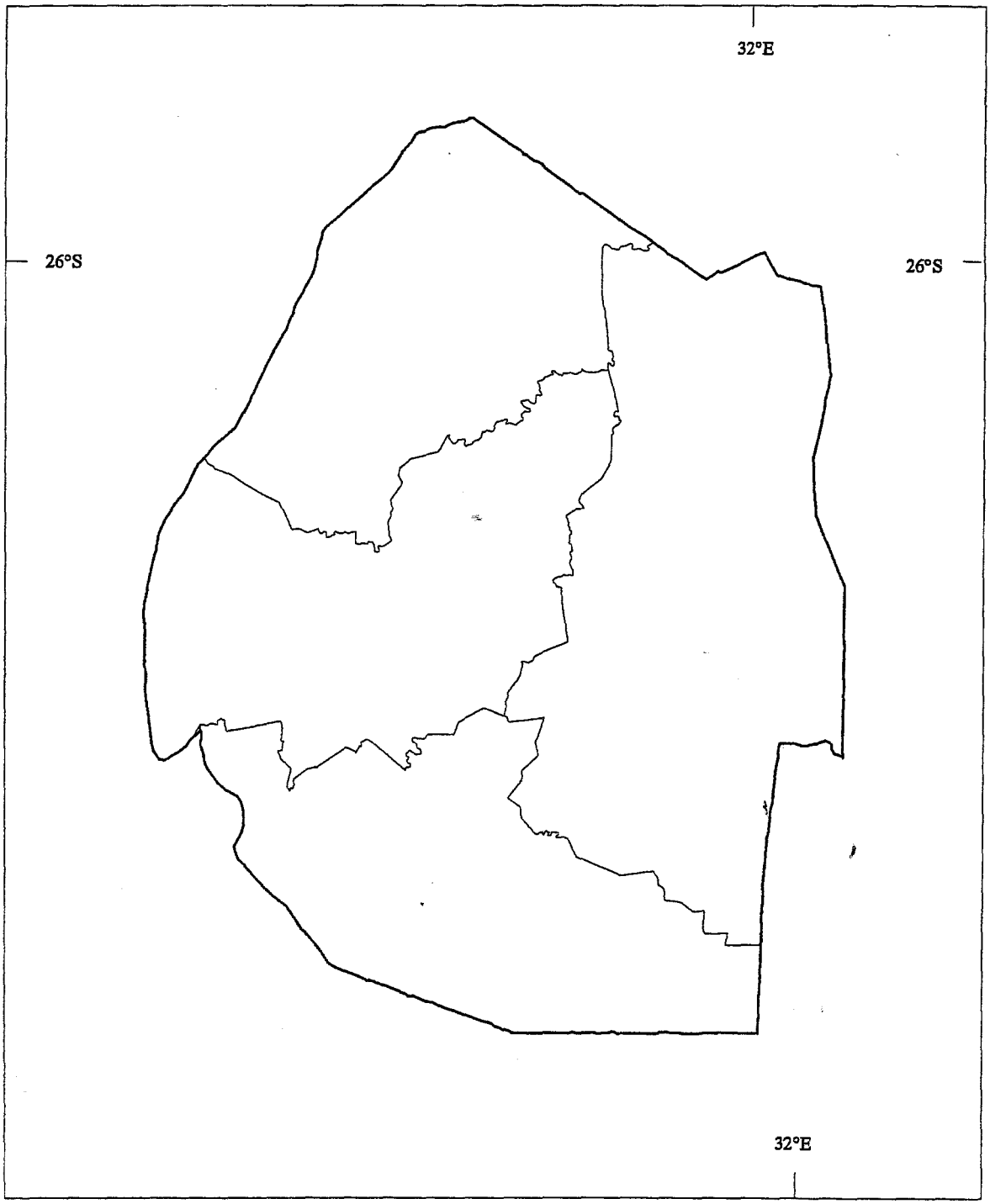


Figure E.78. Digital map layer **sz_adm2** (Swaziland, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:1 300 000

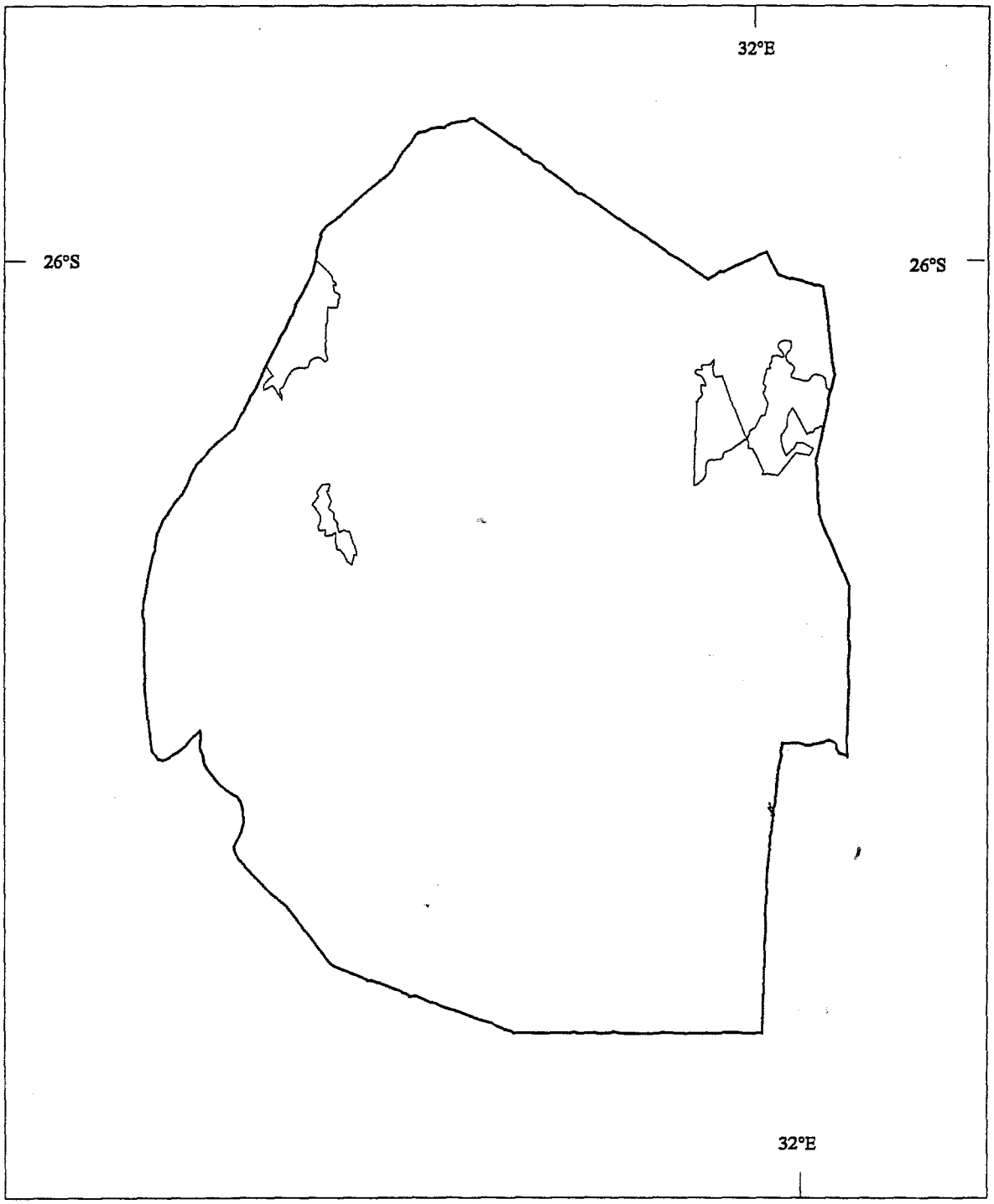


Figure E.79. Digital map layer **sz_park** (Swaziland, national parks) from the atlas of southern African freshwater fish. Scale approximately 1:1 300 000



Figure E.80. Digital map layer **sz_wood** (Swaziland, production forest, classified by type) from the atlas of southern African freshwater fish. Scale approximately 1:1 300 000

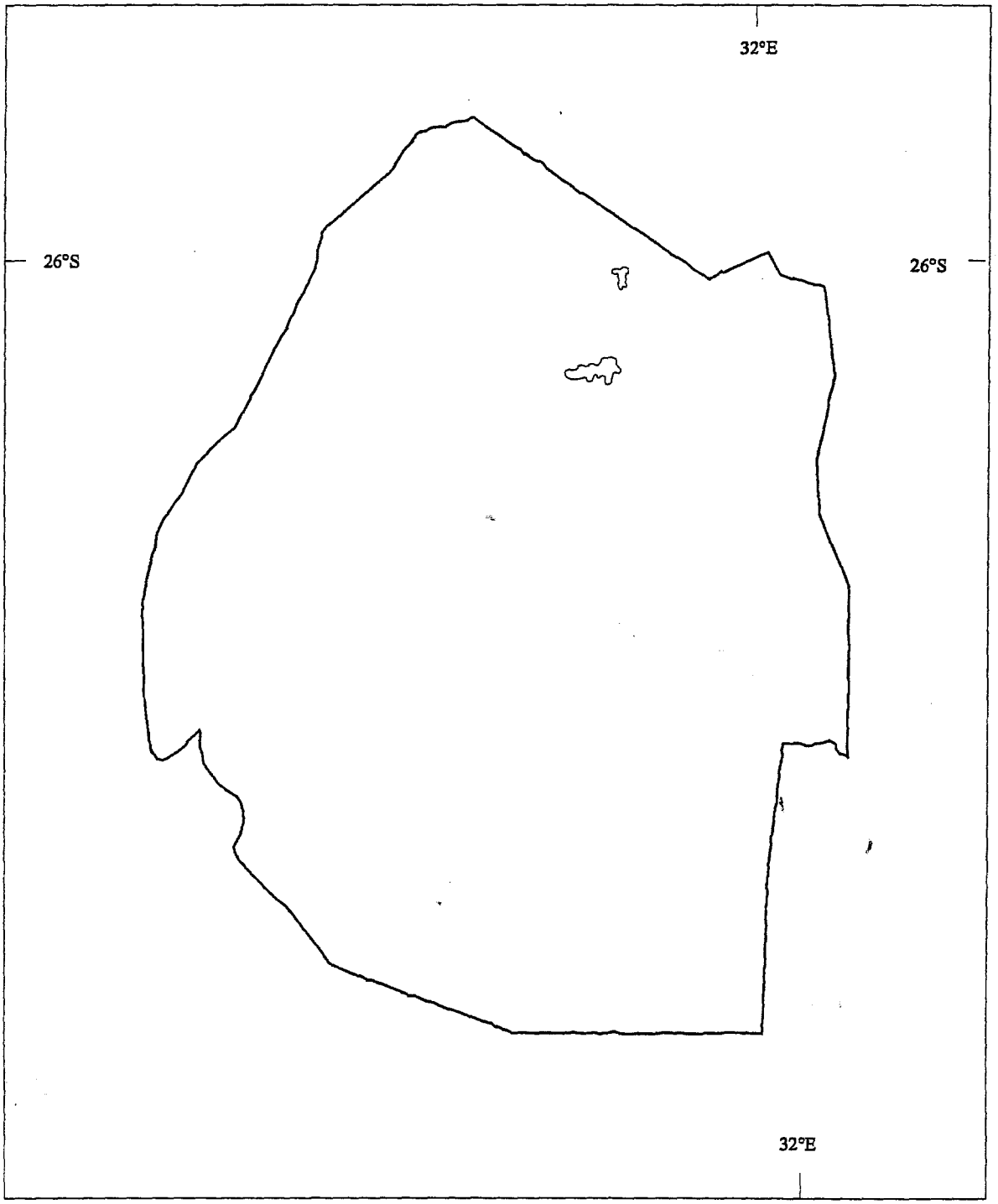


Figure E.81. Digital map layer **sz_wetl** (Swaziland, wetlands, classified by type) from the atlas of southern African freshwater fish. Scale approximately 1:1 300 000

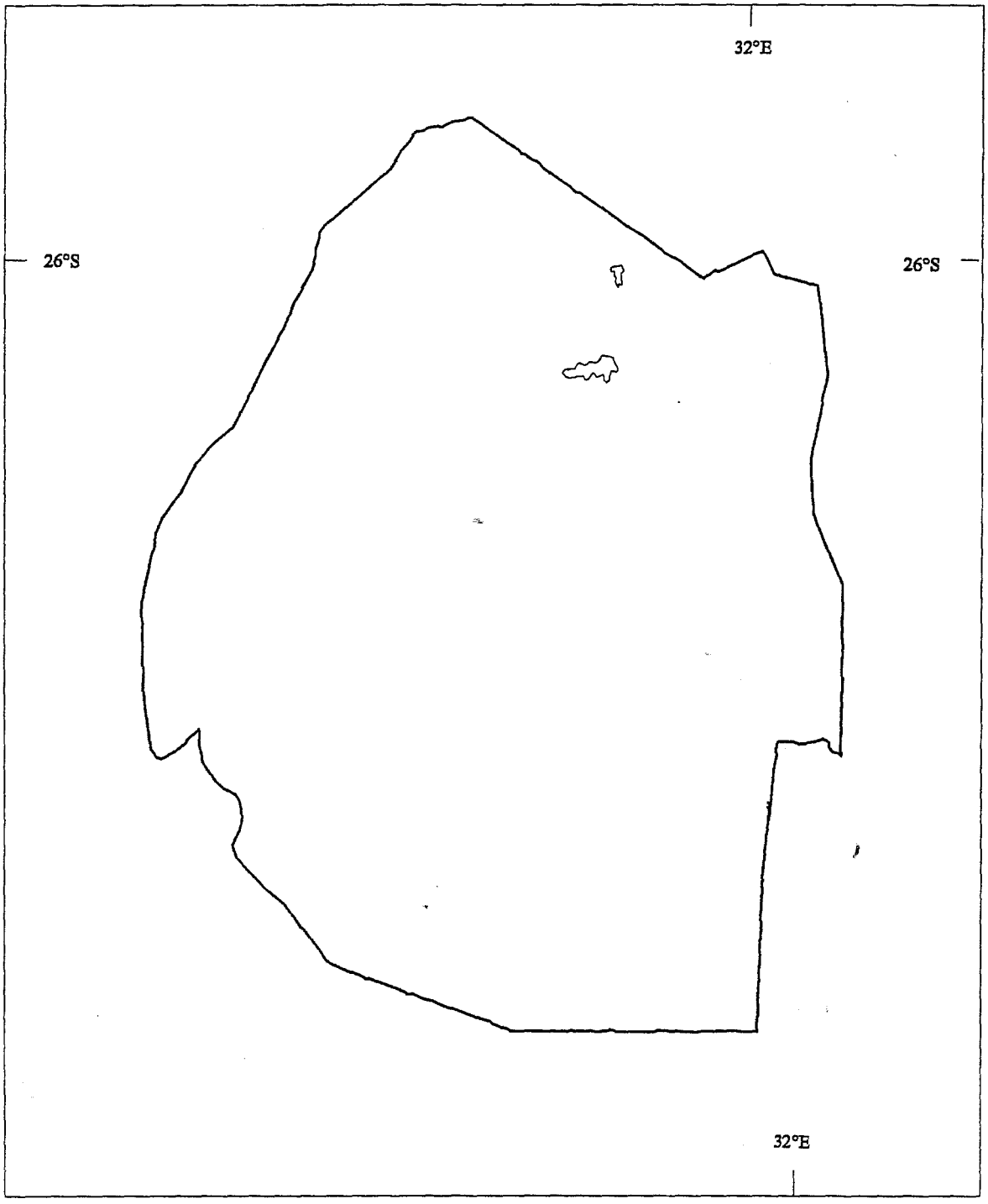


Figure E.82. Digital map layer **sz_lake** (Swaziland, lakes) from the atlas of southern African freshwater fish. Scale approximately 1:1 300 000

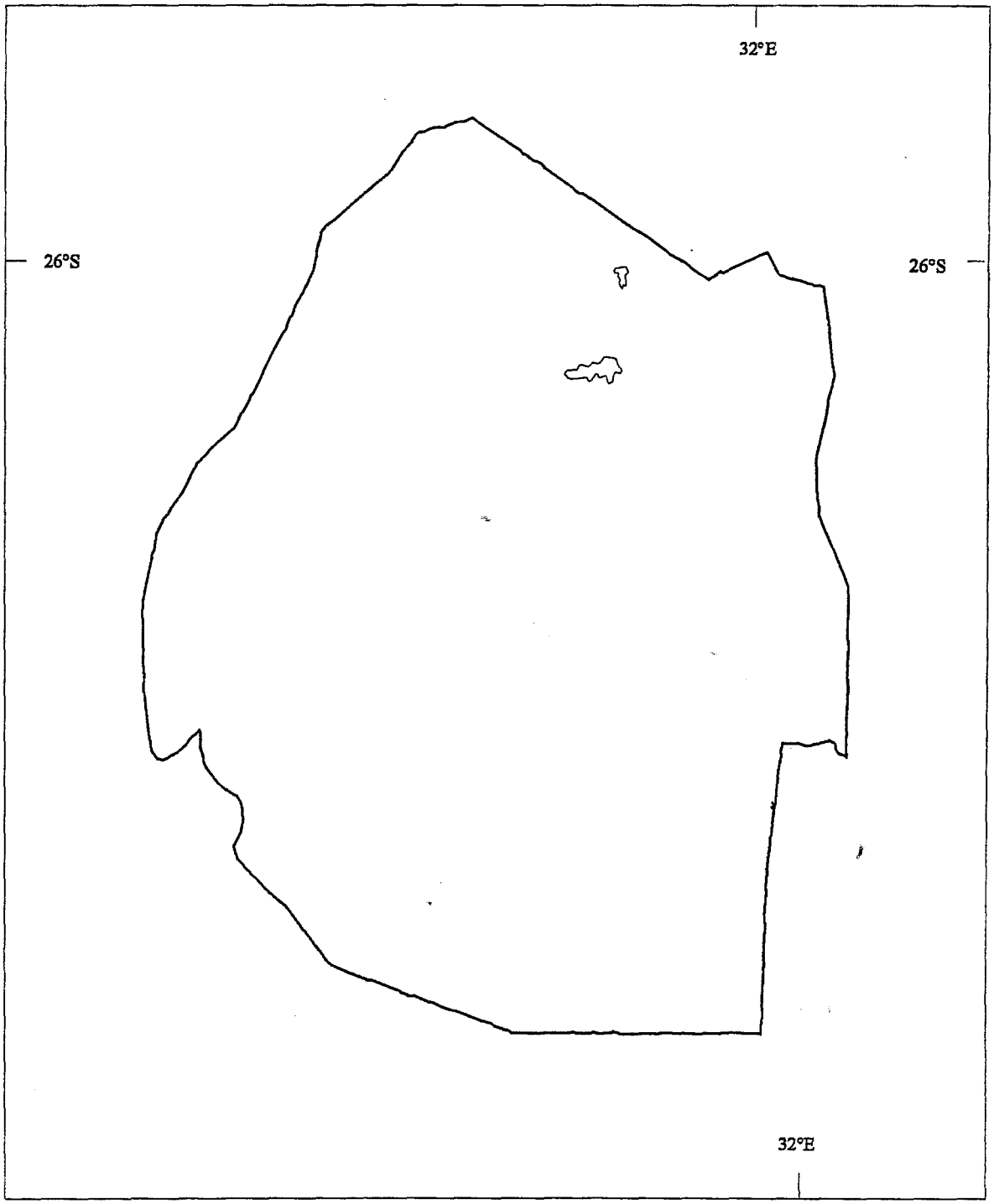


Figure E.83. Digital map layer **sz_pwat** (Swaziland, non-perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:1 300 000

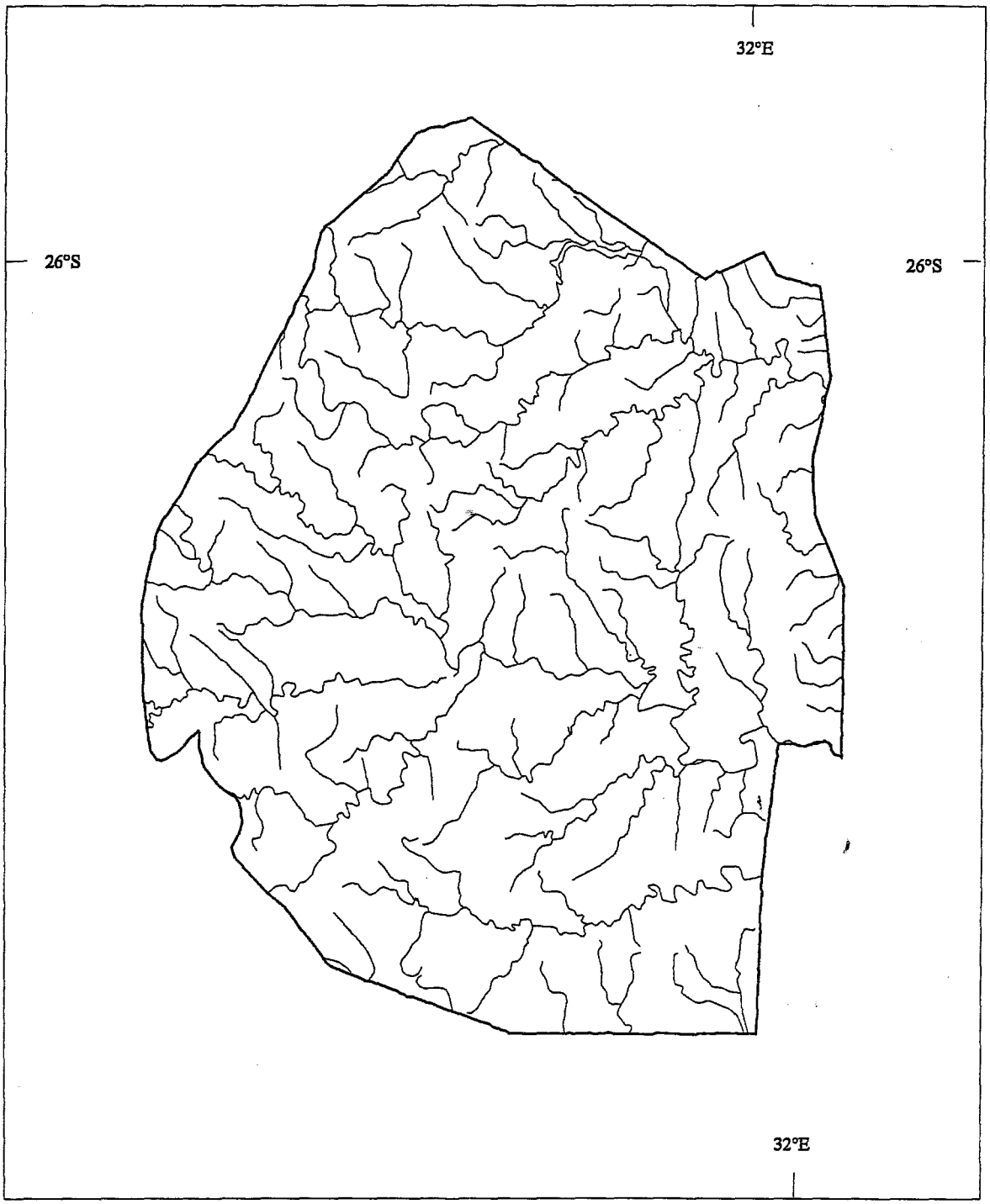


Figure E.84. Digital map layer **sz_riv** (Swaziland, rivers) from the atlas of southern African freshwater fish. Scale approximately 1:1 300 000

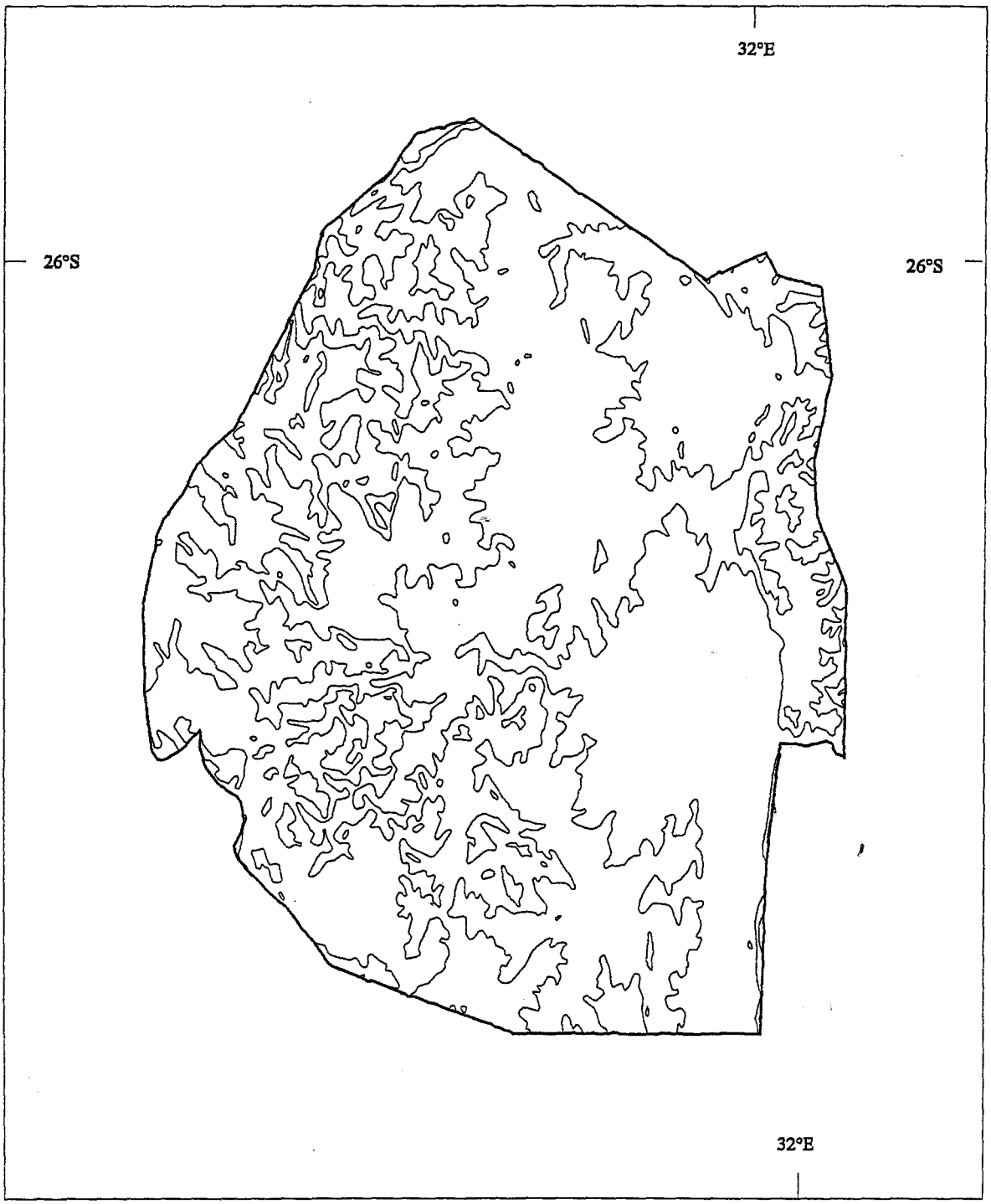


Figure E.85. Digital map layer **sz_elev** (Swaziland, 1000m contours) from the atlas of southern African freshwater fish. Scale approximately 1:1 300 000

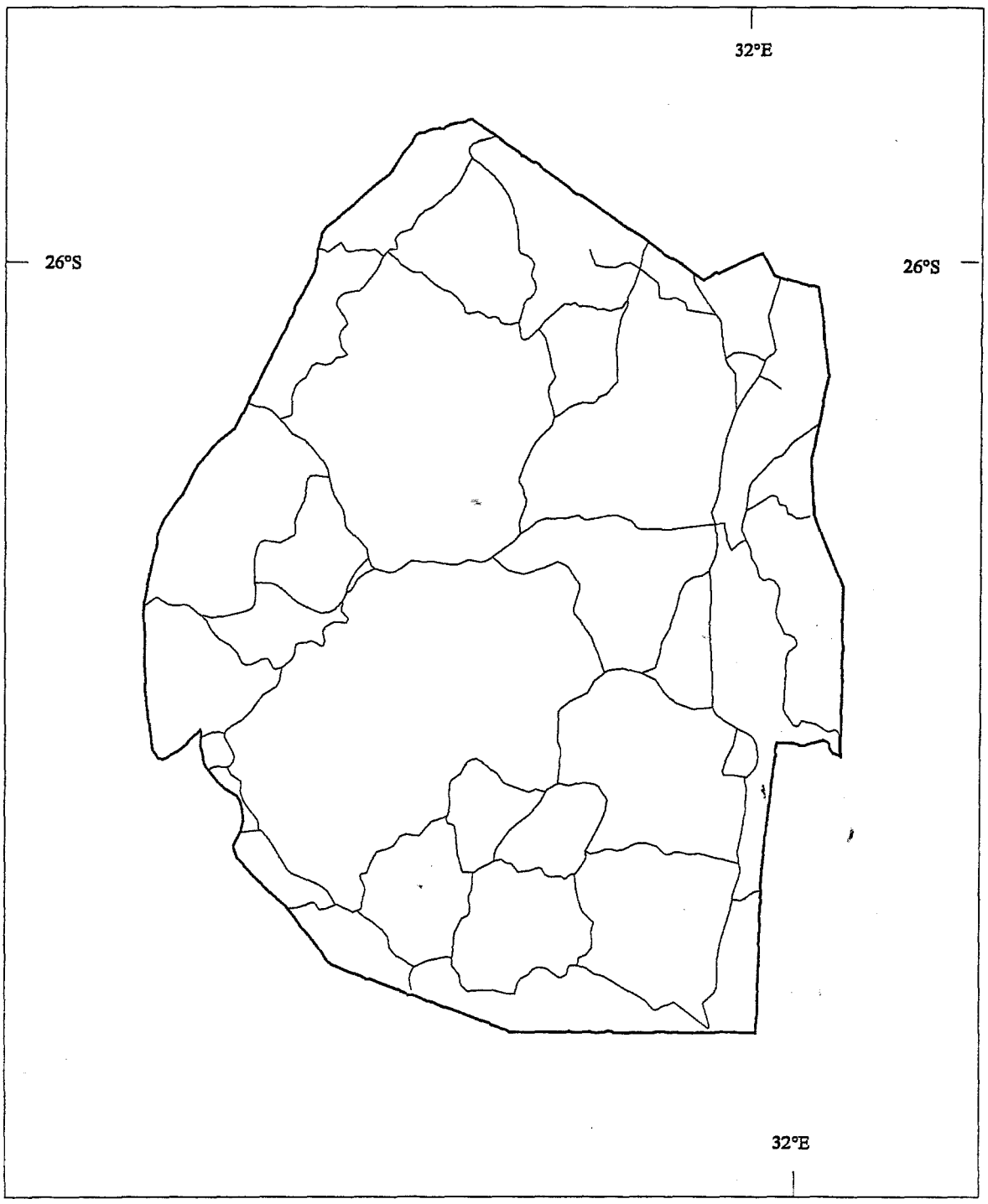


Figure E.86. Digital map layer **sz_road** (Swaziland, roads) from the atlas of southern African freshwater fish. Scale approximately 1:1 300 000

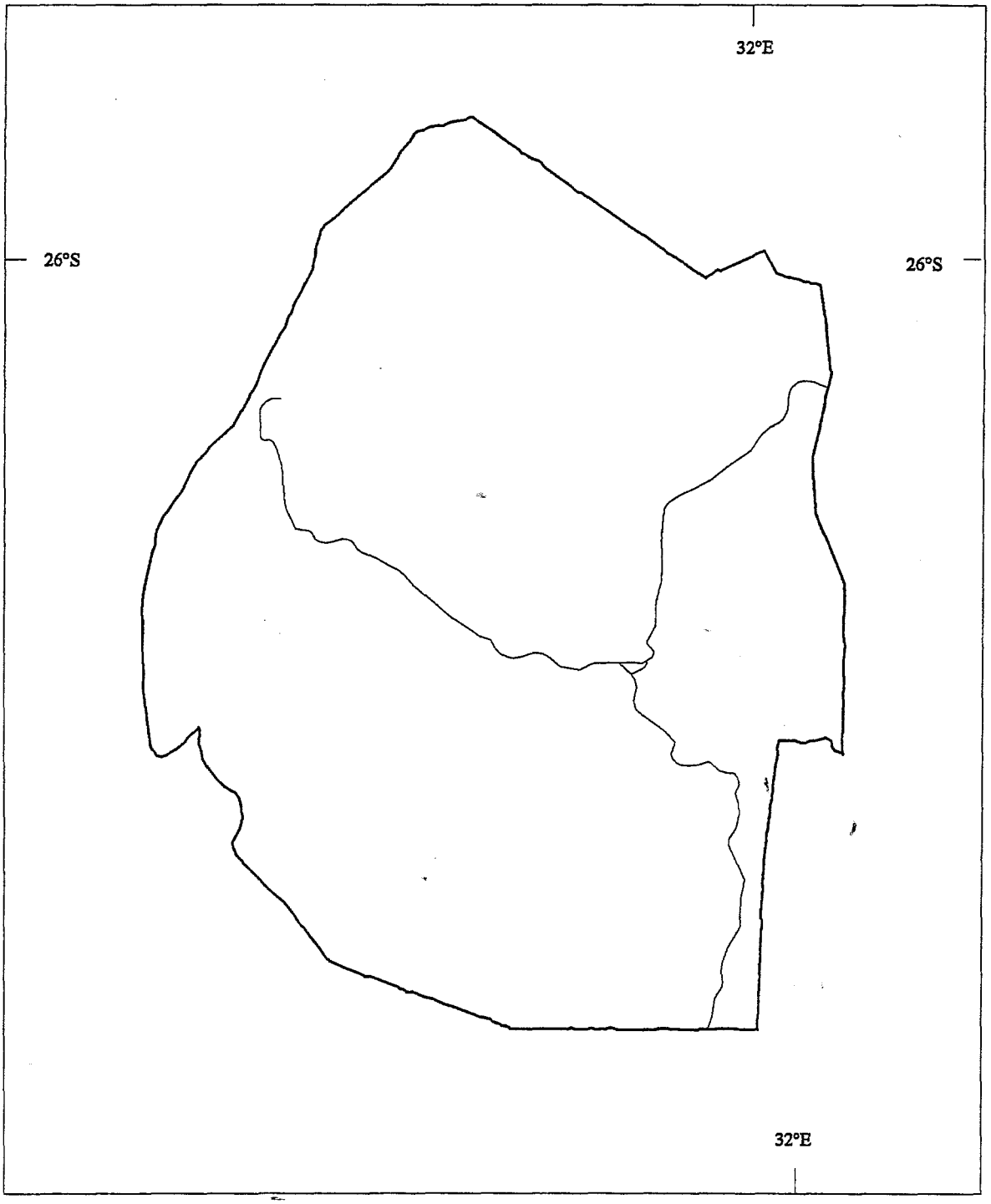


Figure E.87. Digital map layer **sz_rail** (Swaziland, railroads) from the atlas of southern African freshwater fish. Scale approximately 1:1 300 000

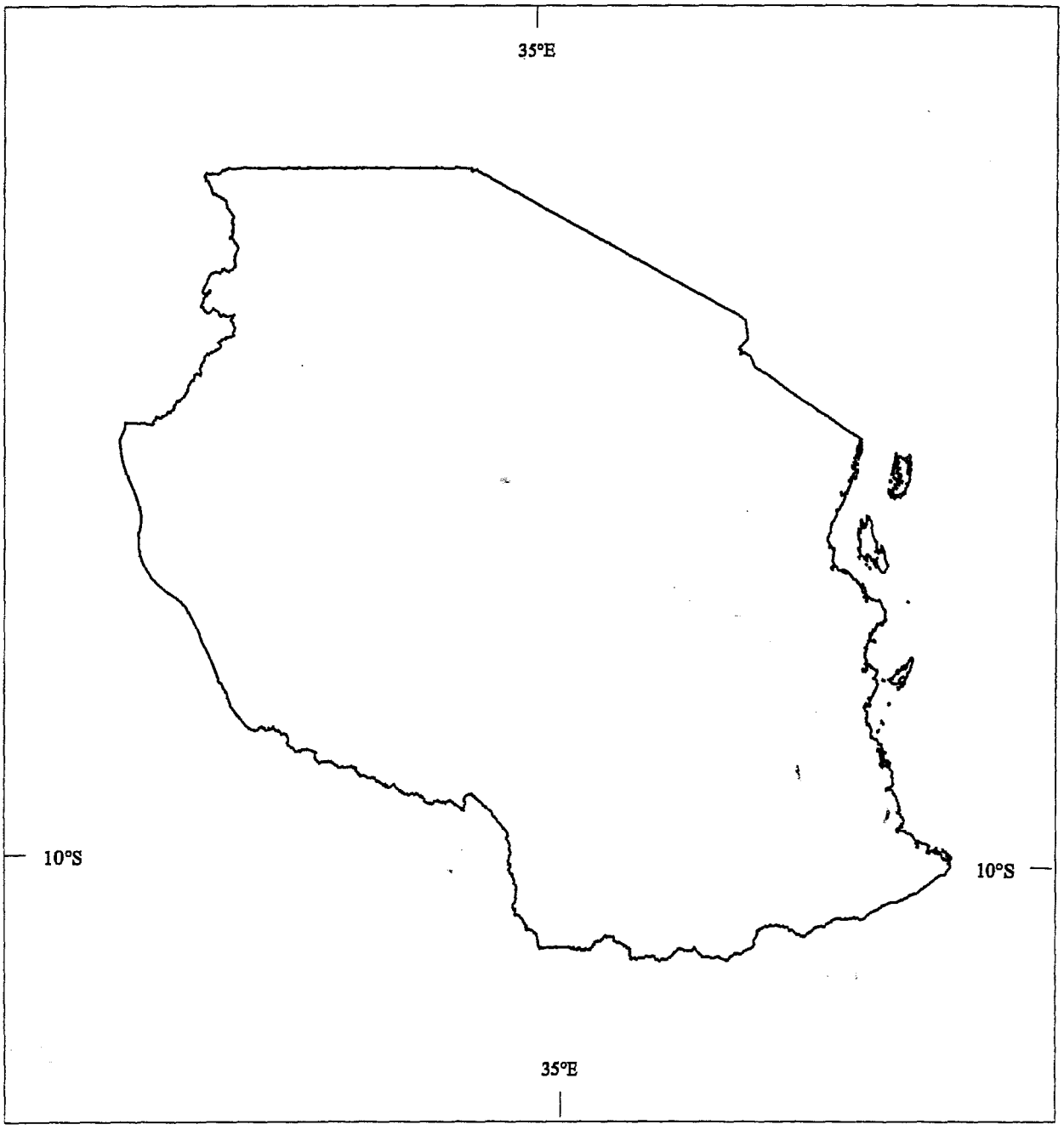


Figure E.88. Digital map layer **tz_adm1** (Tanzania, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:9 700 000

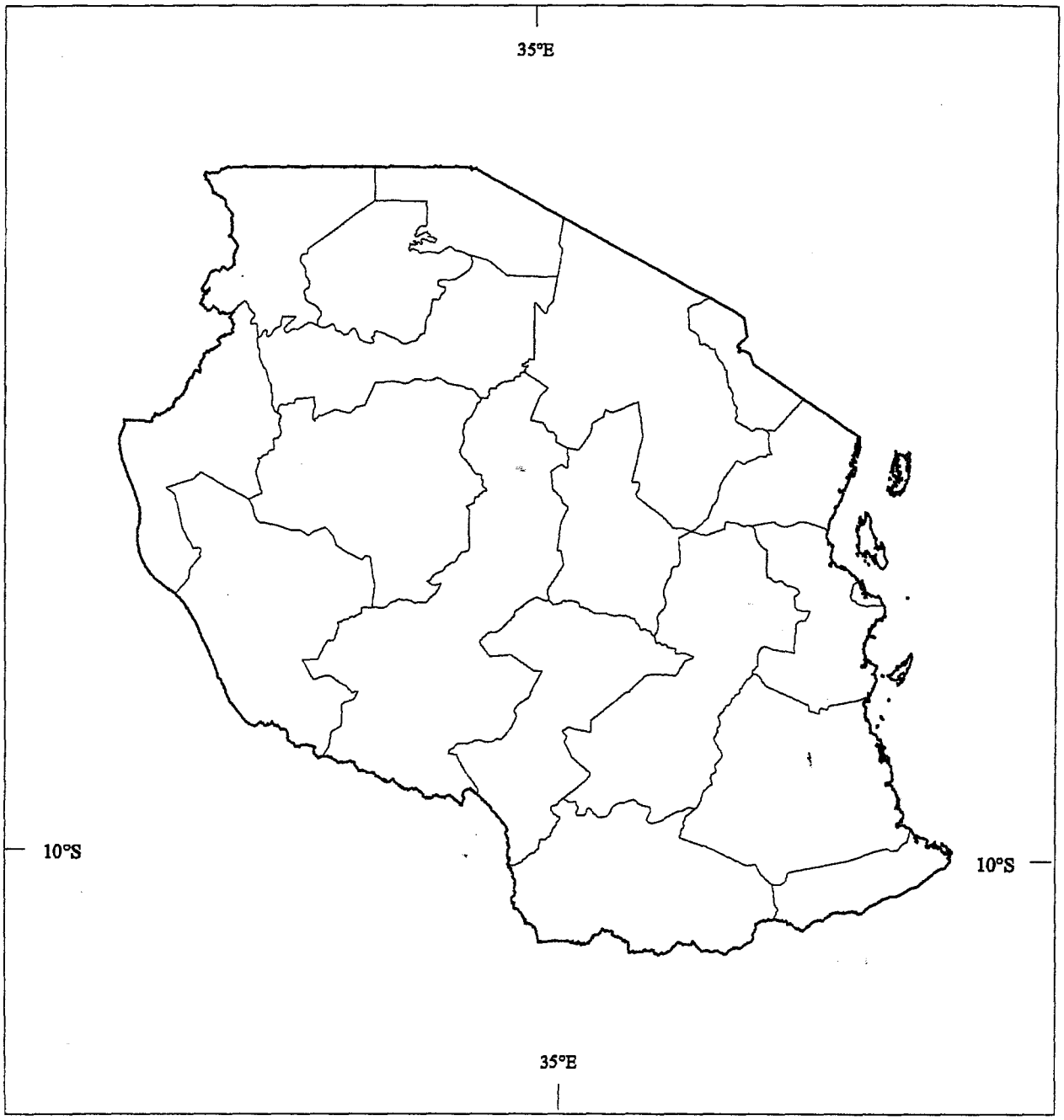


Figure E.89. Digital map layer **tz_adm2** (Tanzania, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:9 700 000

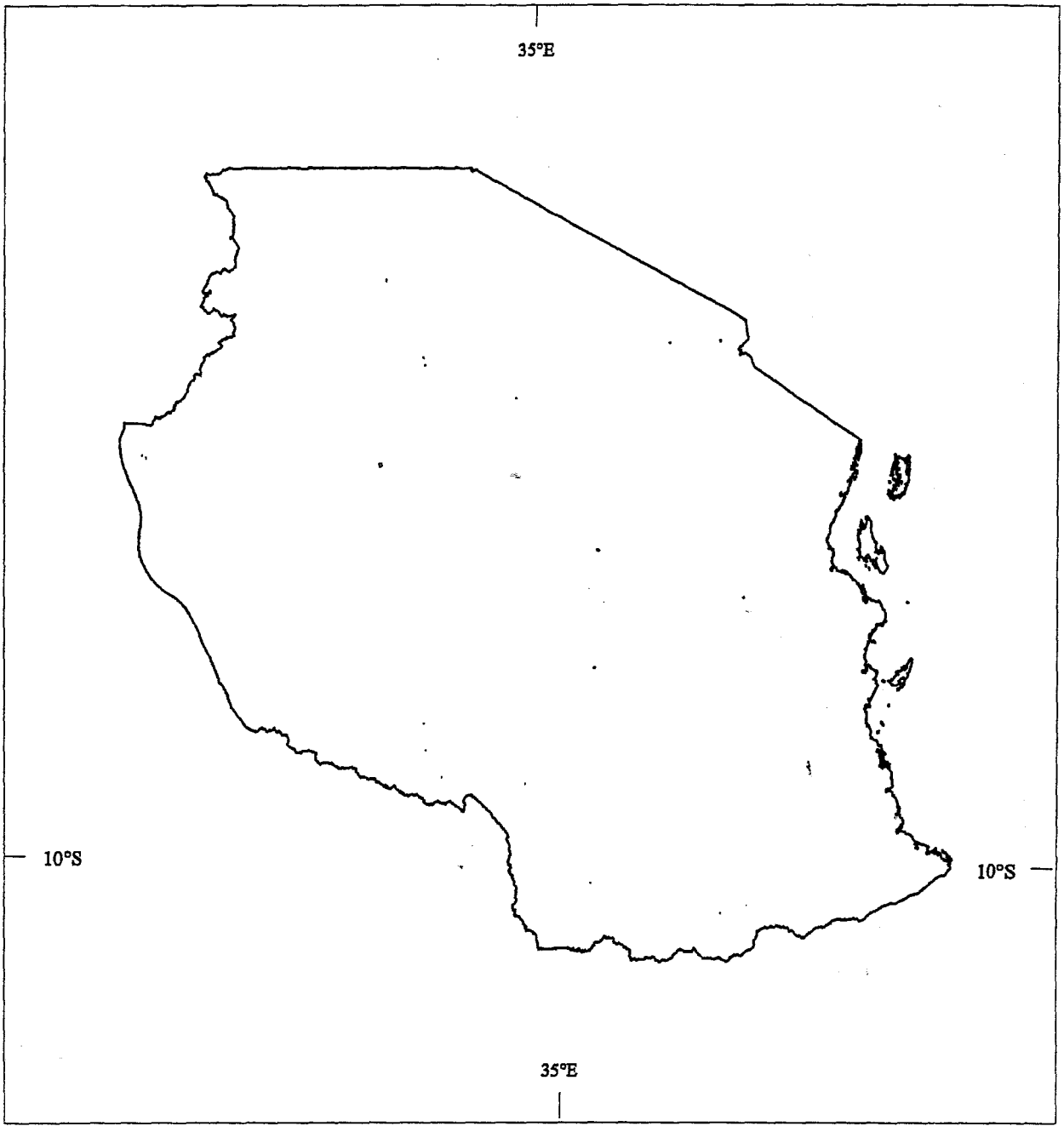


Figure E.90. Digital map layer **tz_urbn** (Tanzania, urbanised areas as polygons) from the atlas of southern African freshwater fish. Scale approximately 1:9 700 000

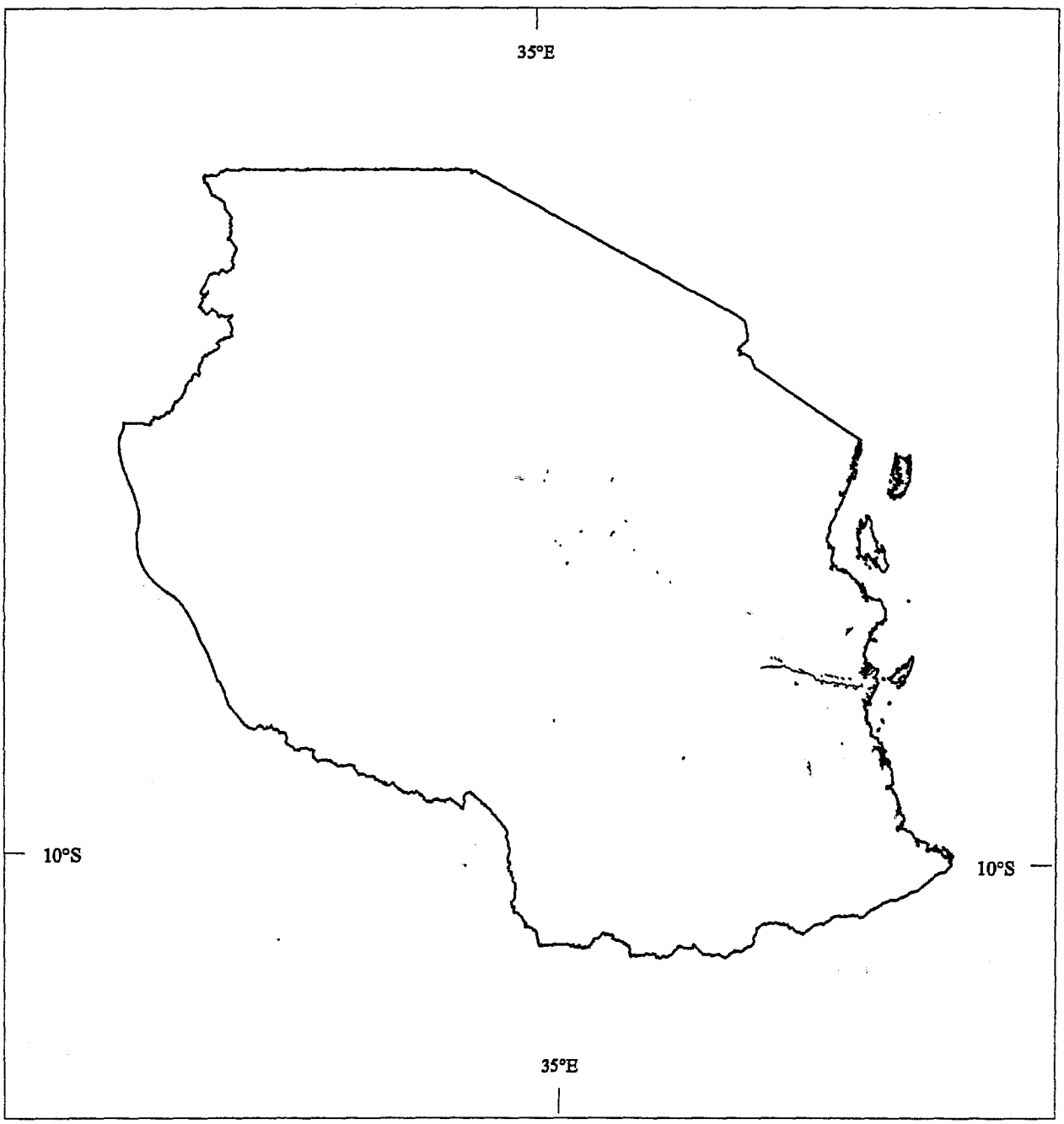


Figure E.91. Digital map layer **tz_lakee** (Tanzania, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 700 000

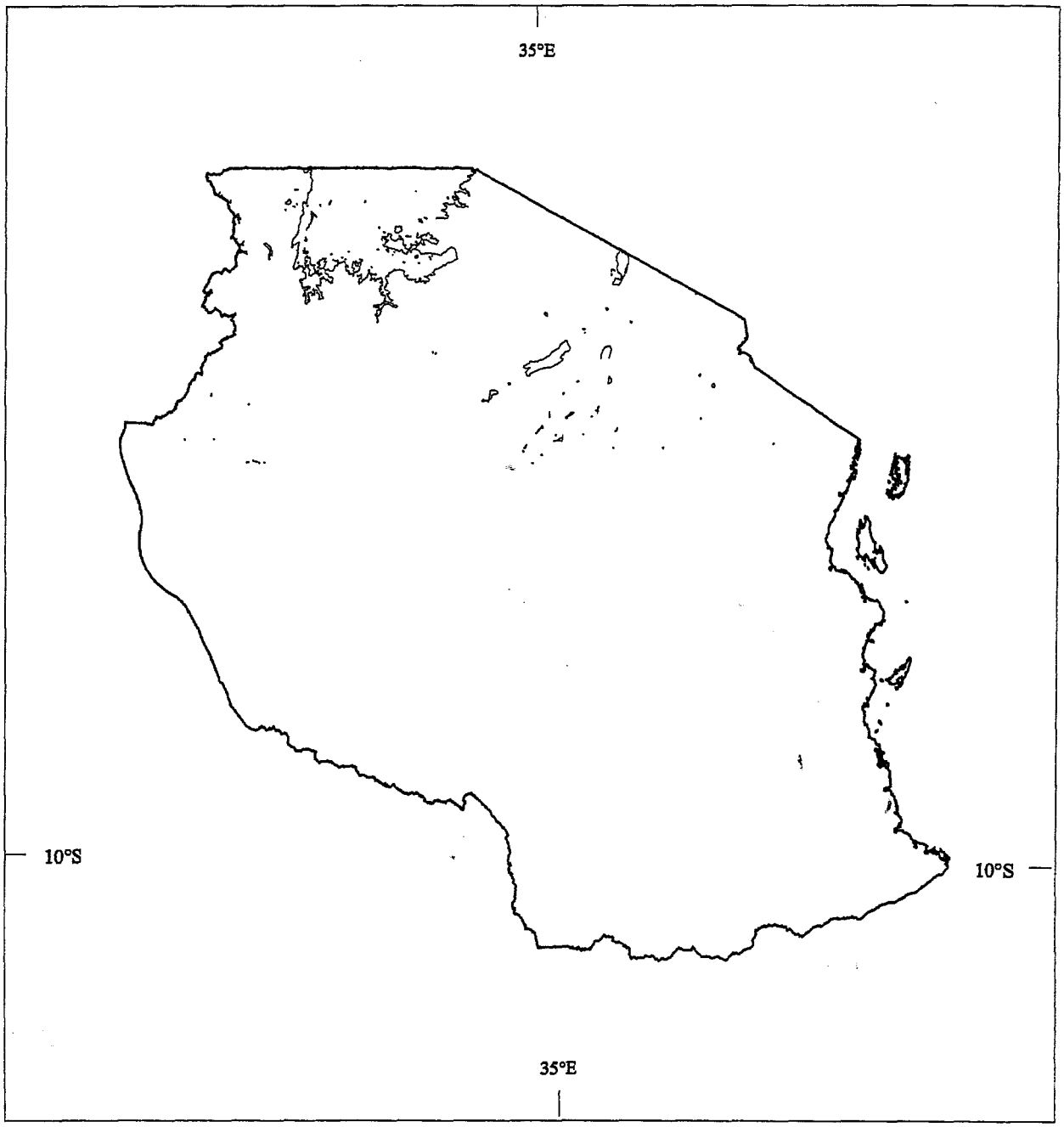


Figure E.92. Digital map layer **tz_laken** (Tanzania, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 700 000

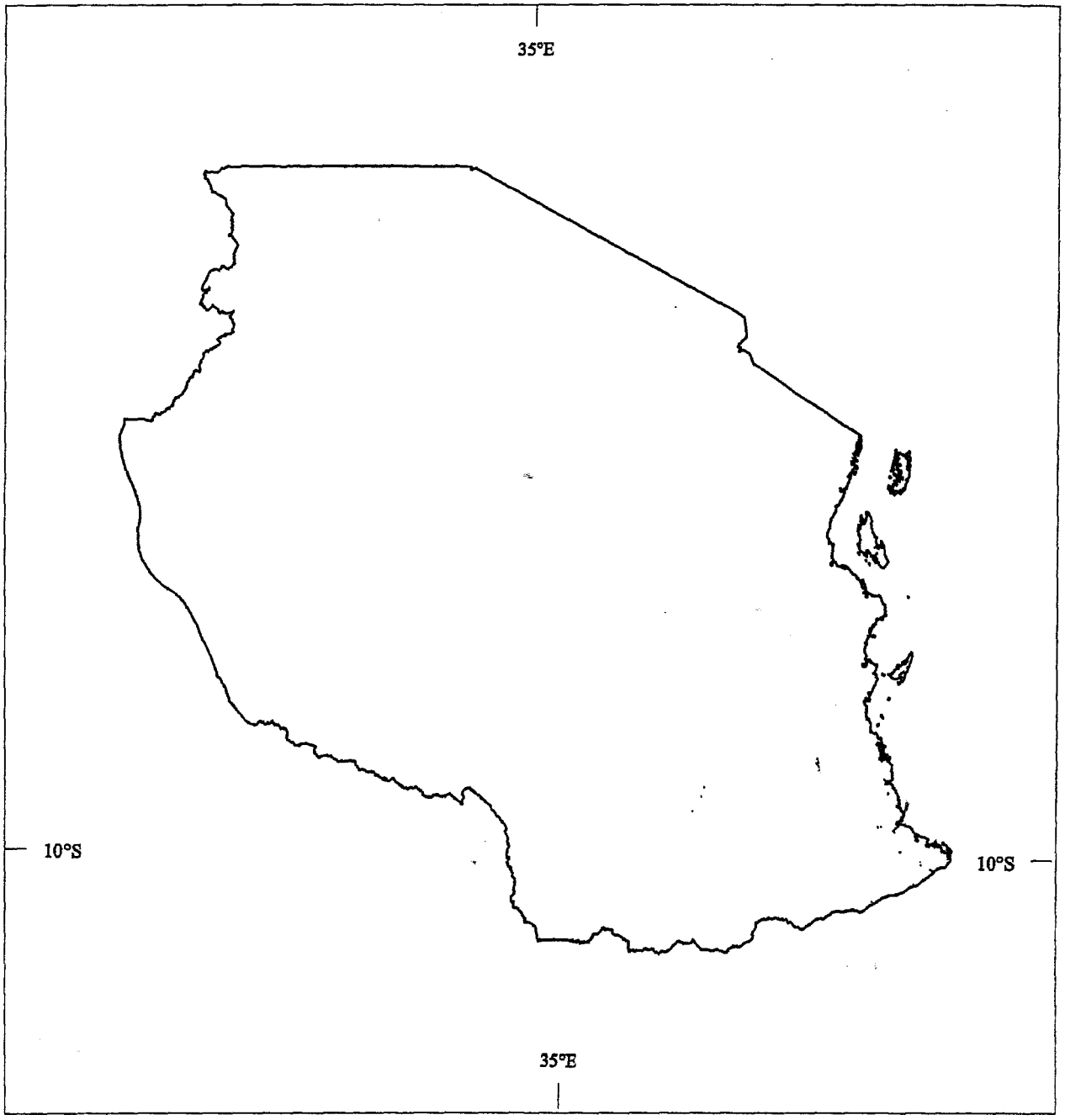


Figure E.93. Digital map layer **tz_lakes** (Tanzania, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 700 000

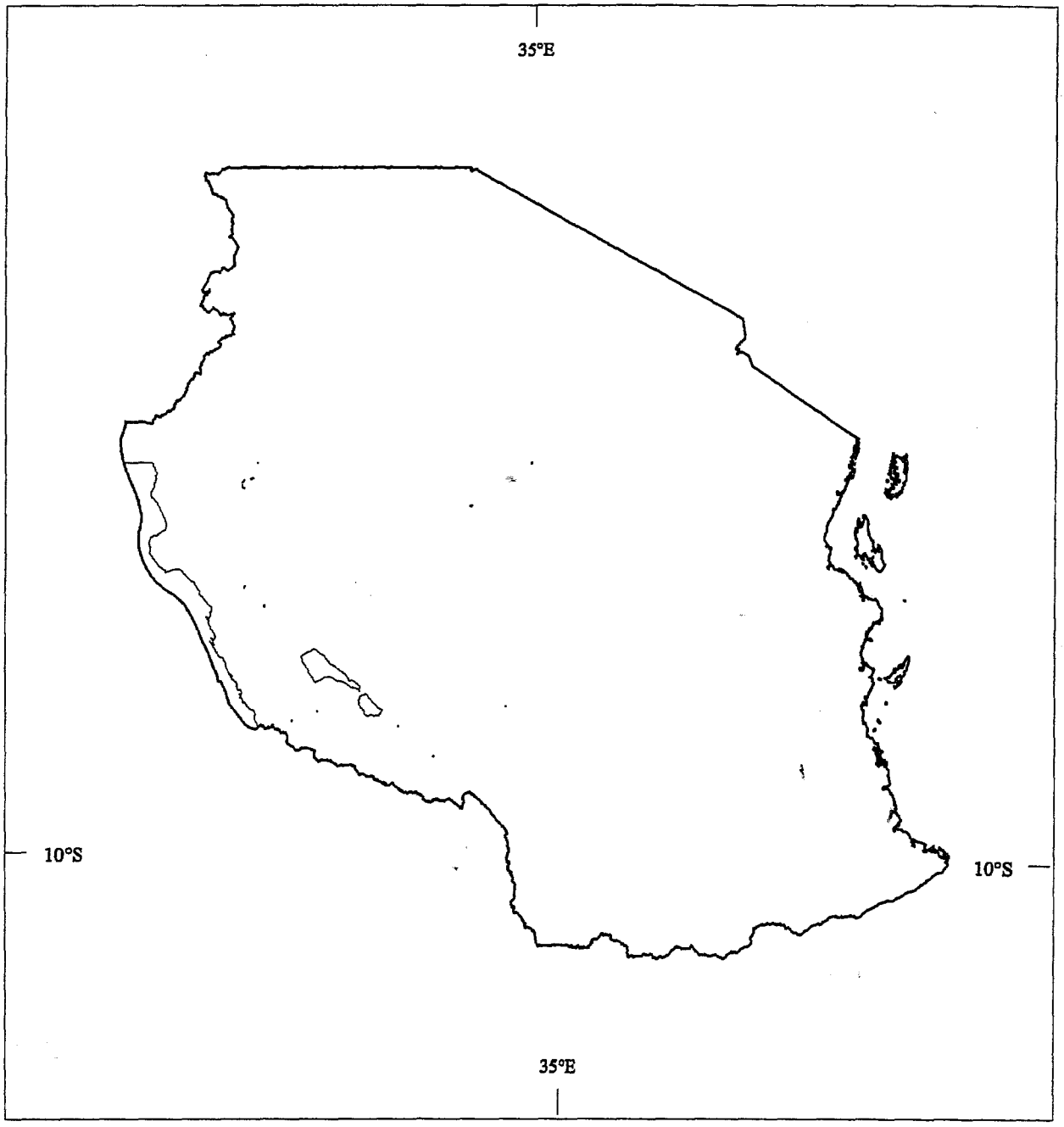


Figure E.94. Digital map layer **tz_lakew** (Tanzania, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 700 000

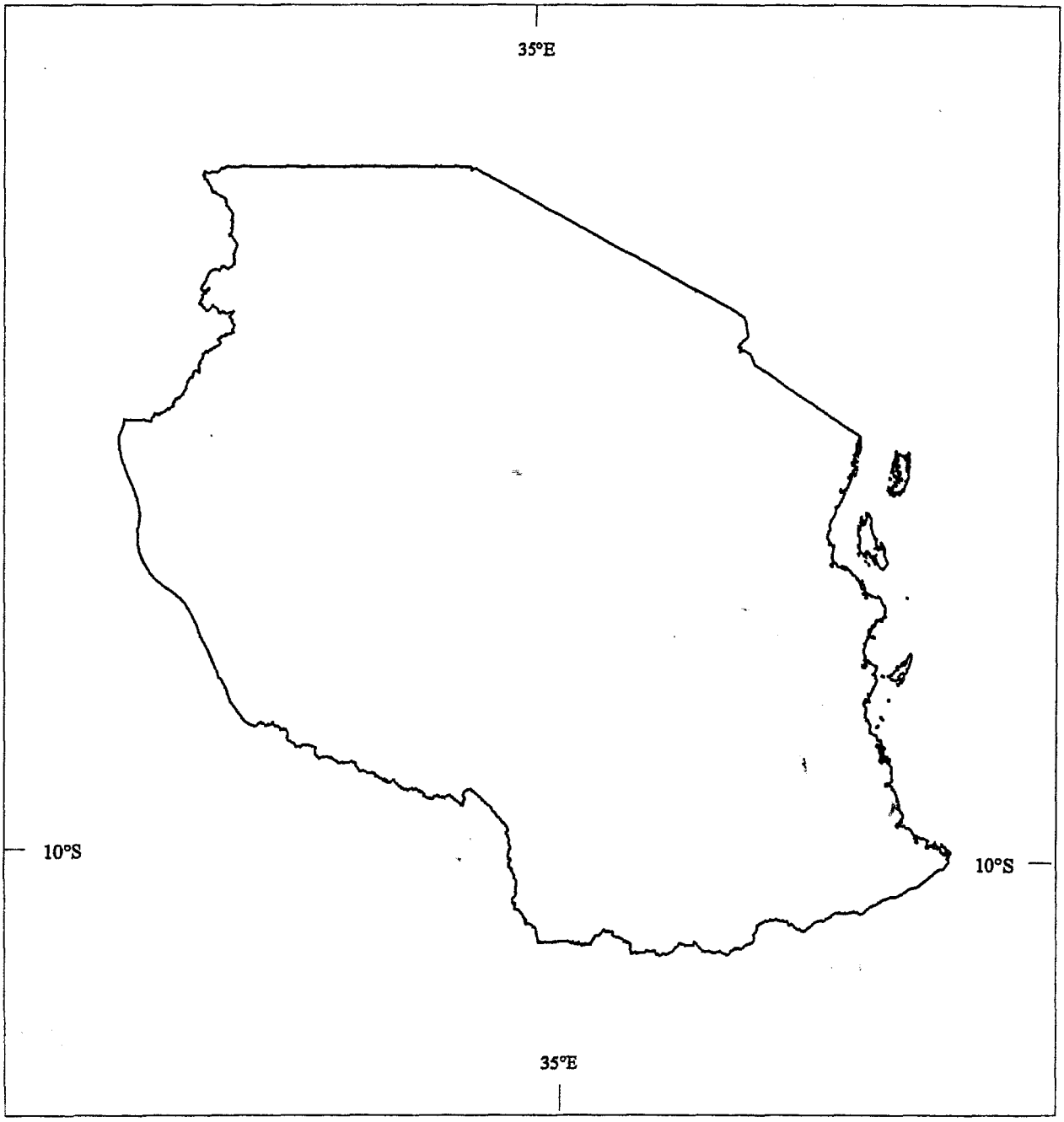


Figure E.95. Digital map layer **tz_npwat** (Tanzania, non-perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:9 700 000

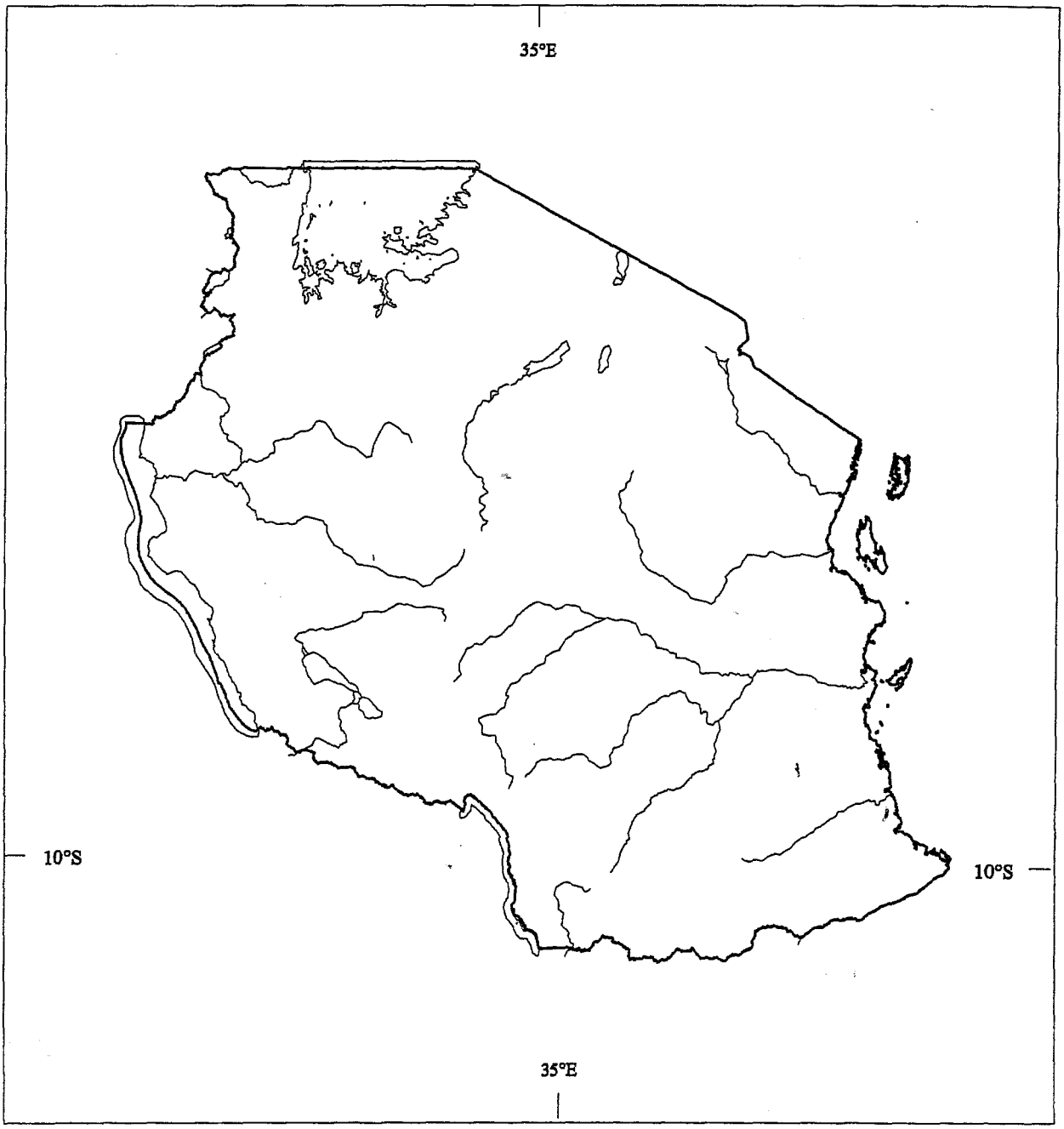


Figure E.96. Digital map layer **tz_riv** (Tanzania, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:9 700 000

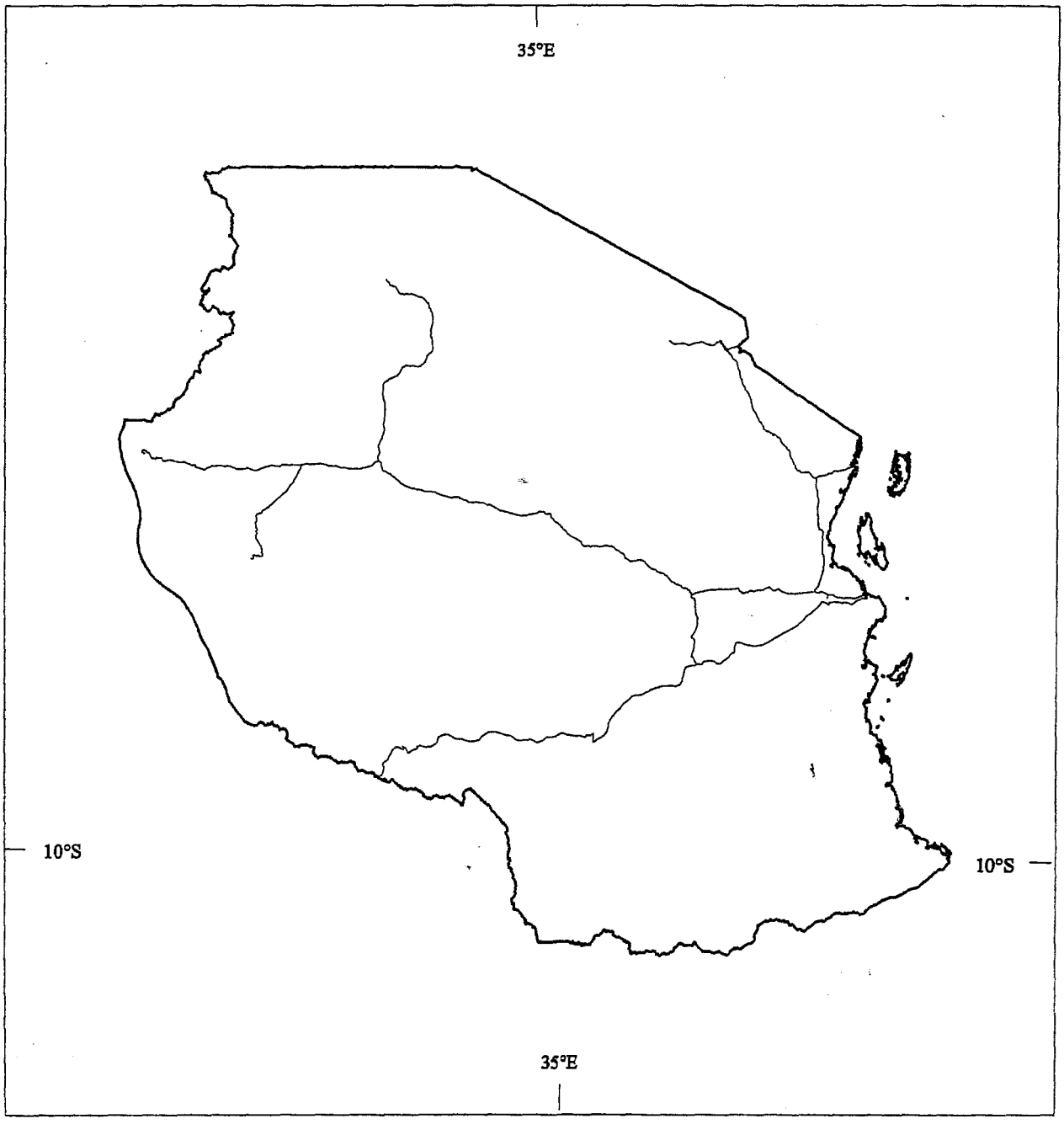


Figure E.97. Digital map layer **tz_rail** (Tanzania, railroads) from the atlas of southern African freshwater fish. Scale approximately 1:9 700 000

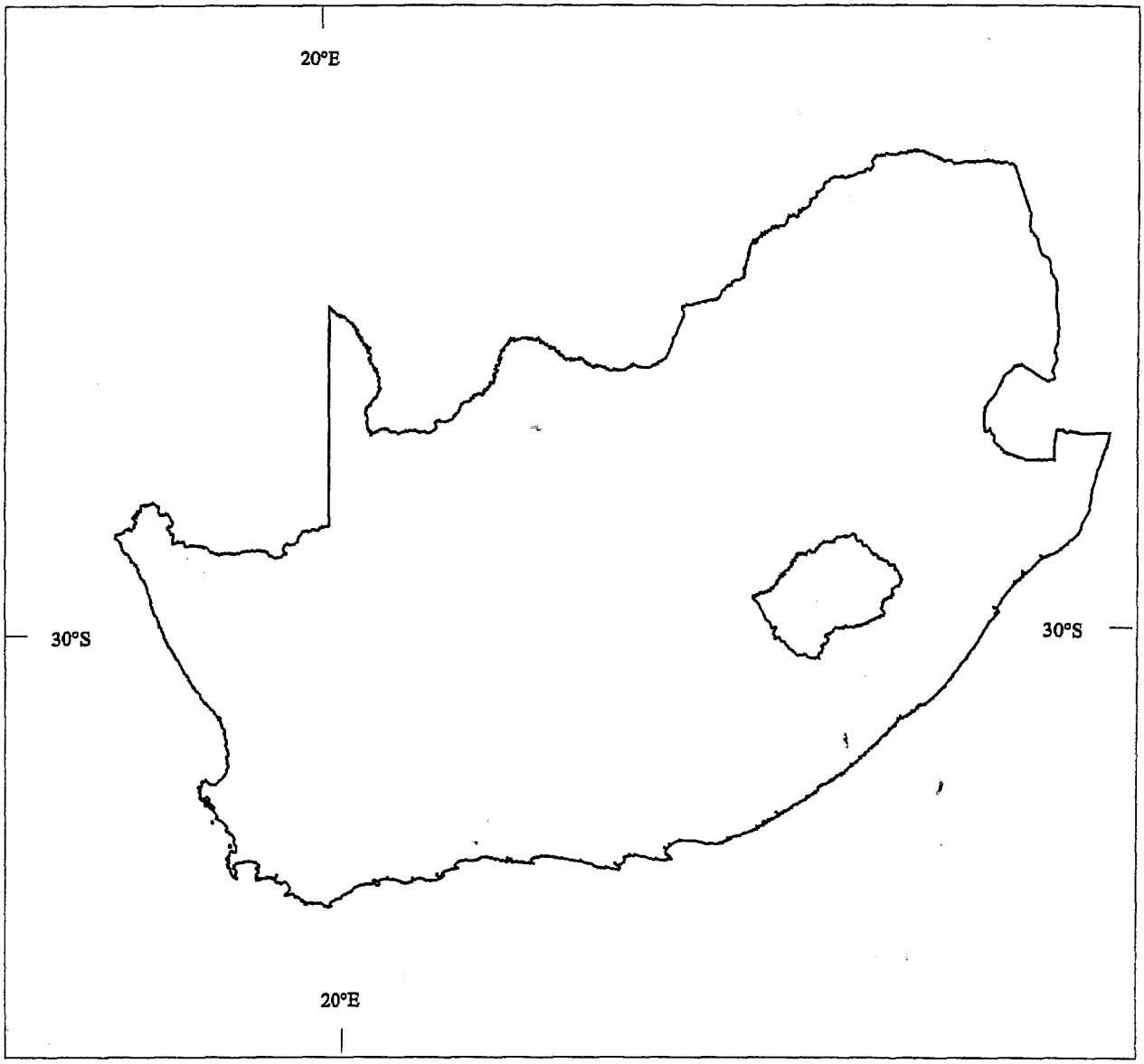


Figure E.98. Digital map layer **za_adm1** (South Africa, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

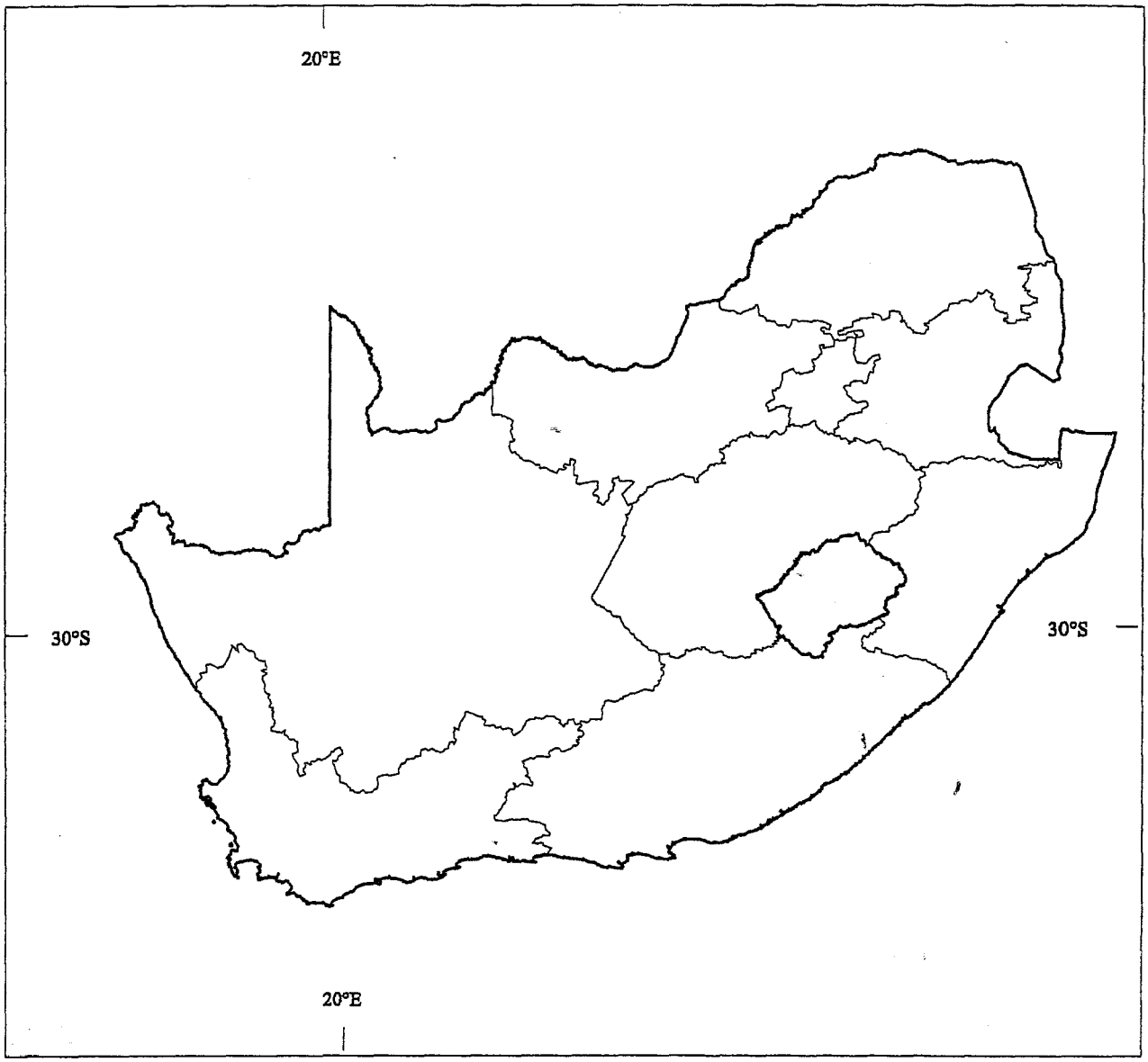


Figure E.99. Digital map layer **za_adm2** (South Africa, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

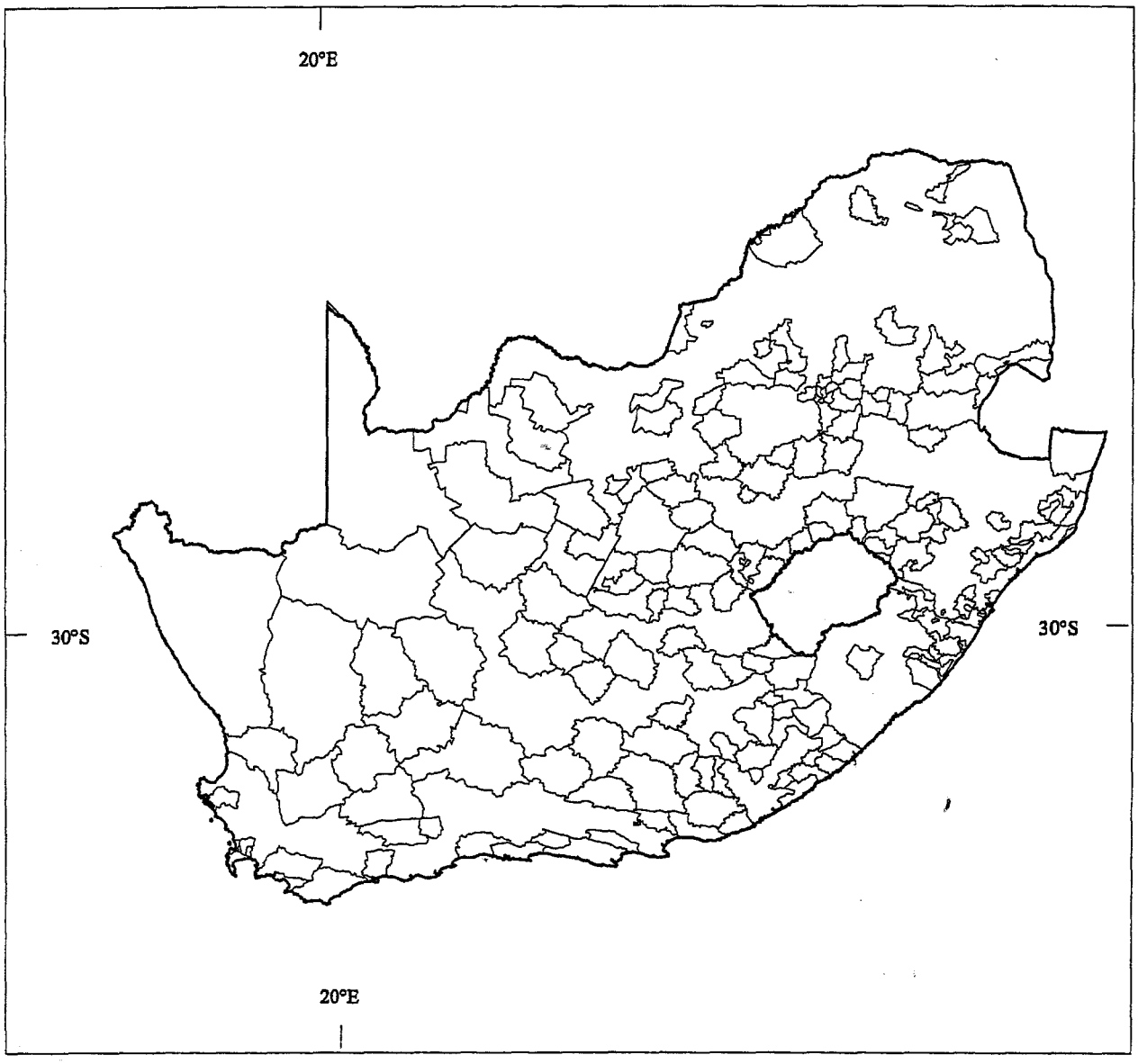


Figure E.100. Digital map layer **za_adm3** (South Africa, district borders) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

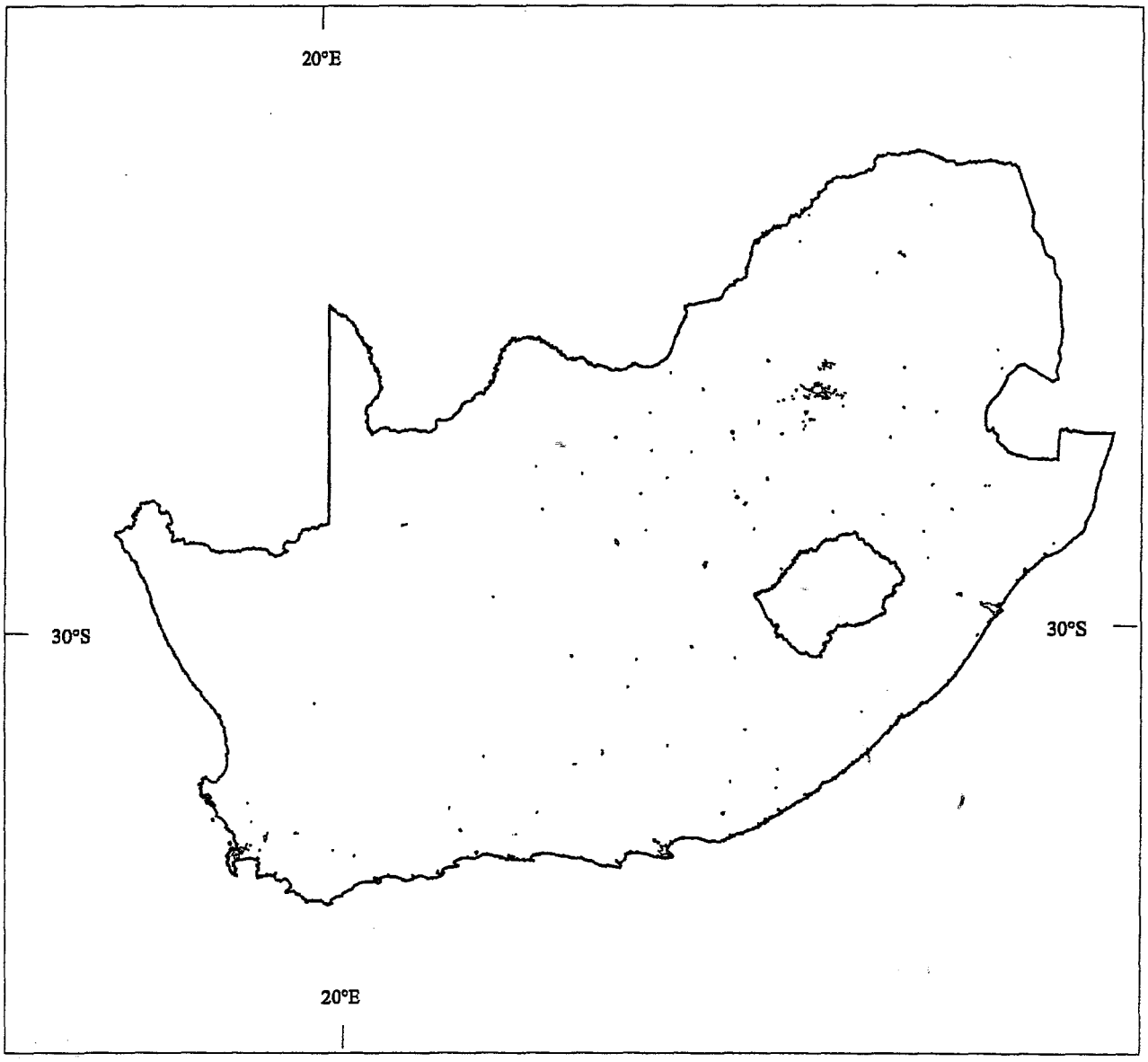


Figure E.101. Digital map layer **za_urbn** (South Africa, urbanised areas as polygons) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

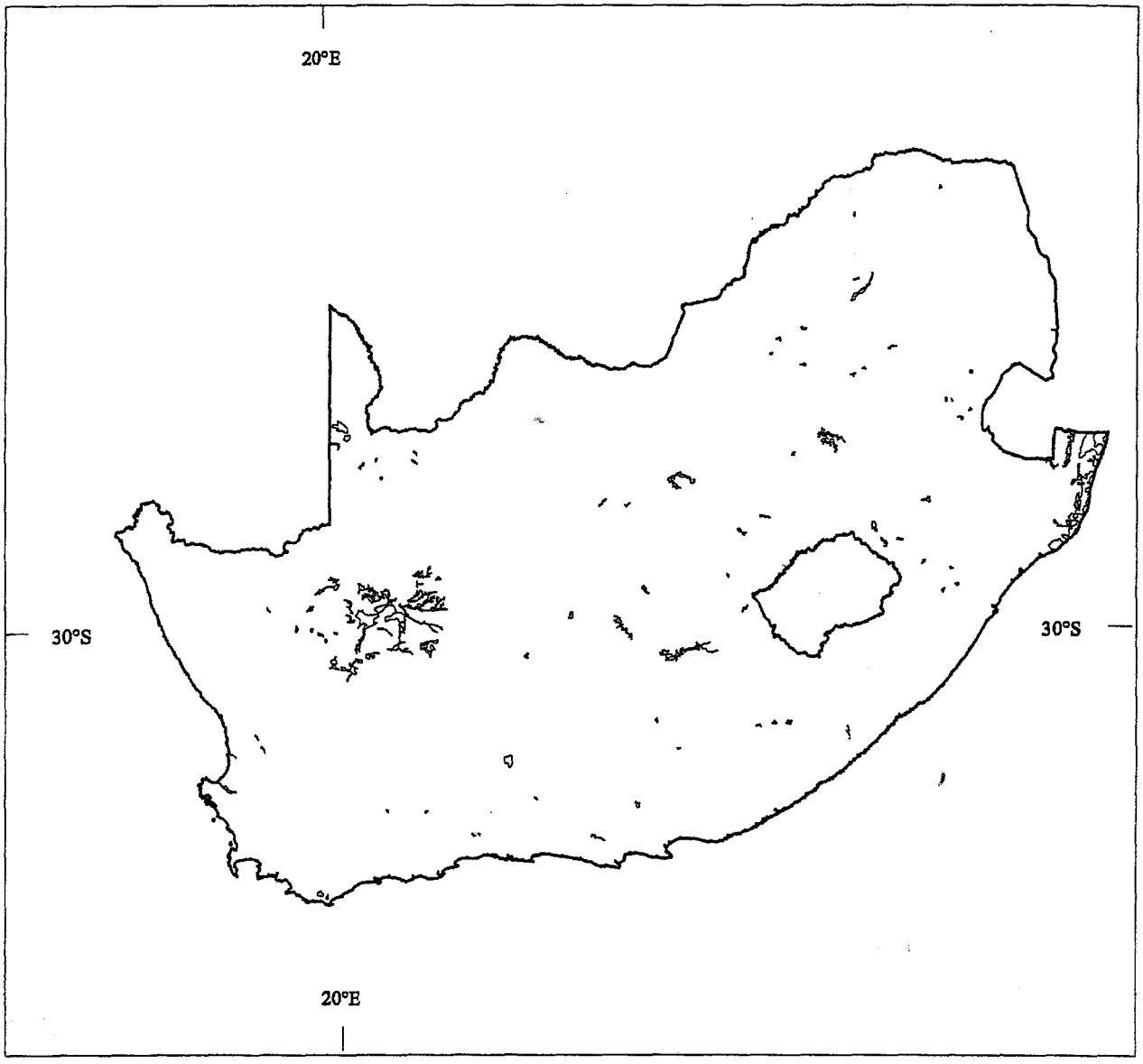


Figure E.102. Digital map layer **za_wetl** (South Africa, wetlands, classified by type) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

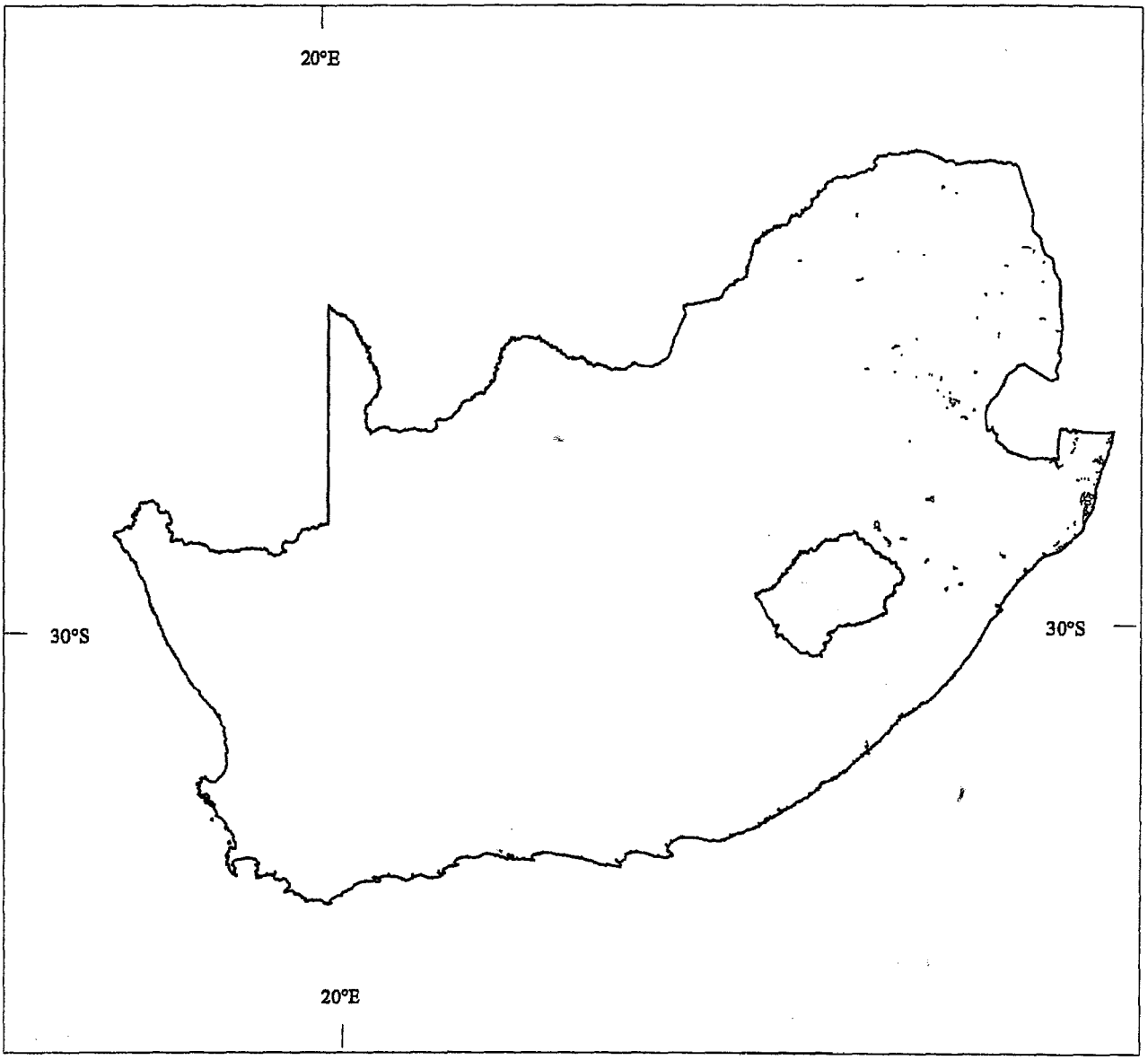


Figure E.103. Digital map layer **za_lakee** (South Africa, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

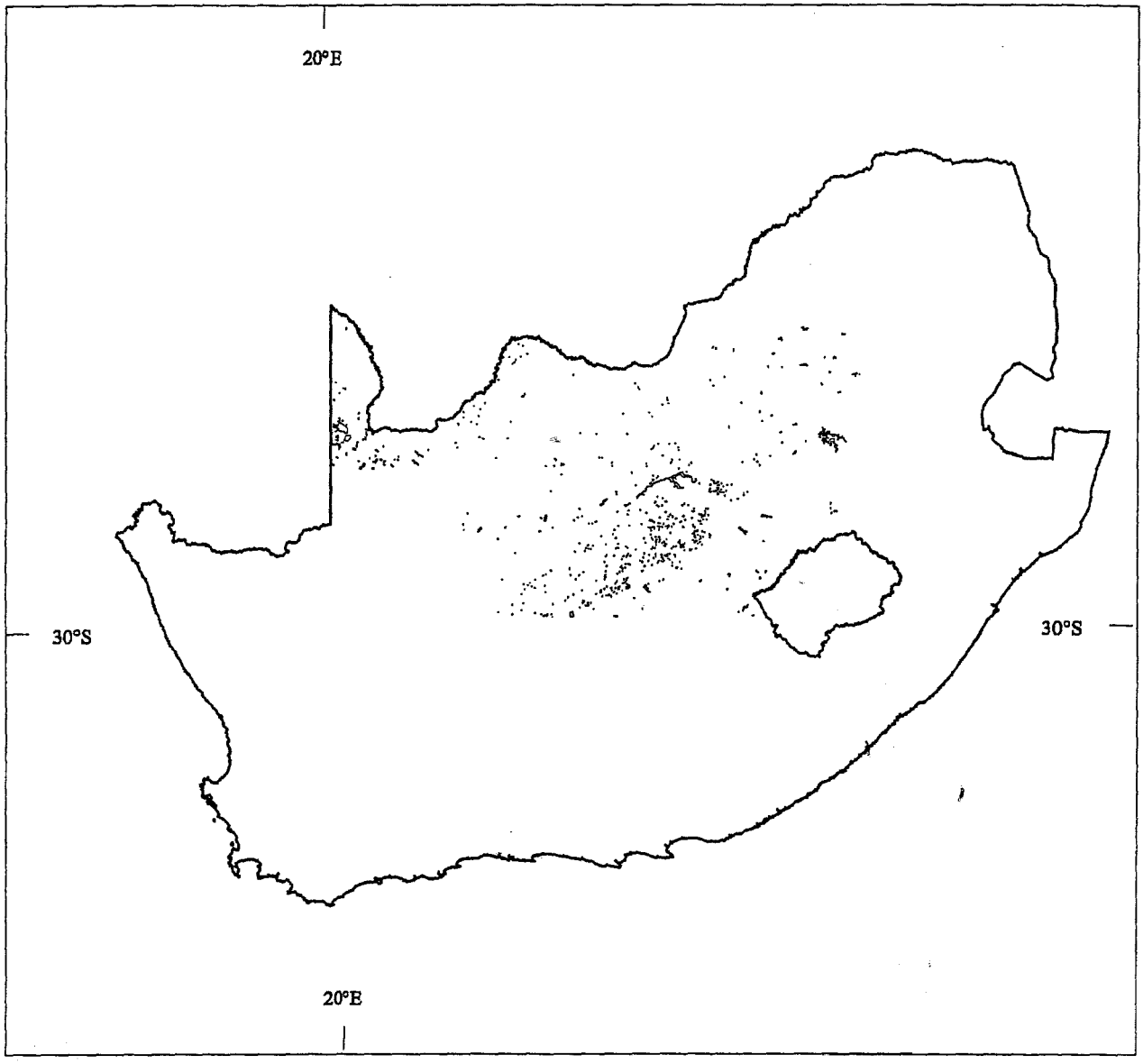


Figure E.104. Digital map layer **za_laken** (South Africa, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

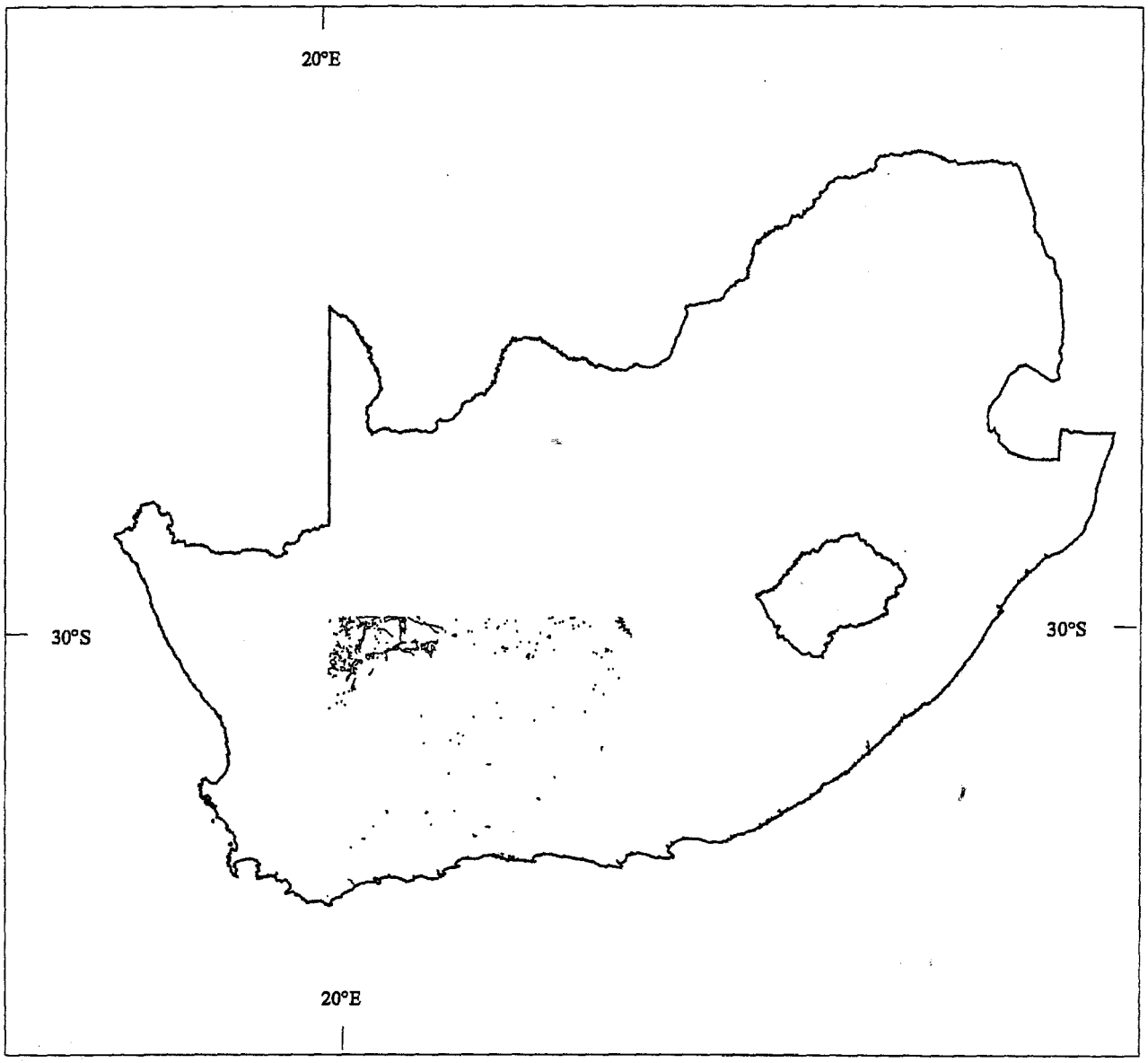


Figure E.105. Digital map layer **za_lakes** (South Africa, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

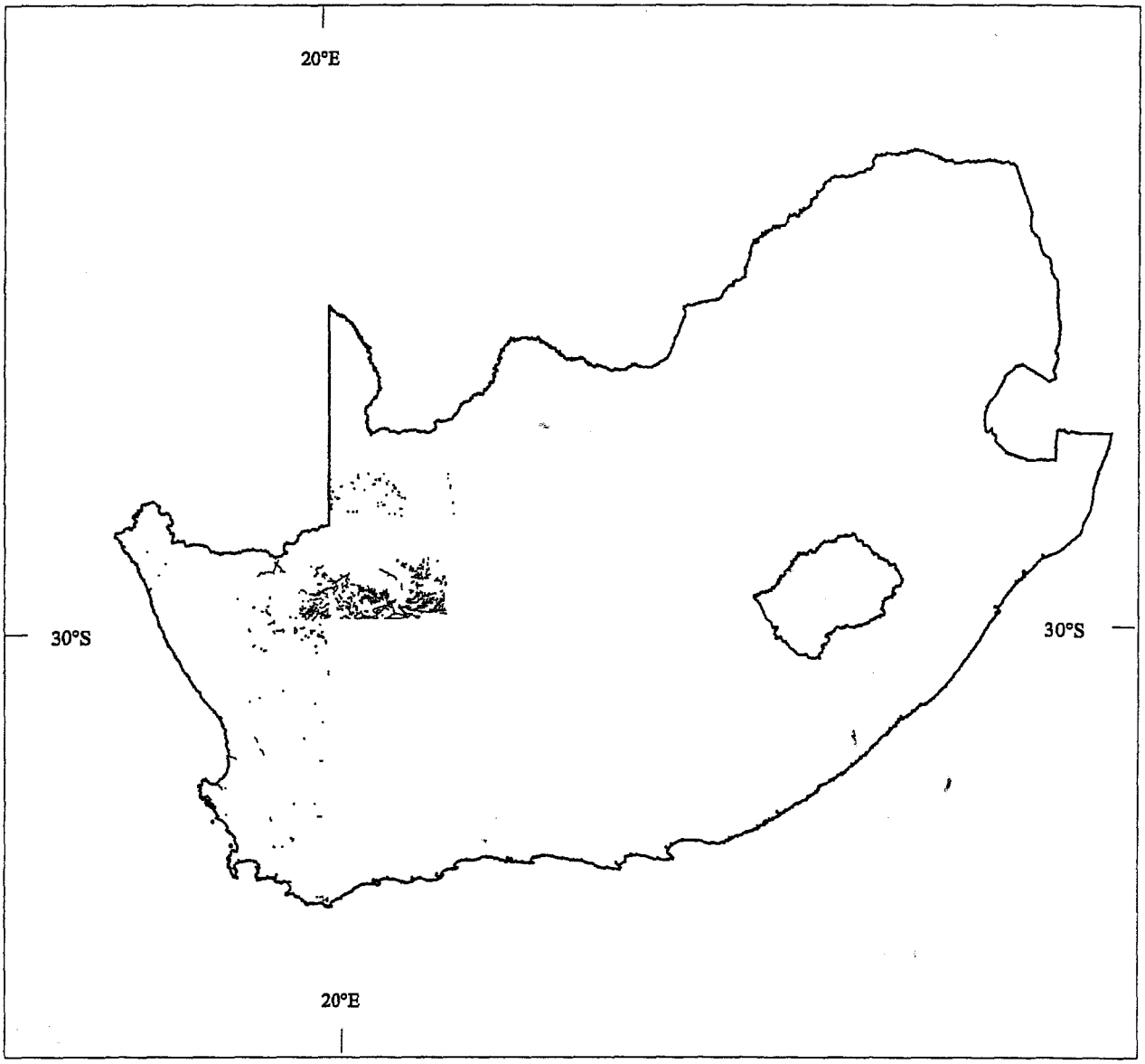


Figure E.106. Digital map layer **za_lakew** (South Africa, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

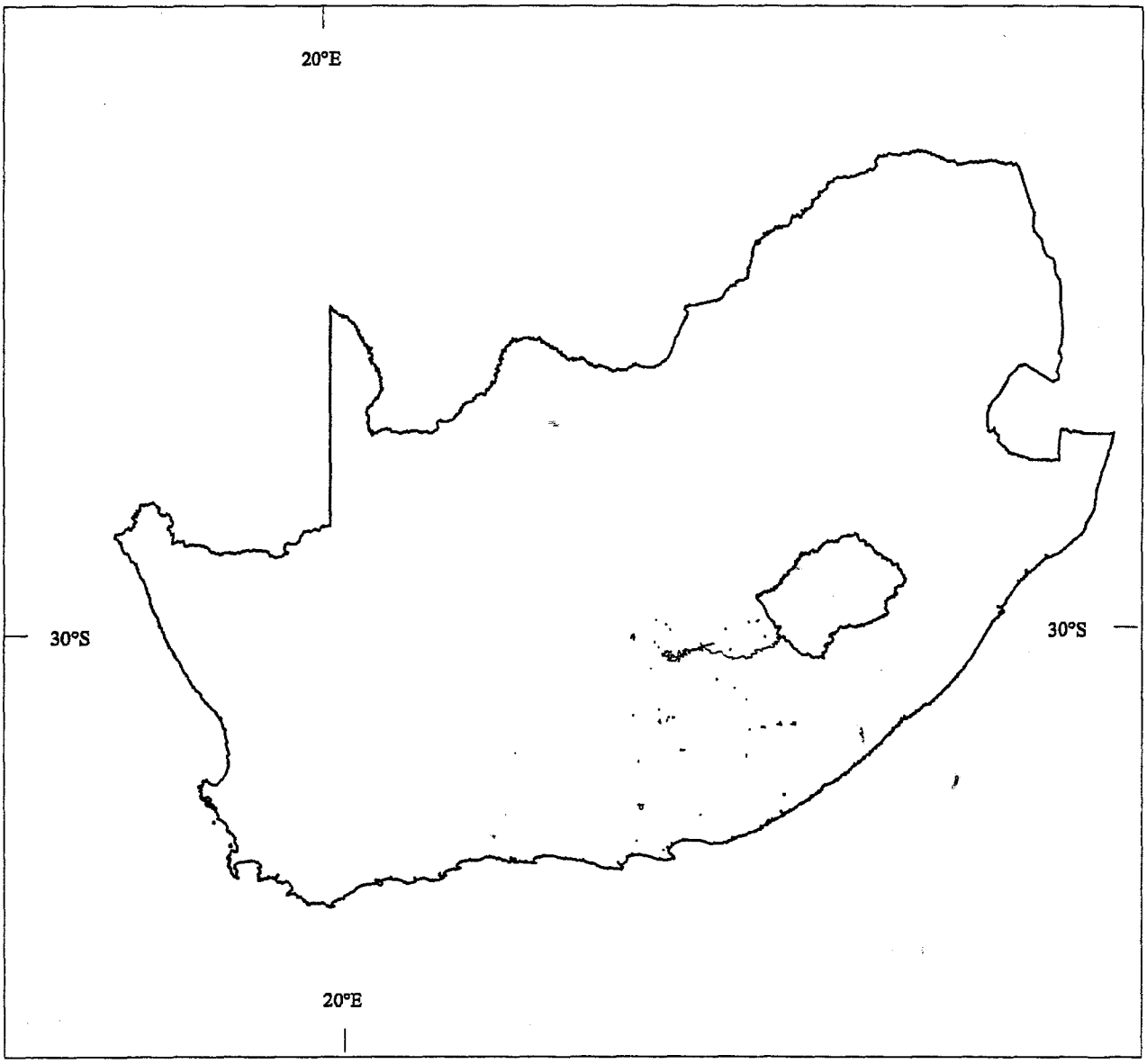


Figure E.107. Digital map layer **za_lakex** (South Africa, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

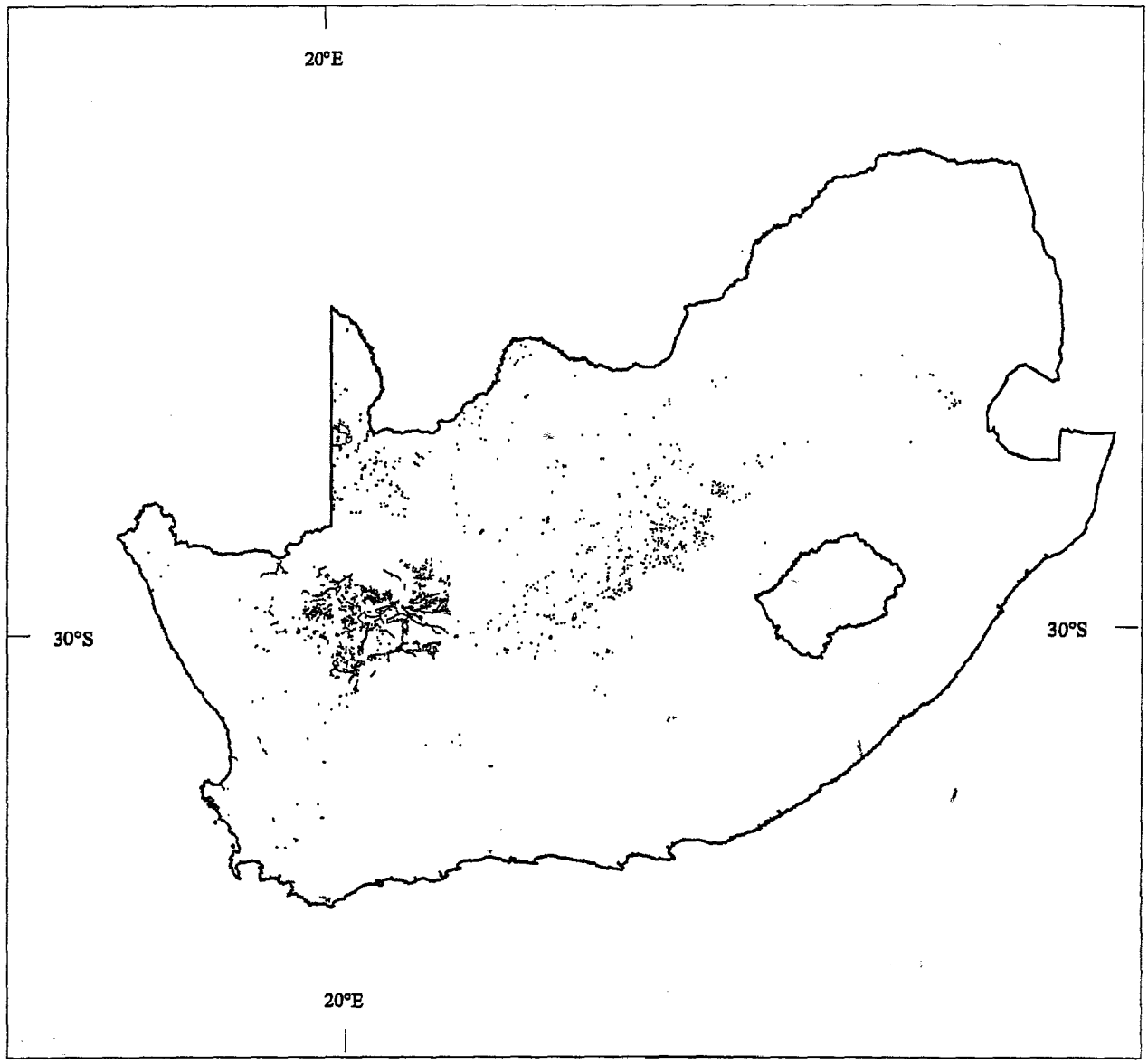


Figure E.108. Digital map layer **za_npwat** (South Africa, non-perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

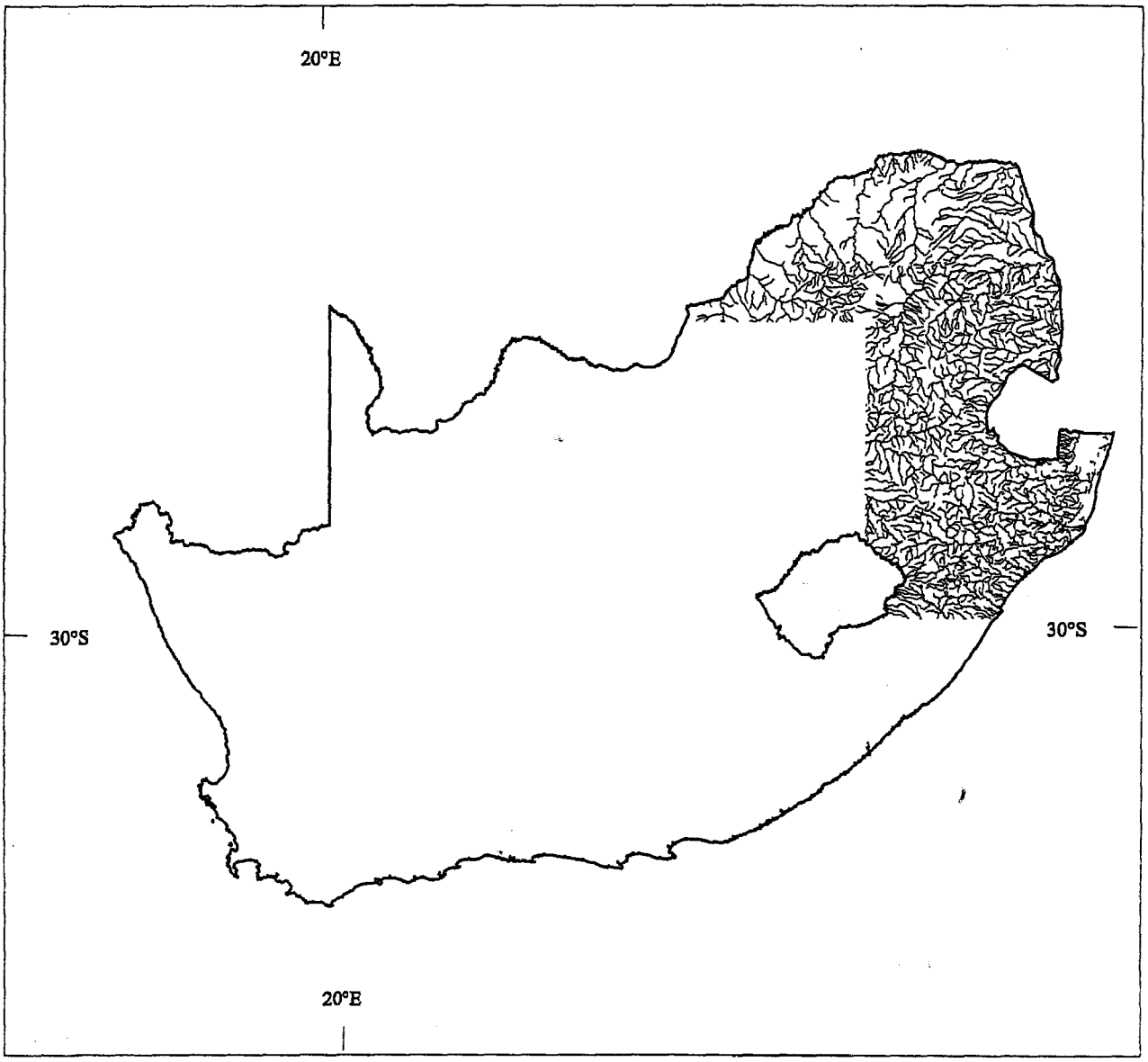


Figure E.109. Digital map layer **za_rive** (South Africa, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

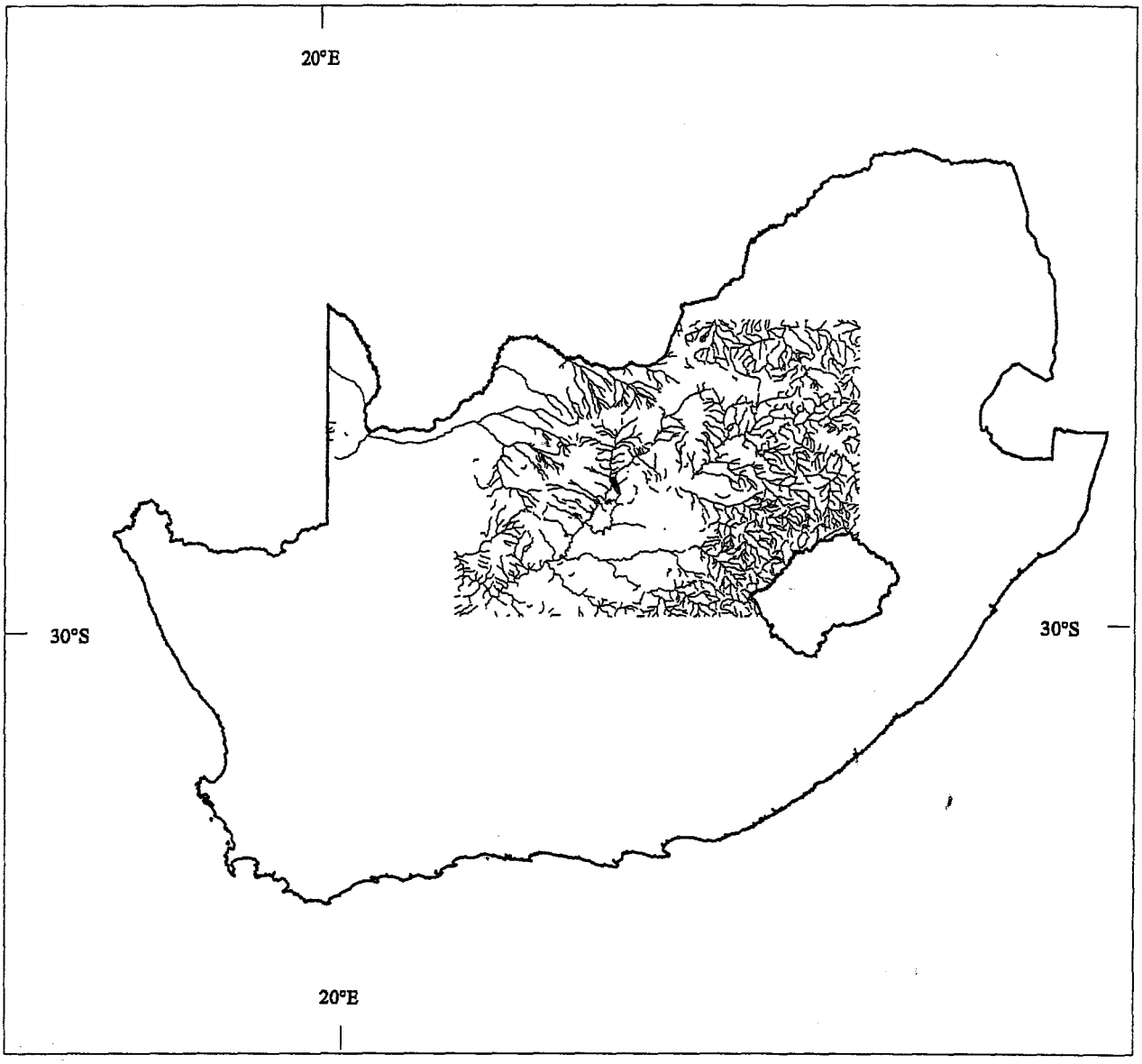


Figure E.110. Digital map layer **za_rivn** (South Africa, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

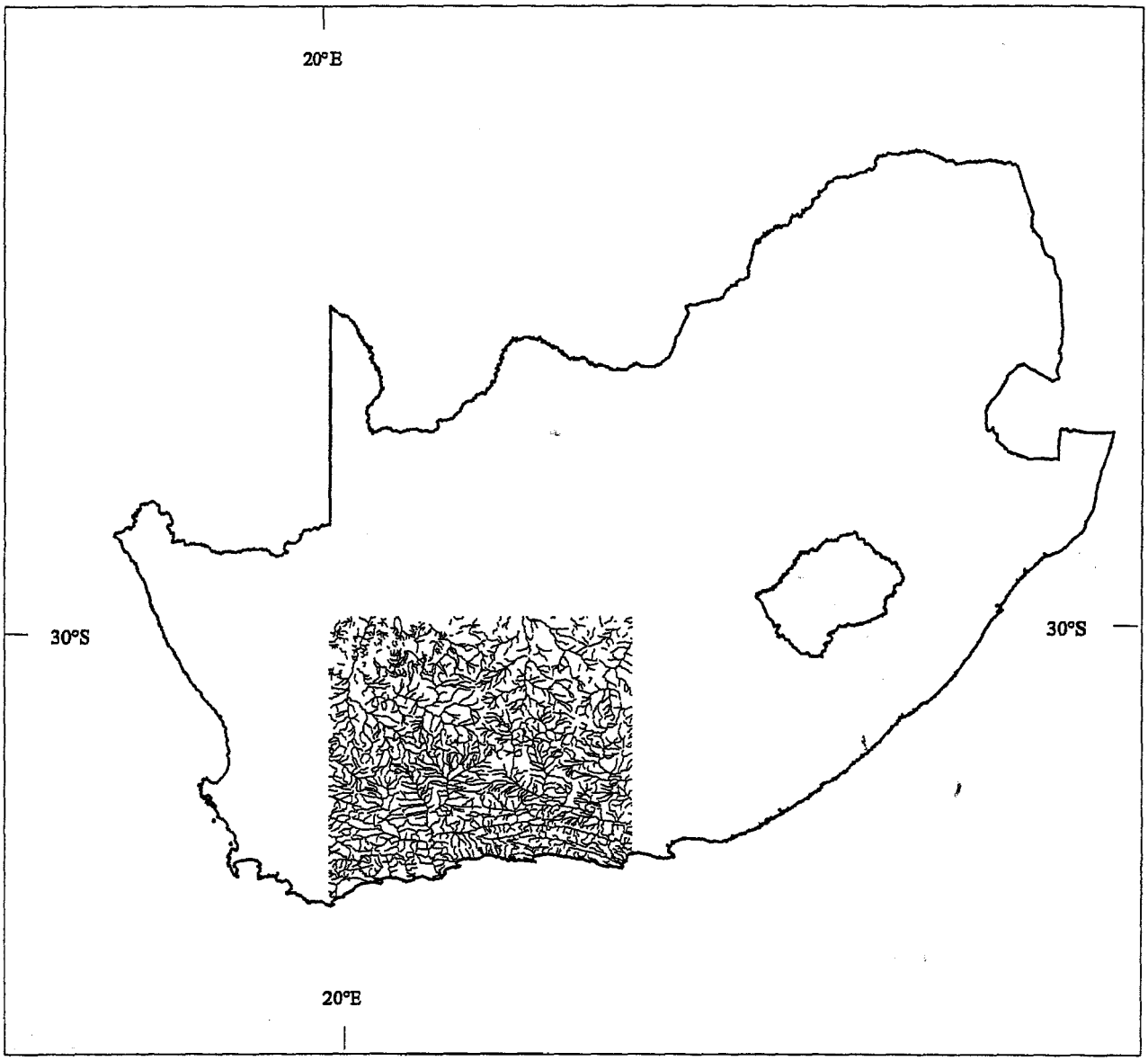


Figure E.111. Digital map layer **za_rivs** (South Africa, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

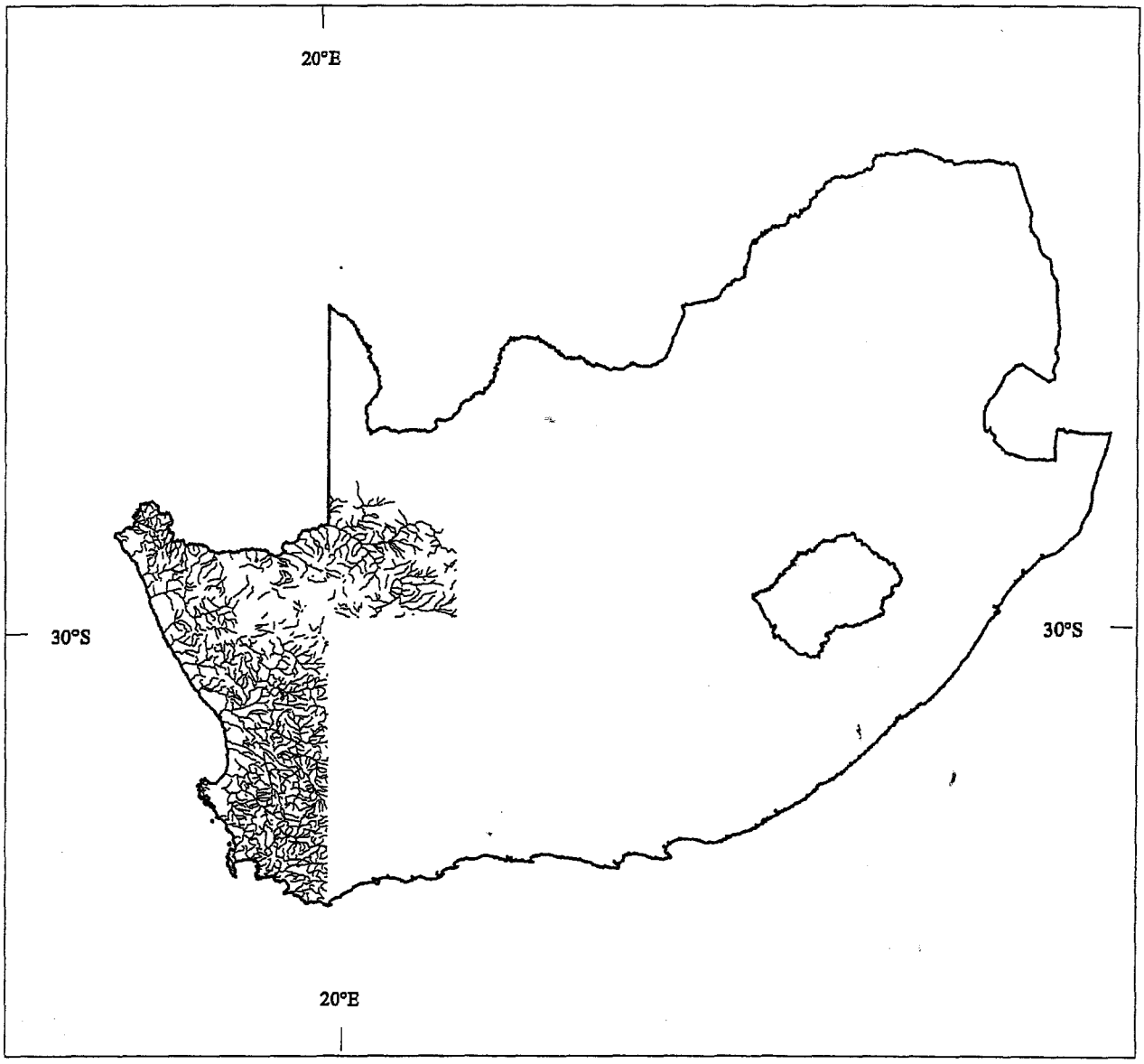


Figure E.112. Digital map layer **za_rivw** (South Africa, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

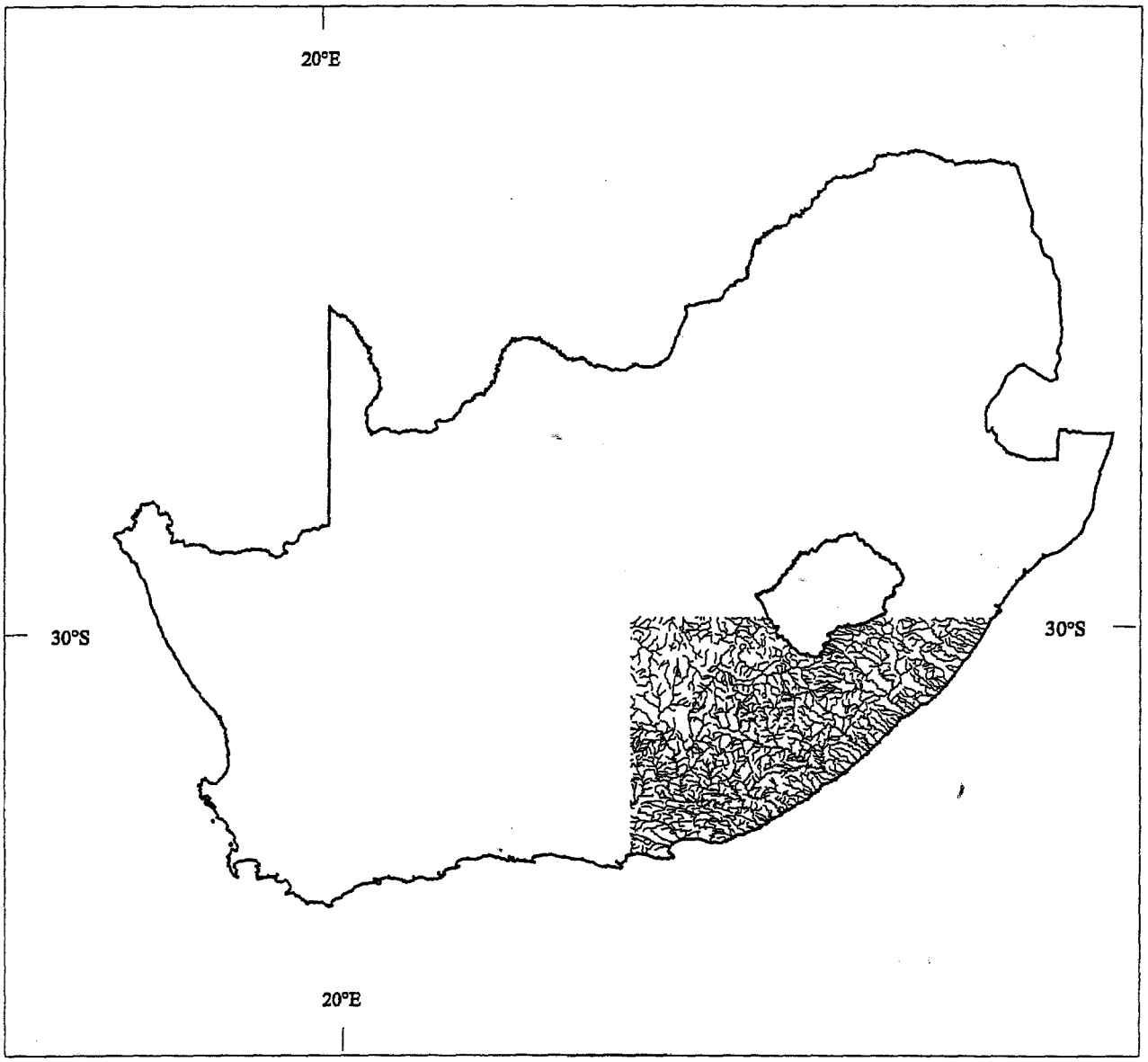


Figure E.113. Digital map layer **za_rivx** (South Africa, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

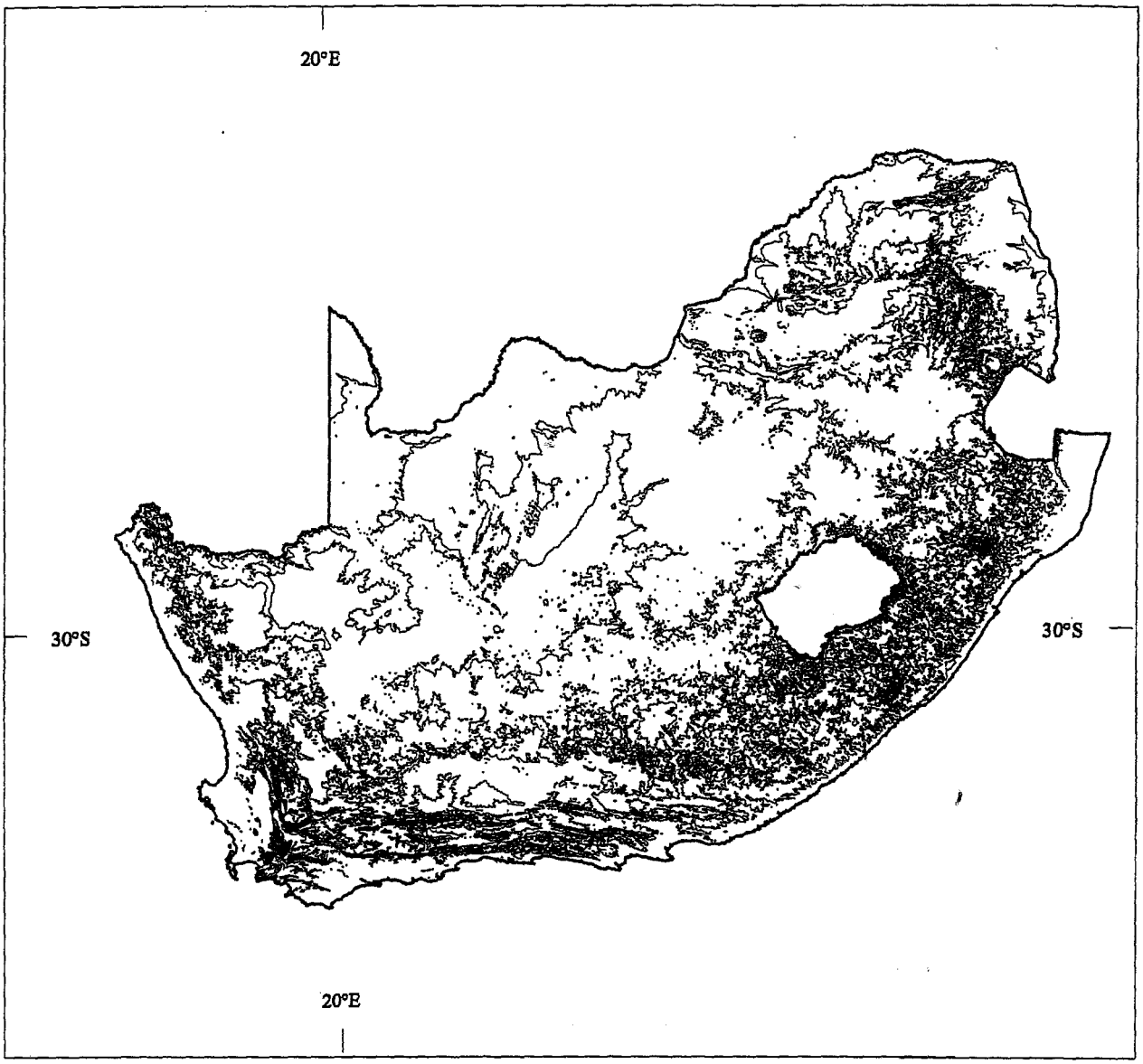


Figure E.114. Digital map layer **za_elev** (South Africa, 1000m contours) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

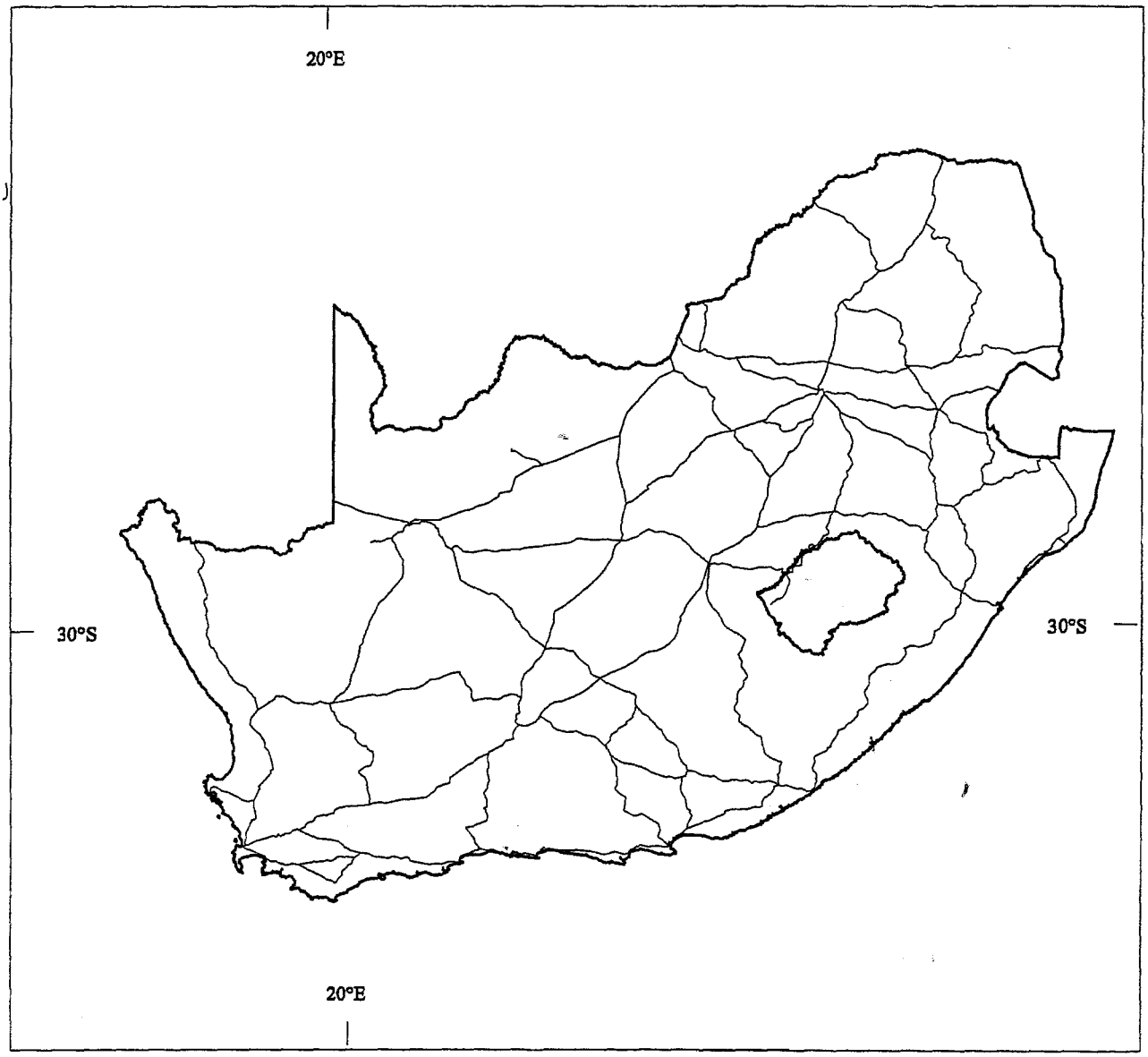


Figure E.115. Digital map layer **za_road** (South Africa, roads) from the atlas of southern African freshwater fish. Scale approximately 1:12 100 000

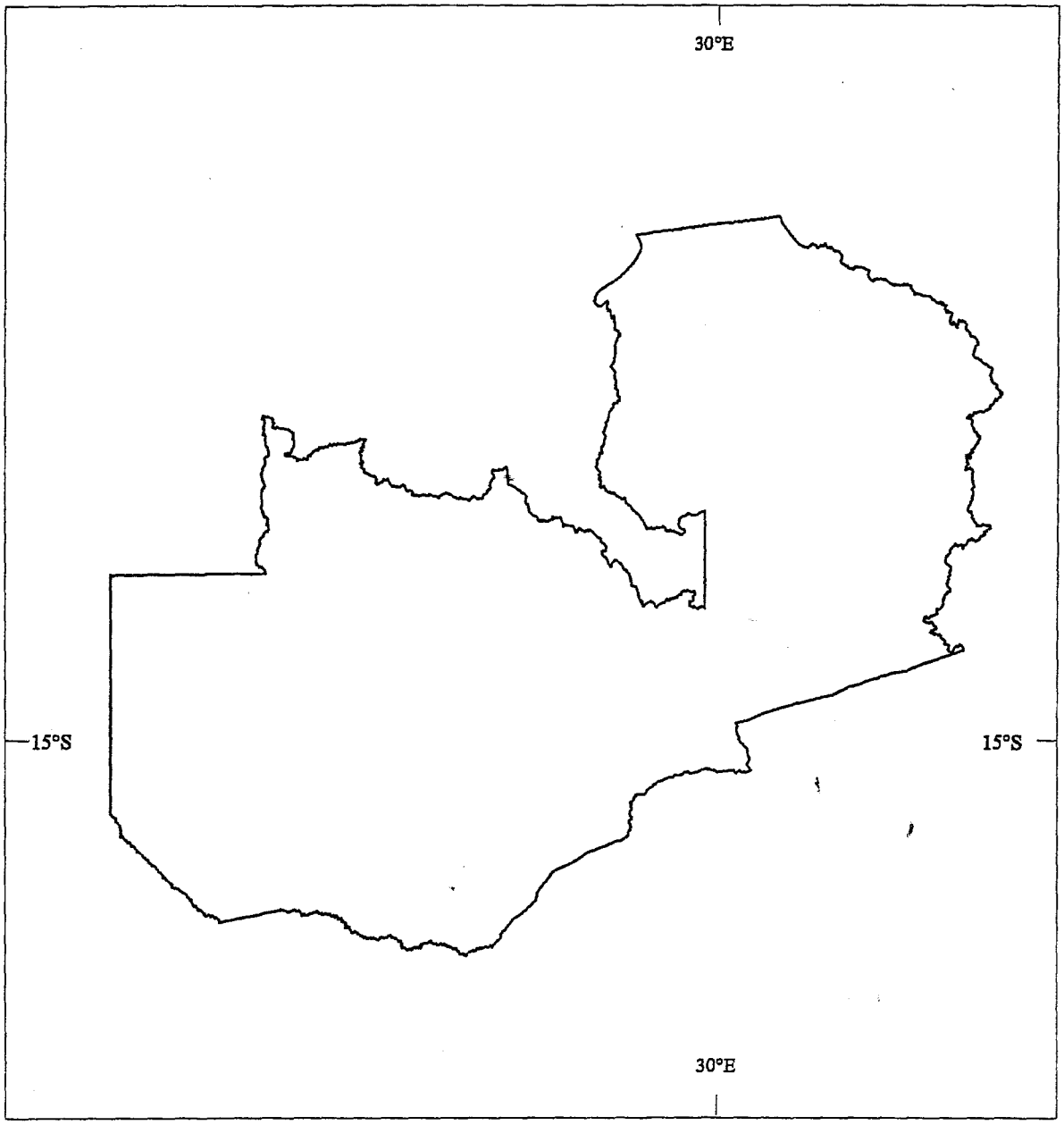


Figure E.116. Digital map layer **zm_adm1** (Zambia, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

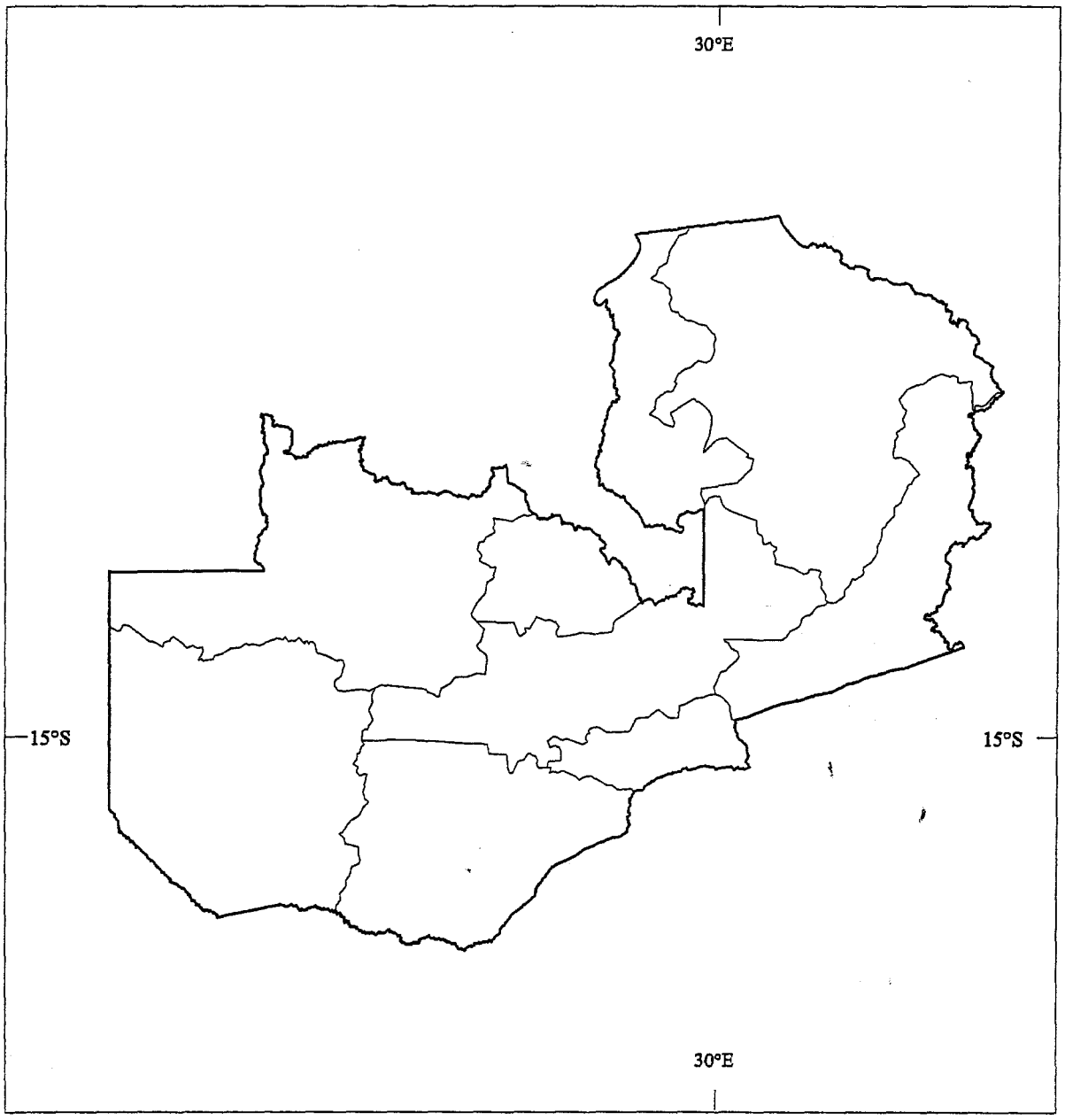


Figure E.117. Digital map layer **zm_adm2** (Zambia, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

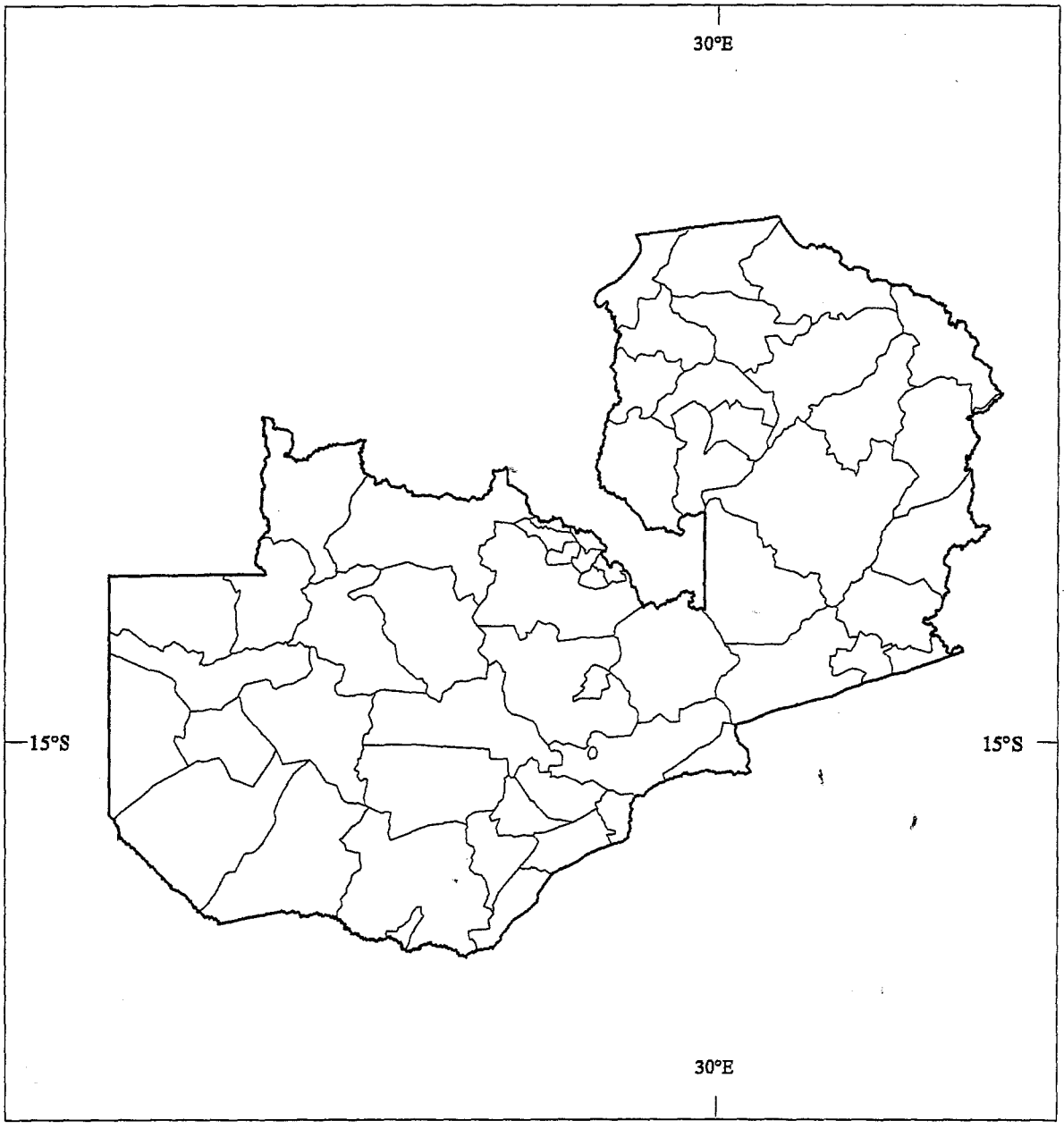


Figure E.118. Digital map layer **zm_adm3** (Zambia, district borders) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

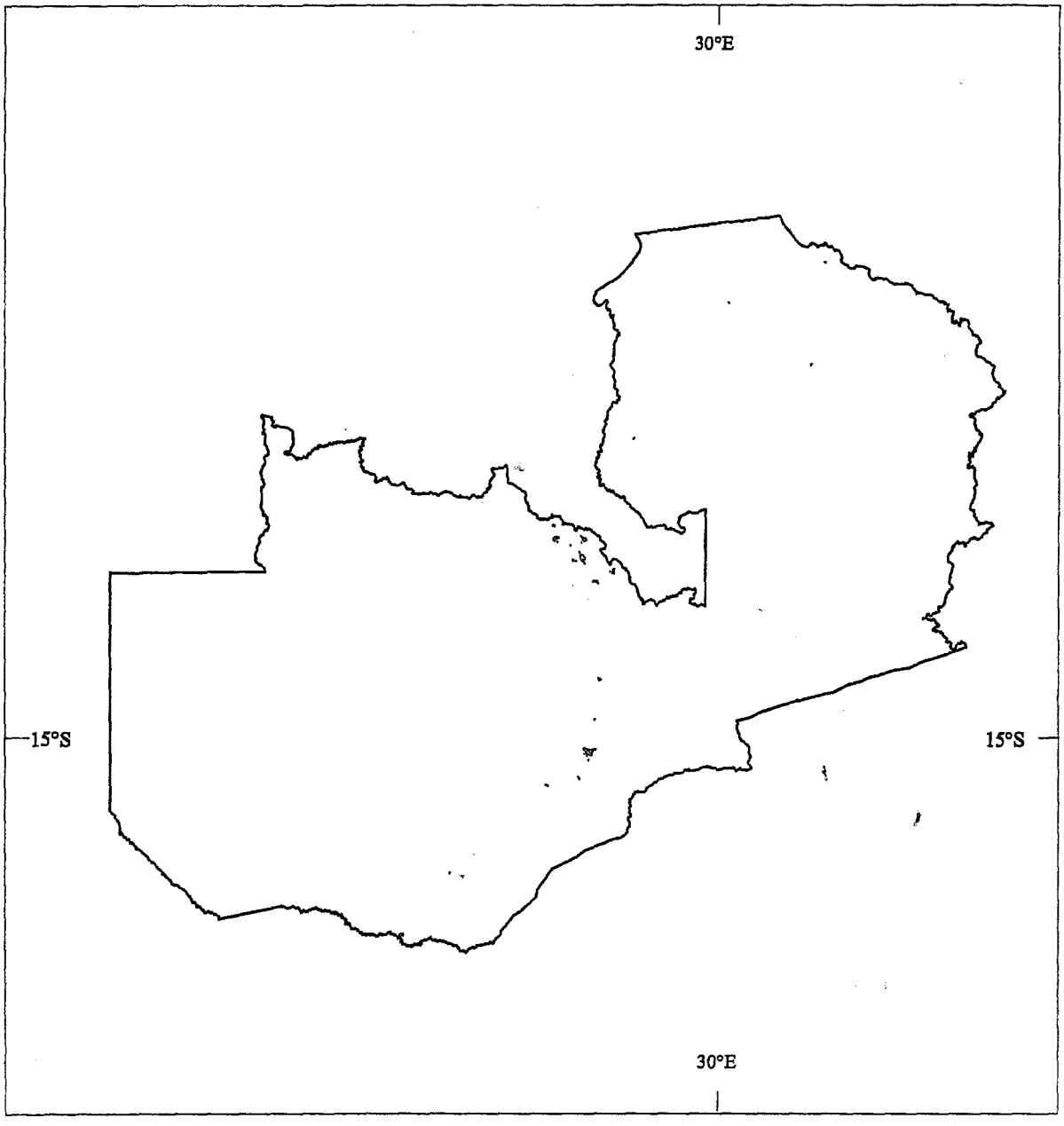


Figure E.119. Digital map layer **zm_urbn** (Zambia, urbanised areas as polygons) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

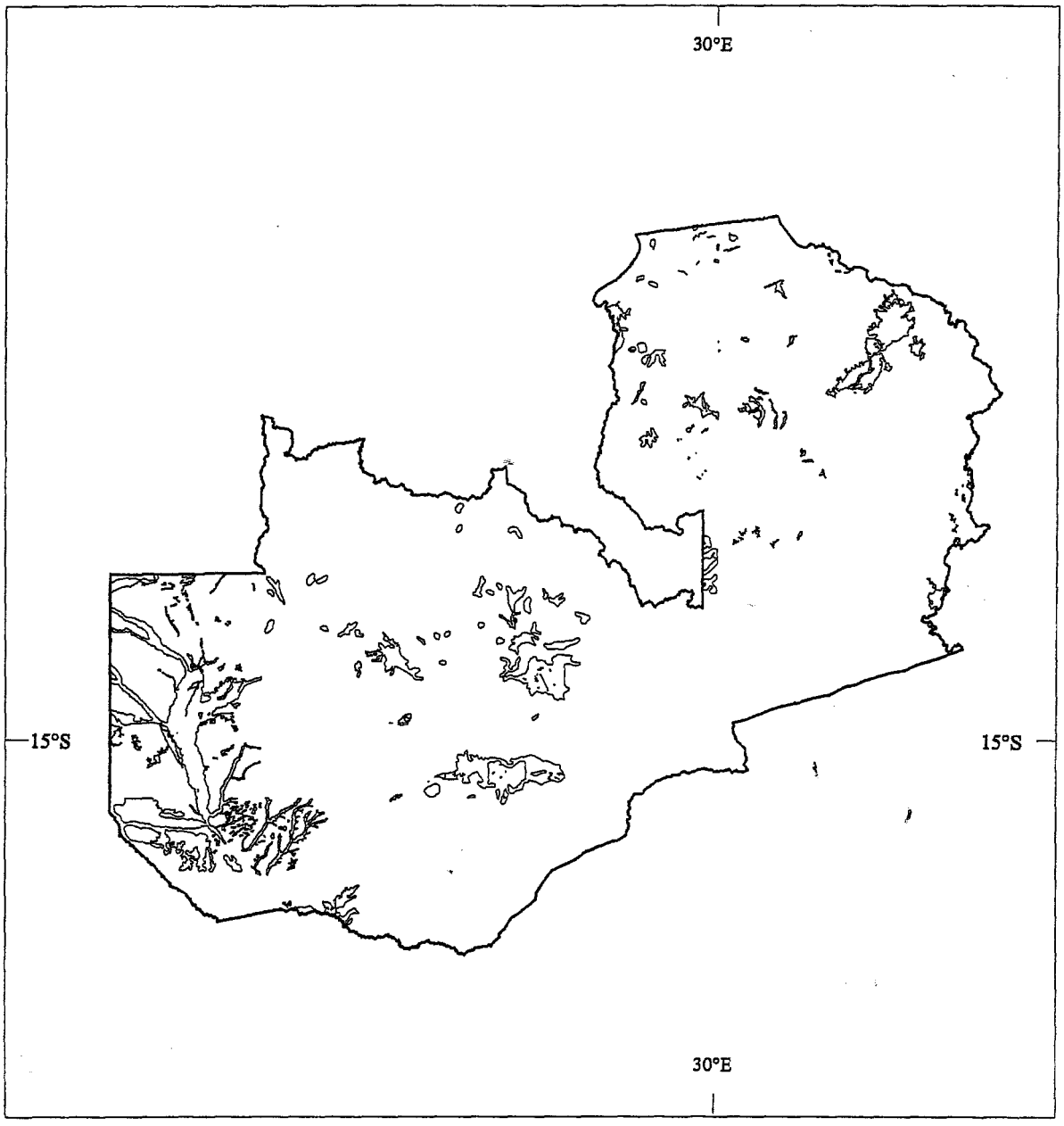


Figure E.120. Digital map layer **zm_cova** (Zambia, wetlands and other land cover areas) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

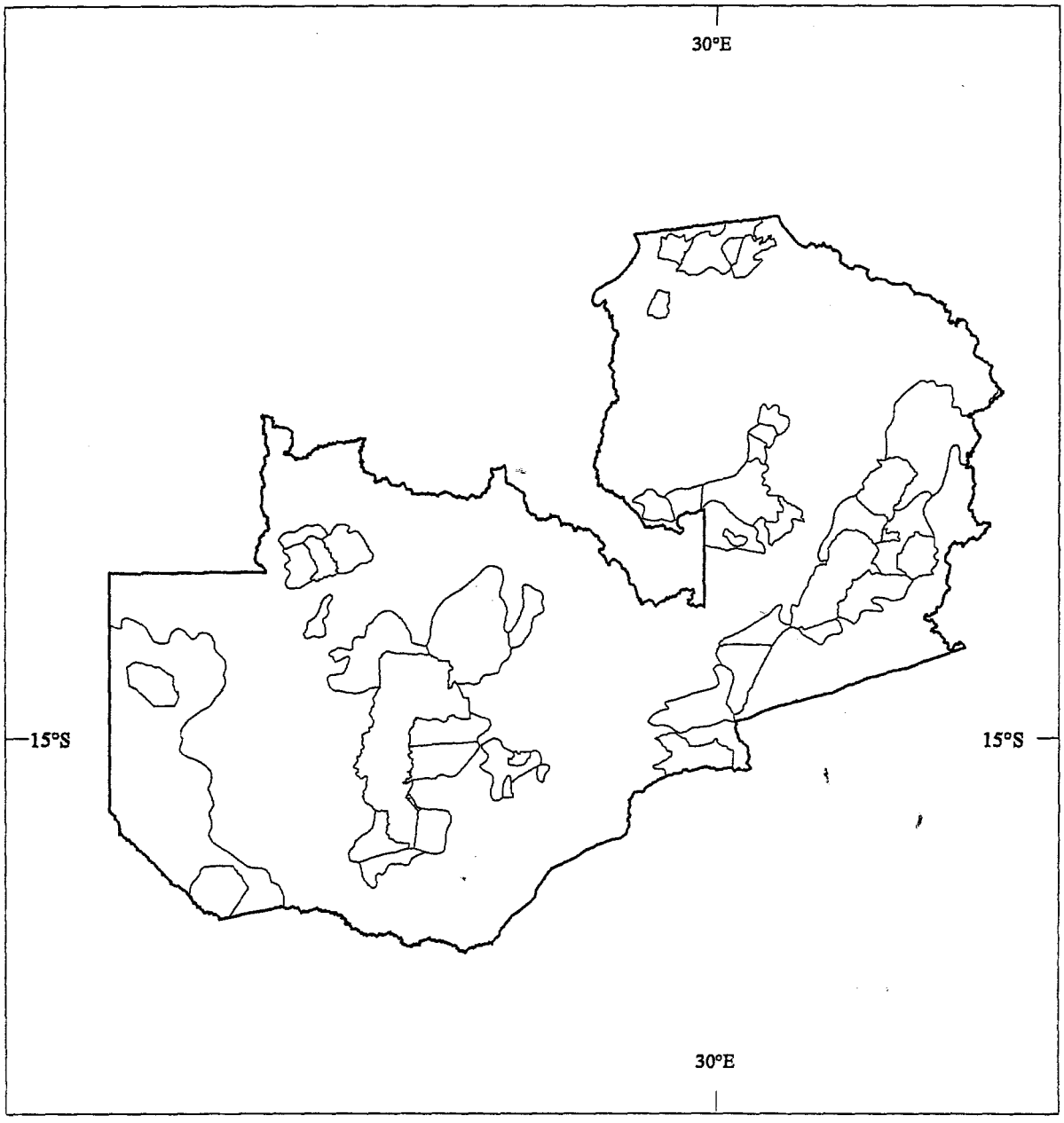


Figure E.121. Digital map layer **zm_park** (Zambia, national parks) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

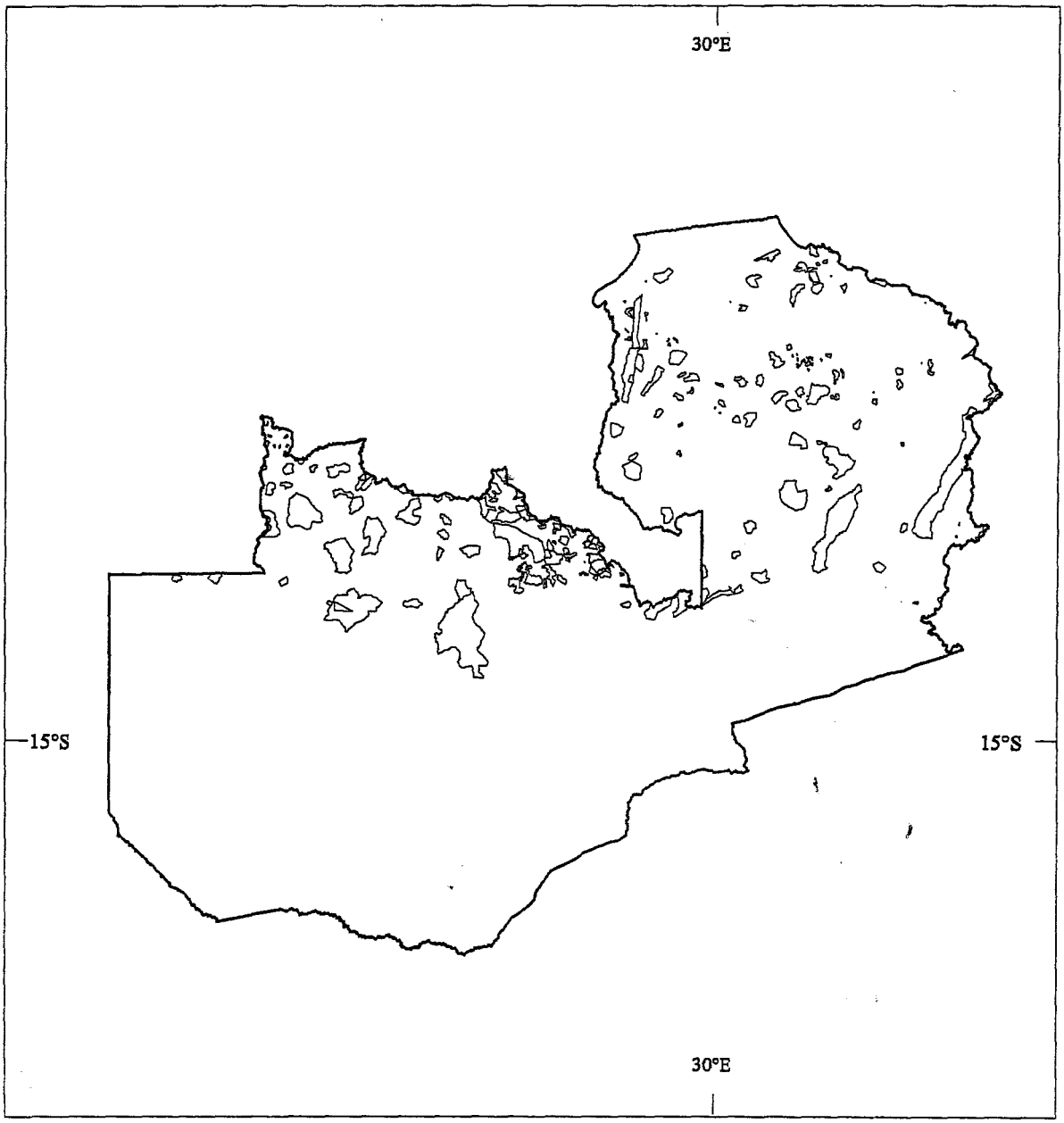


Figure E.122. Digital map layer **zm_wood** (Zambia, production forest, classified by type) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

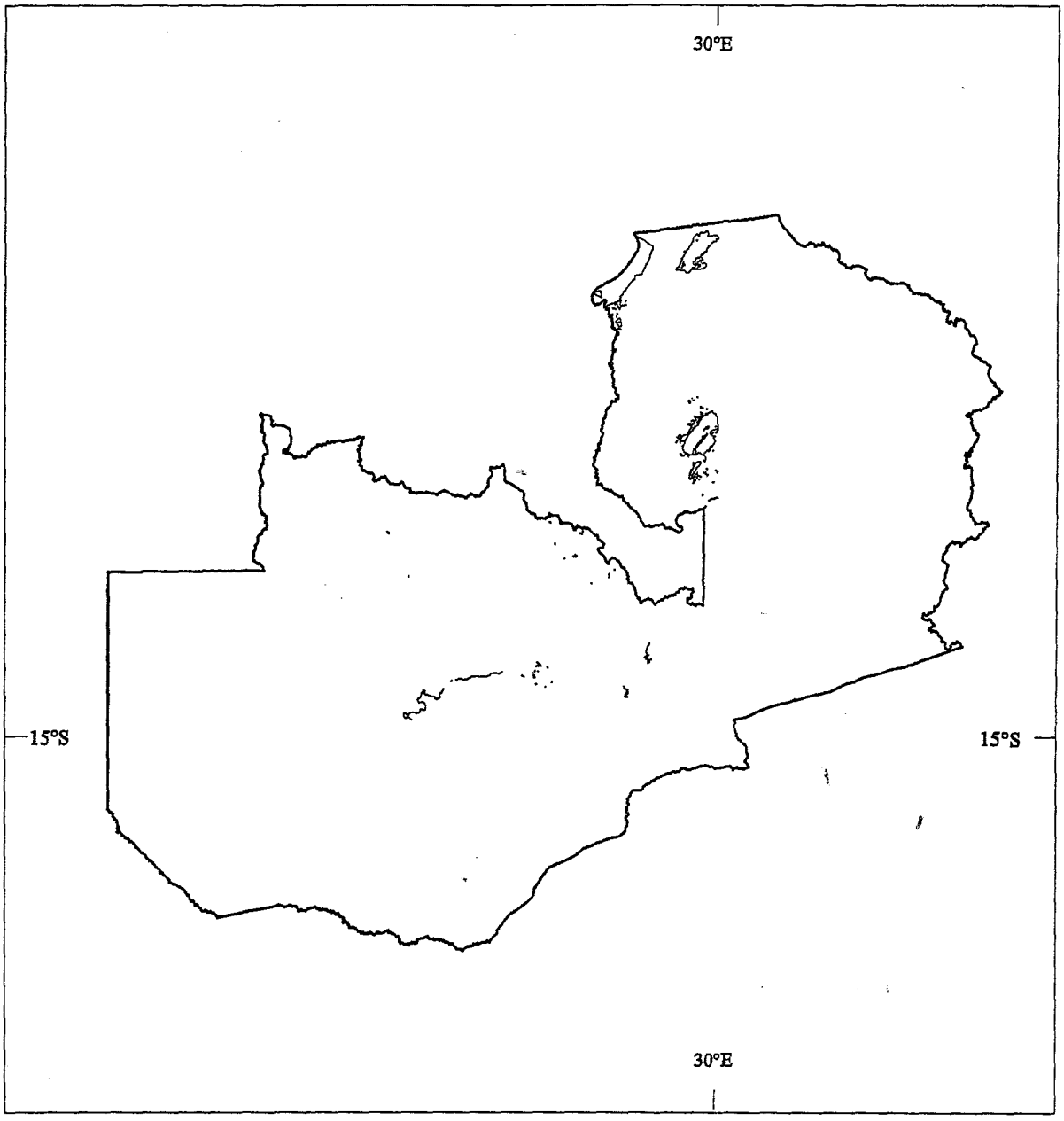


Figure E.123. Digital map layer **zm_lakec** (Zambia, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

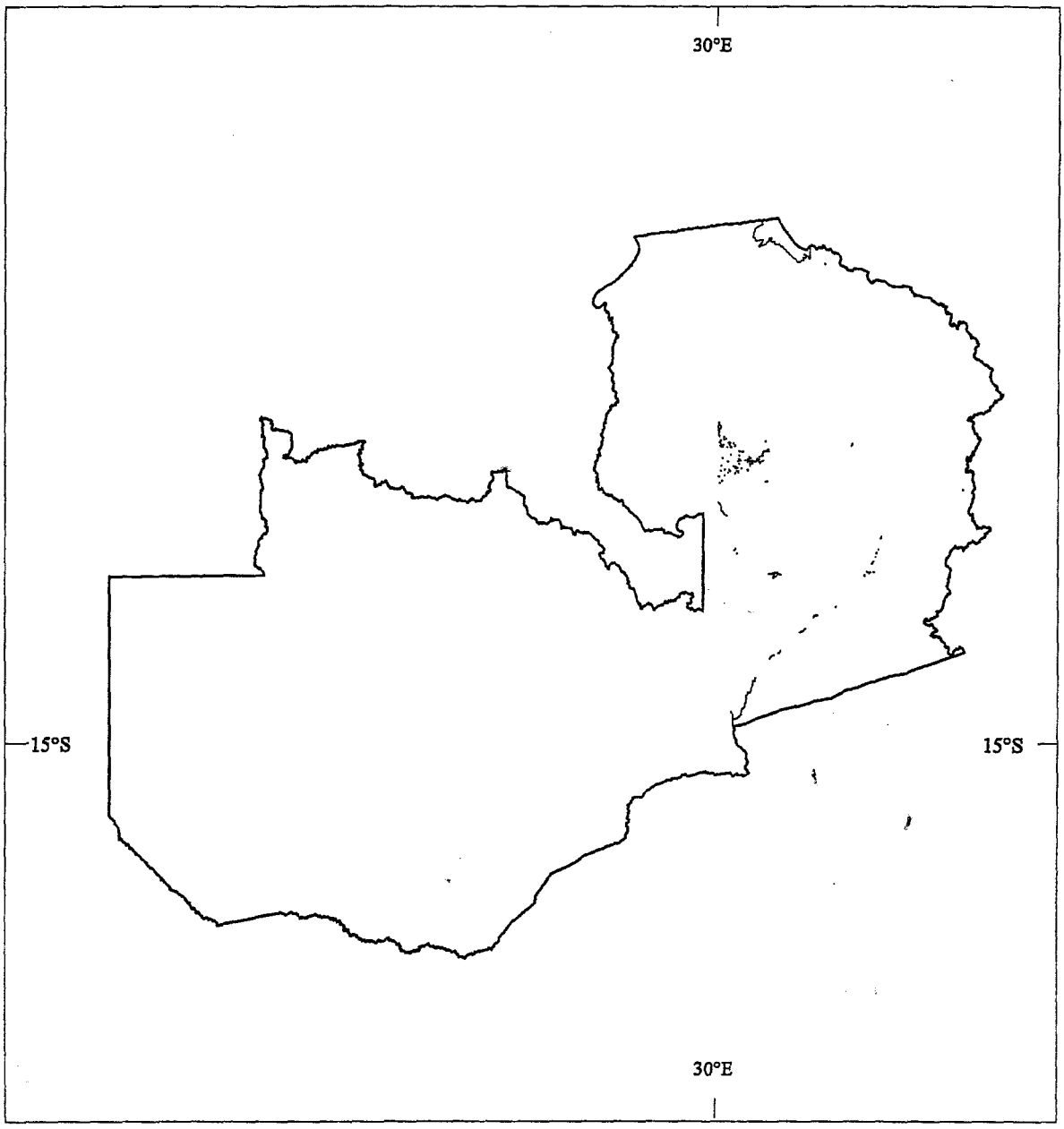


Figure E.124. Digital map layer **zm_lakee** (Zambia, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

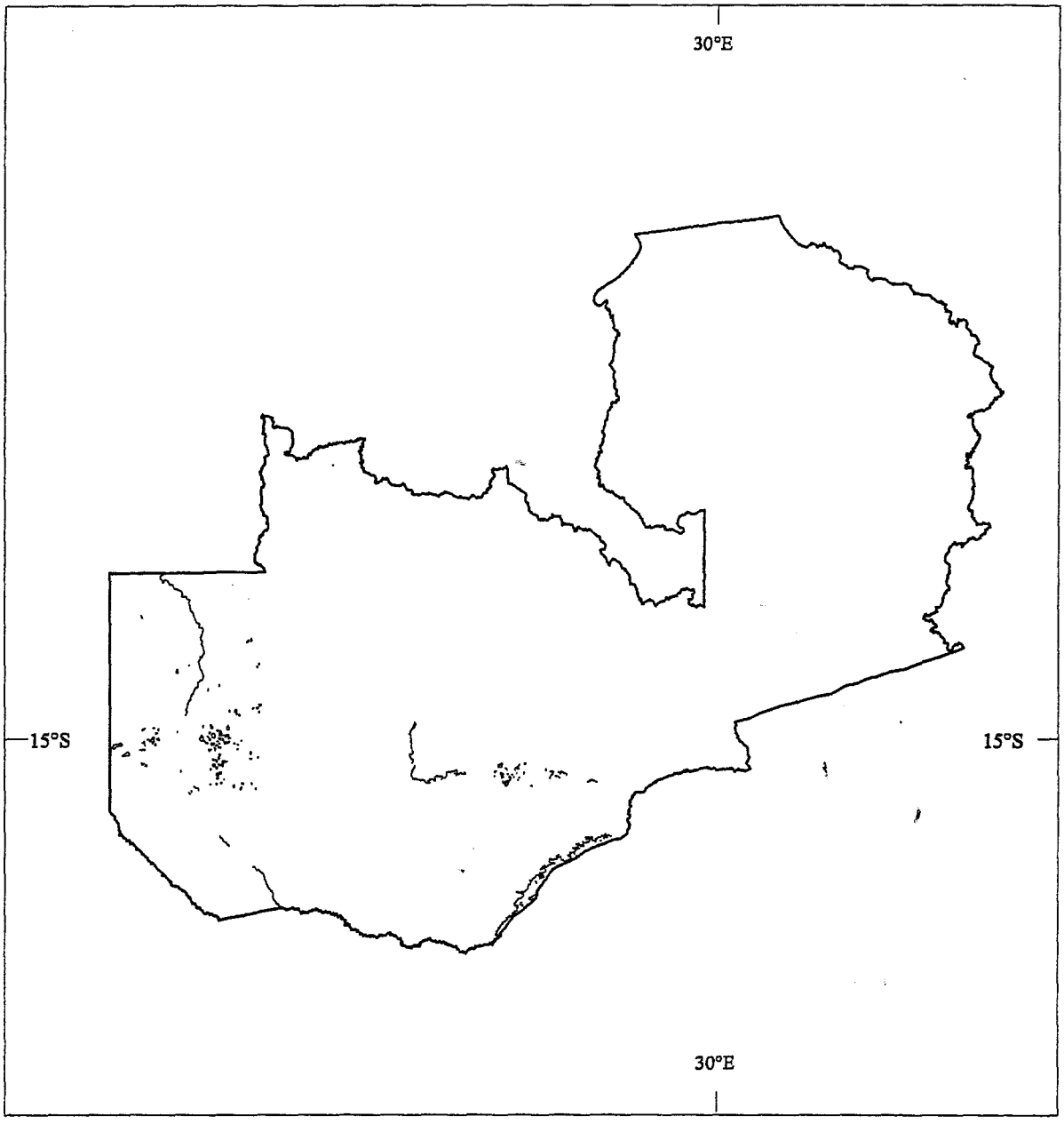


Figure E.125. Digital map layer **zm_lakew** (Zambia, lakes (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

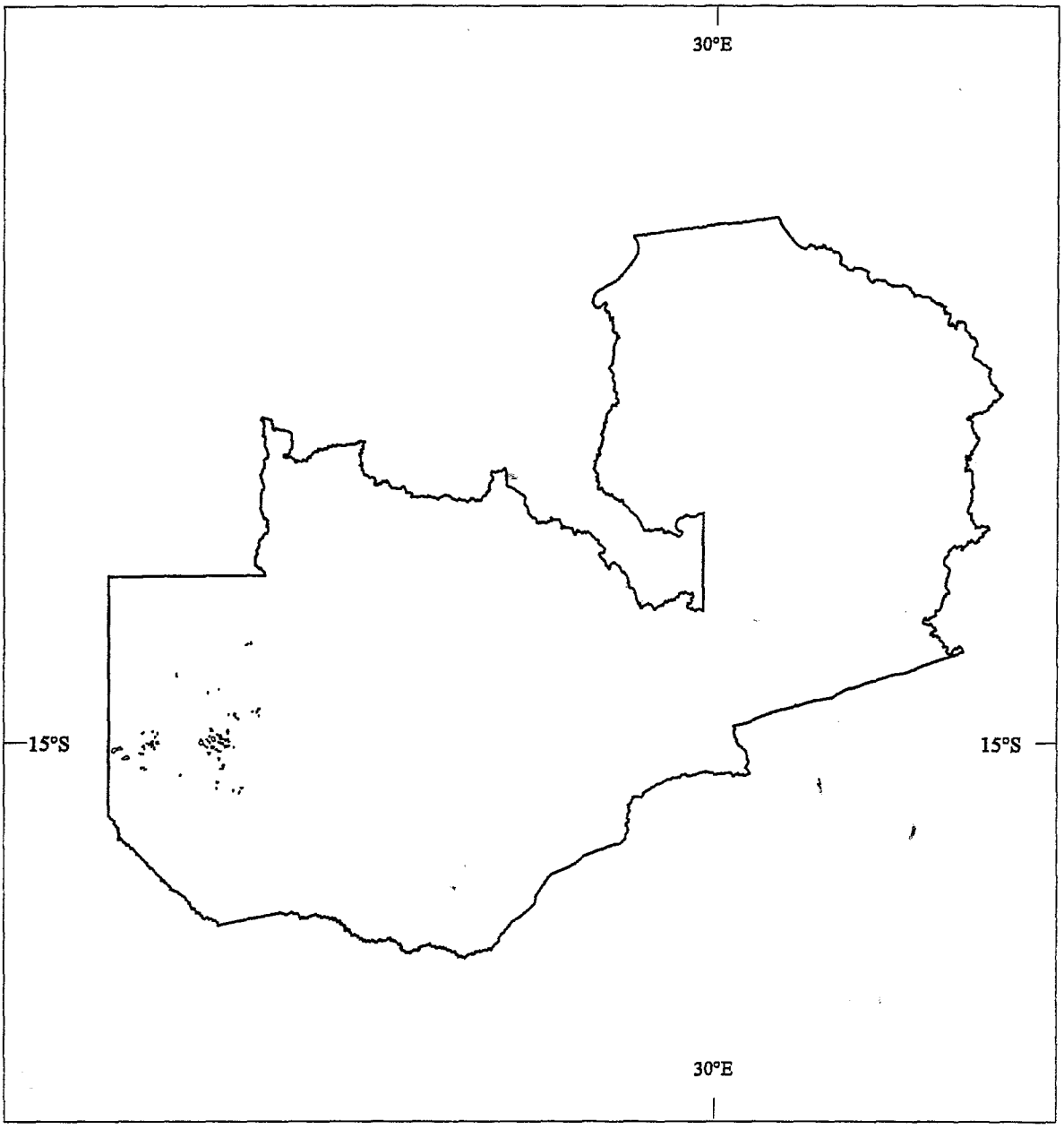


Figure E.126. Digital map layer **zm_npwat** (Zambia, non-perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

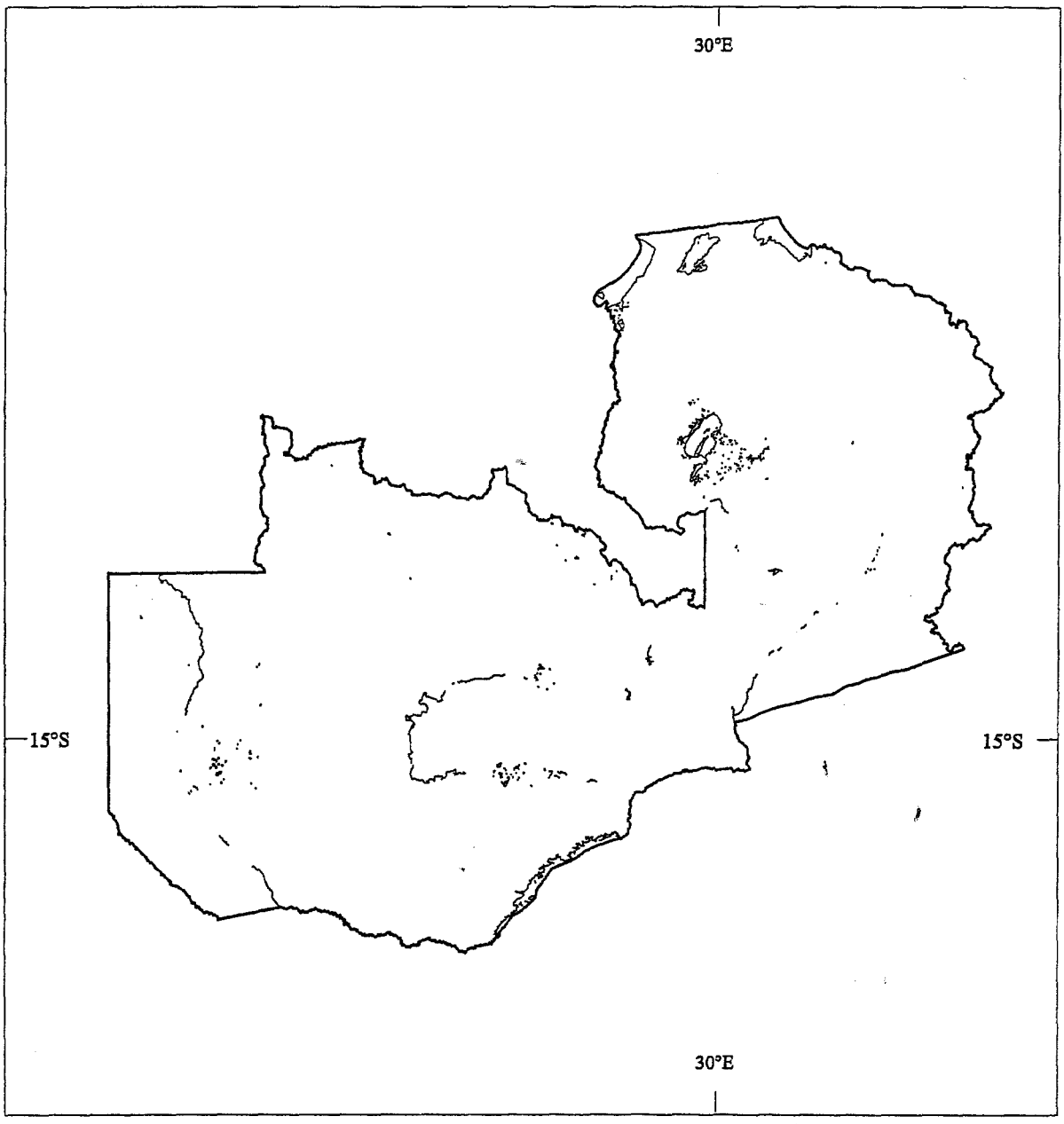


Figure E.127. Digital map layer **zm_pwat** (Zambia, perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

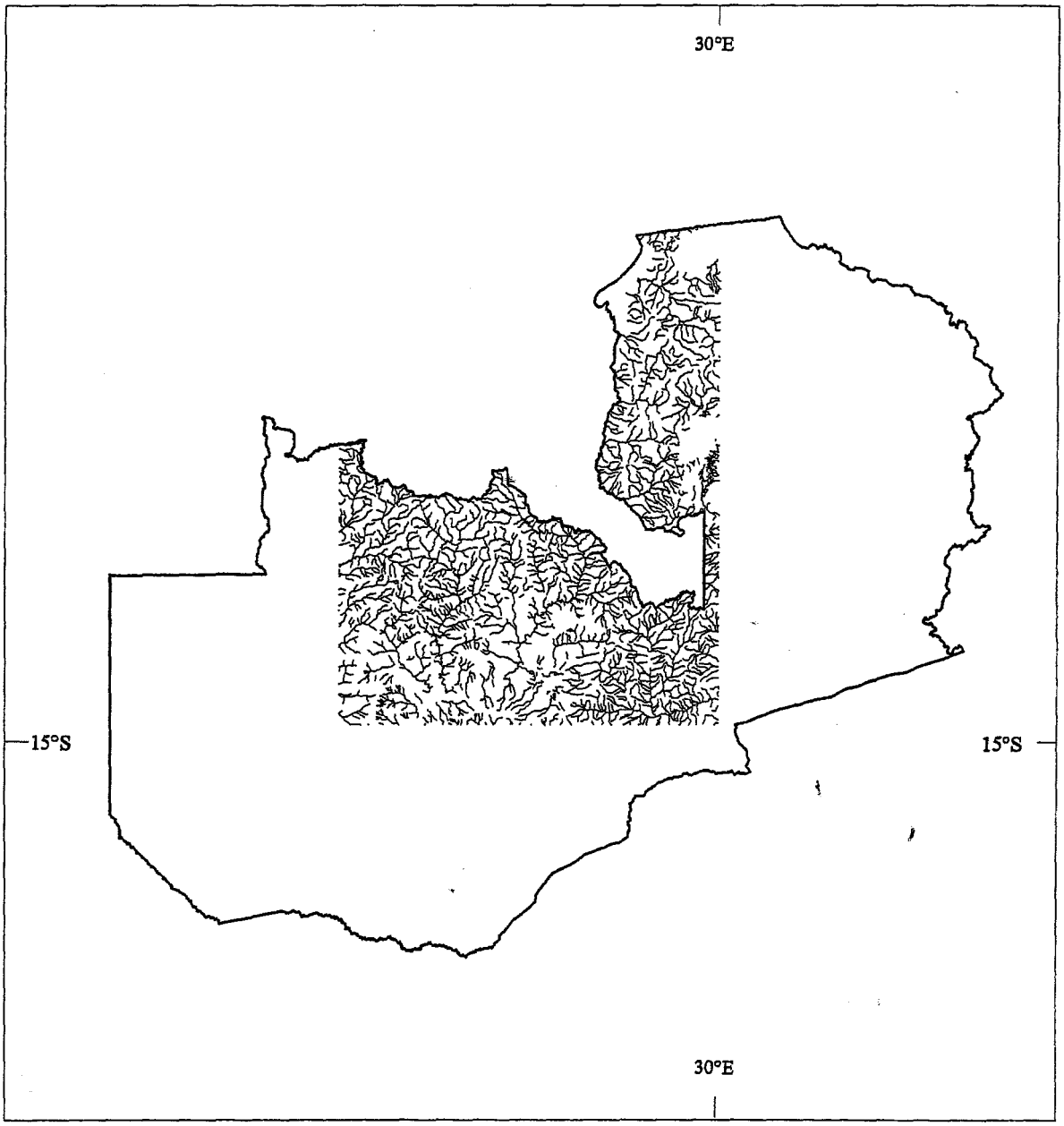


Figure E.128. Digital map layer **zm_rivc** (Zambia, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

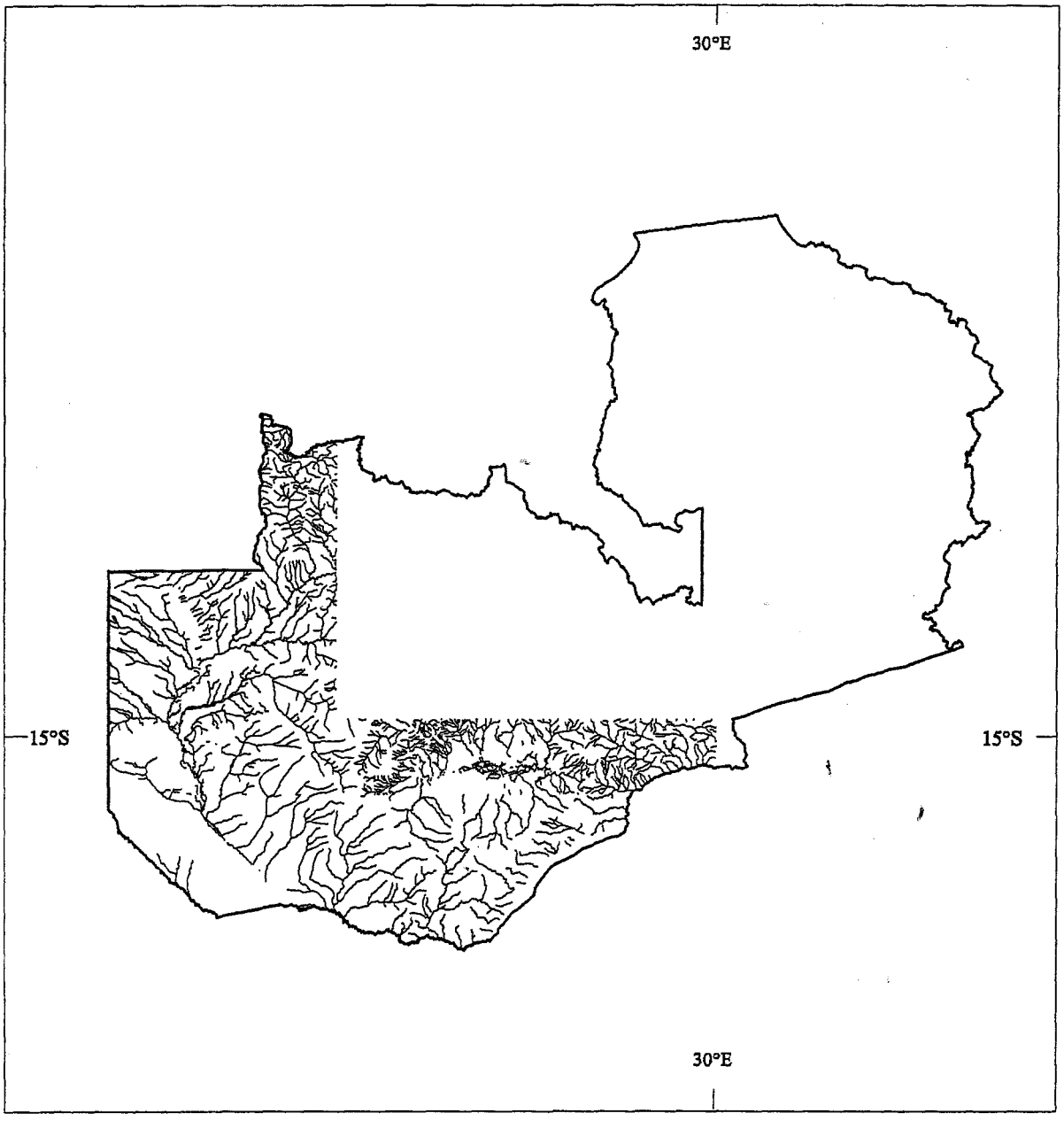


Figure E.129. Digital map layer **zm_rive** (Zambia, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

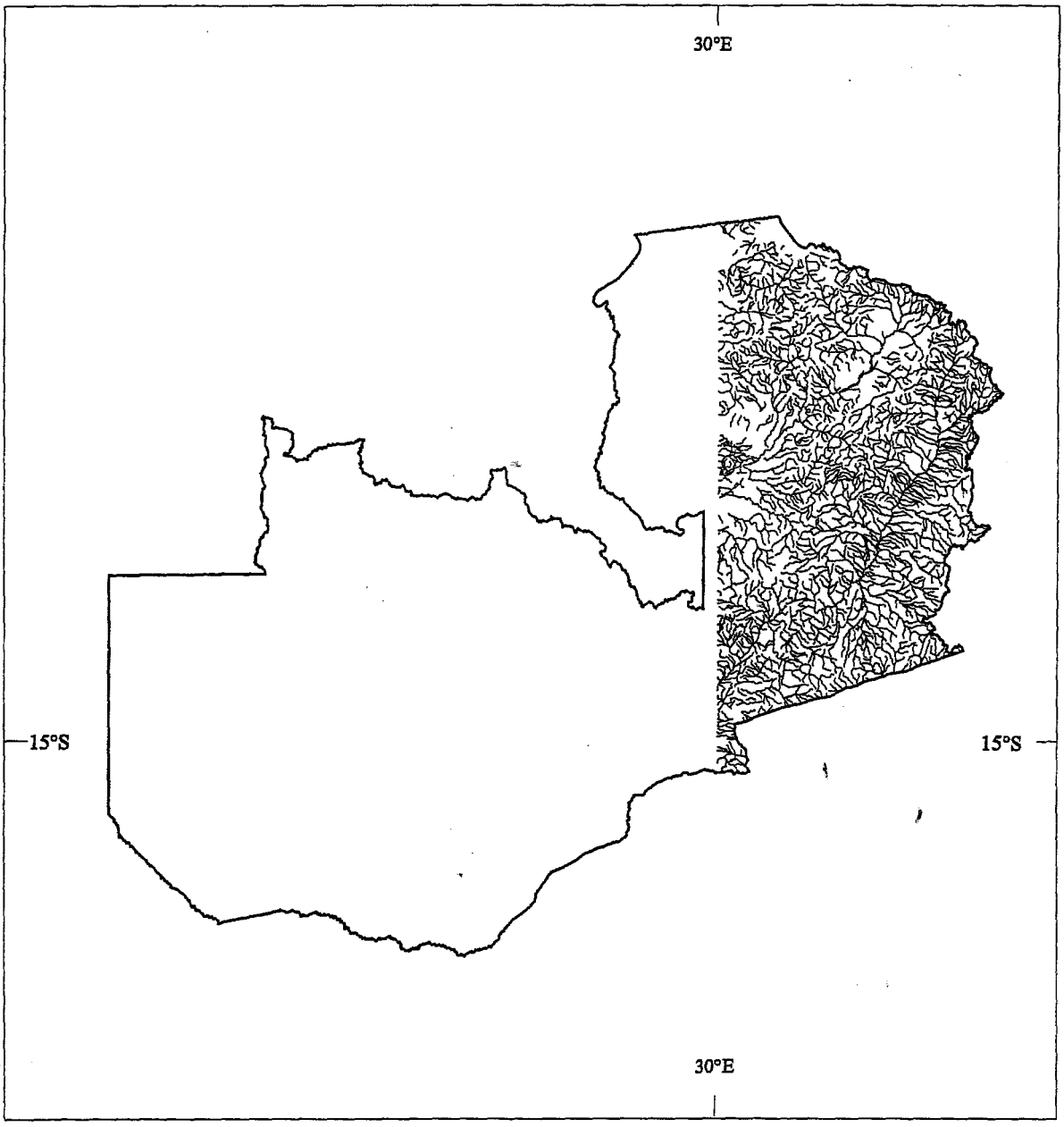


Figure E.130. Digital map layer **zm_rivw** (Zambia, rivers (one subdivision)) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

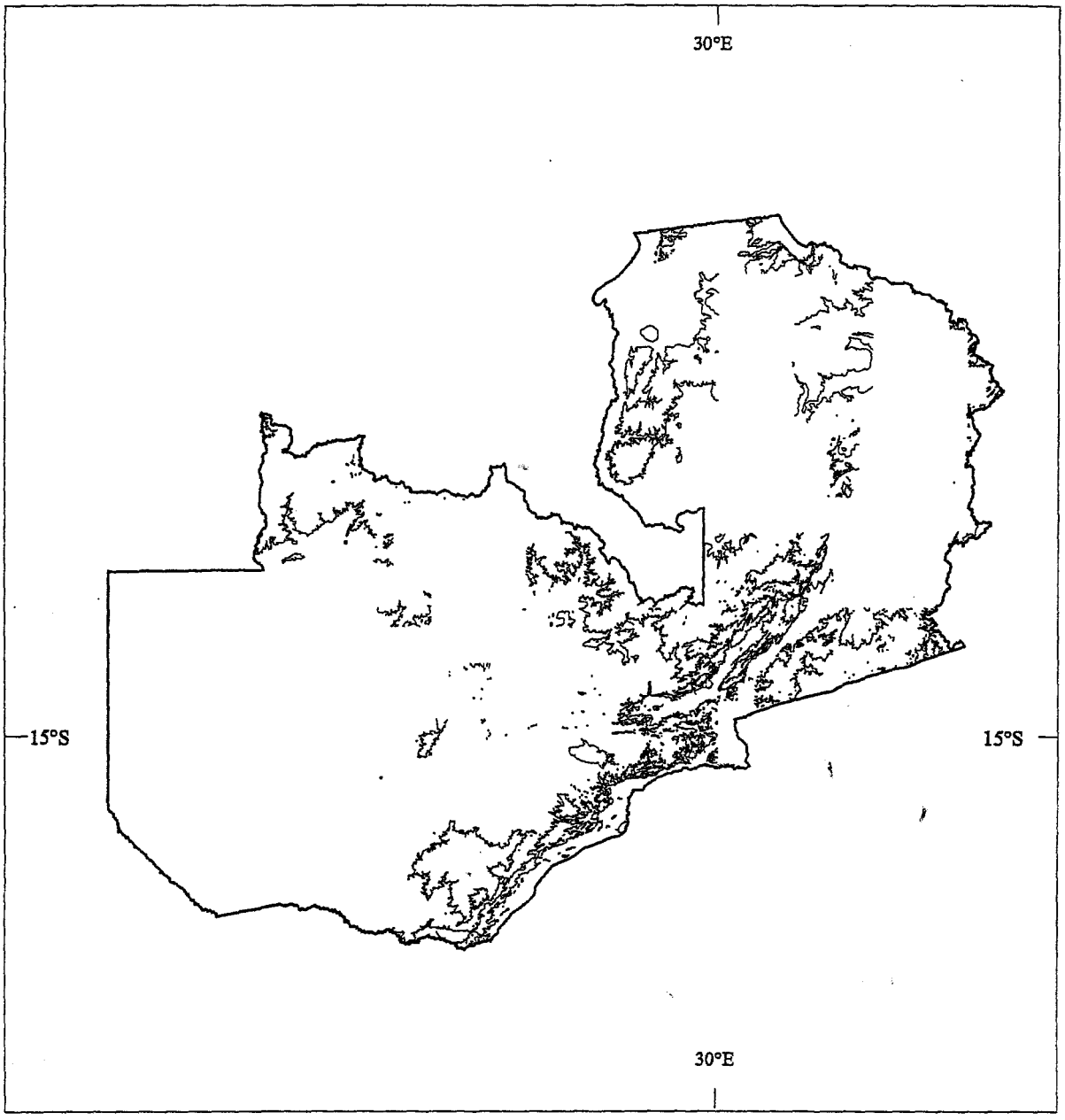


Figure E.131. Digital map layer **zm_elev** (Zambia, 1000m contours) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

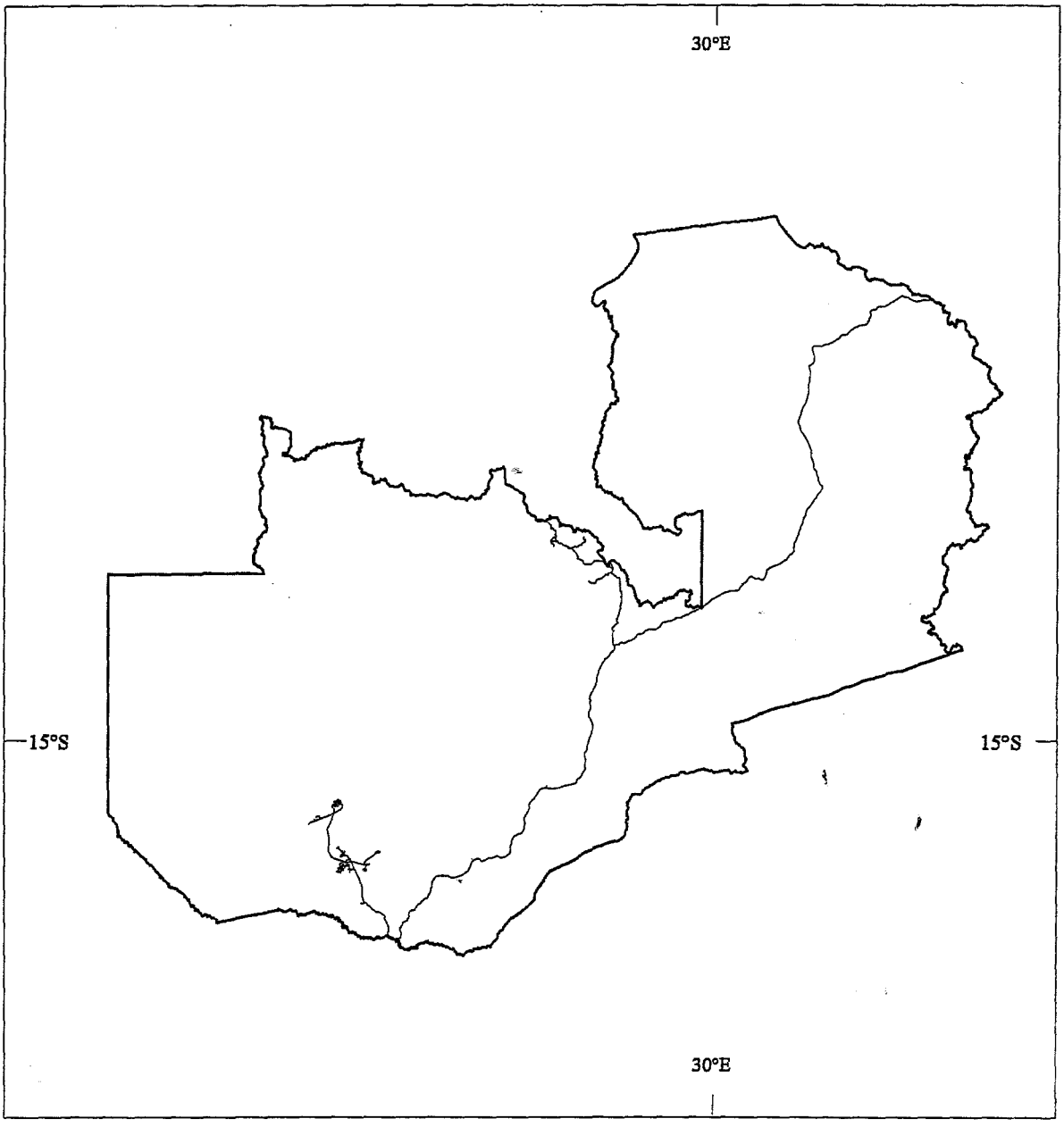


Figure E.132. Digital map layer **zm_rail** (Zambia, railroads) from the atlas of southern African freshwater fish. Scale approximately 1:10 100 000

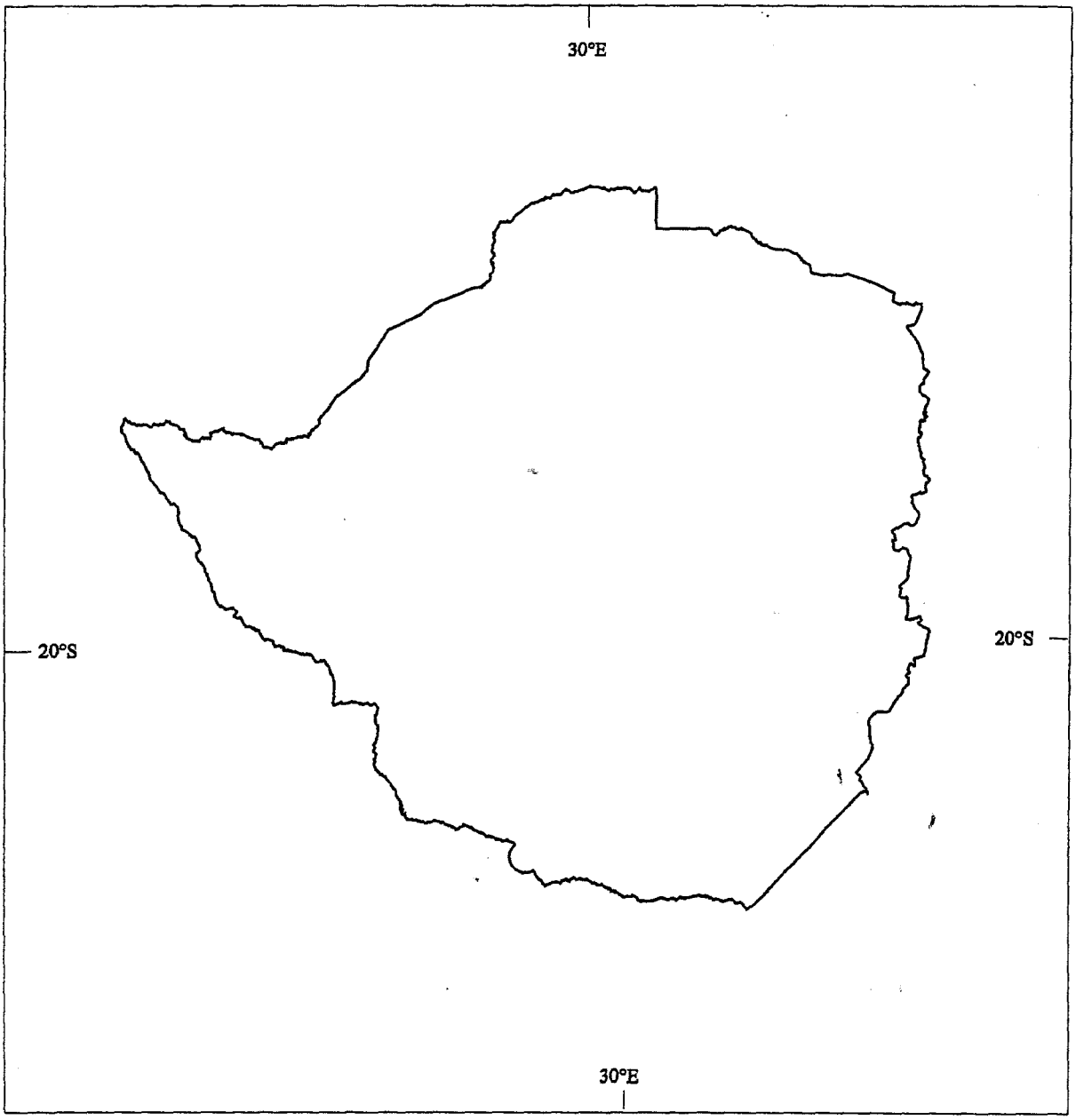


Figure E.133. Digital map layer **zw_adm1** (Zimbabwe, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

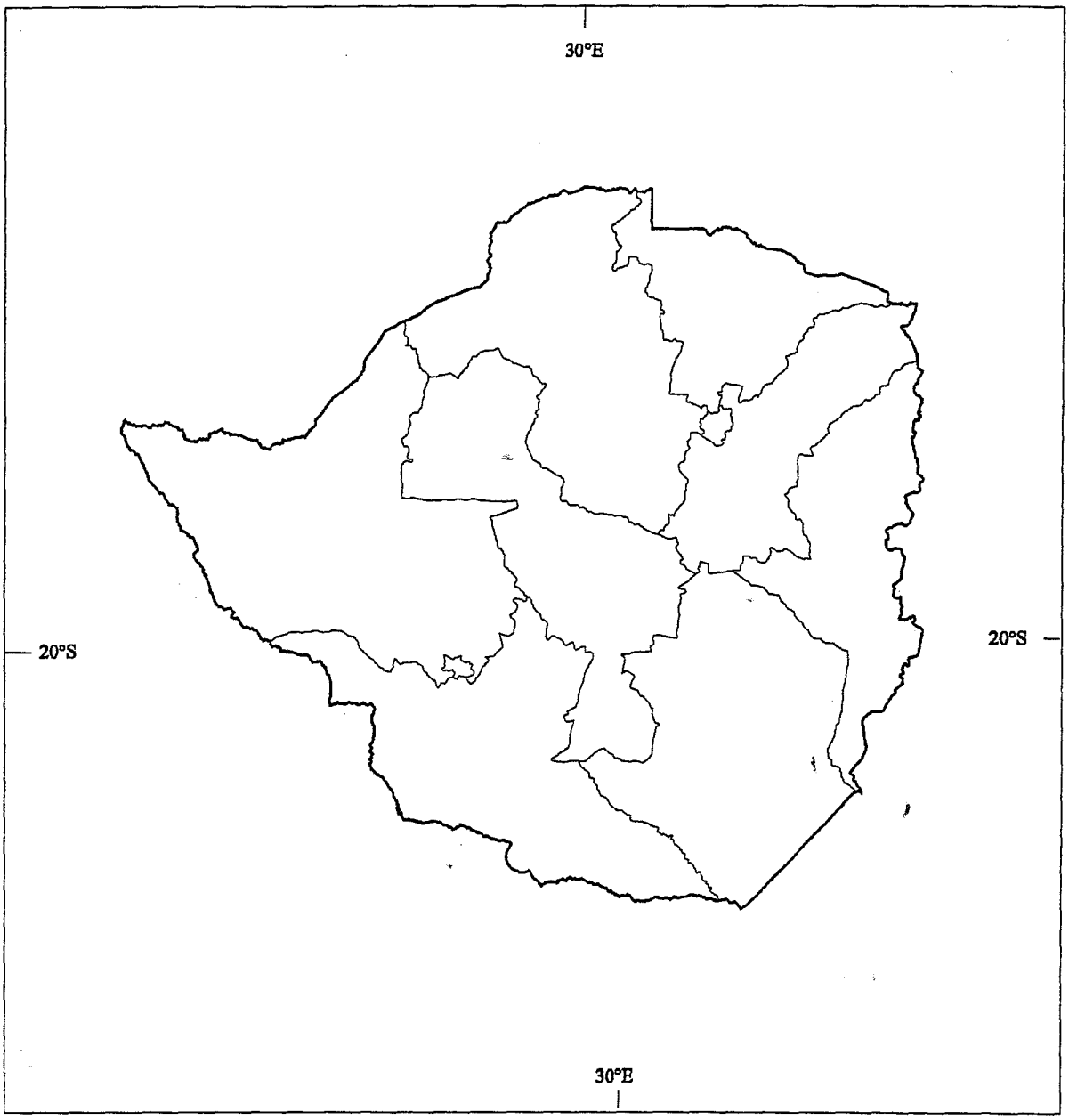


Figure E.134. Digital map layer **zw_adm2** (Zimbabwe, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

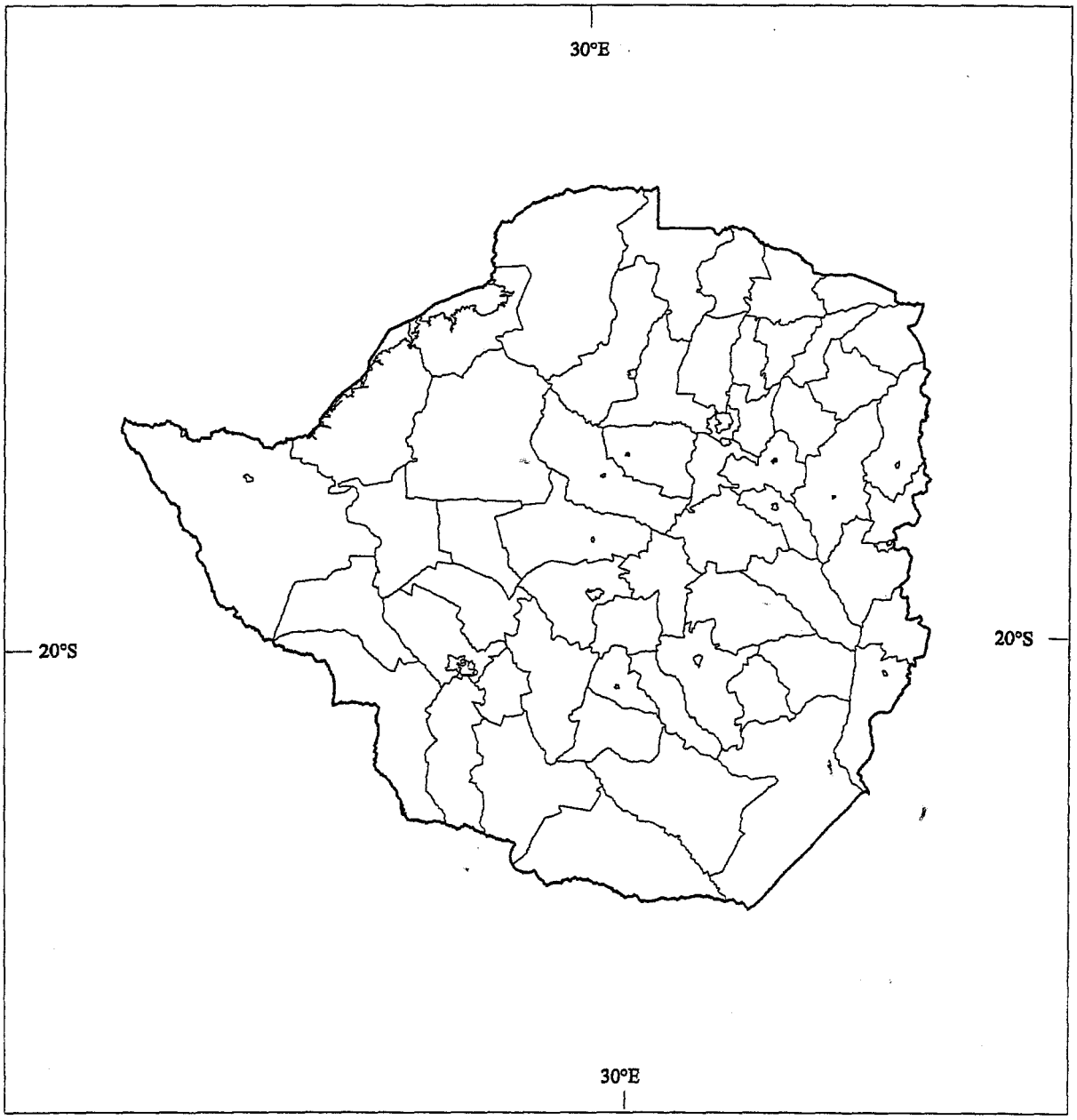


Figure E.135. Digital map layer **zw_adm3** (Zimbabwe, district borders) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

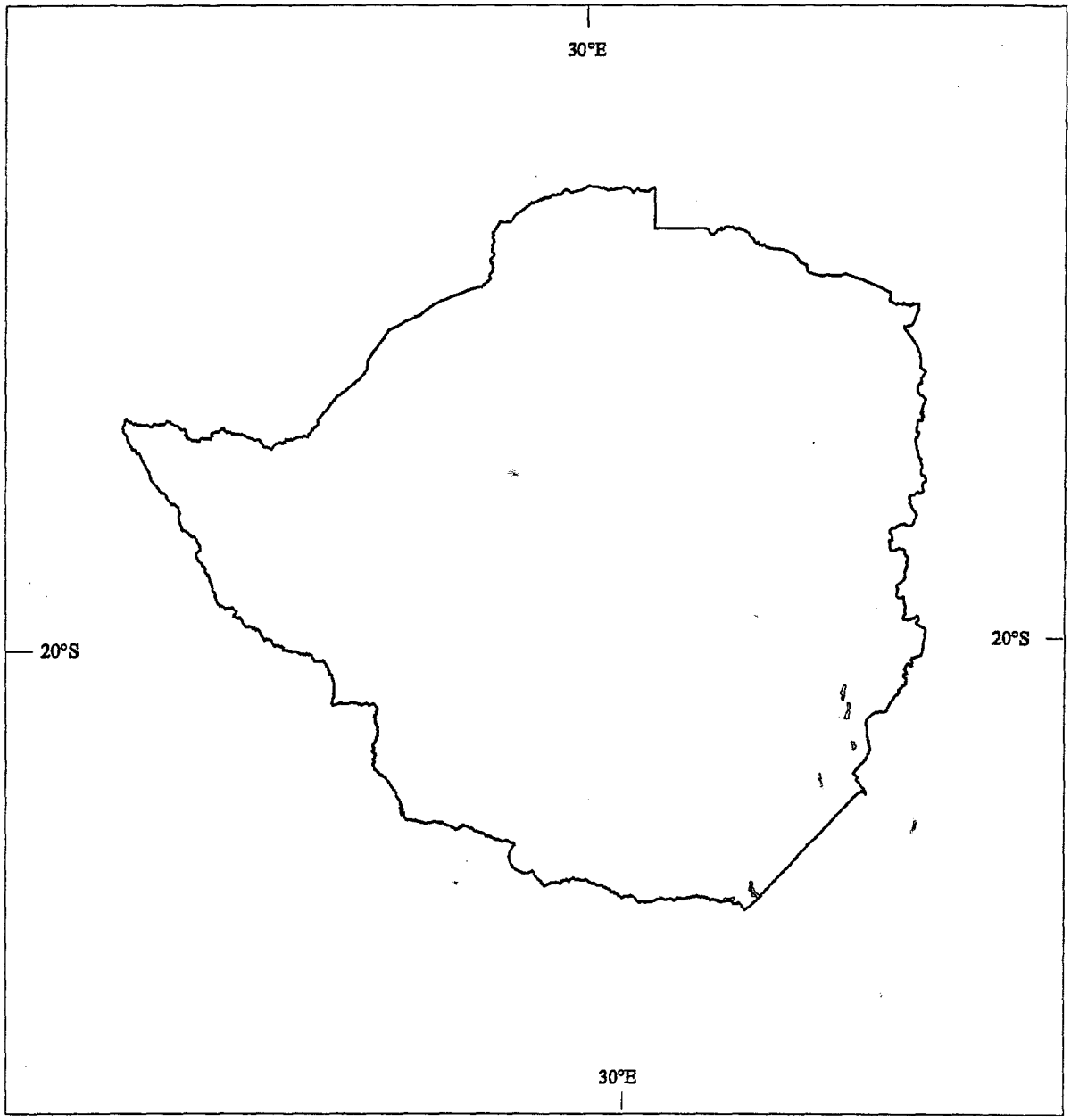


Figure E.136. Digital map layer **zw_cova** (Zimbabwe, wetlands and other land cover areas) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

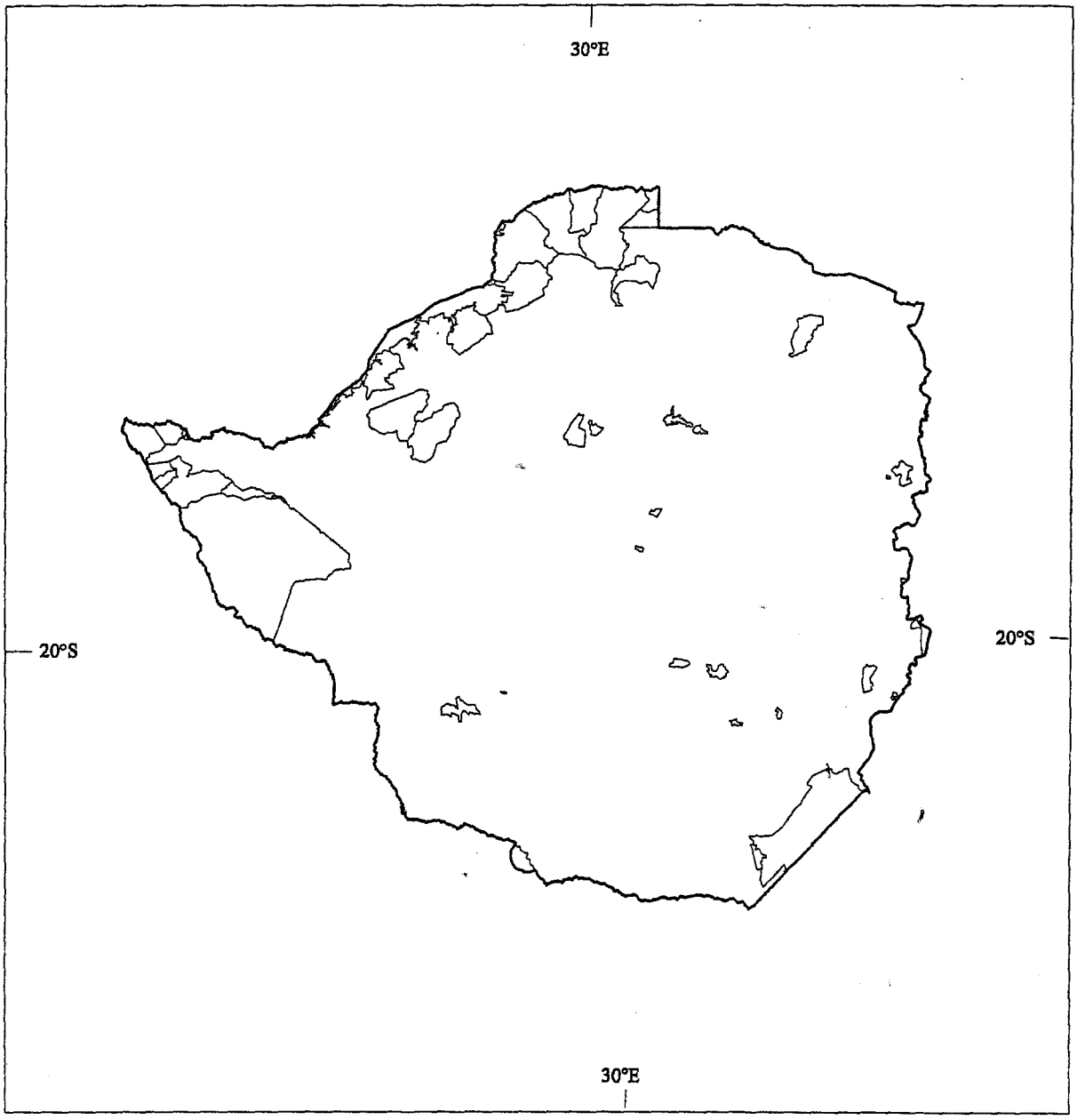


Figure E.137. Digital map layer **zw_park** (Zimbabwe, national parks) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

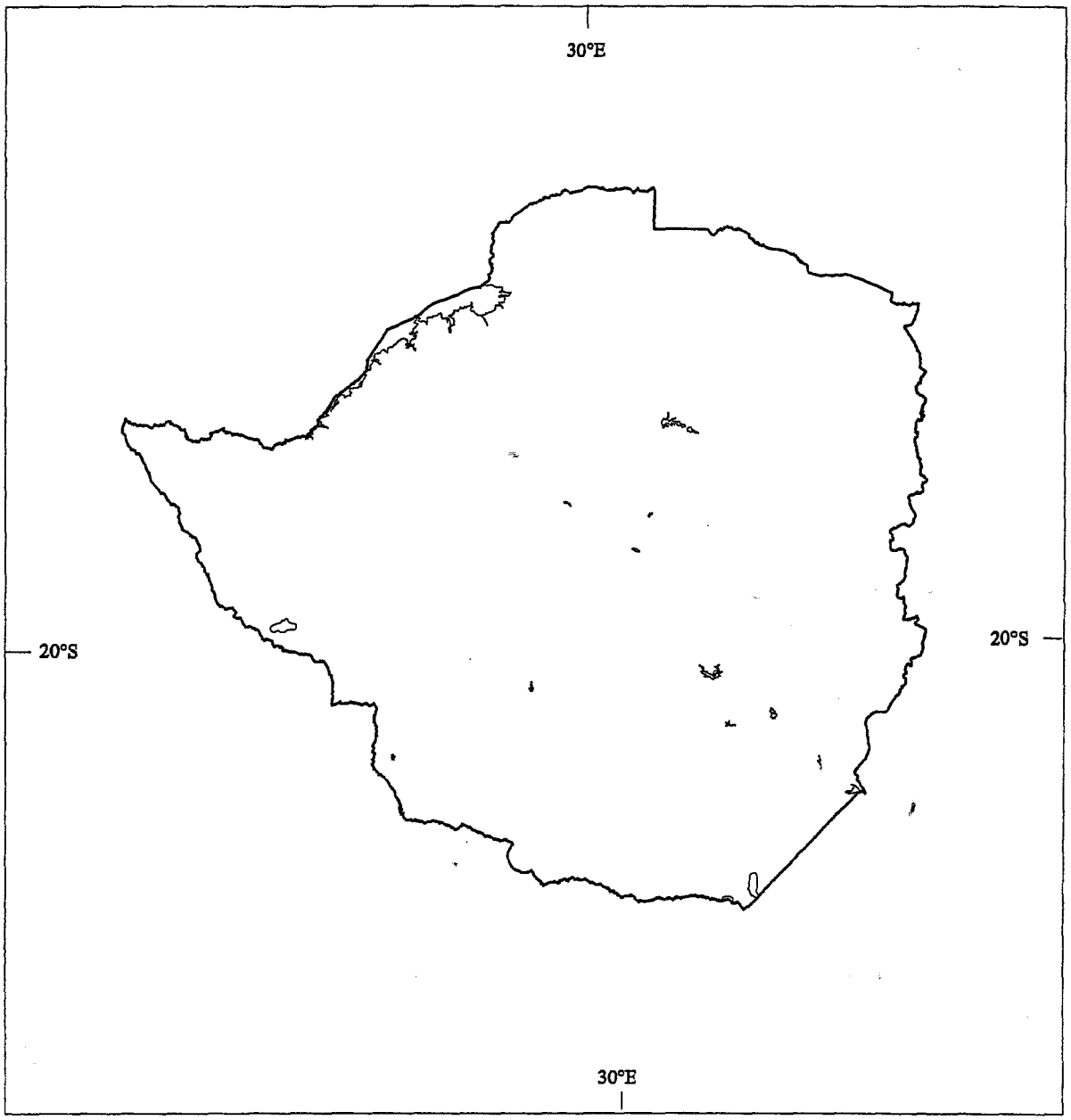


Figure E.138. Digital map layer **zw_wetl** (Zimbabwe, wetlands, classified by type) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

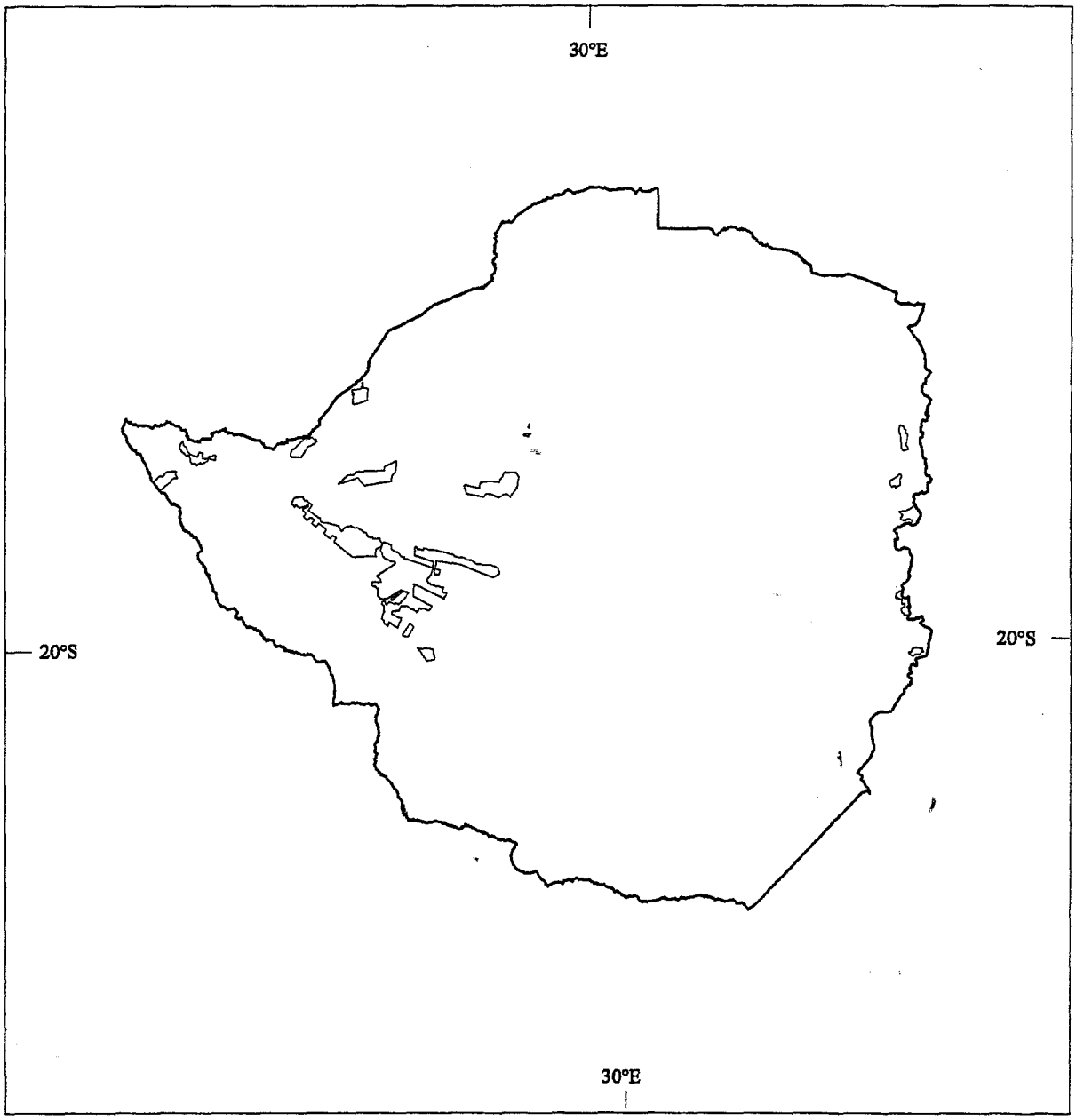


Figure E.139. Digital map layer **zw_wood** (Zimbabwe, production forest, classified by type) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

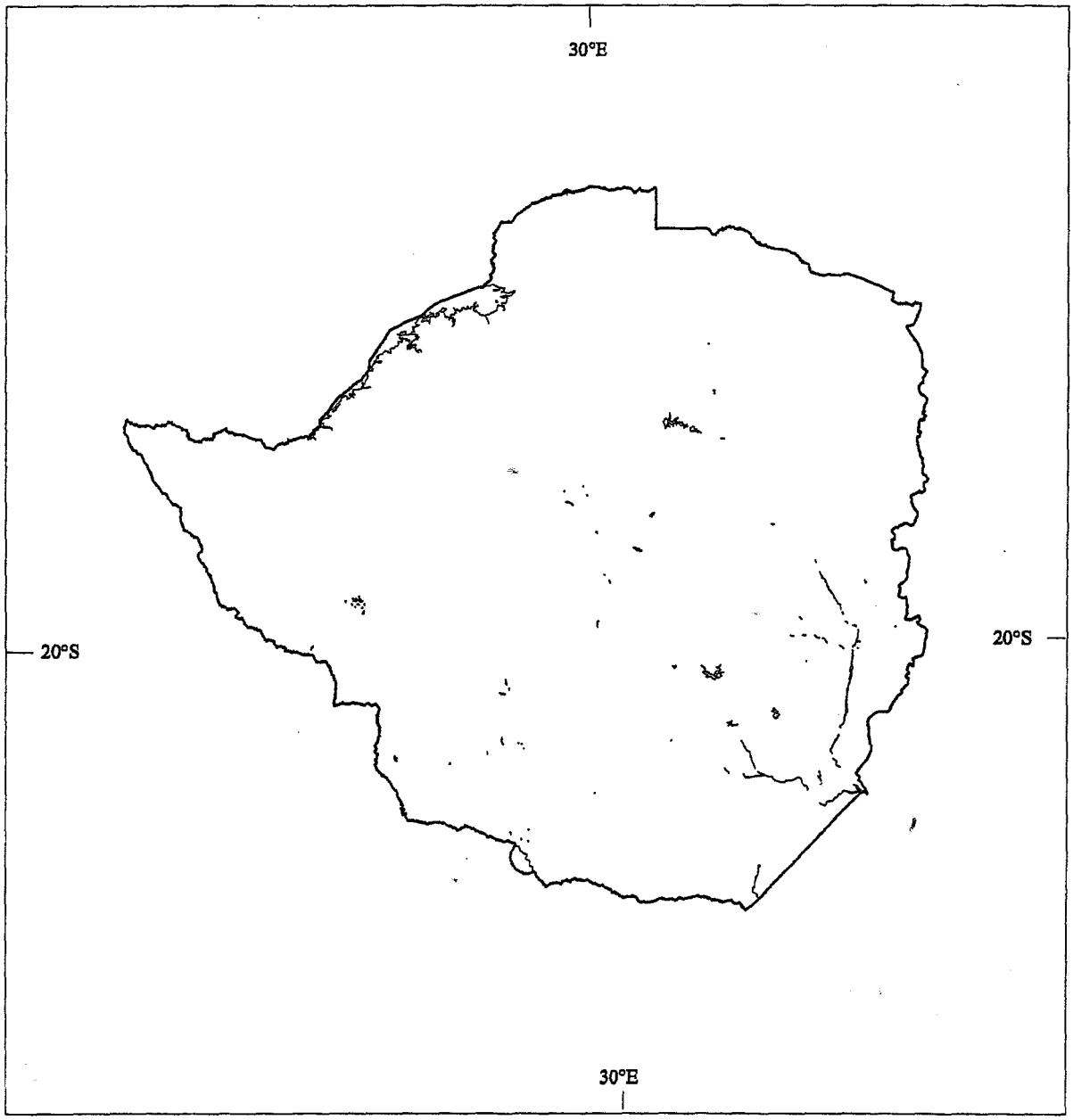


Figure E.140. Digital map layer **zw_lake** (Zimbabwe, lakes) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

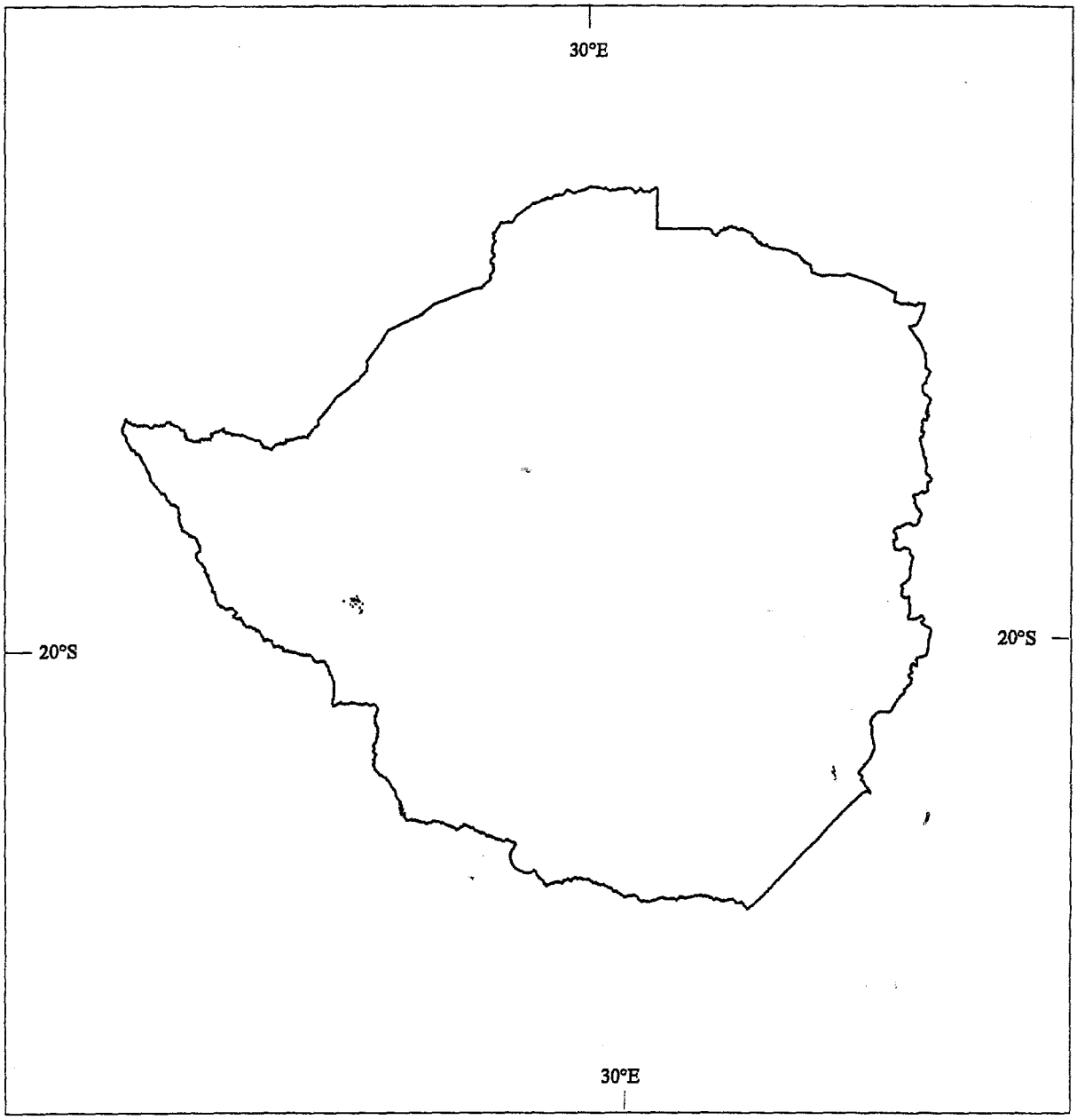


Figure E.141. Digital map layer **zw_npwat** (Zimbabwe, non-perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

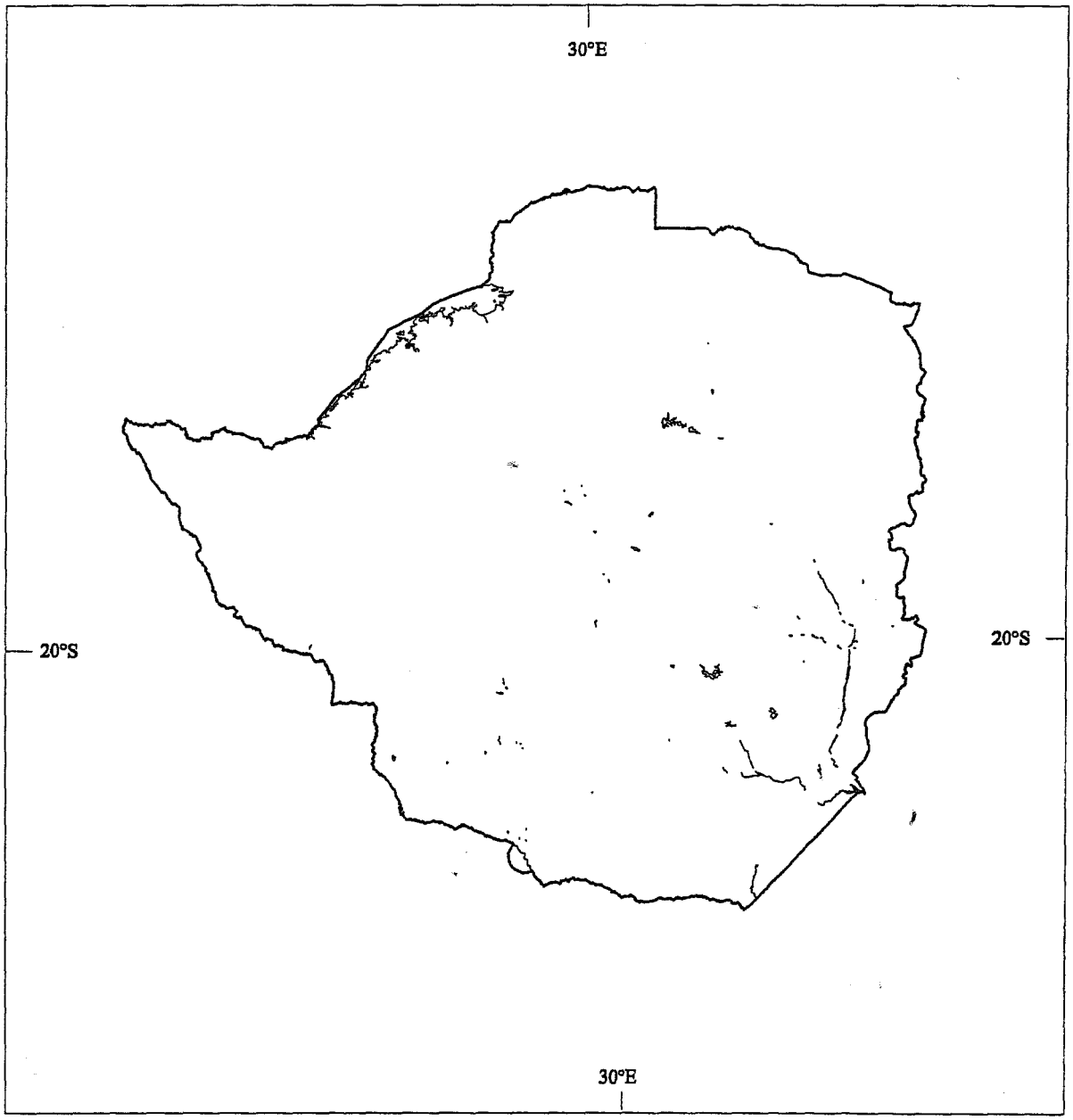


Figure E.142. Digital map layer **zw_pwat** (Zimbabwe, perrenial water polygons) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

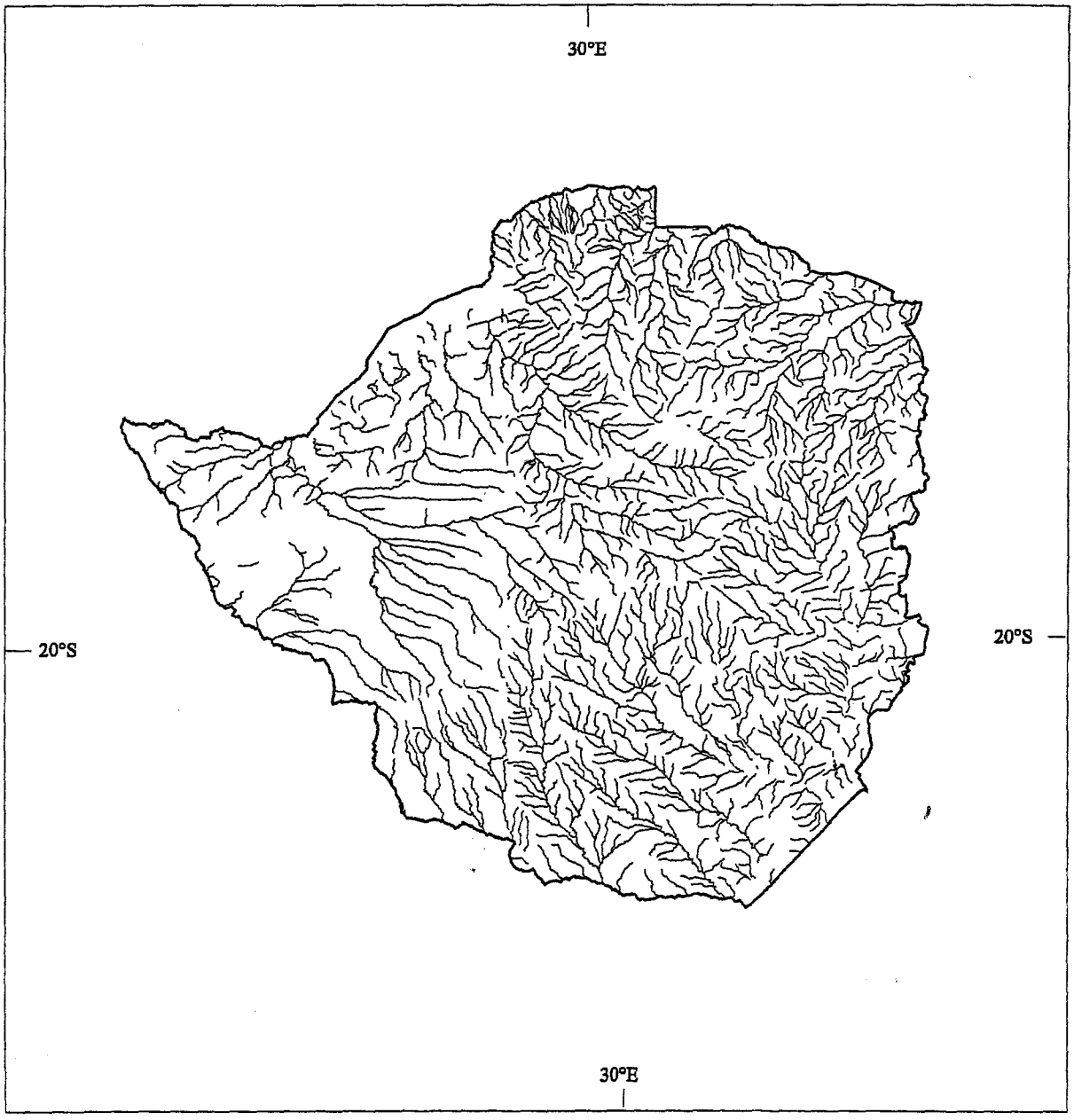


Figure E.143. Digital map layer **zw_riv** (Zimbabwe, rivers) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

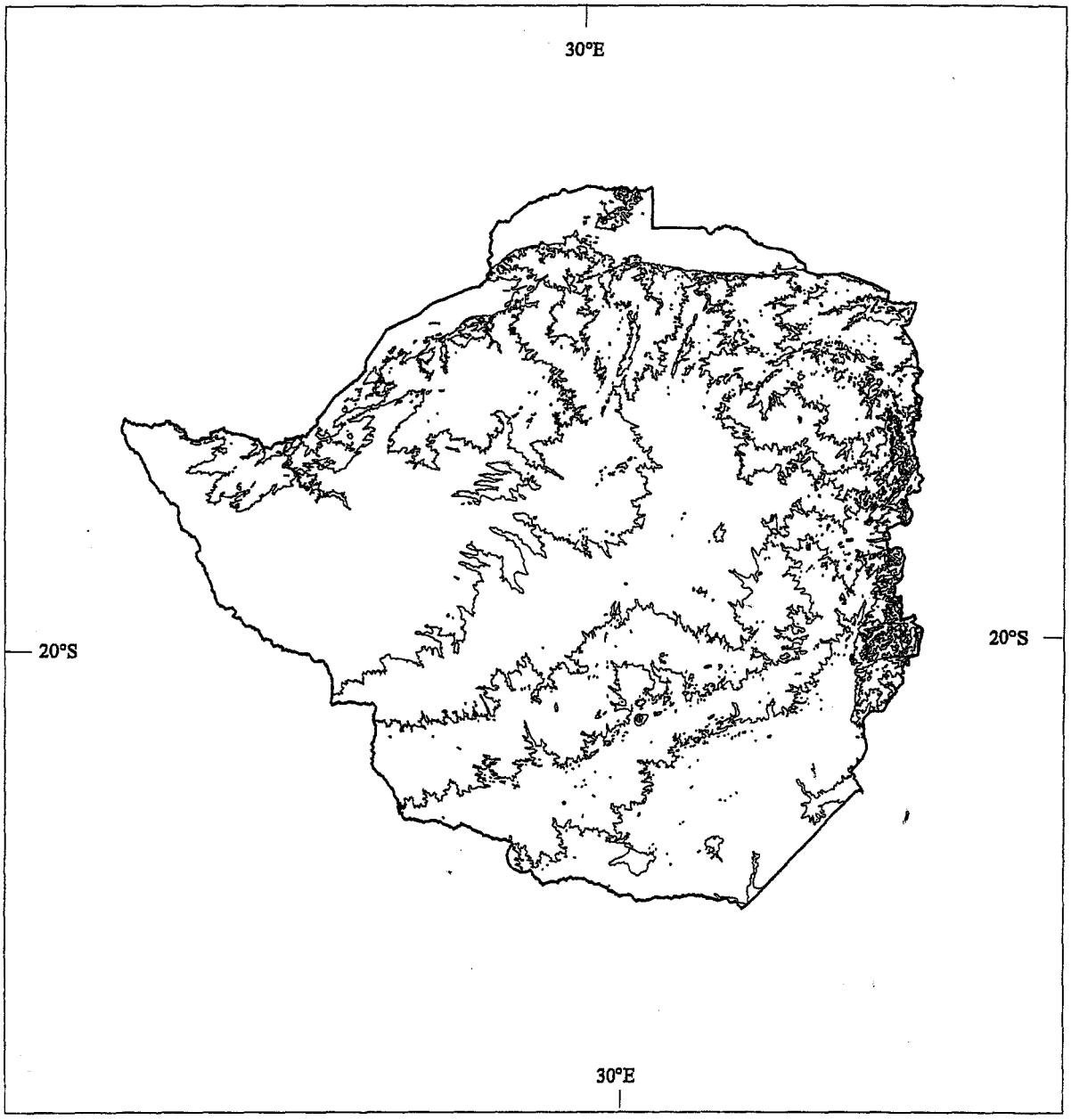


Figure E.144. Digital map layer **zw_elev** (Zimbabwe, 1000m contours) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

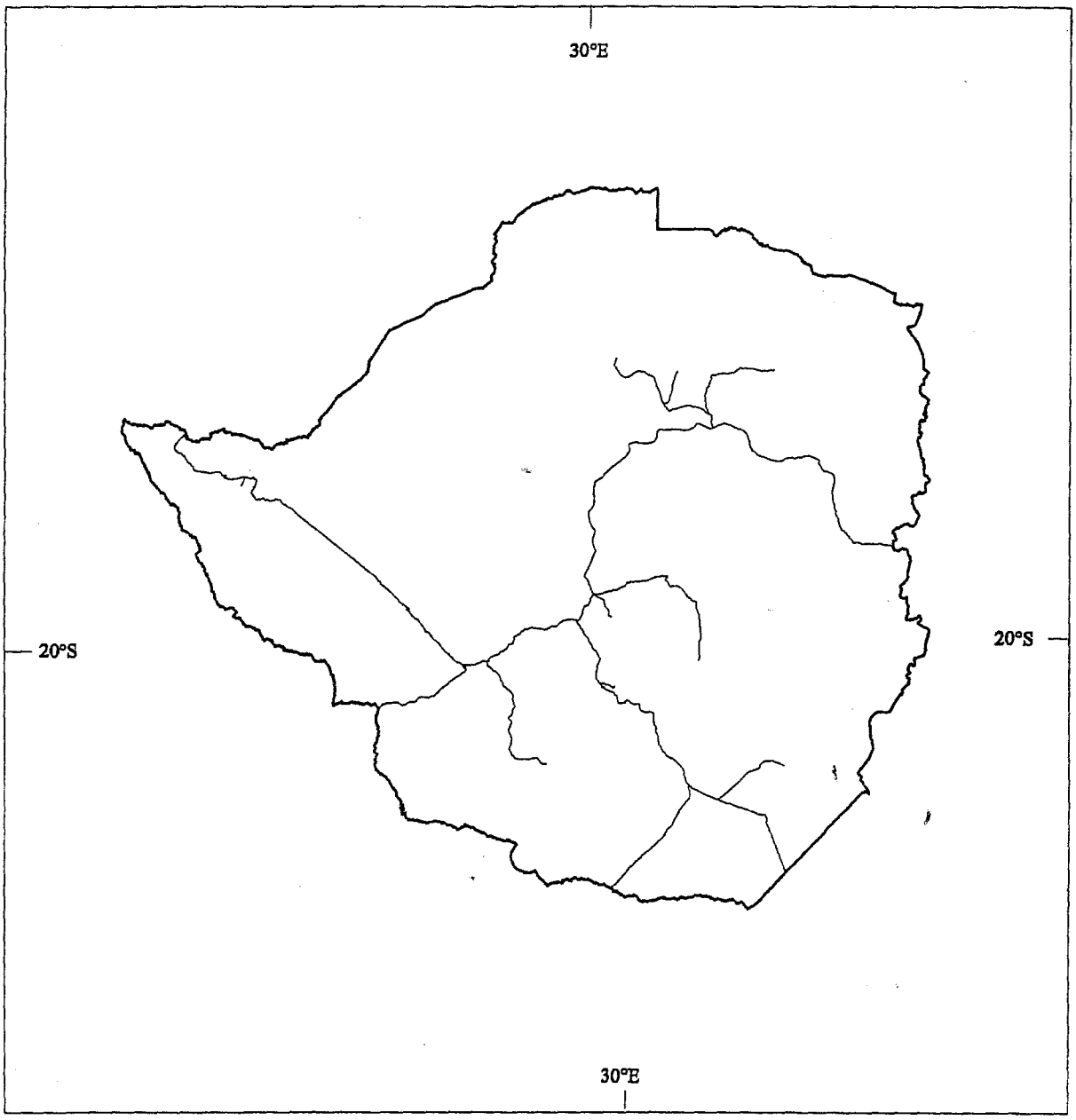


Figure E.145. Digital map layer **zw_rail** (Zimbabwe, railroads) from the atlas of southern African freshwater fish. Scale approximately 1:7 000 000

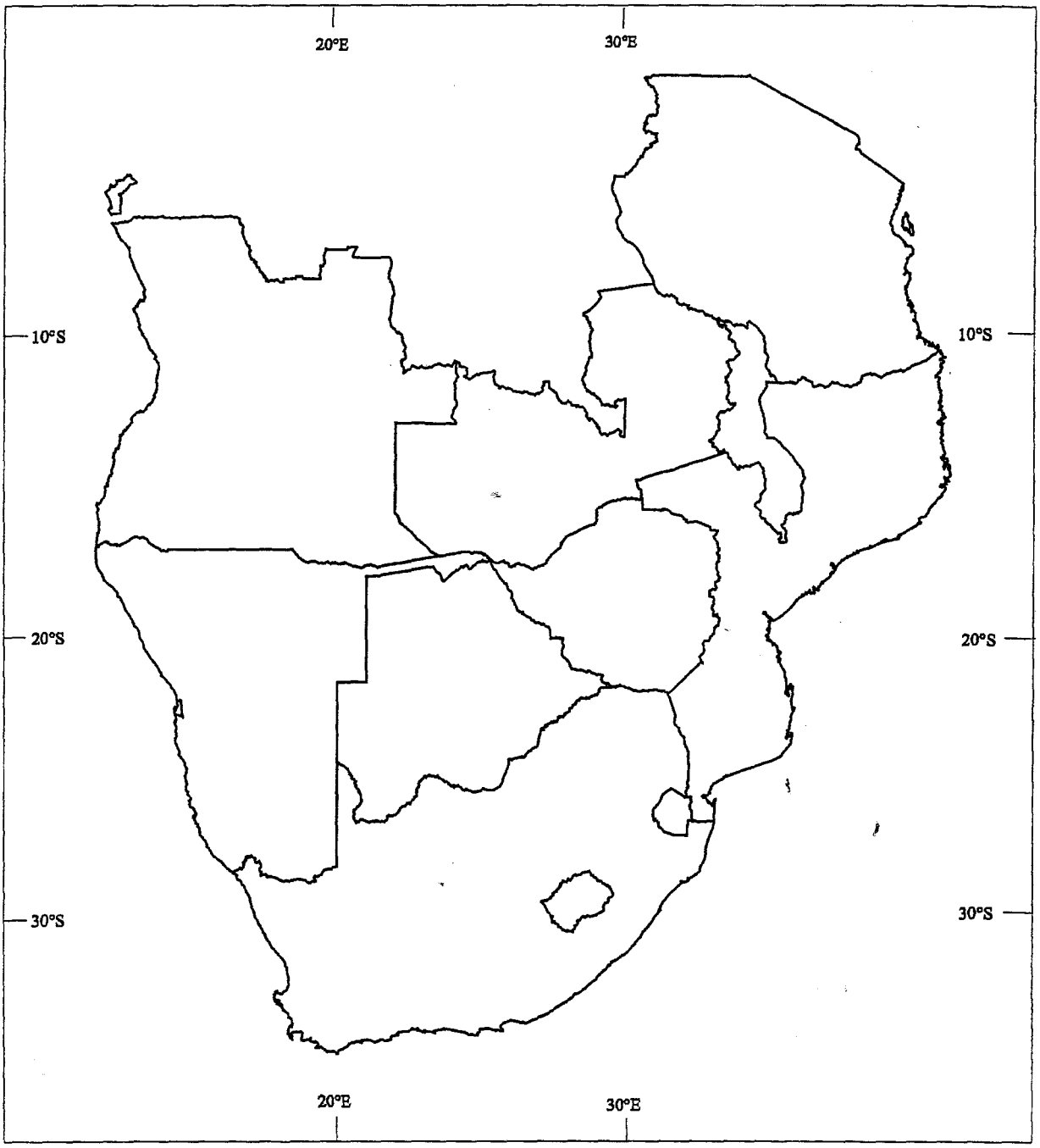


Figure E.146. Digital map layer **dc_adm1** (SADC region, national borders) from the atlas of southern African freshwater fish. Scale approximately 1:25 000 000

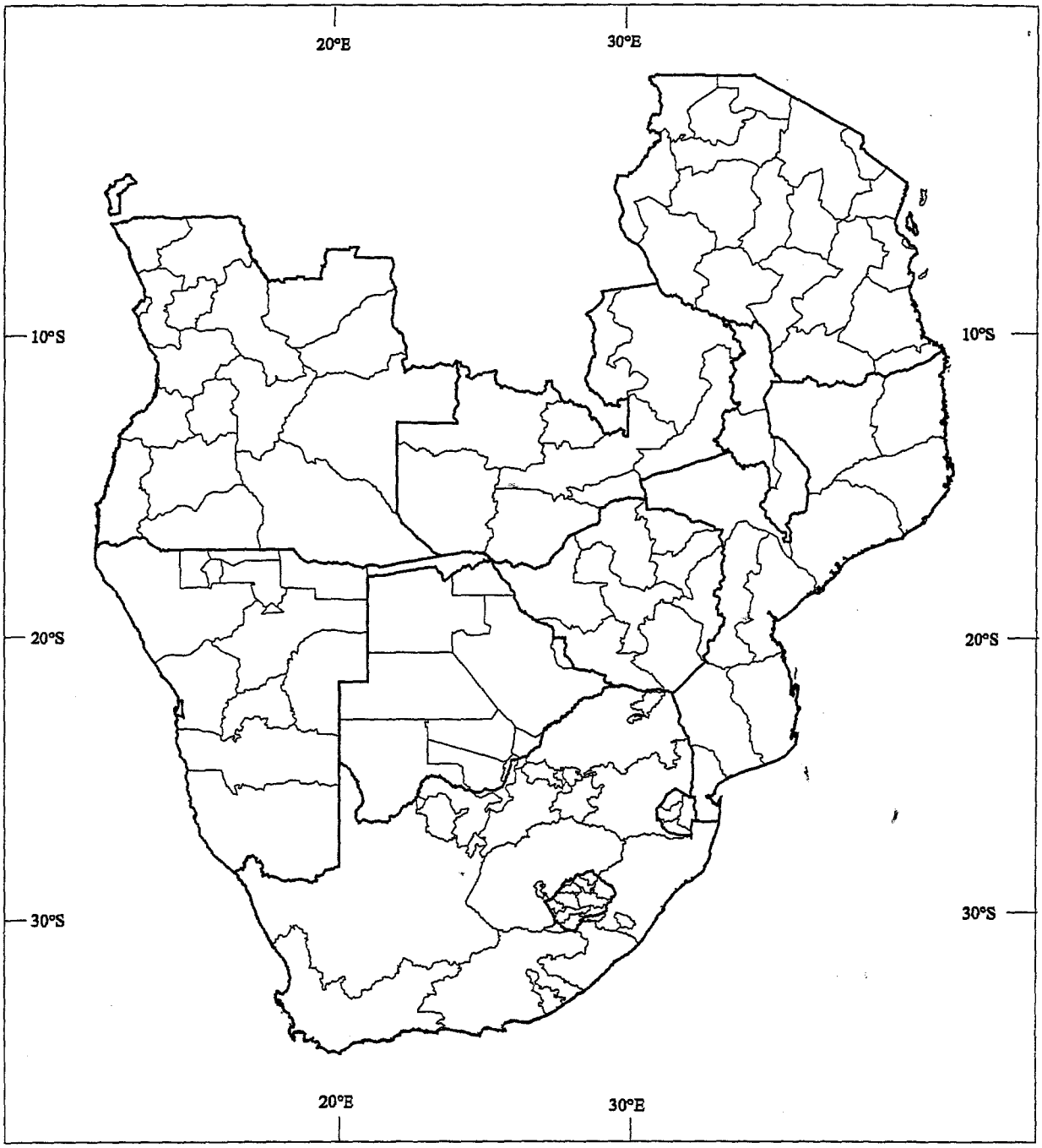


Figure E.147. Digital map layer **dc_adm2** (SADC region, province borders) from the atlas of southern African freshwater fish. Scale approximately 1:25 000 000

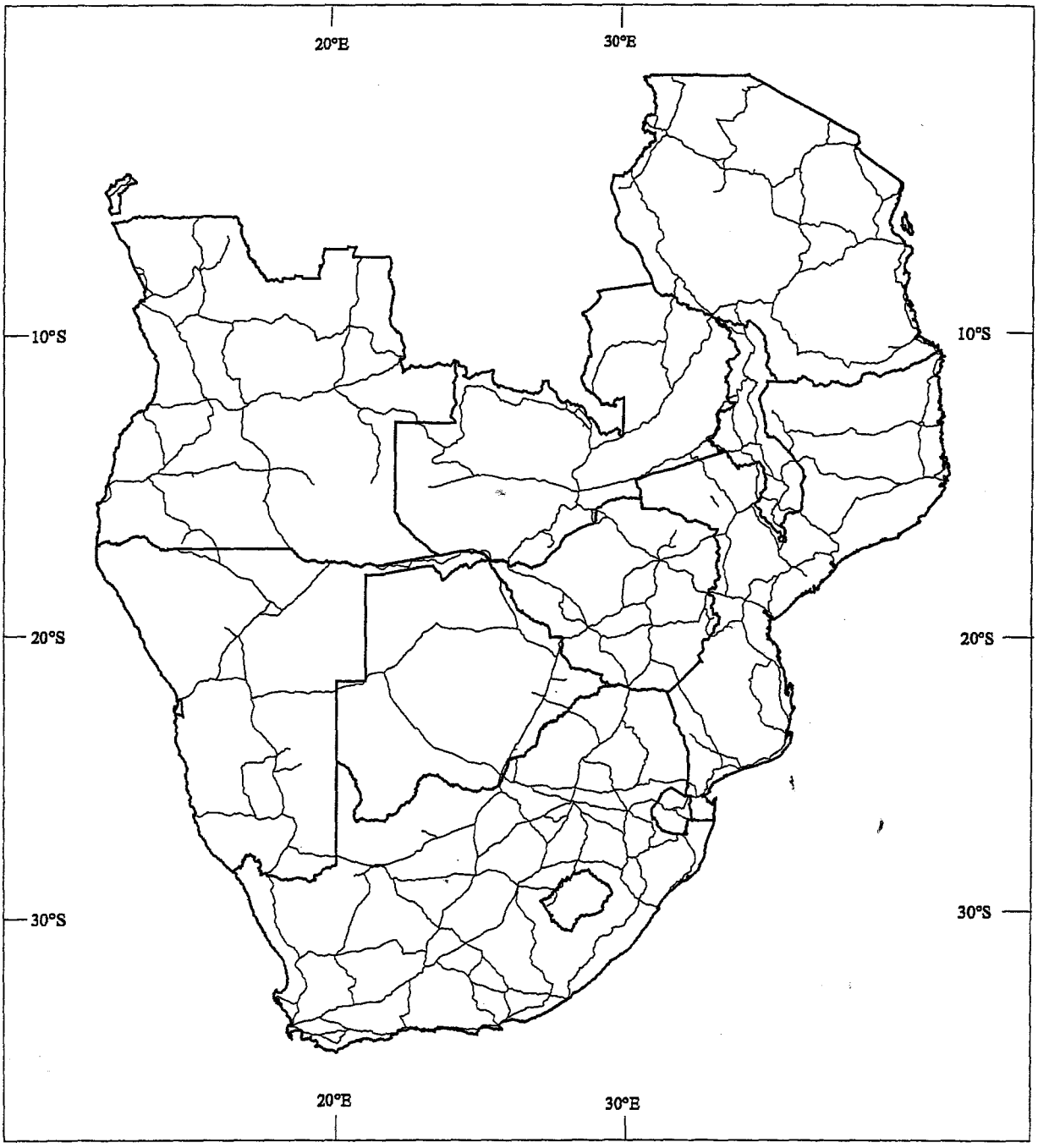


Figure E.148. Digital map layer **dc_roads** (SADC region, roads) from the atlas of southern African freshwater fish. Scale approximately 1:25 000 000

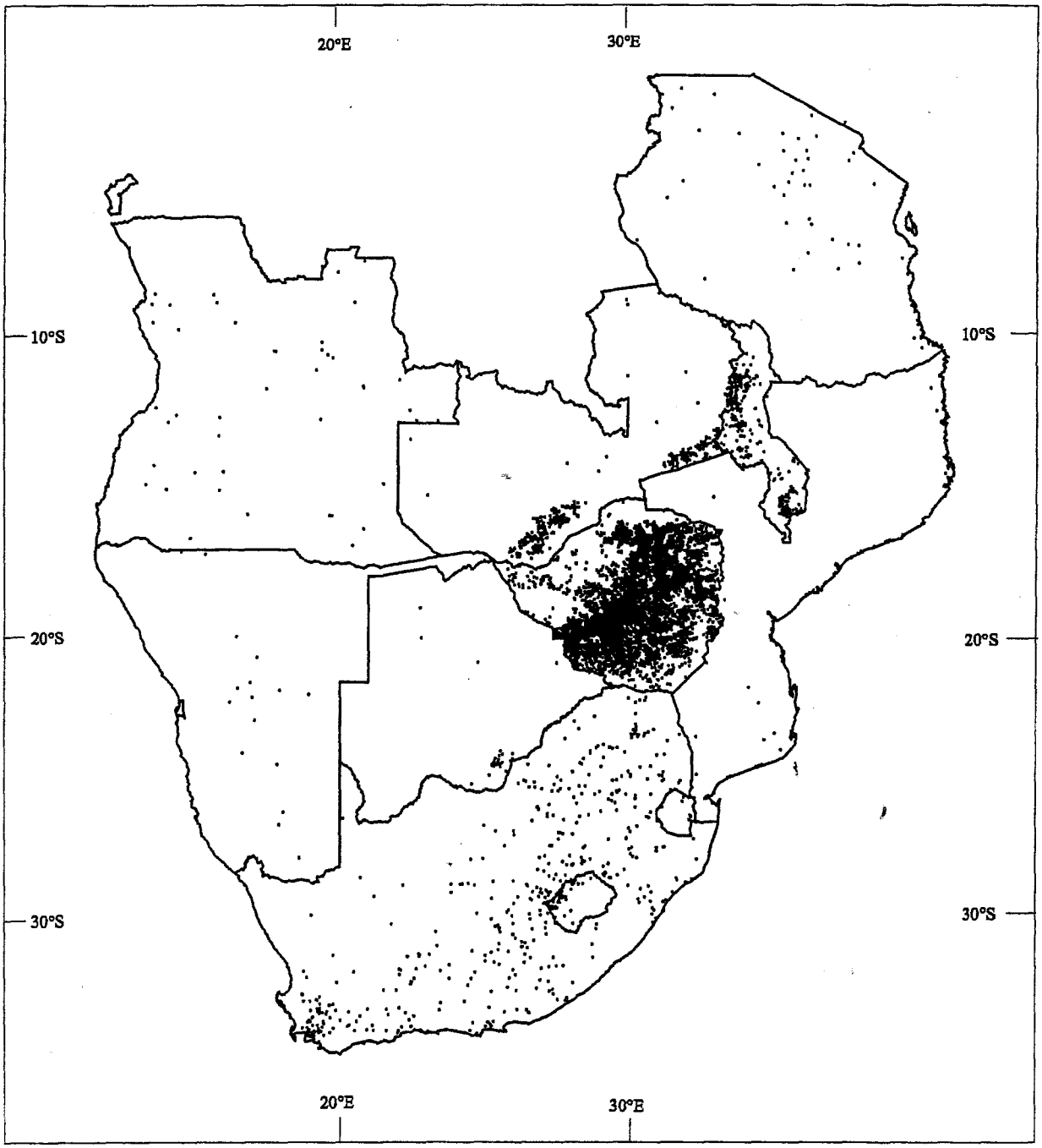


Figure E.149. Digital map layer **dc_swb** (SADC region, surface water bodies) from the atlas of southern African freshwater fish. Scale approximately 1:25 000 000

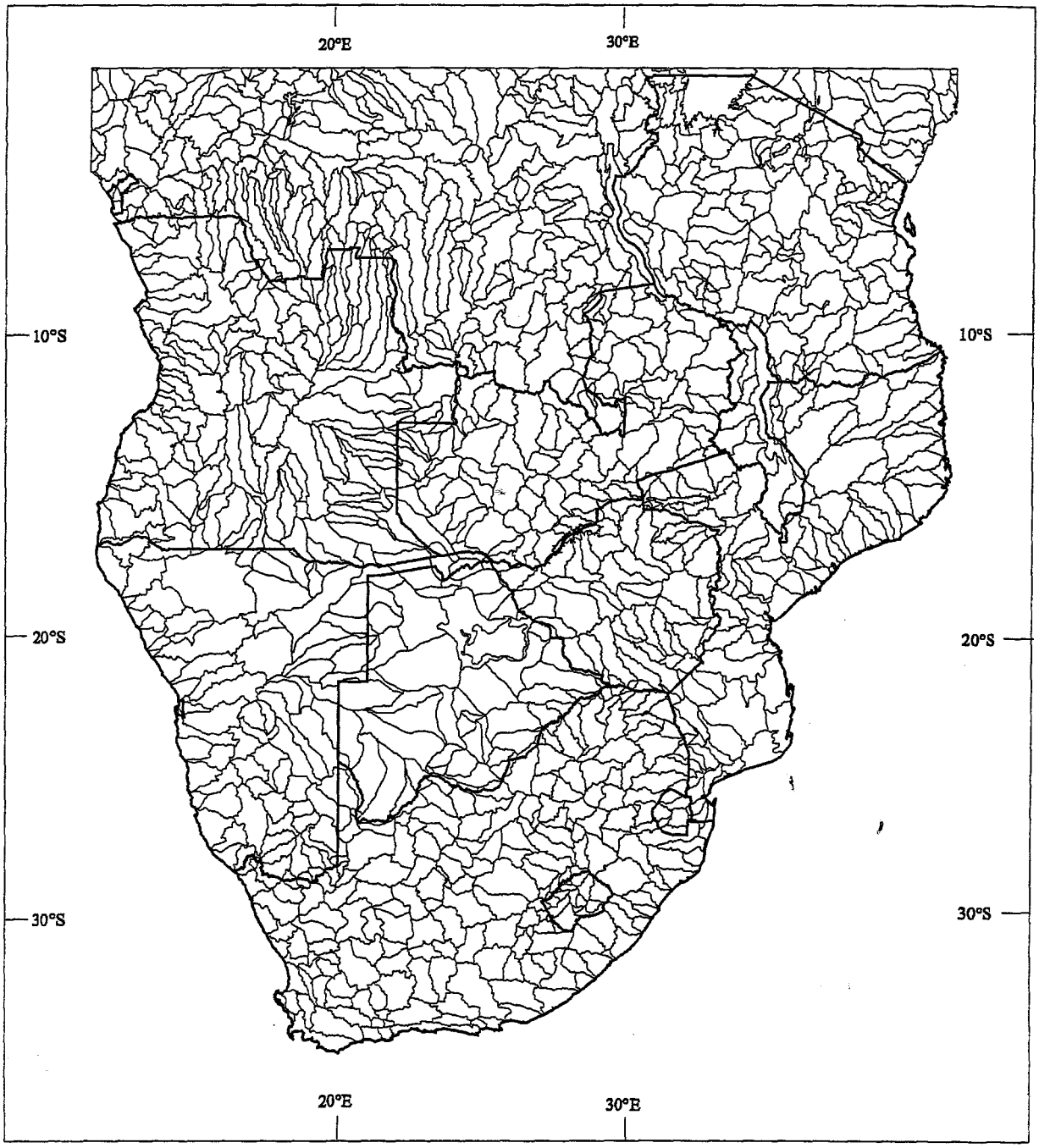


Figure E.150. Digital map layer **dc_ws** (SADC region, watersheds) from the atlas of southern African freshwater fish. Scale approximately 1:25 000 000

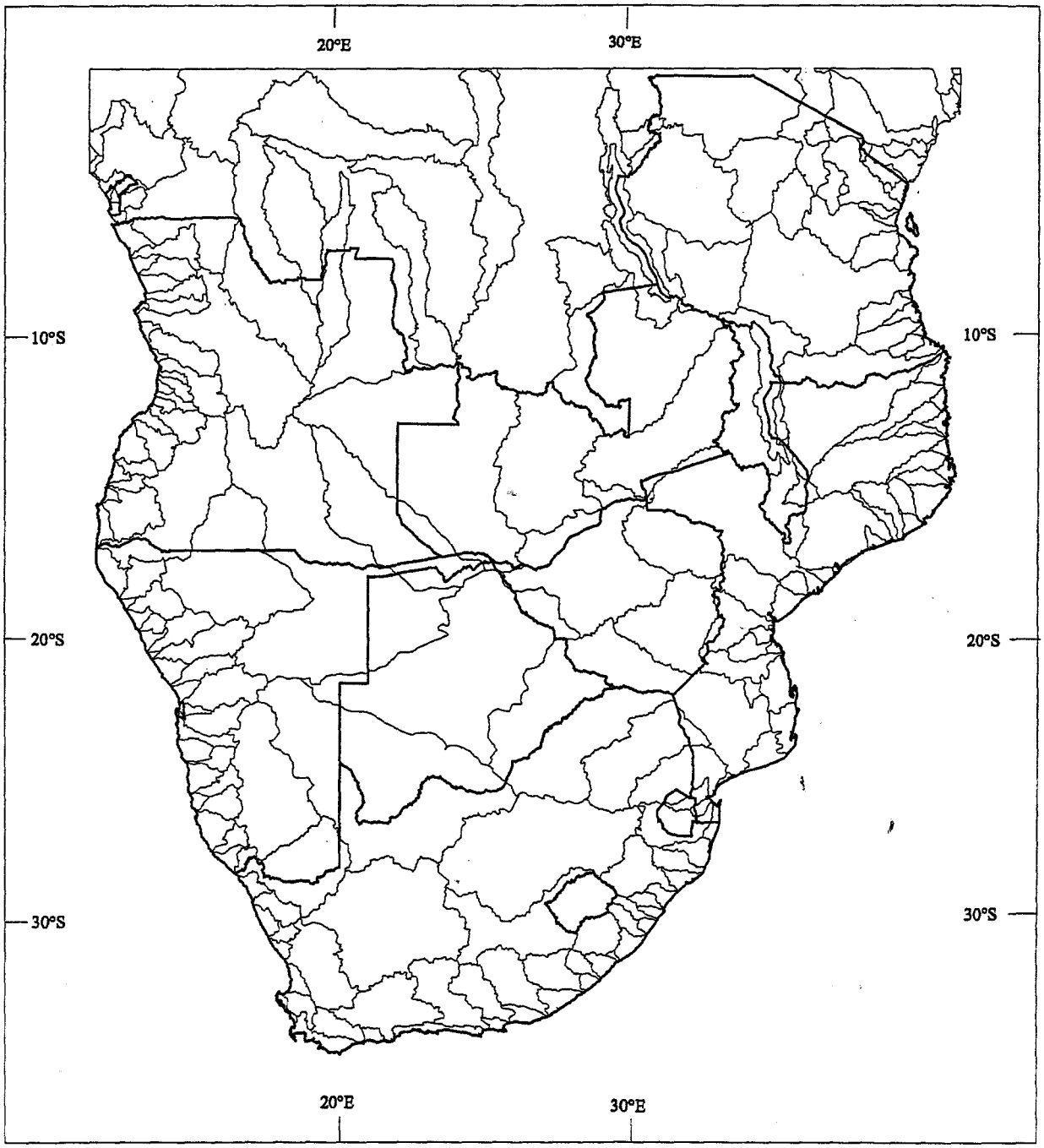


Figure E.151. Digital map layer **dc_mb** (SADC region, megabasins) from the atlas of southern African freshwater fish. Scale approximately 1:25 000 000

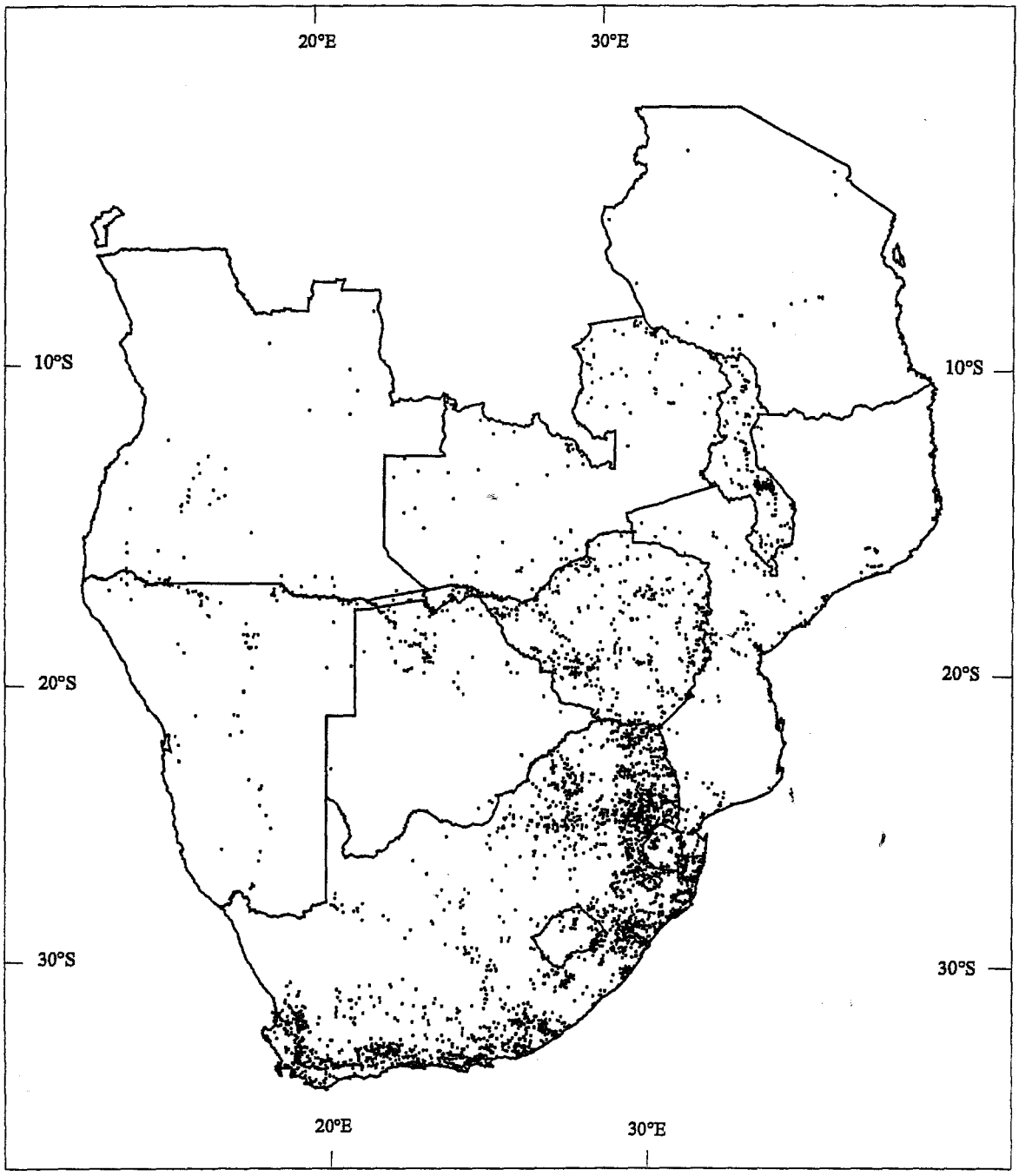


Figure E.152. Digital map layer **dc_frdb** (SADC region, fish record points) from the atlas of southern African freshwater fish. Scale approximately 1:25 000 000

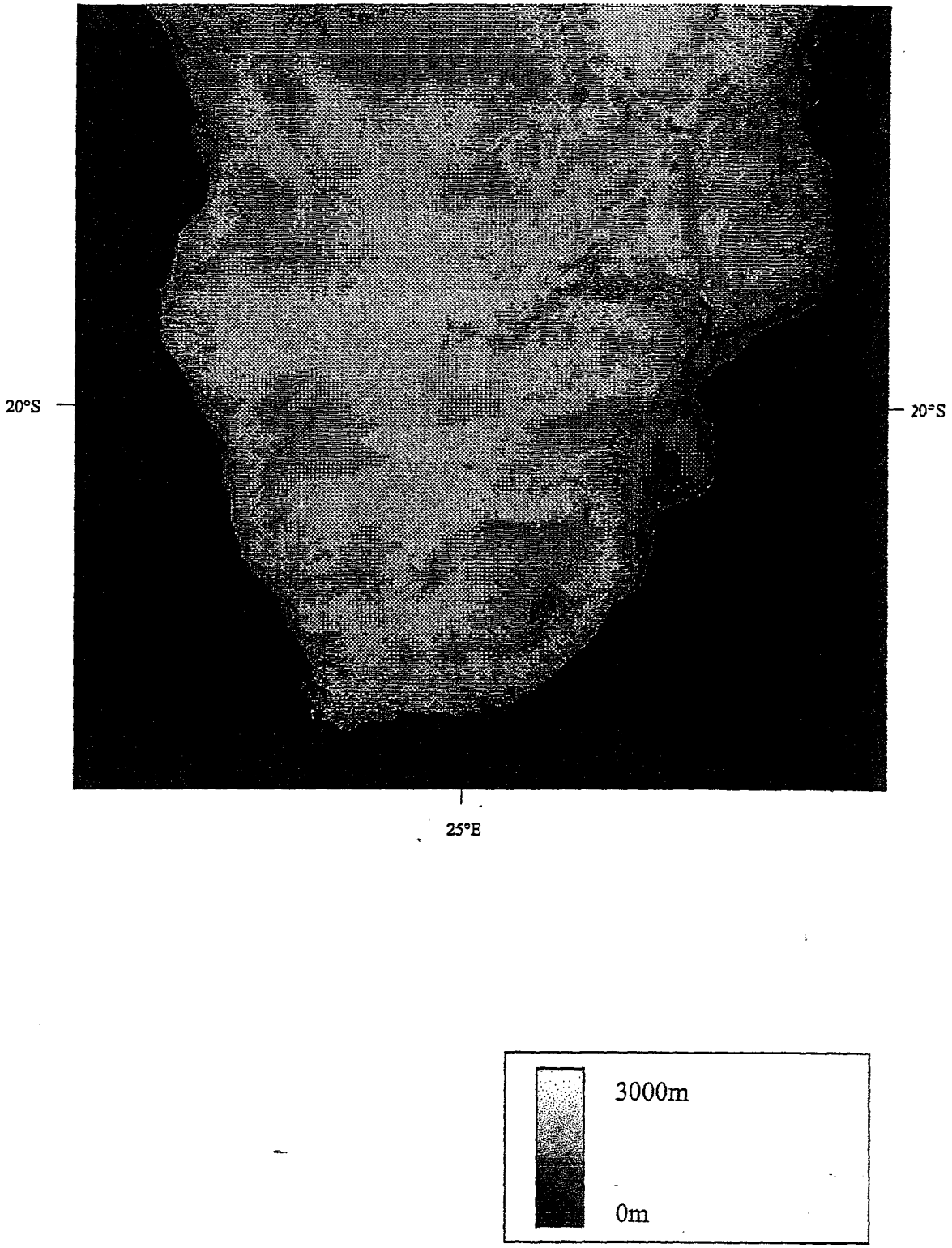


Figure E.153. Digital map layer **DEM** (SADC region, digital elevation model) from the atlas of southern African freshwater fish. Scale approximately 1:32 000 000

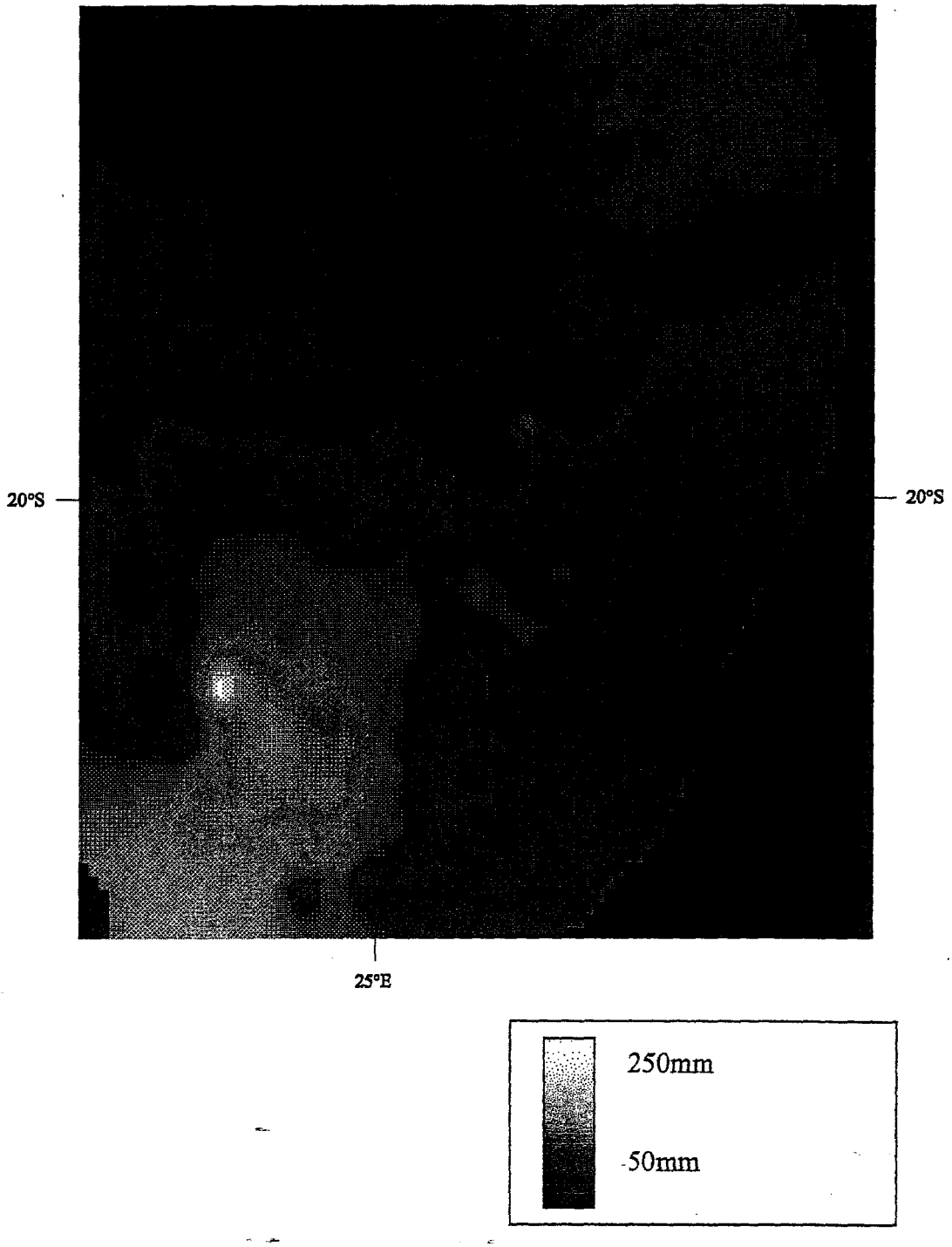


Figure E.154. Digital map layer **pet_jan** (SADC region, normal evapo-transpiration surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

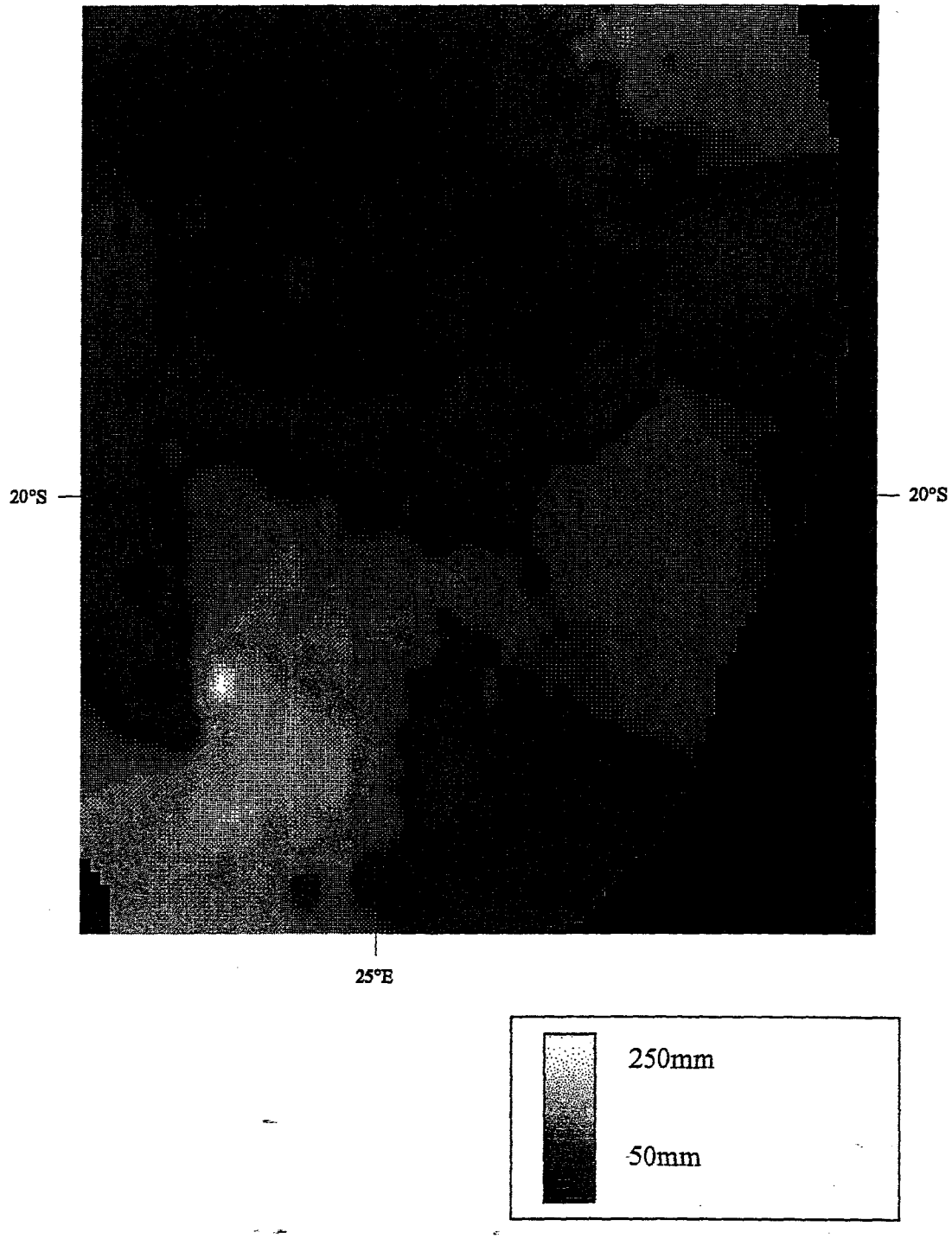


Figure E.155. Digital map layer **pet_feb** (SADC region, normal evapo-transpiration surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

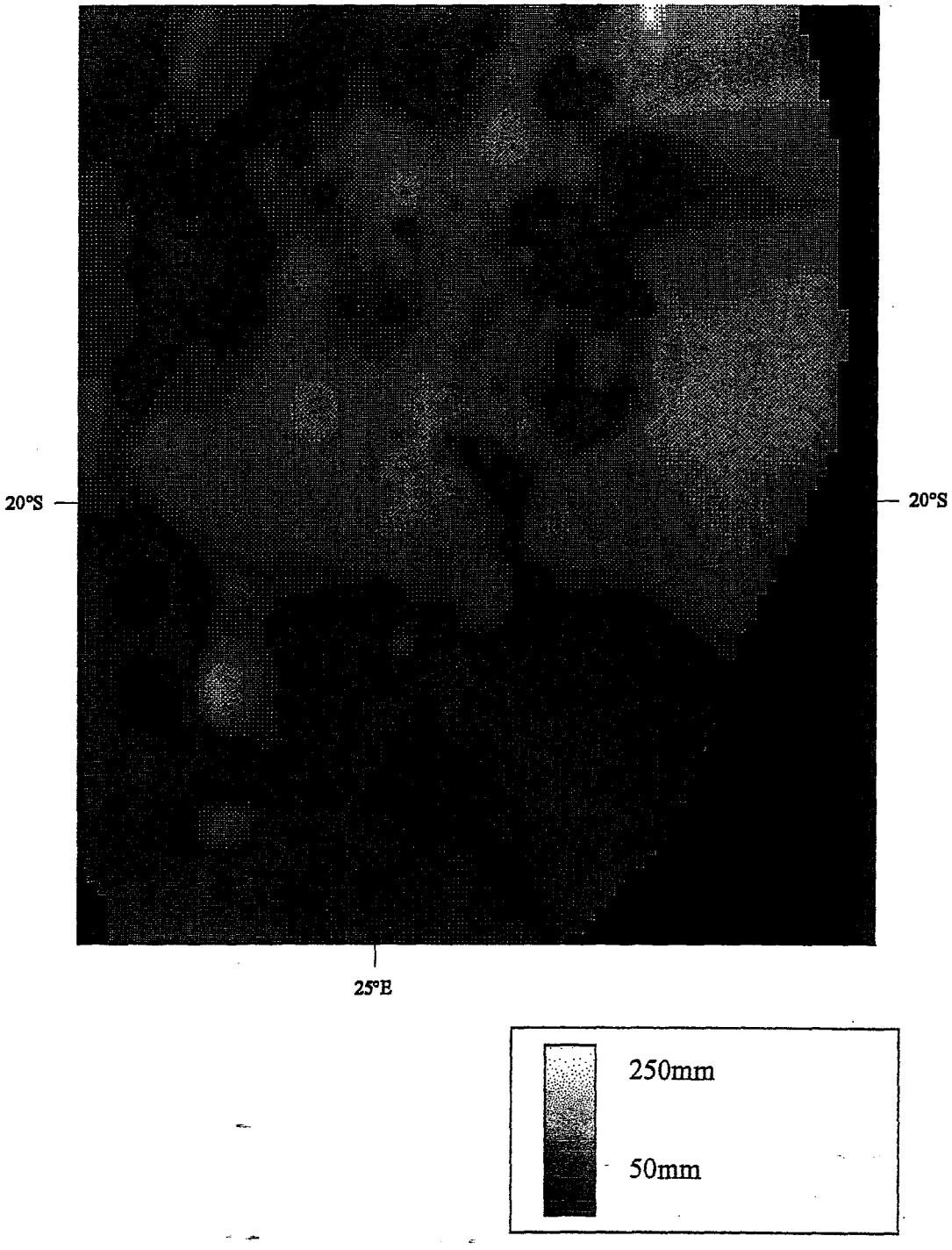


Figure E.156. Digital map layer **pet_apr** (SADC region, normal evapo-transpiration surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

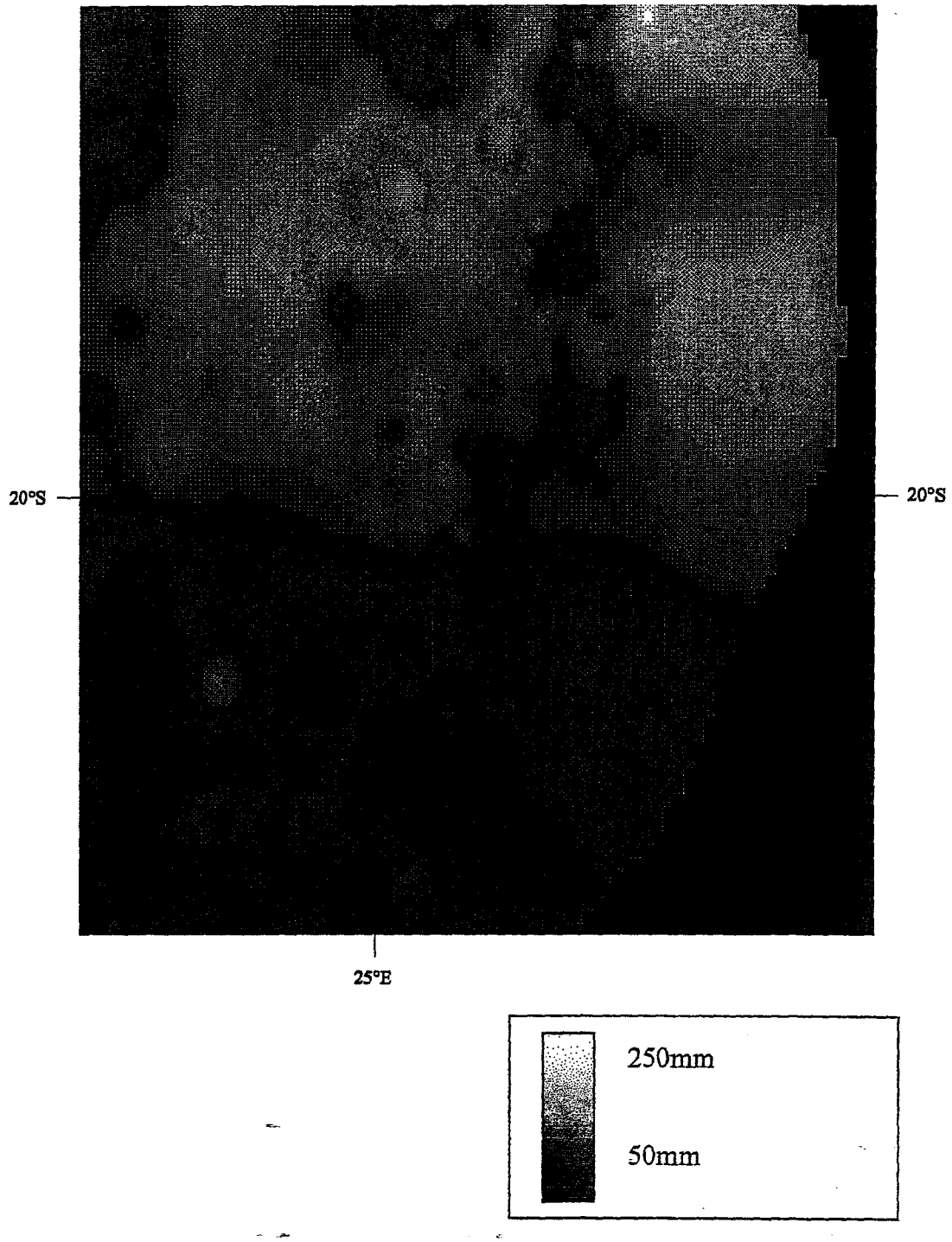


Figure E.157. Digital map layer **pet_may** (SADC region, normal evapo-transpiration surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

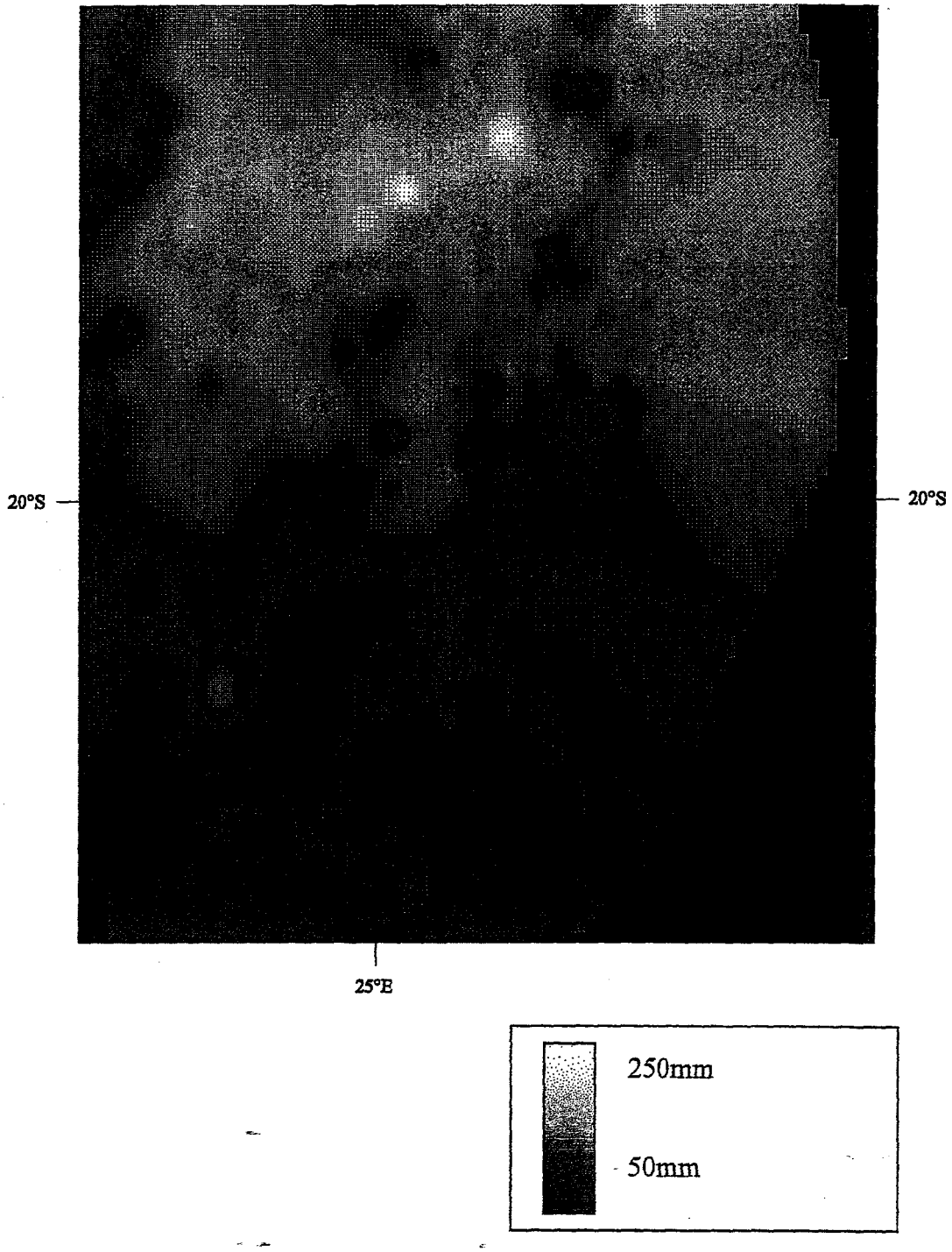


Figure E.158. Digital map layer **pet_jun** (SADC region, normal evapo-transpiration surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

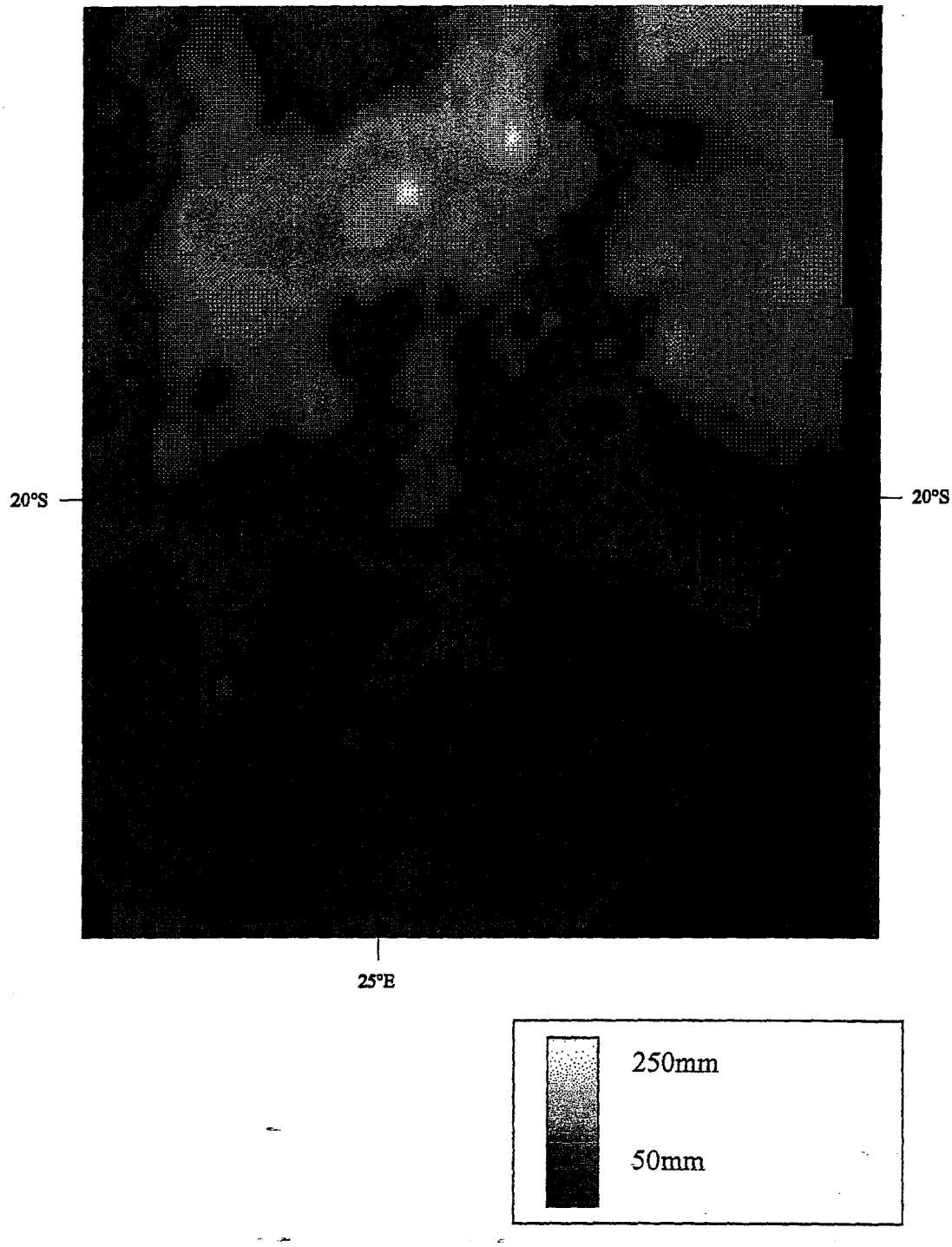


Figure E.159. Digital map layer **pet_jul** (SADC region, normal evapo-transpiration surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

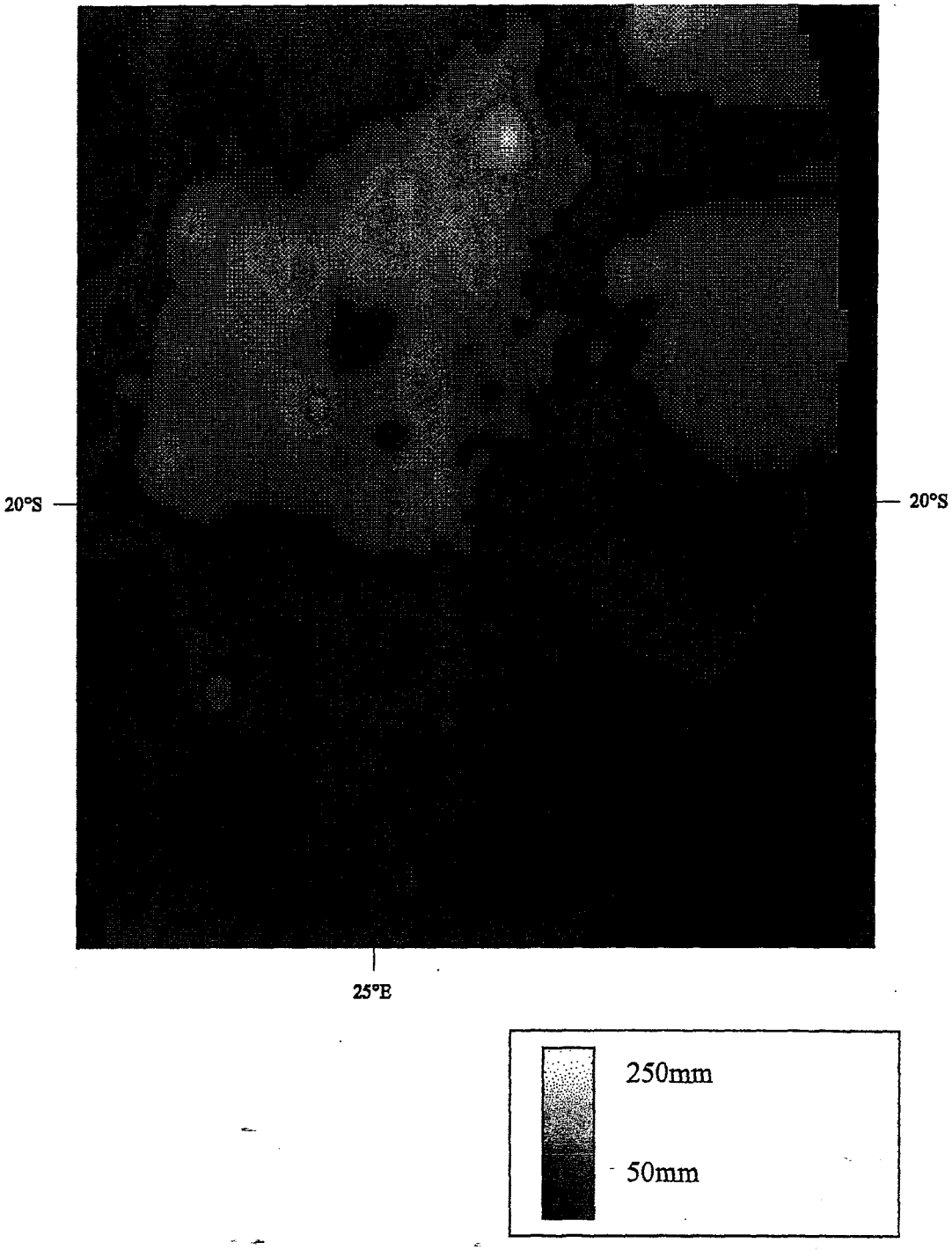


Figure E.160. Digital map layer **pet_aug** (SADC region, normal evapo-transpiration surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

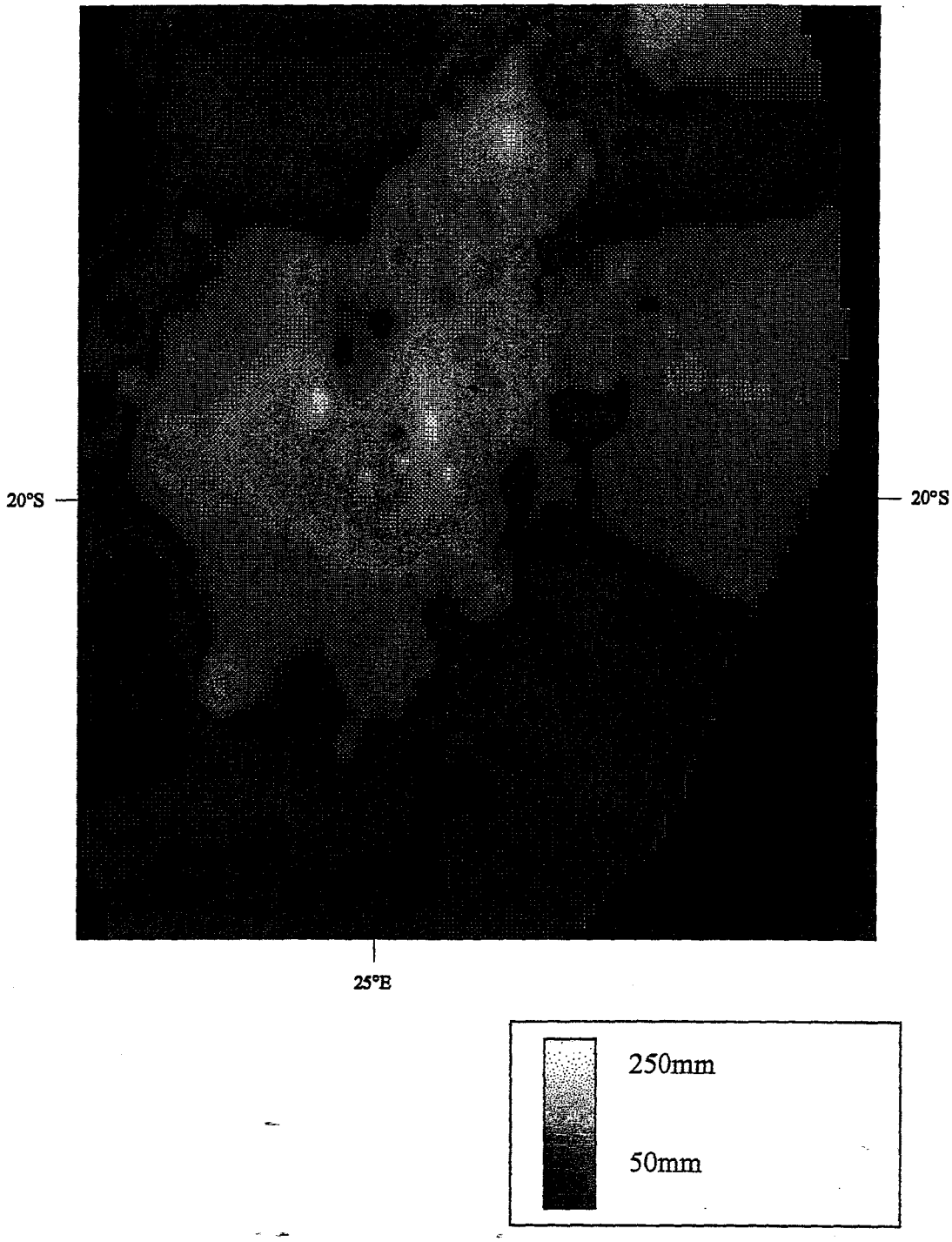


Figure E.161. Digital map layer **pet_sep** (SADC region, normal evapo-transpiration surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

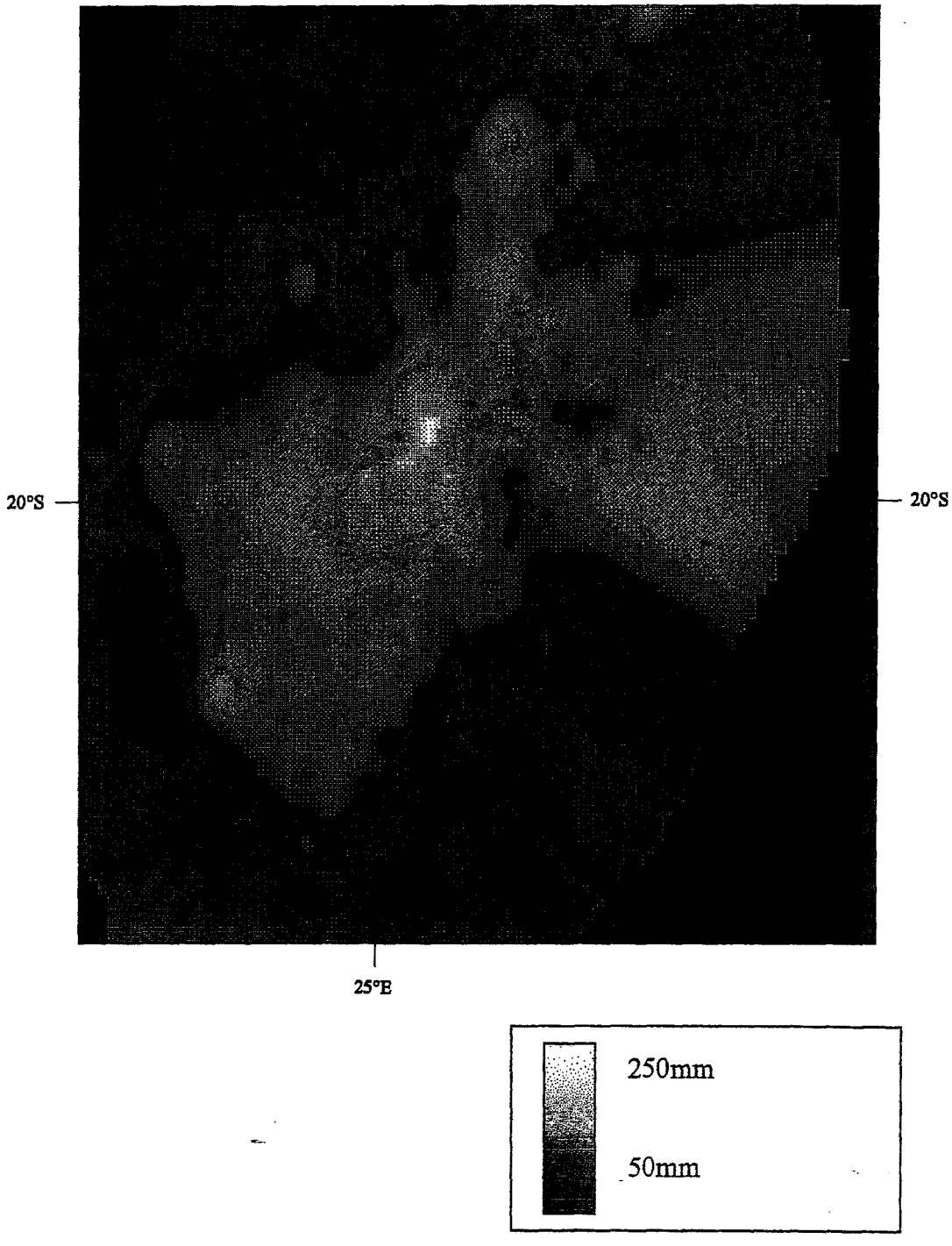


Figure E.162. Digital map layer **pet_oct** (SADC region, normal evapo-transpiration surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

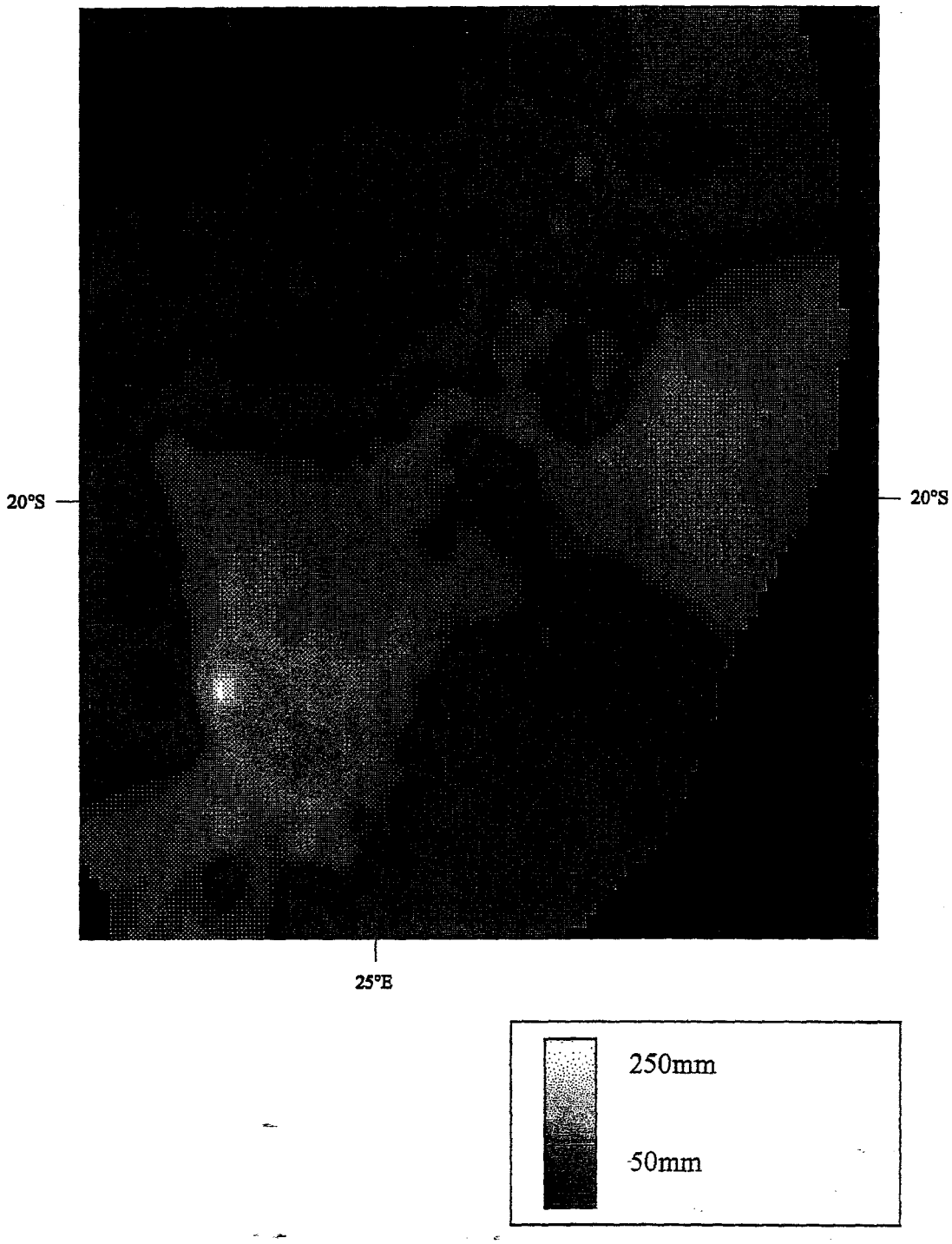


Figure E.163. Digital map layer **pet_nov** (SADC region, normal evapo-transpiration surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

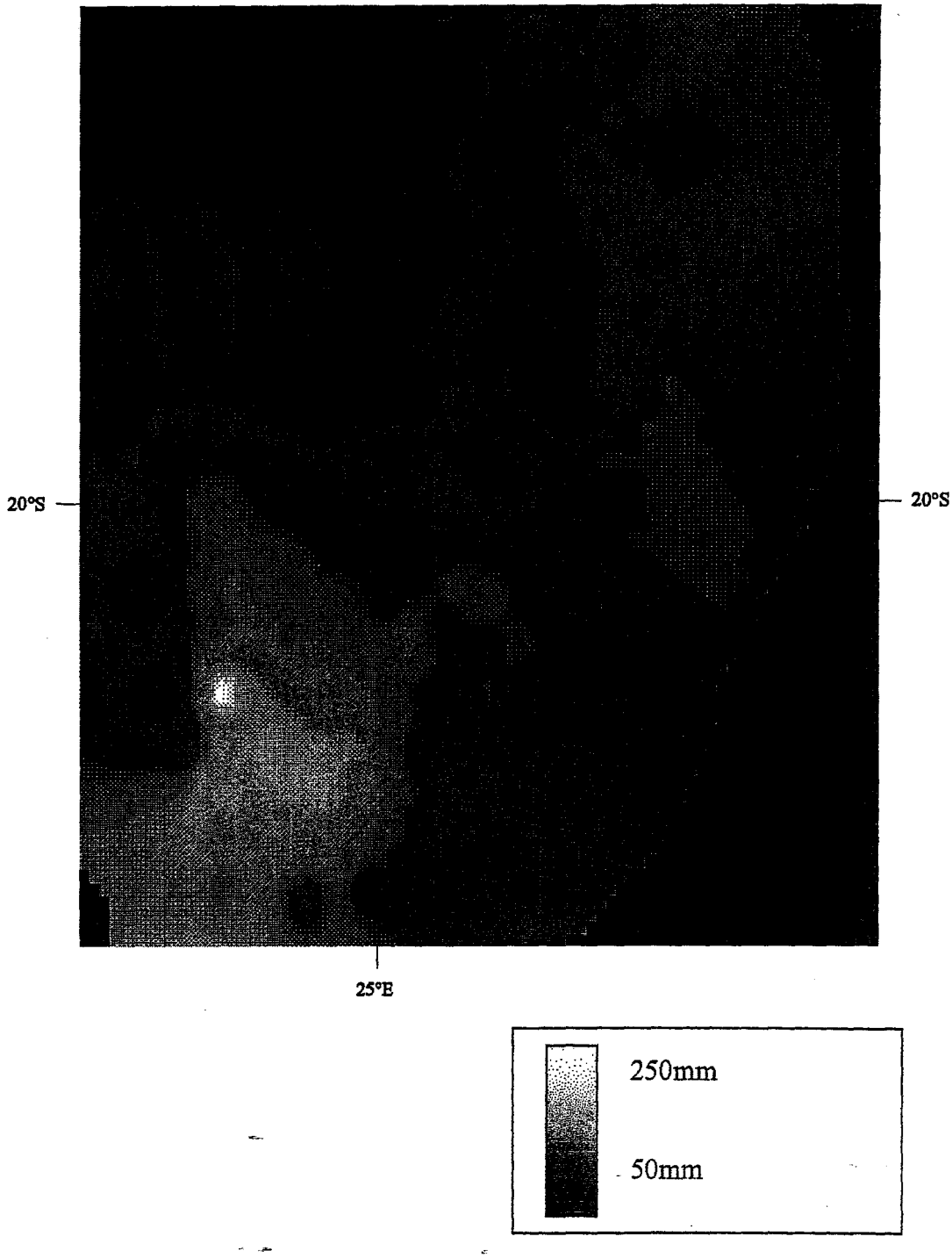


Figure E.164. Digital map layer **pet_dec** (SADC region, normal evapo-transpiration surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

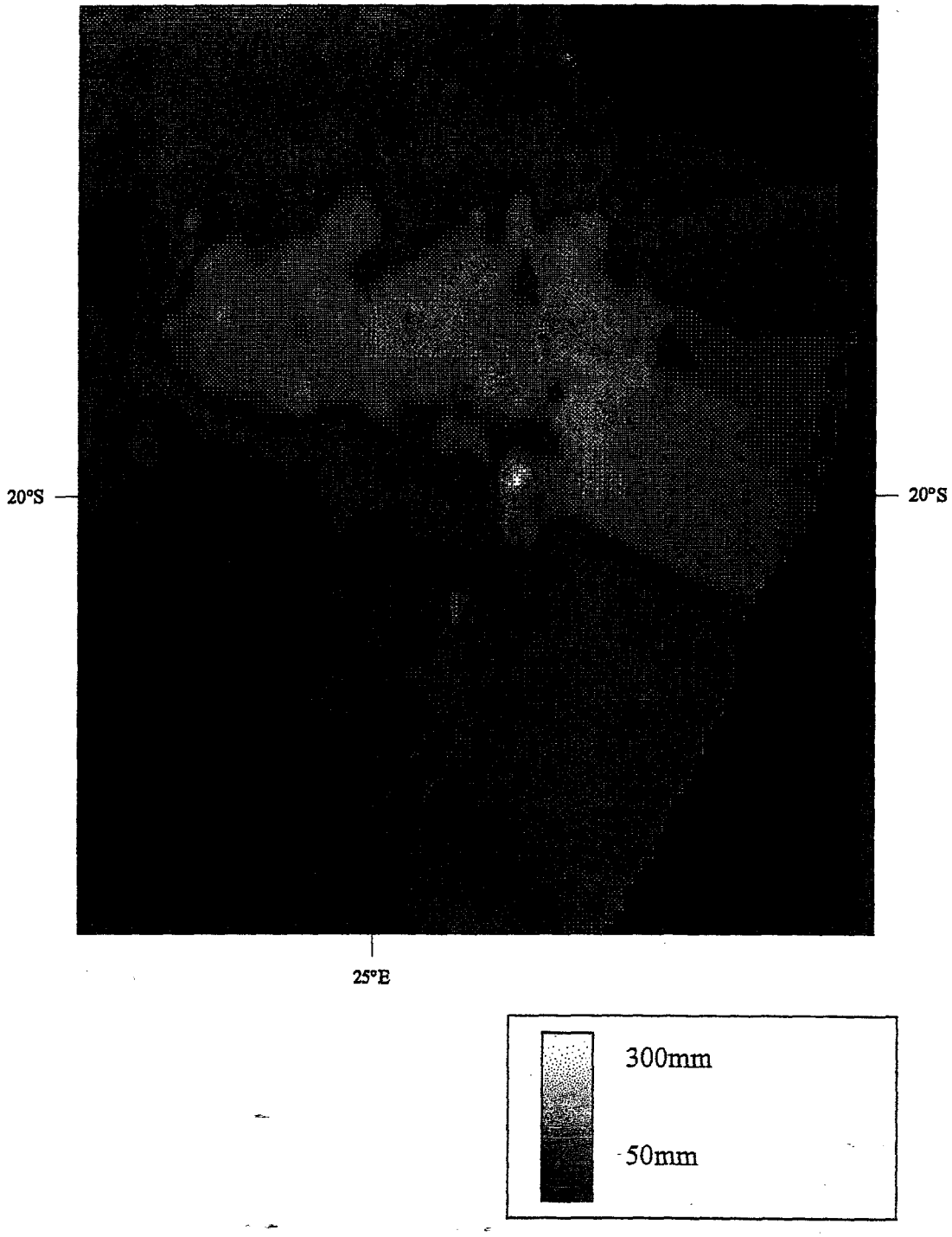


Figure E.165. Digital map layer **pre_jan** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

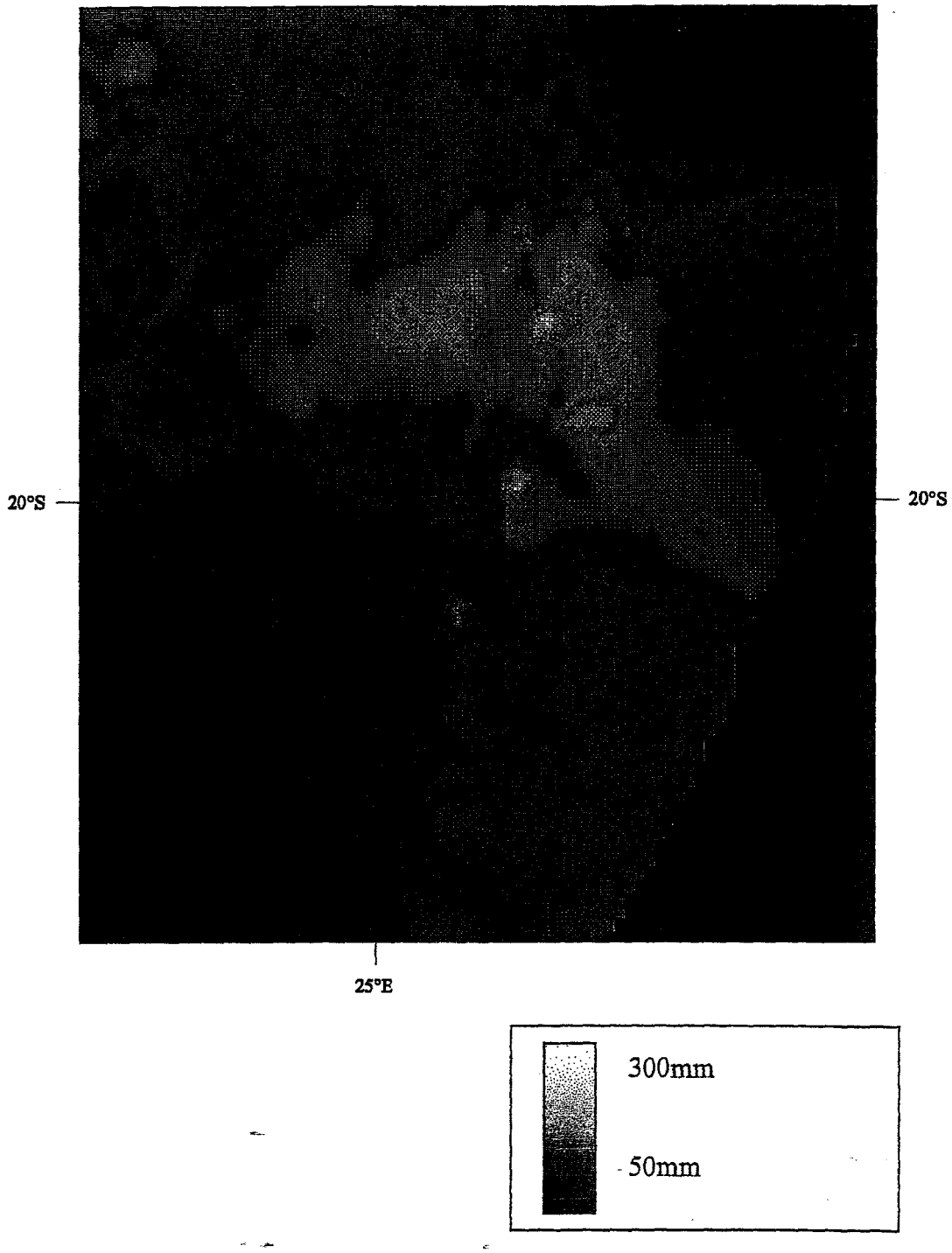


Figure E.166. Digital map layer **pre_feb** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

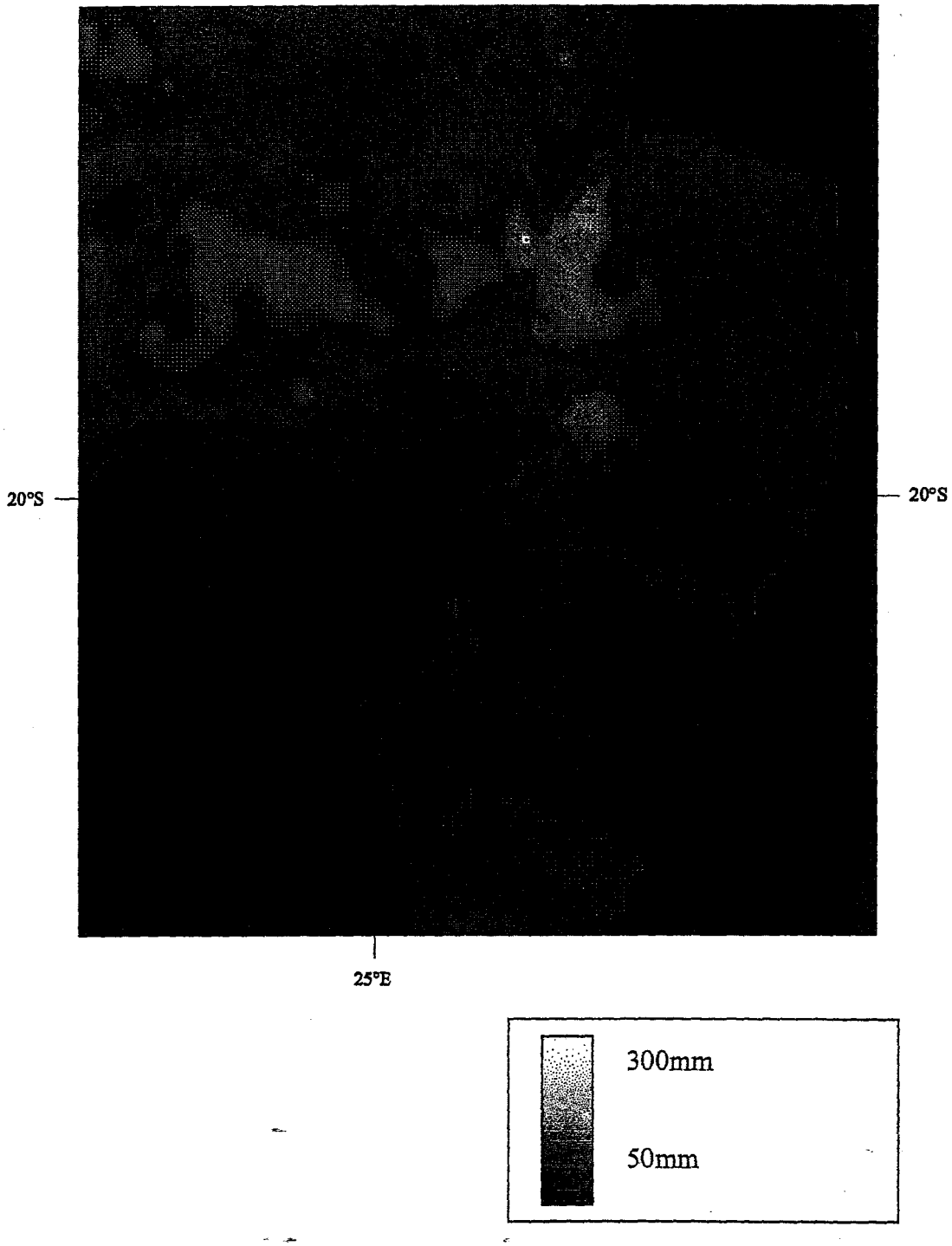


Figure E.167. Digital map layer **pre_mar** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

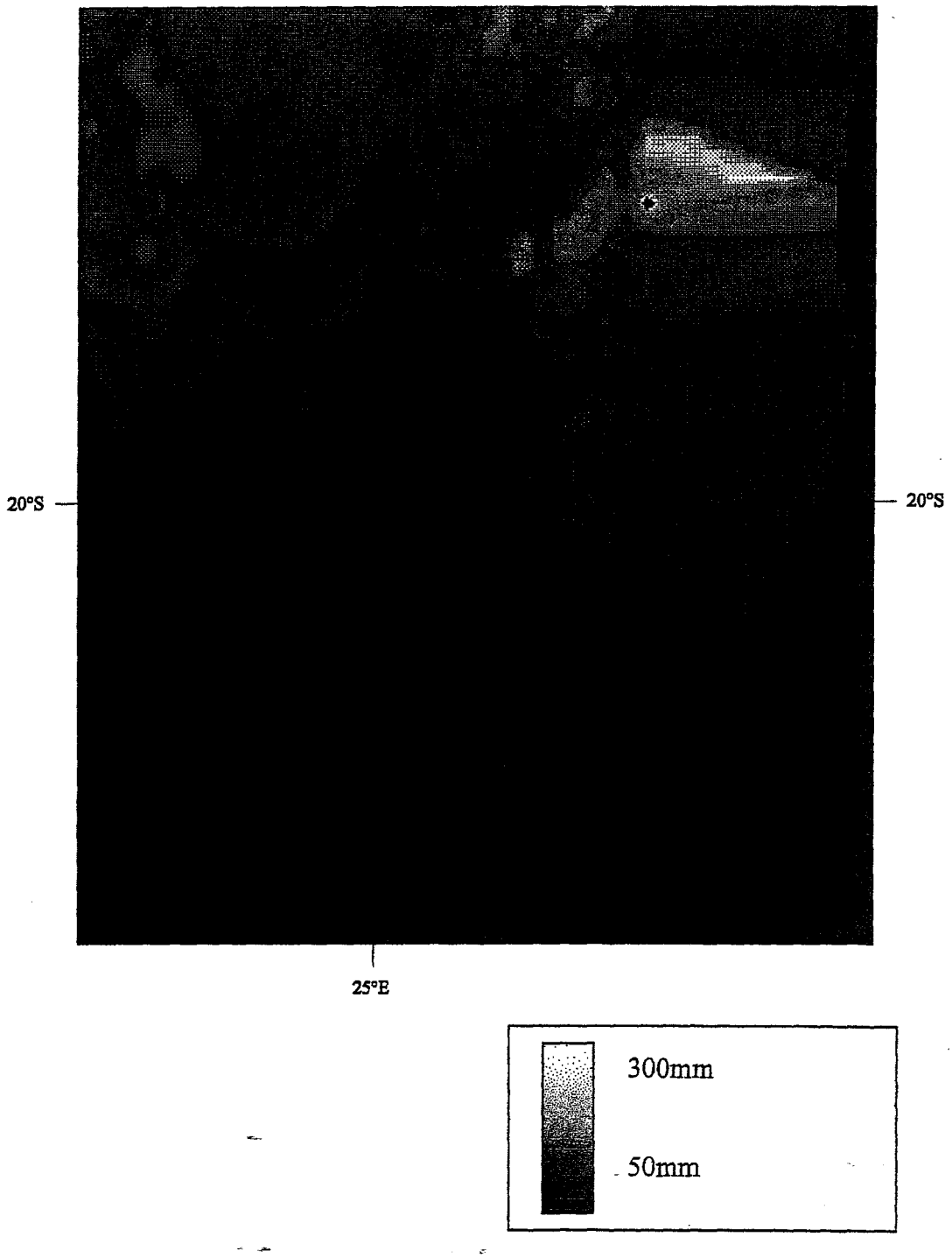


Figure E.168. Digital map layer **pre_apr** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

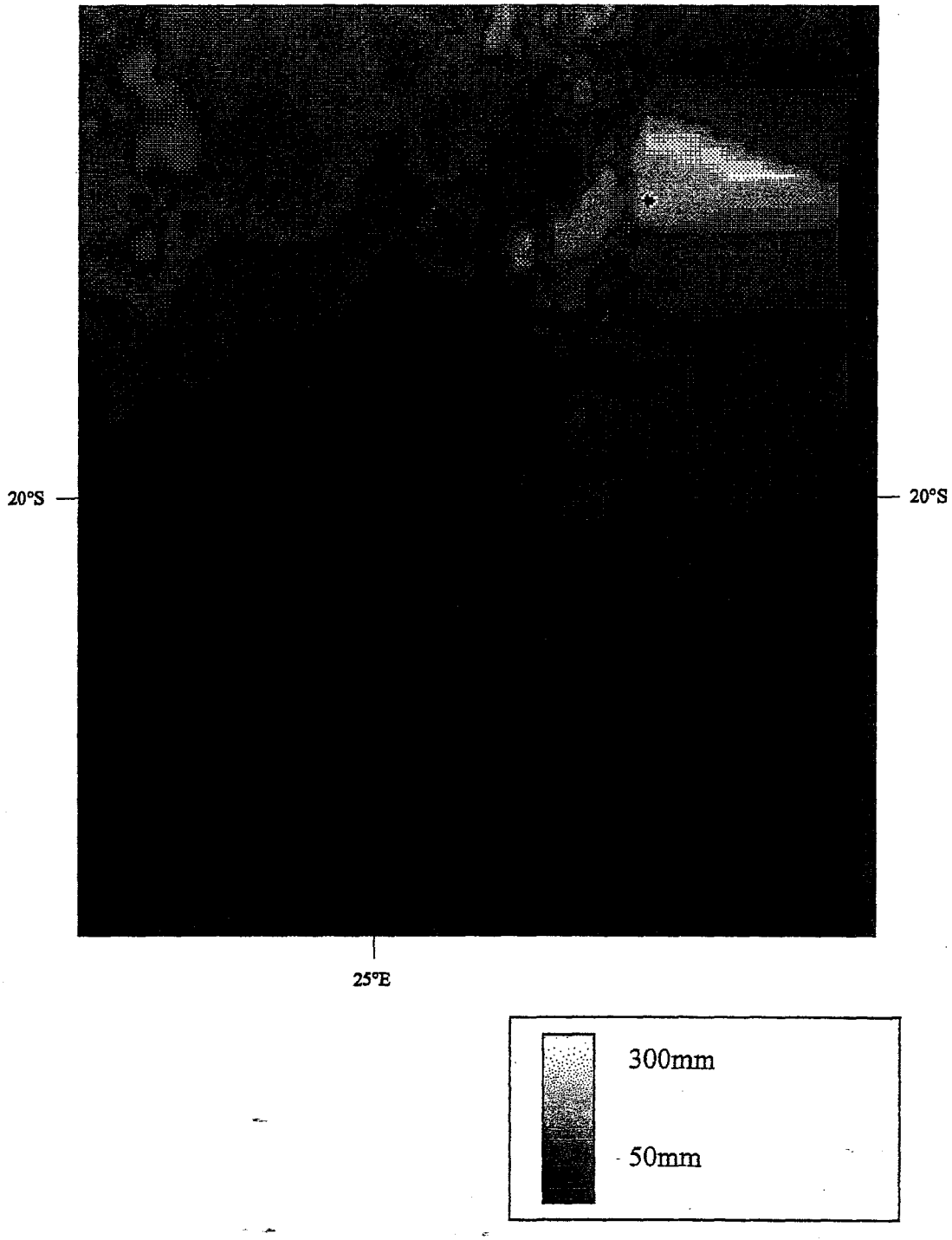


Figure E.169. Digital map layer **pre_may** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

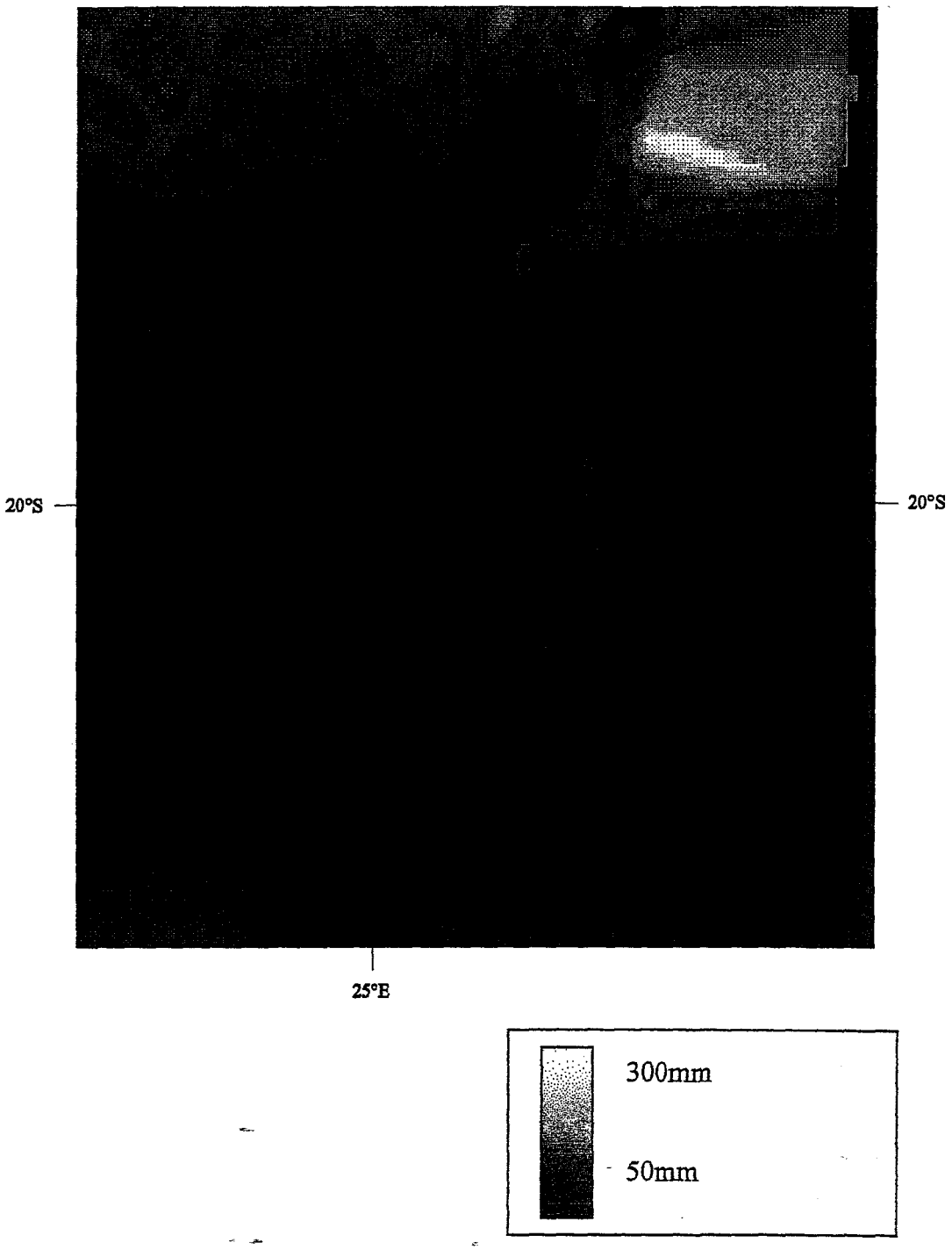


Figure E.170. Digital map layer **pre_jun** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

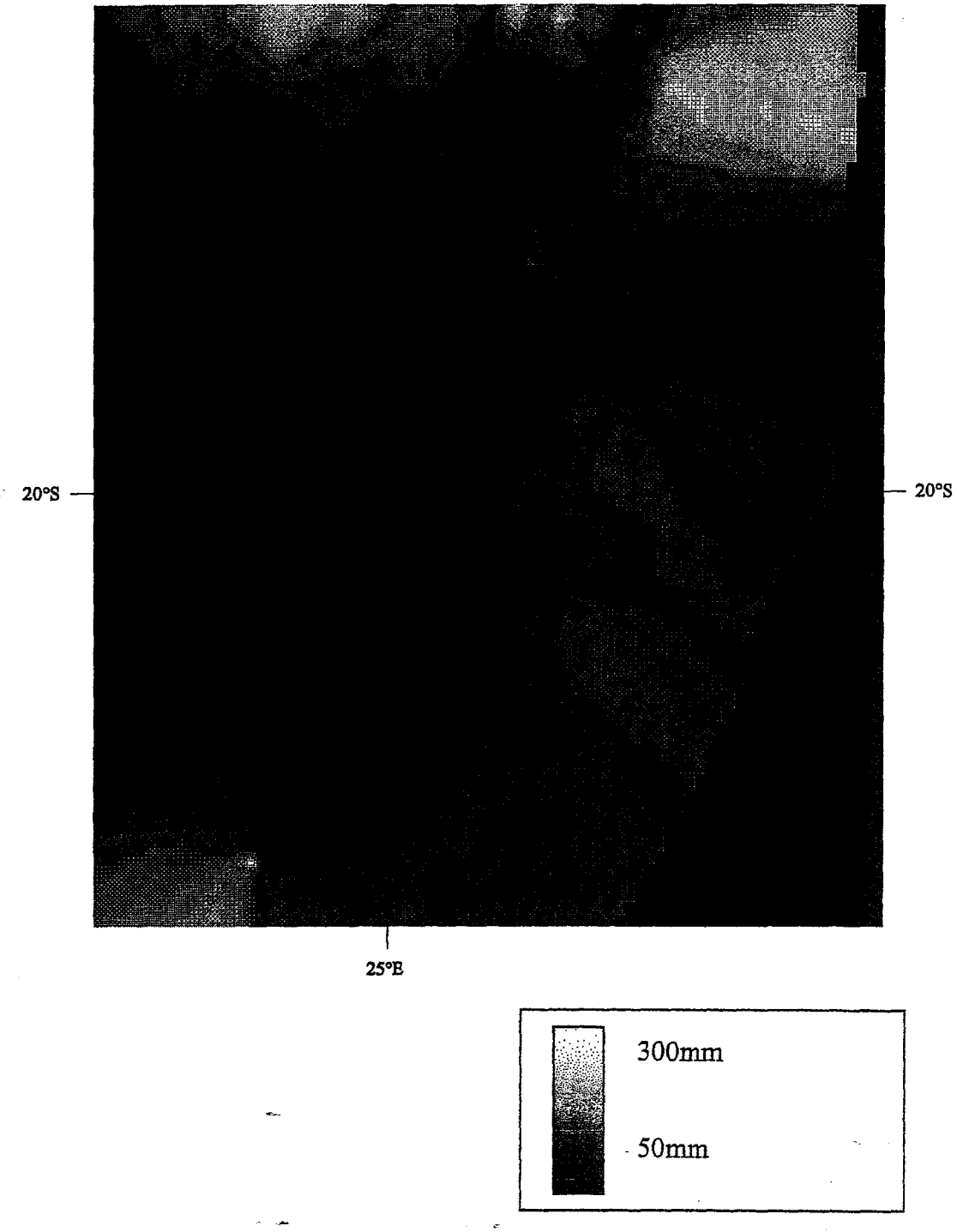


Figure E.171. Digital map layer **pre_jul** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

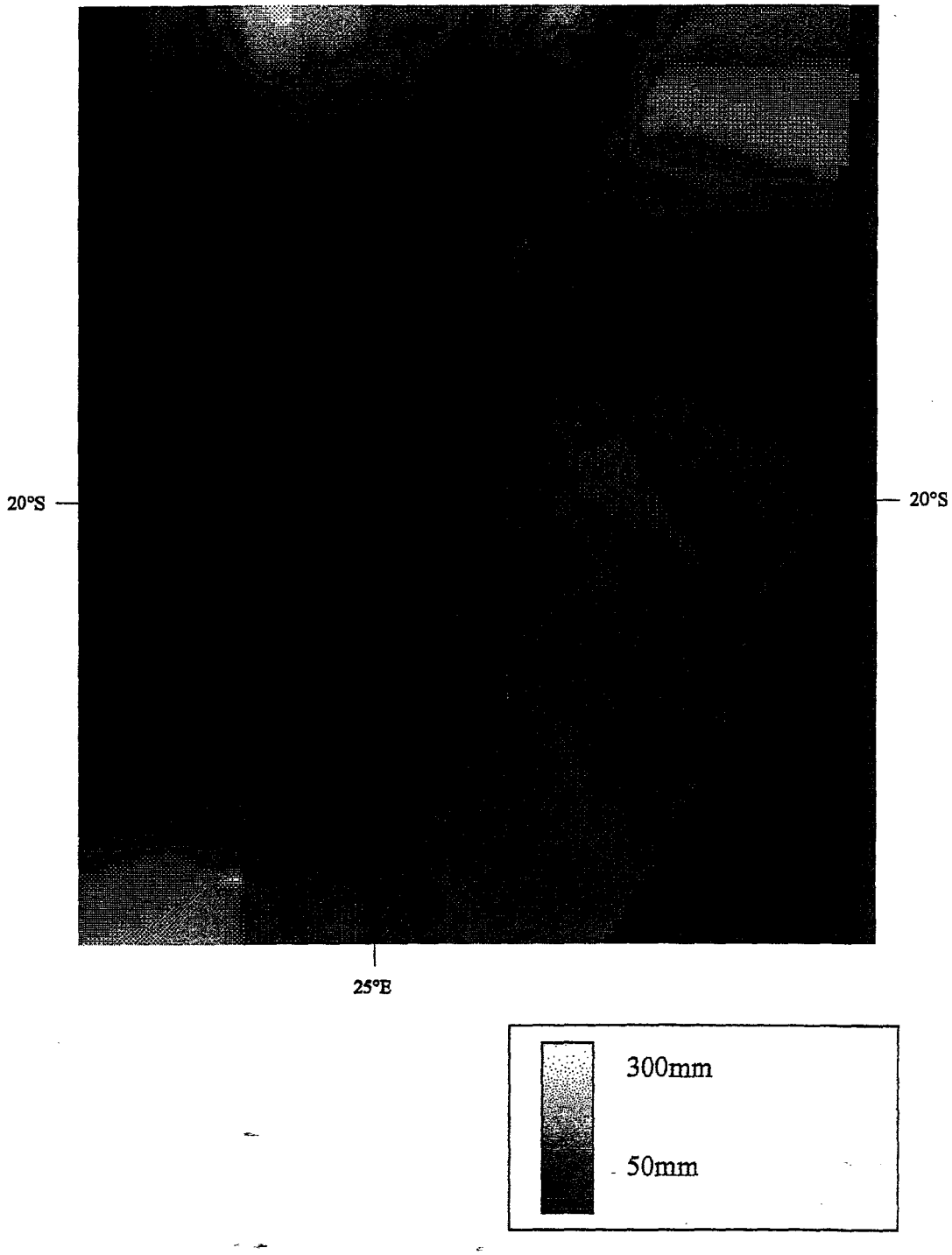


Figure E.172. Digital map layer **pre_aug** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

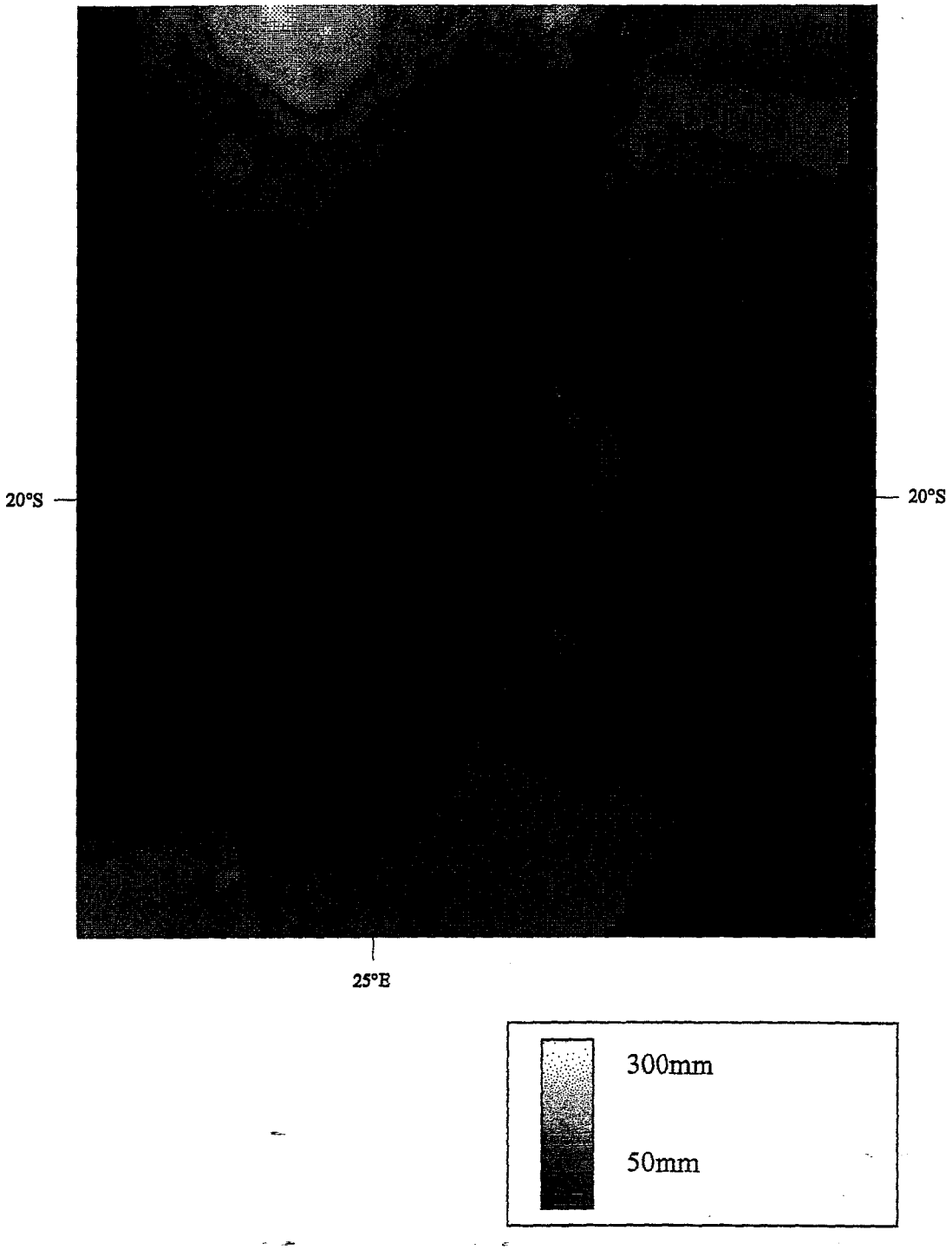


Figure E.173. Digital map layer **pre_sep** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

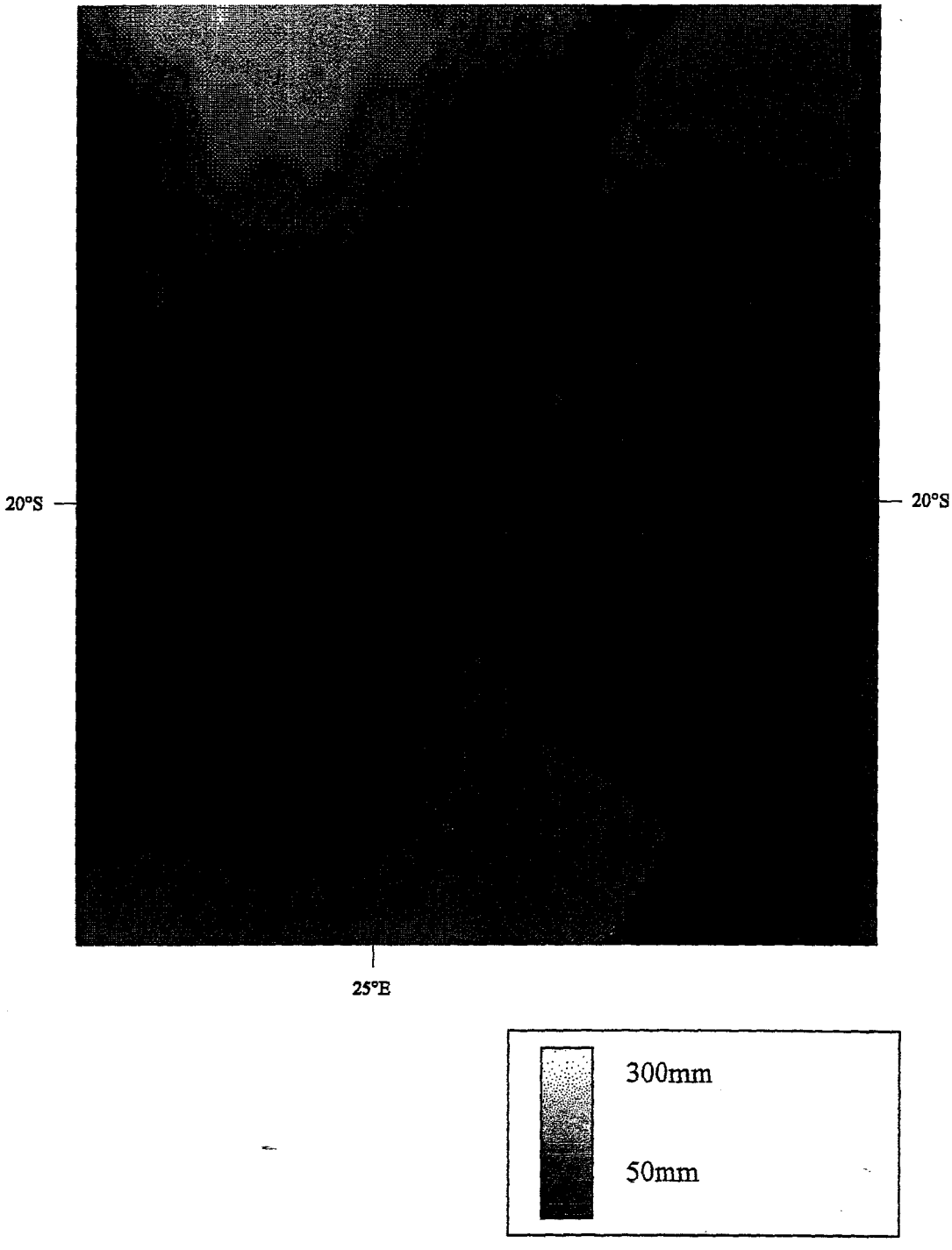


Figure E.174. Digital map layer **pre_oct** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

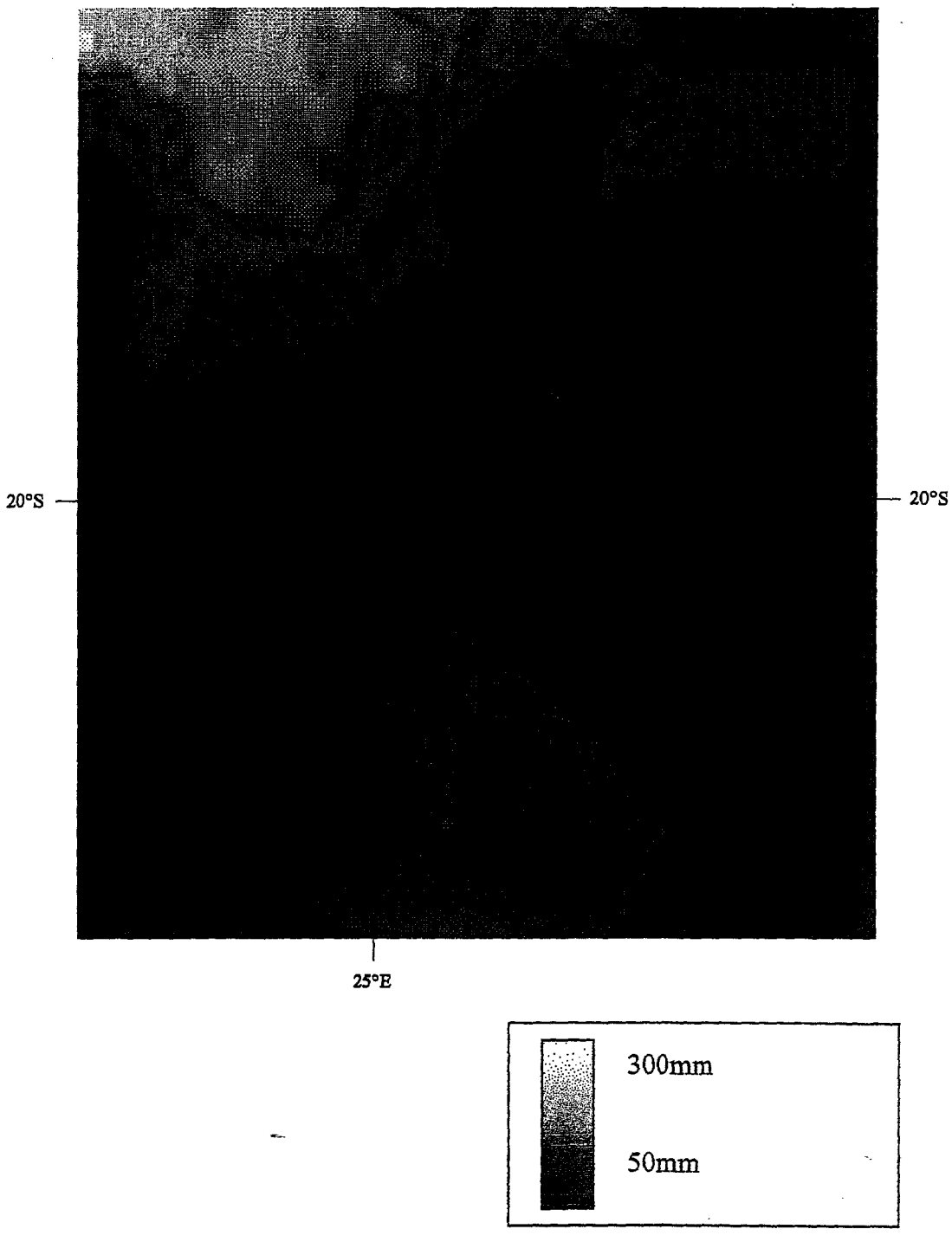


Figure E.175. Digital map layer **pre_nov** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

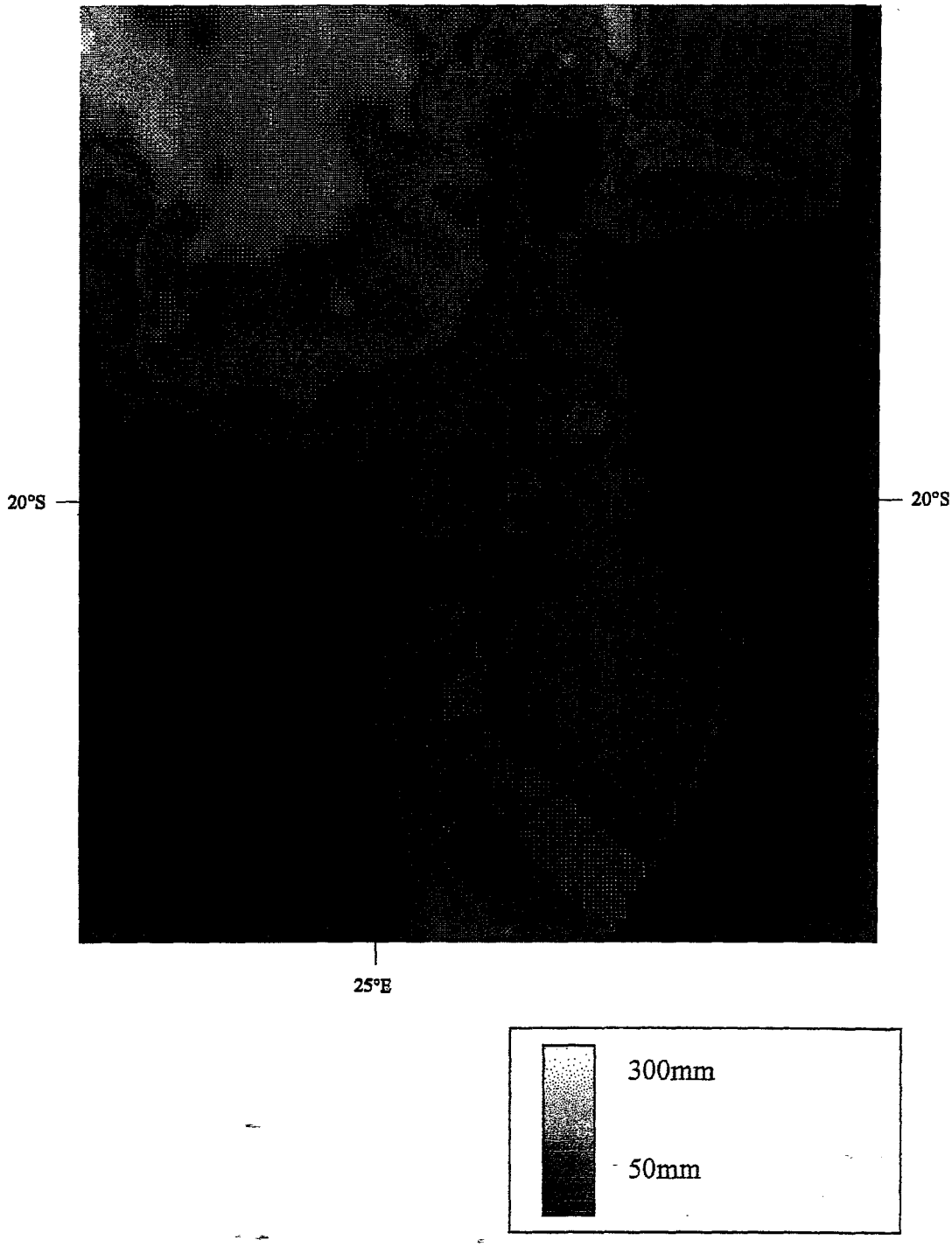


Figure E.176. Digital map layer **pre_dec** (SADC region, normal precipitation surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

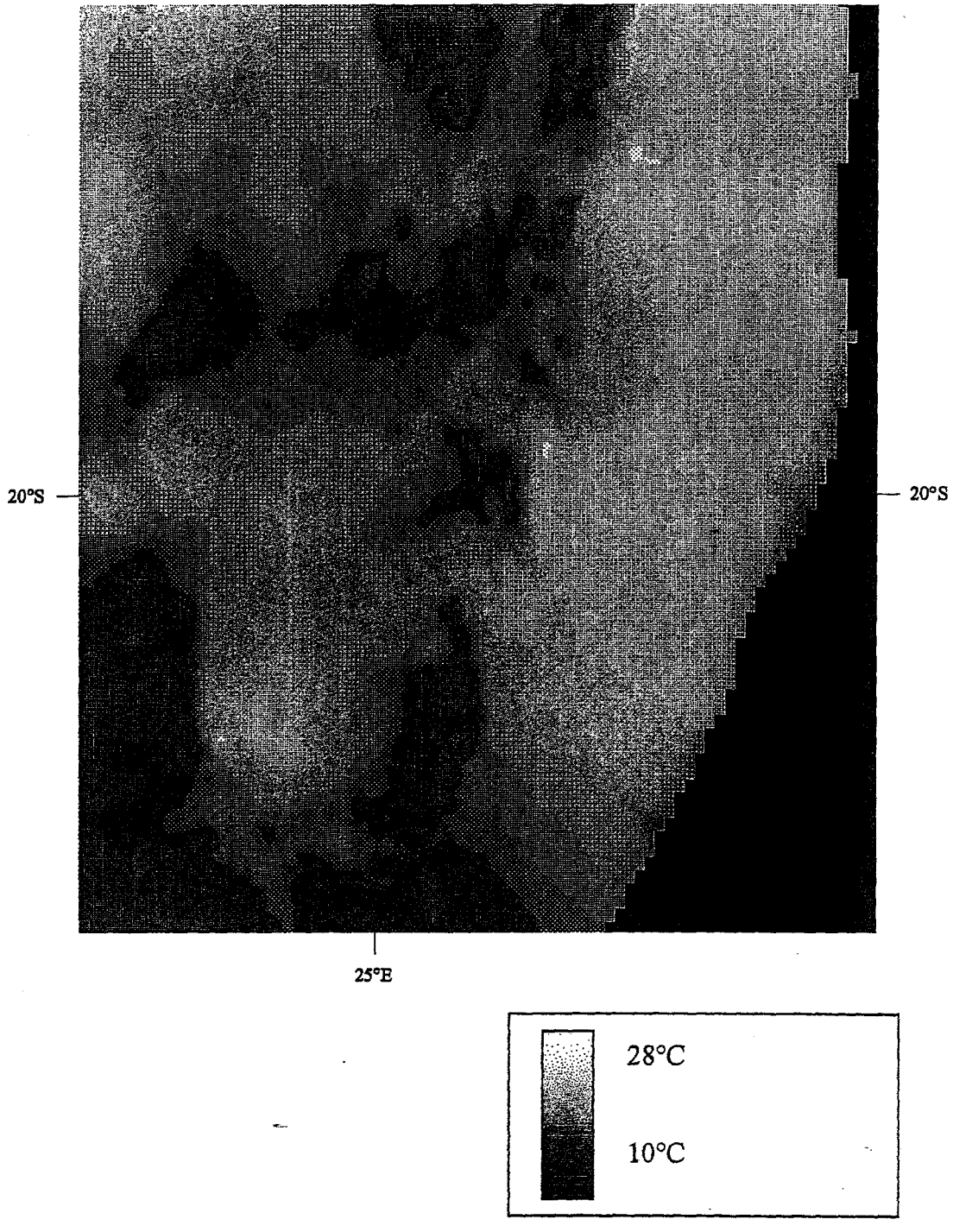


Figure E.177. Digital map layer **tav_jan** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

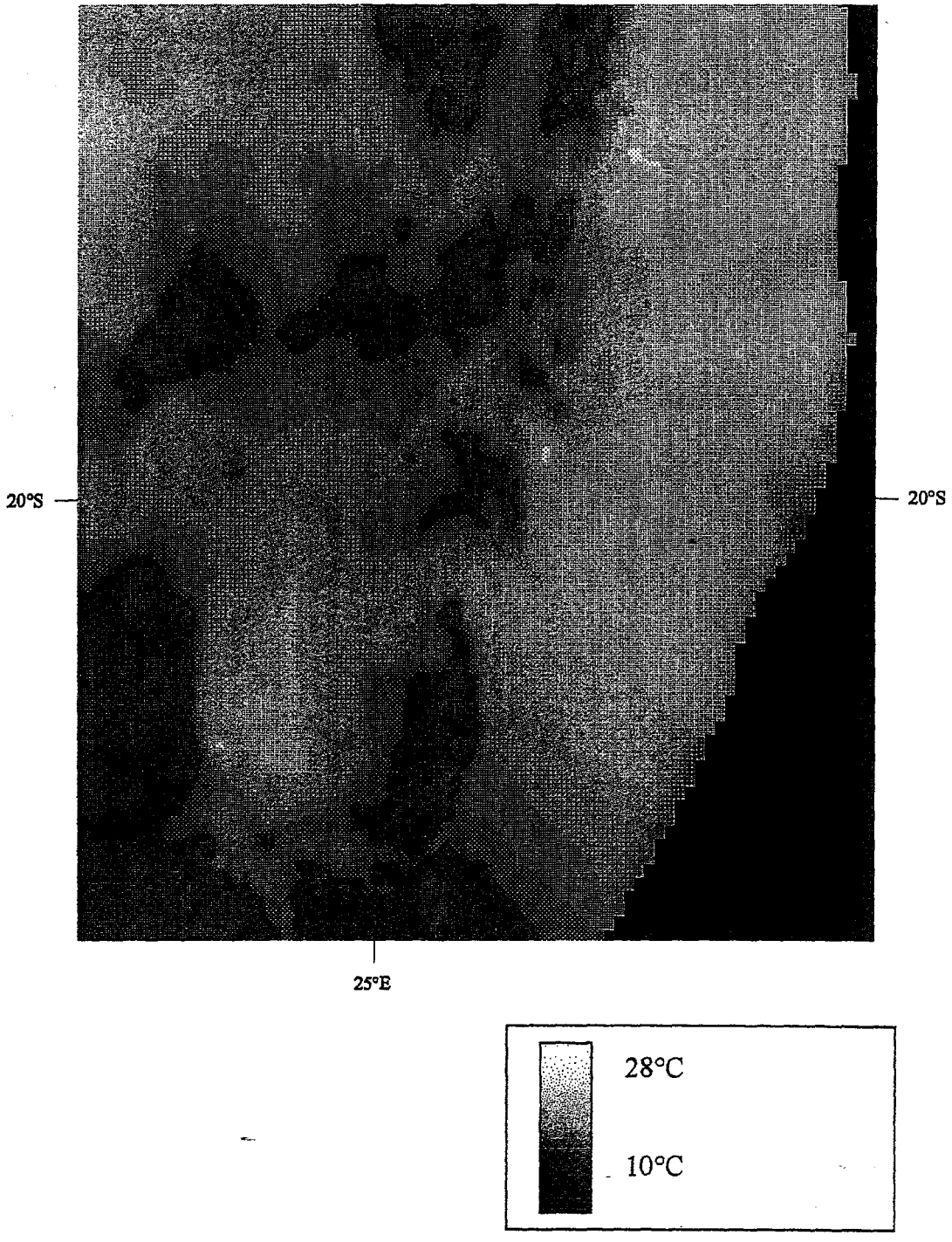


Figure E.178. Digital map layer **tav_feb** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

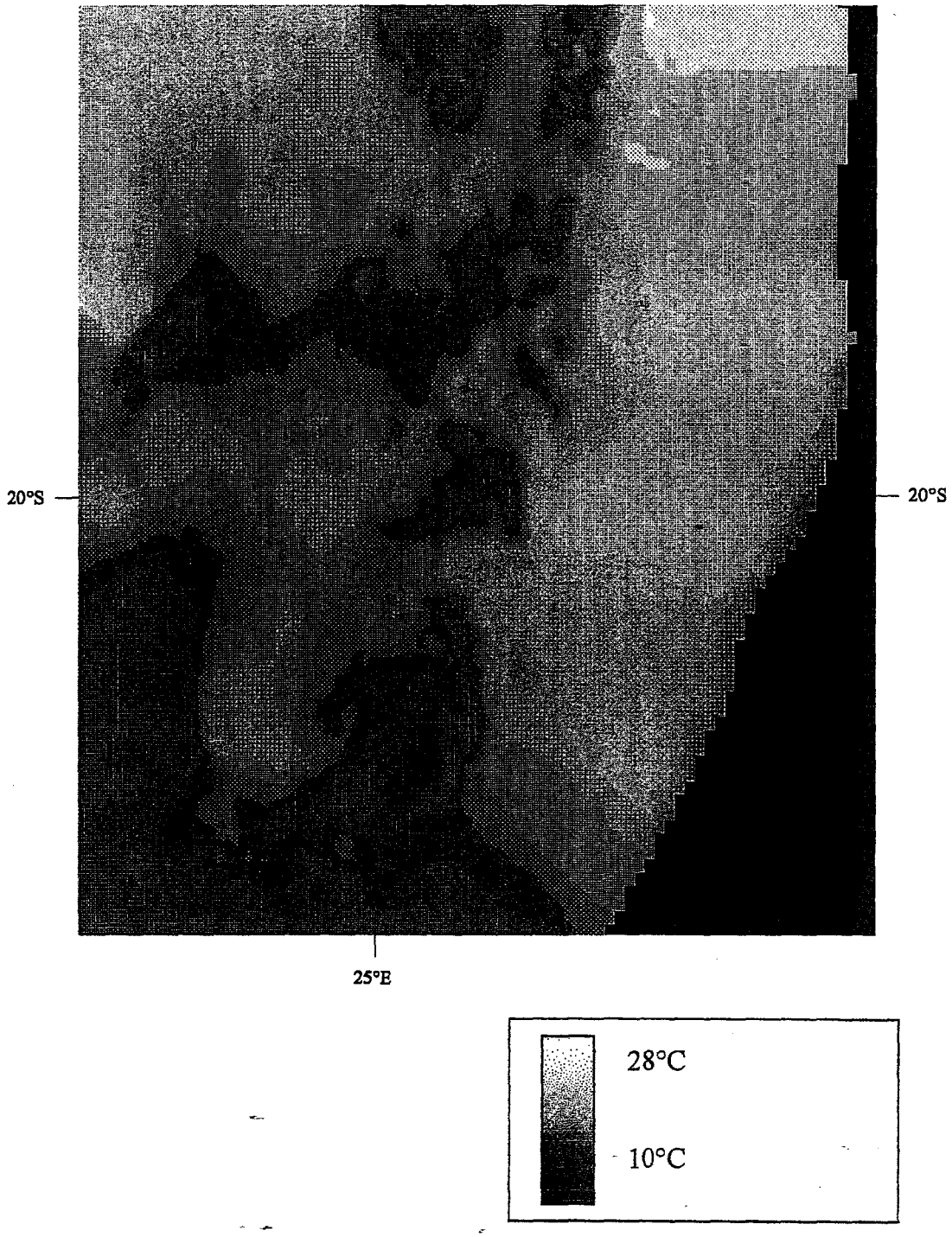


Figure E.179. Digital map layer **tav_mar** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

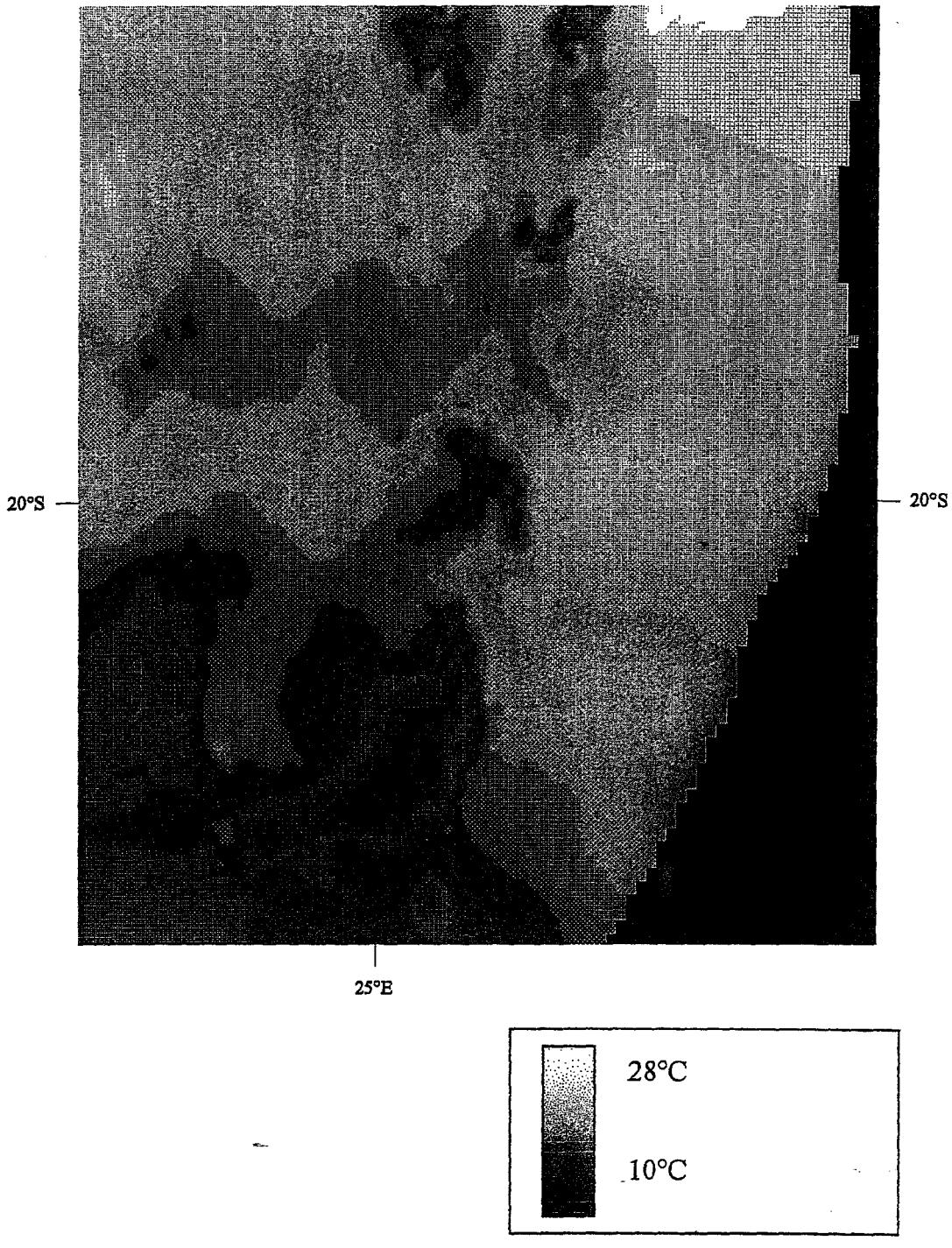


Figure E.180. Digital map layer **tav_apr** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

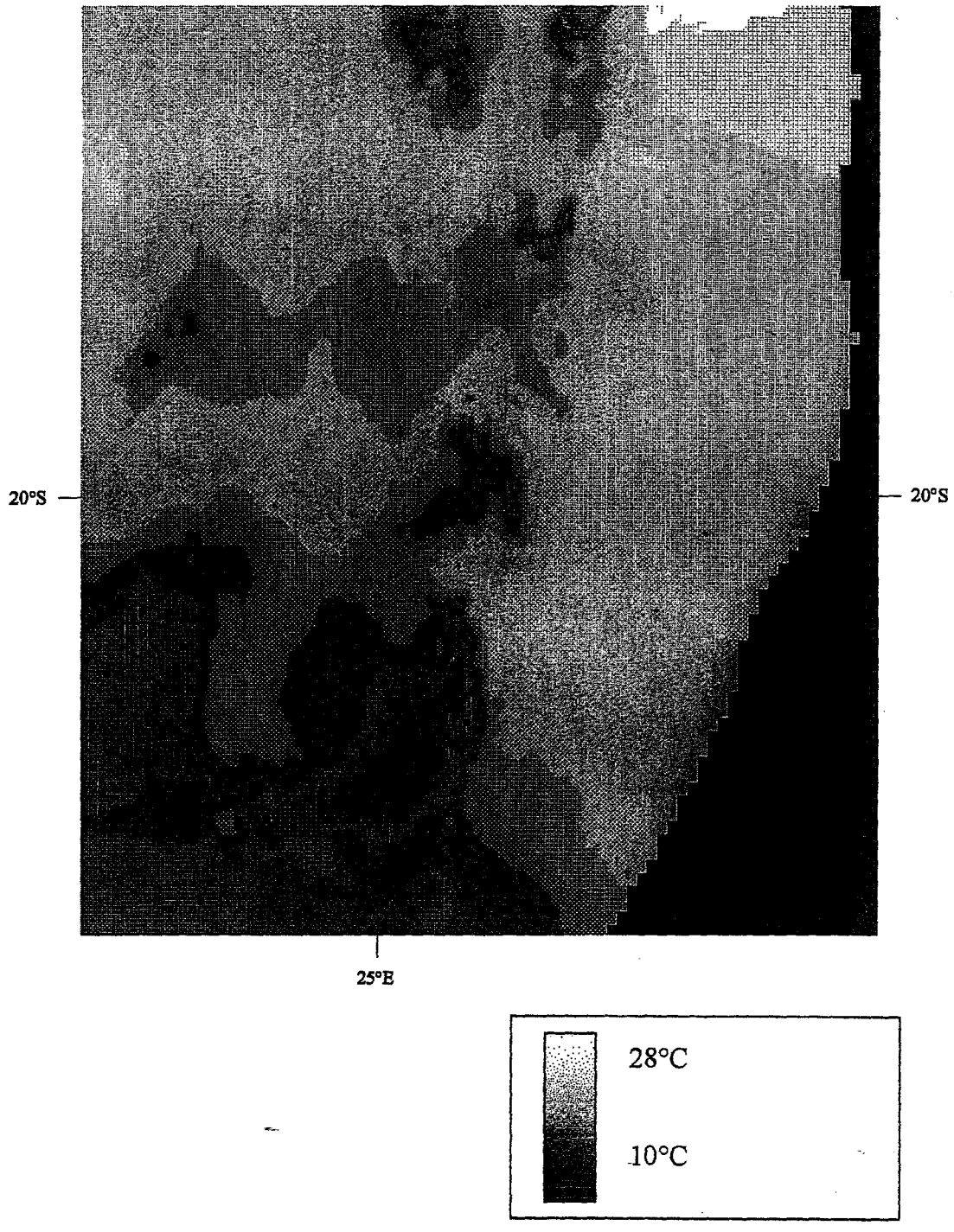


Figure E.181. Digital map layer **tav_may** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

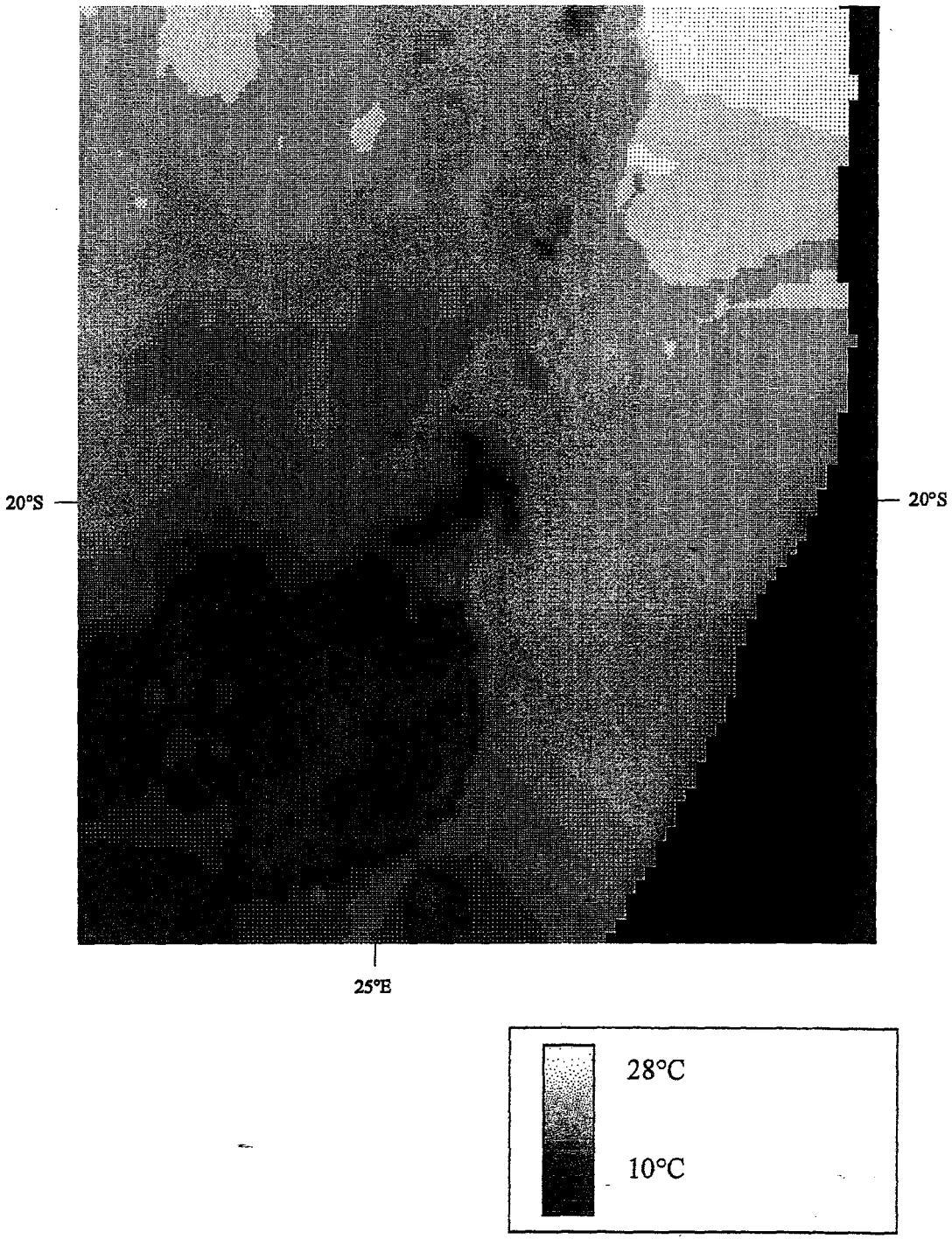


Figure E.182. Digital map layer **tav_jun** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

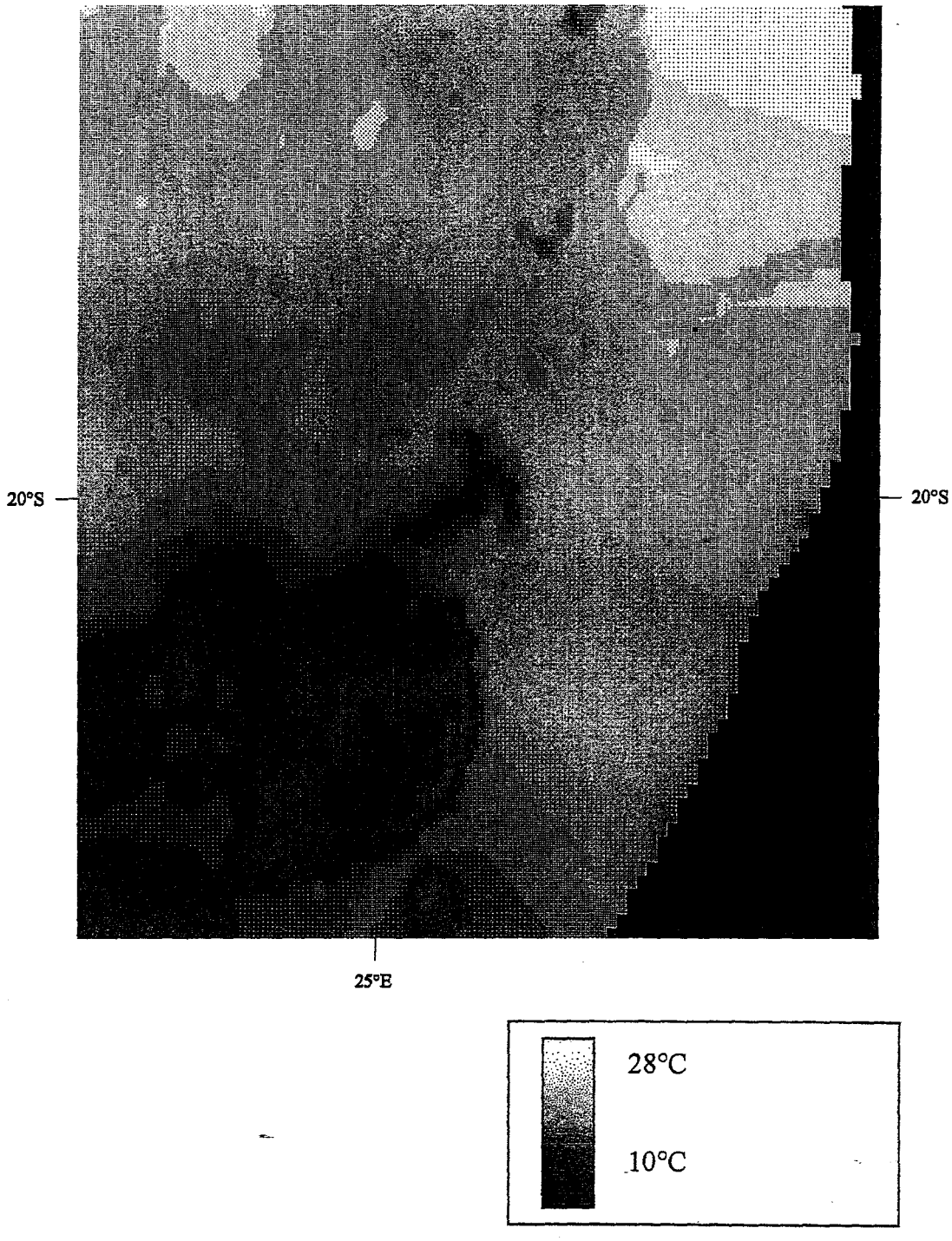


Figure E.183. Digital map layer **tav_jul** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

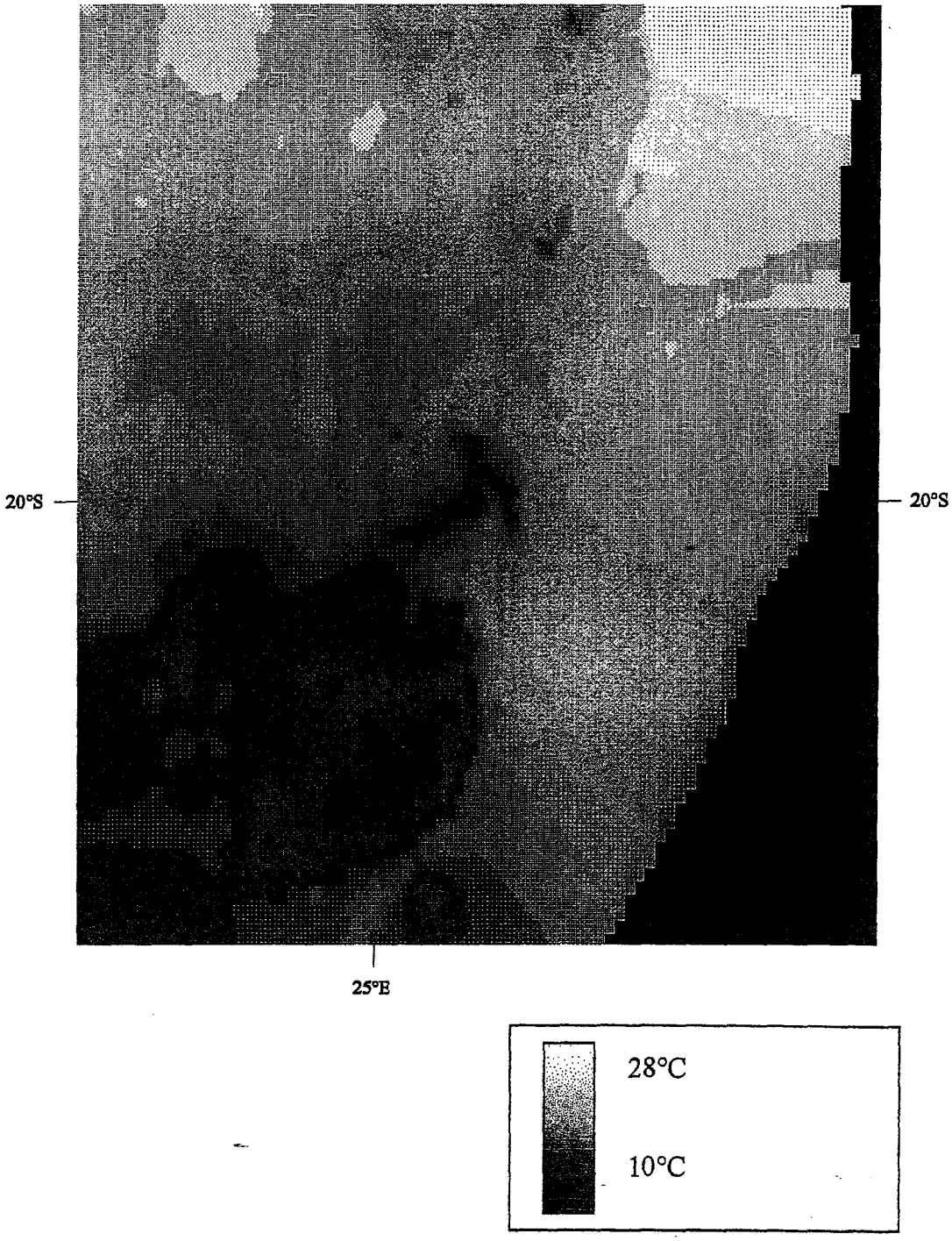


Figure E.184. Digital map layer **tav_aug** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

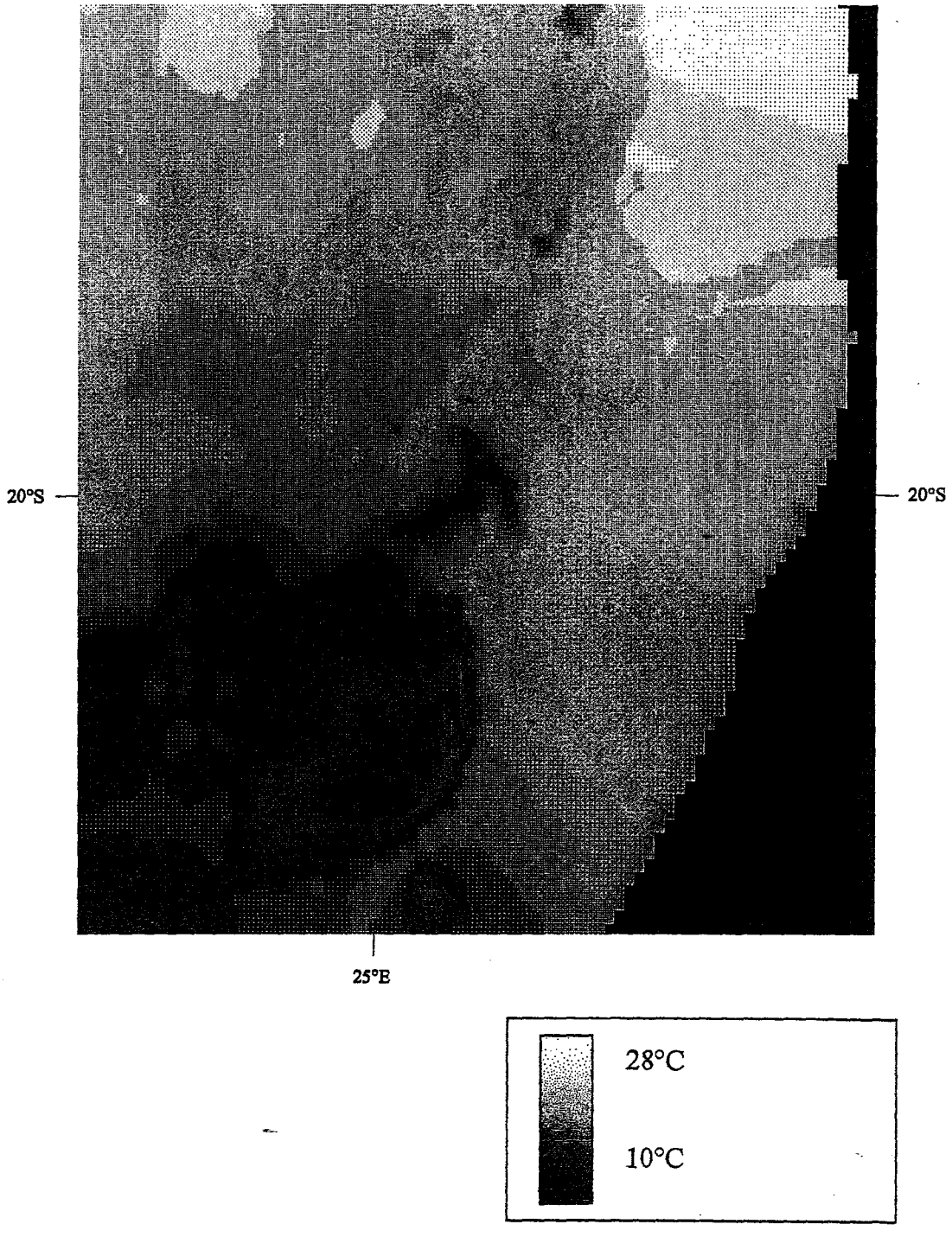


Figure E.185. Digital map layer **tav_sep** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

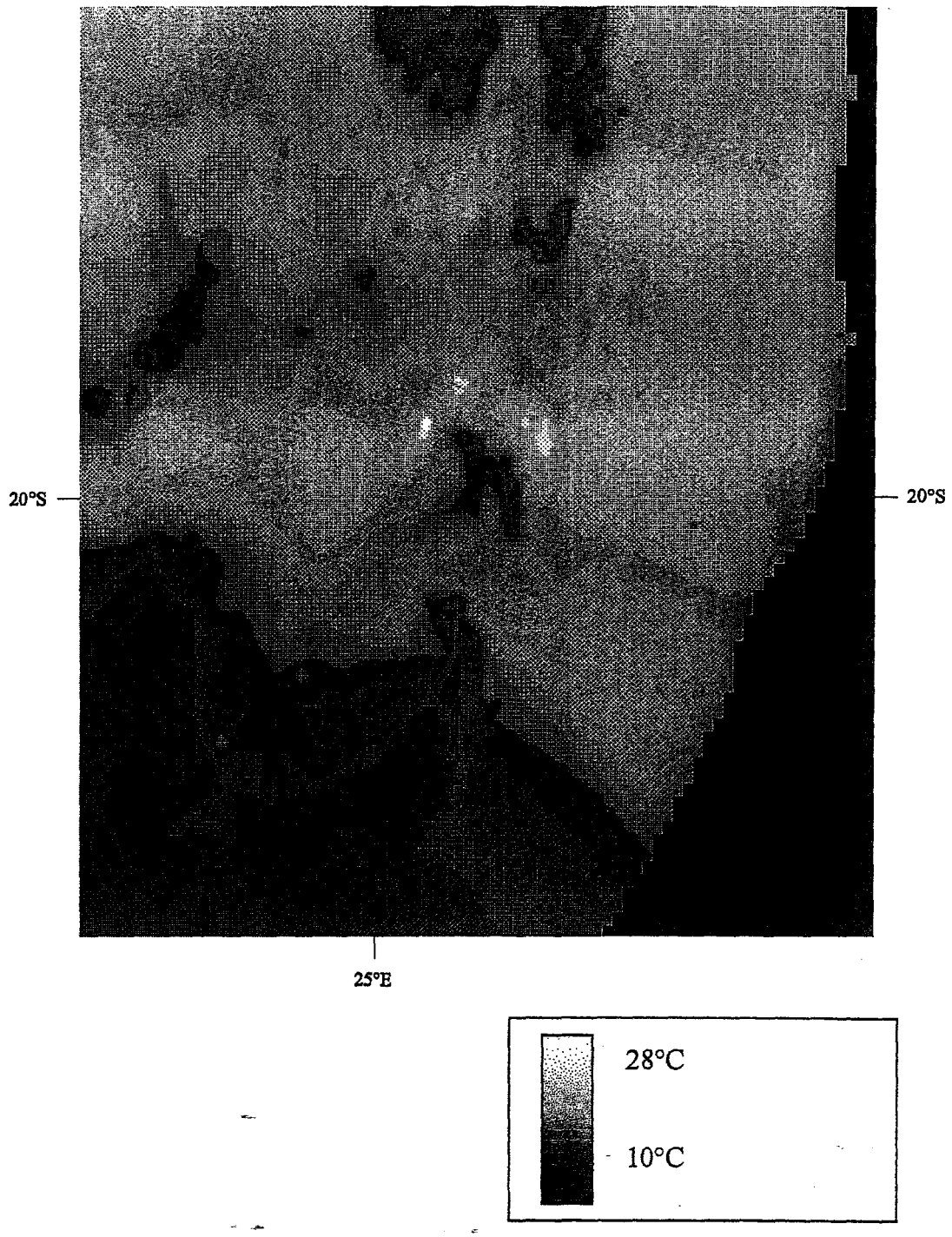


Figure E.186. Digital map layer **tav_oct** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

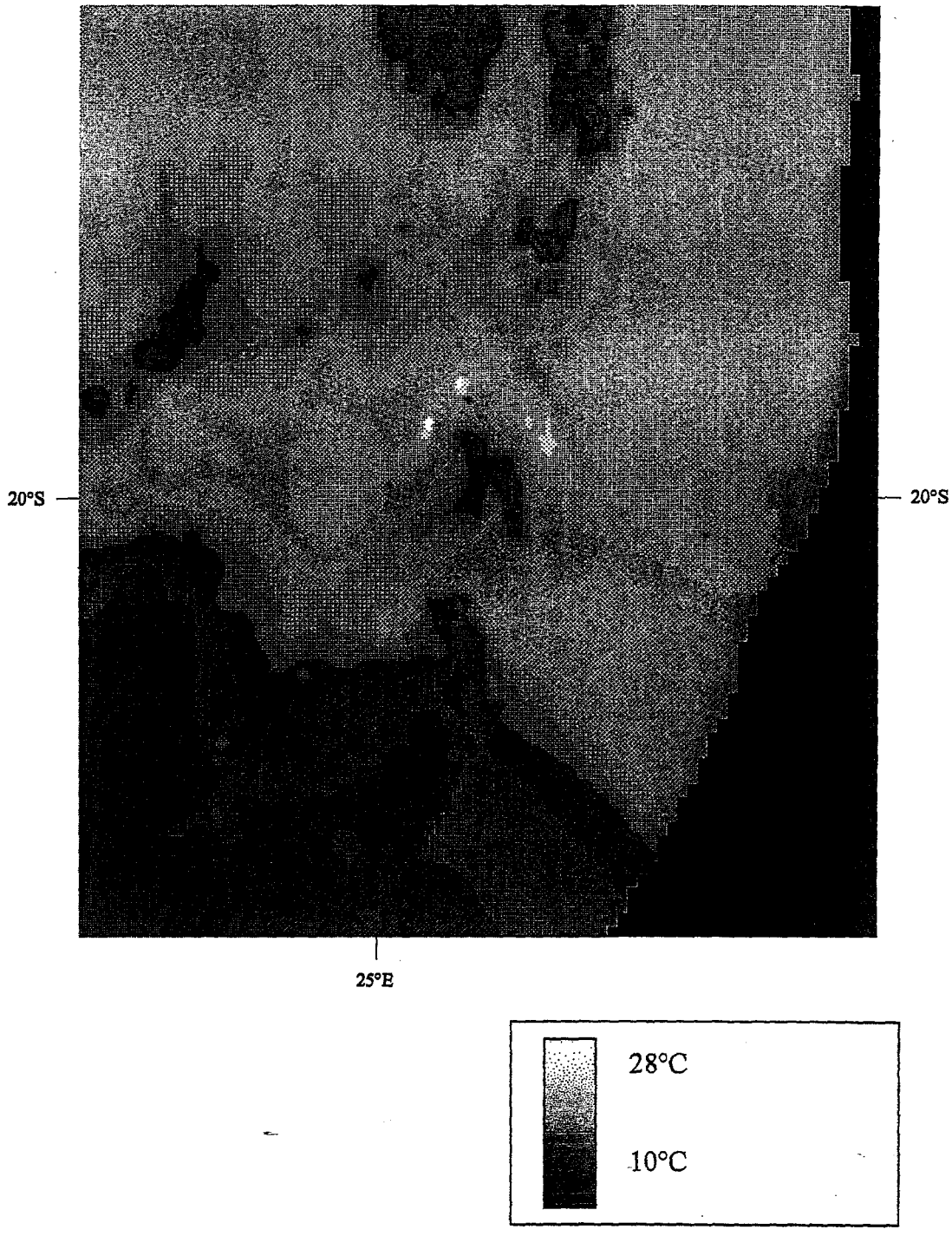


Figure E.187. Digital map layer **tav_nov** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

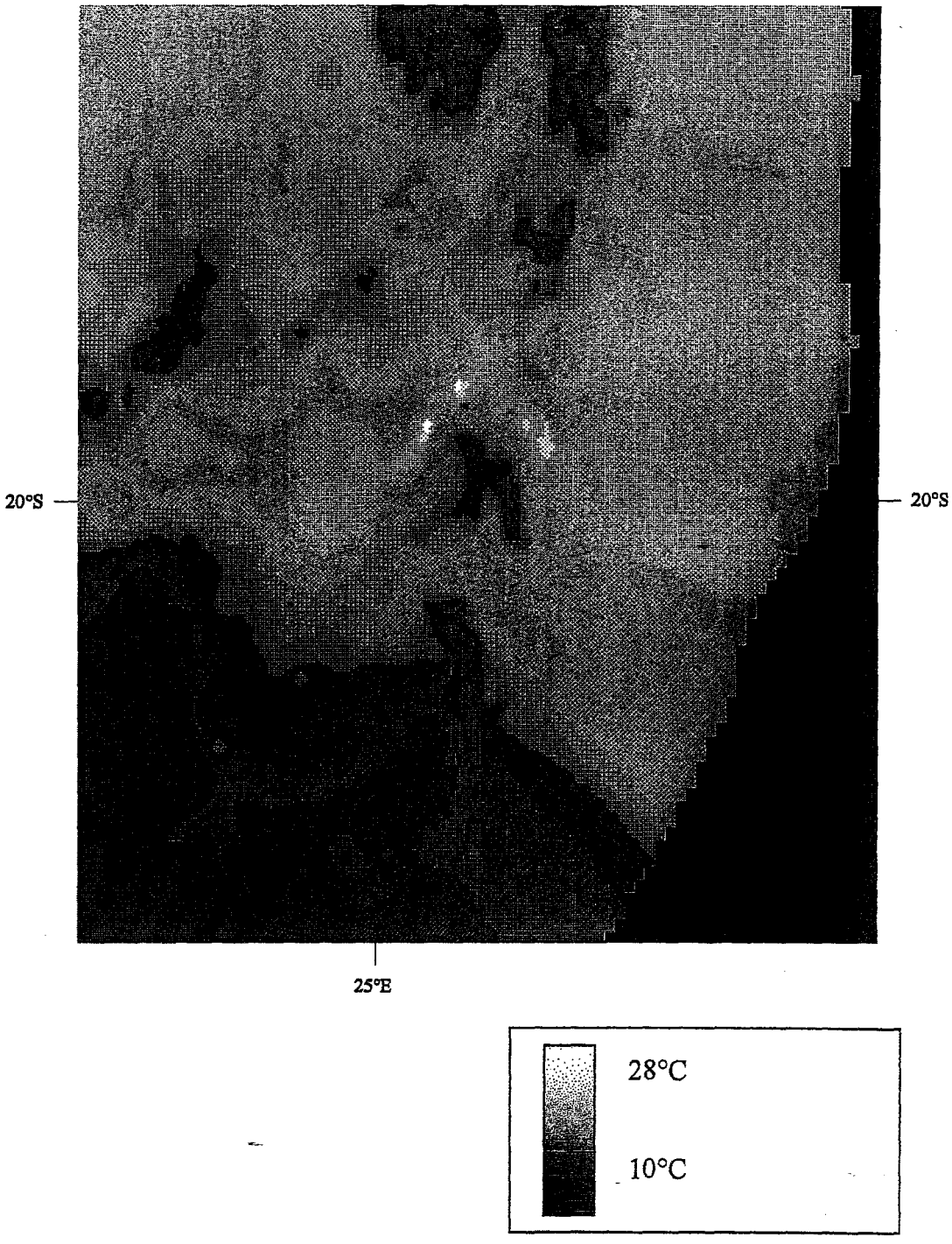


Figure E.188. Digital map layer **tav_dec** (SADC region, normal average temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

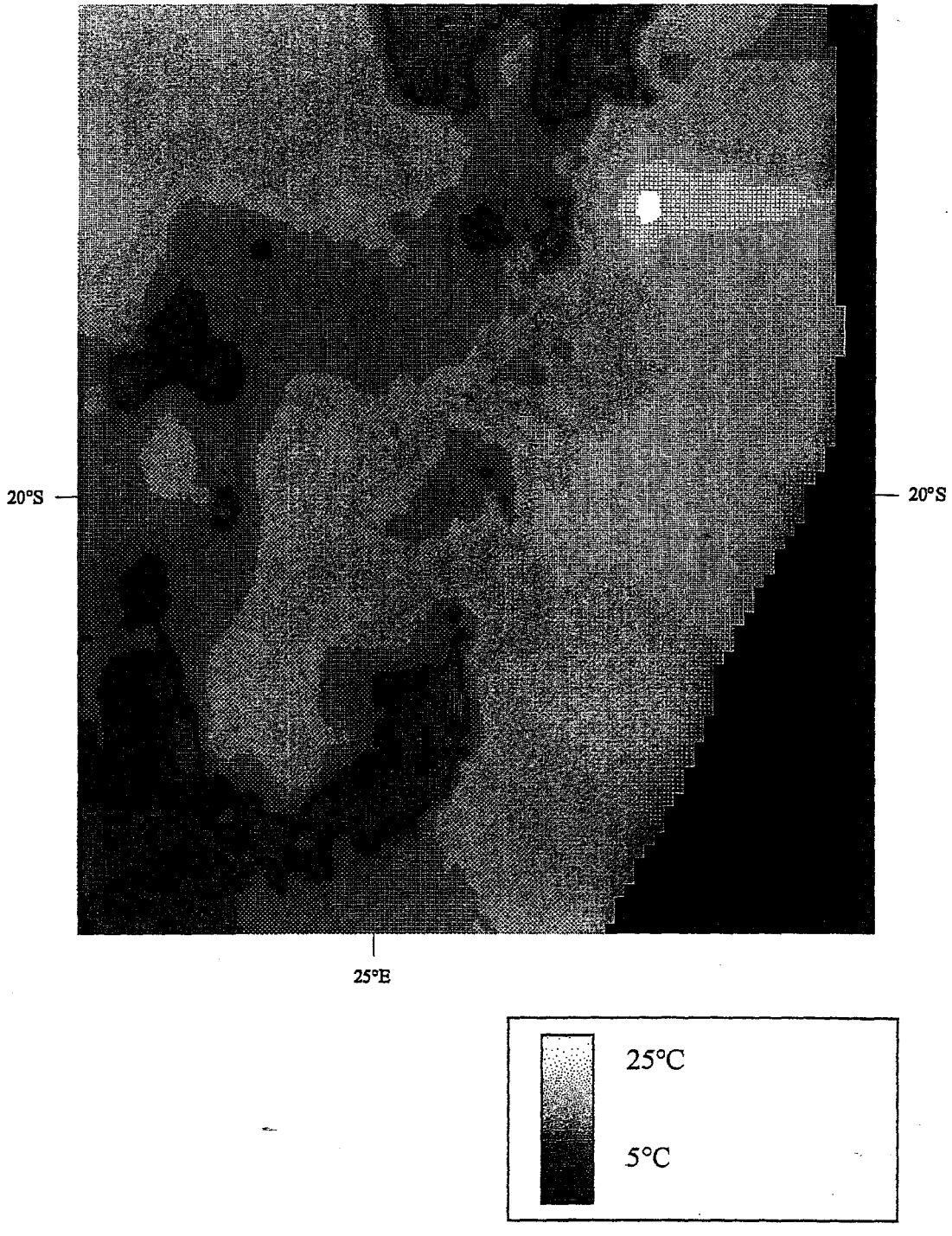


Figure E.189. Digital map layer **tmn_jan** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

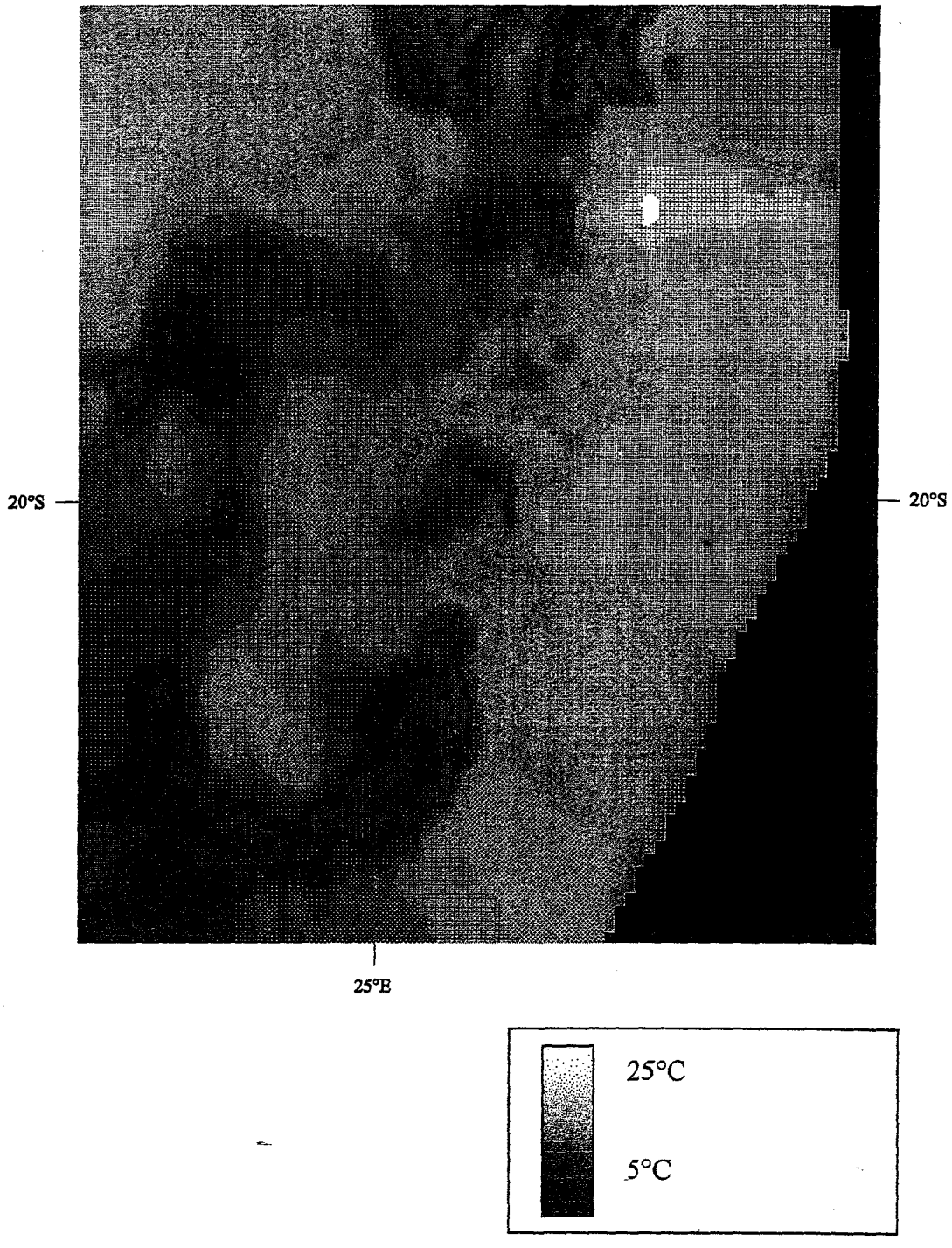


Figure E.190. Digital map layer **tmn_feb** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

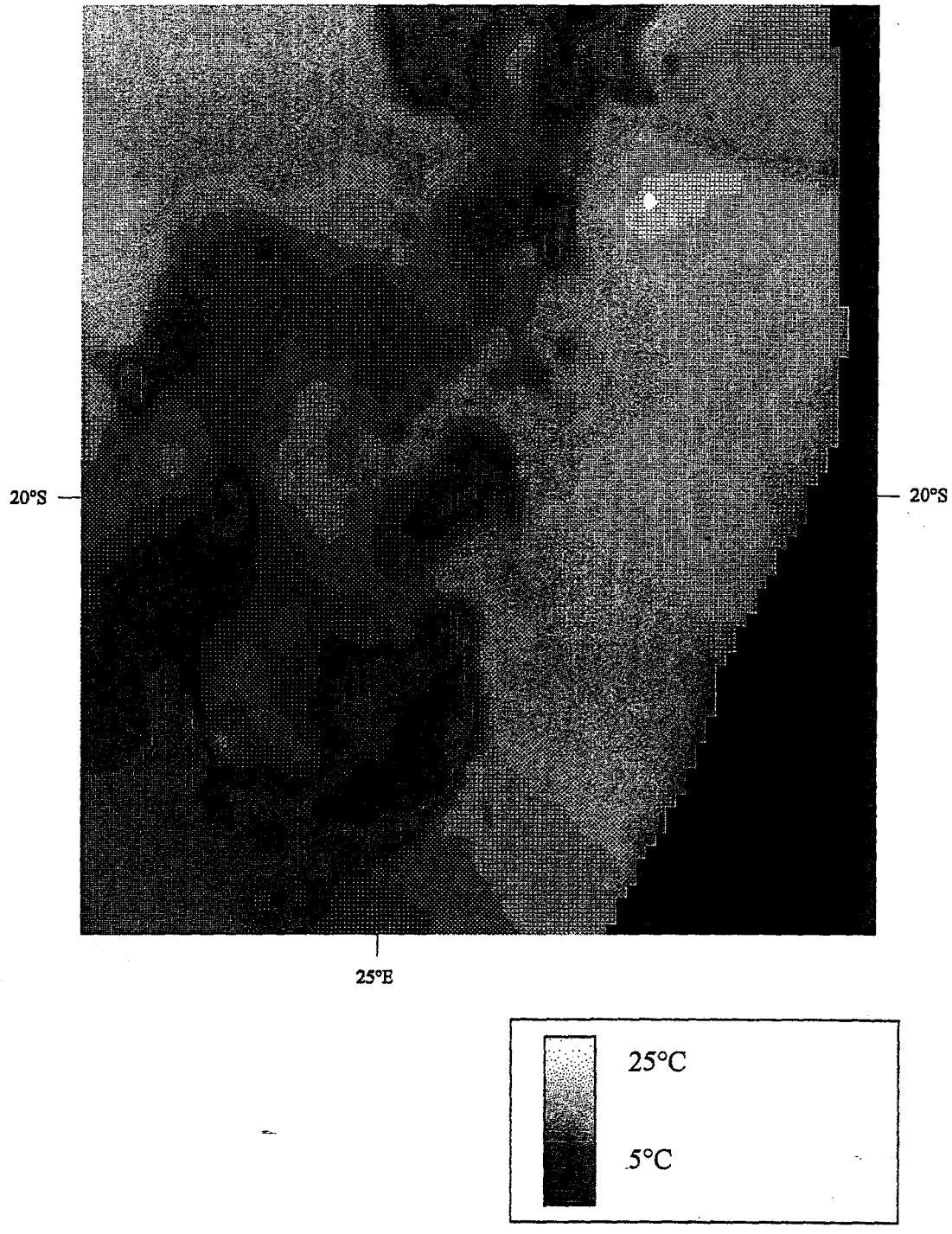


Figure E.191. Digital map layer **tmn_mar** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

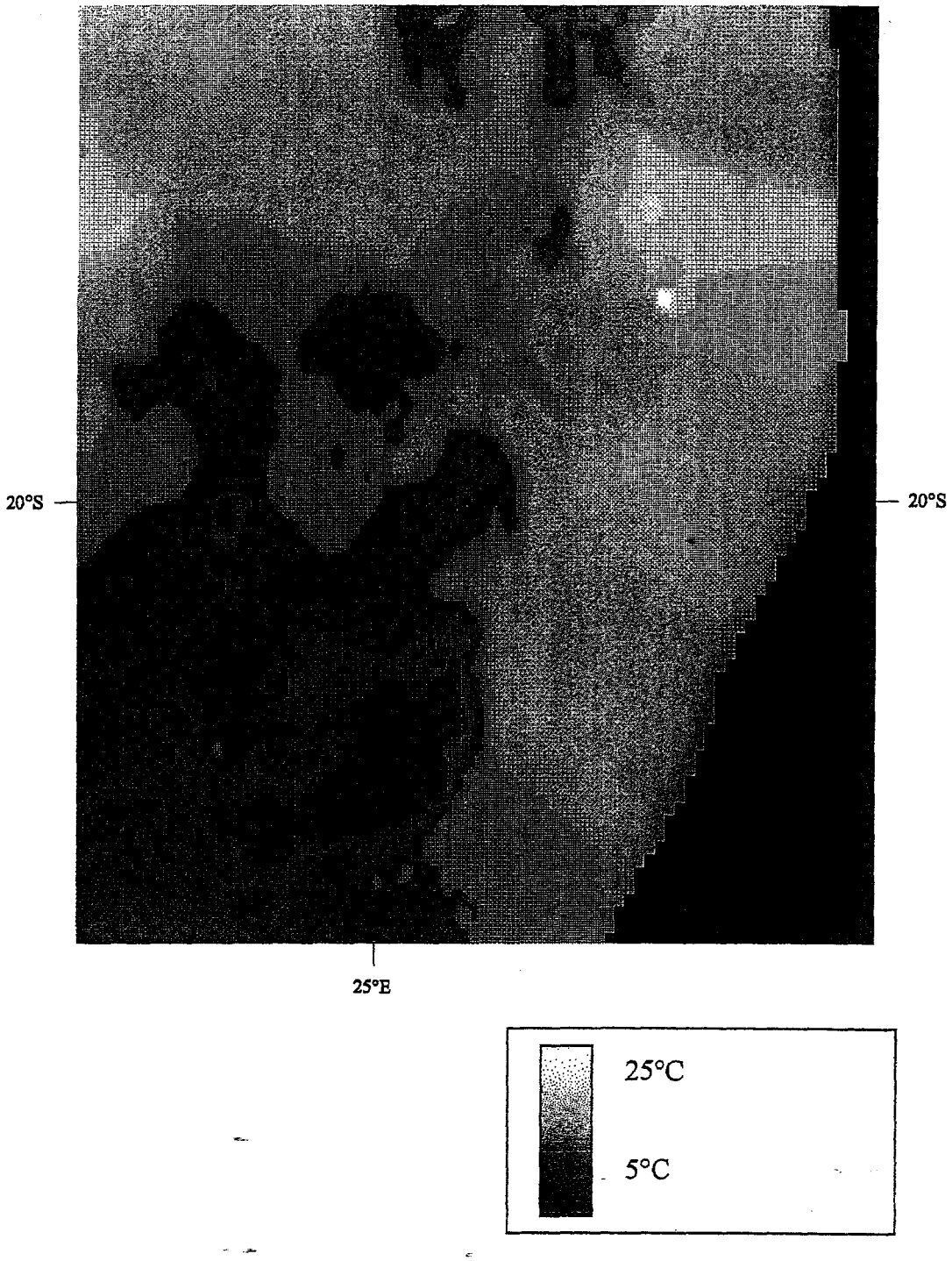


Figure E.192. Digital map layer **tmn_apr** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

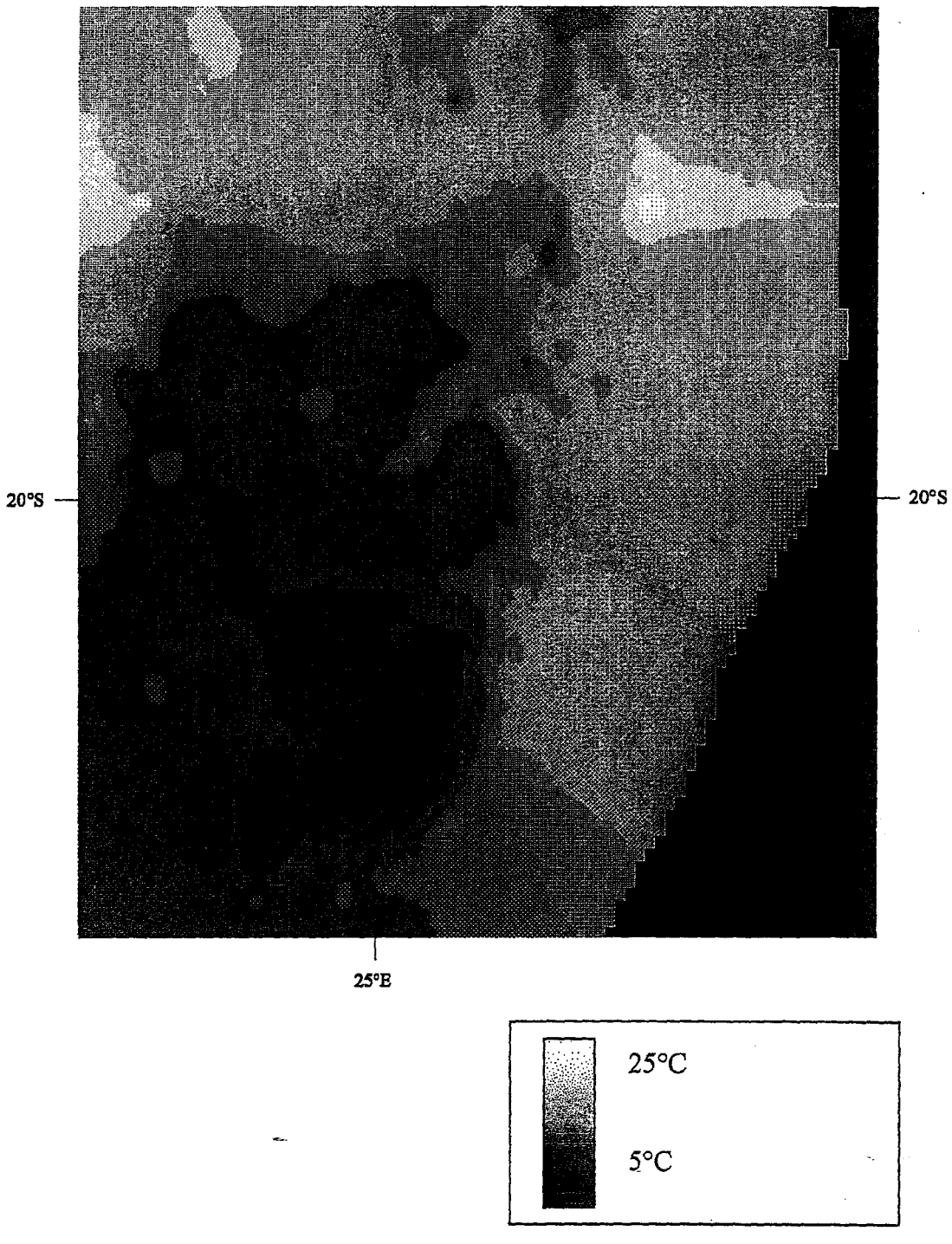


Figure E.193. Digital map layer **tmn_may** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

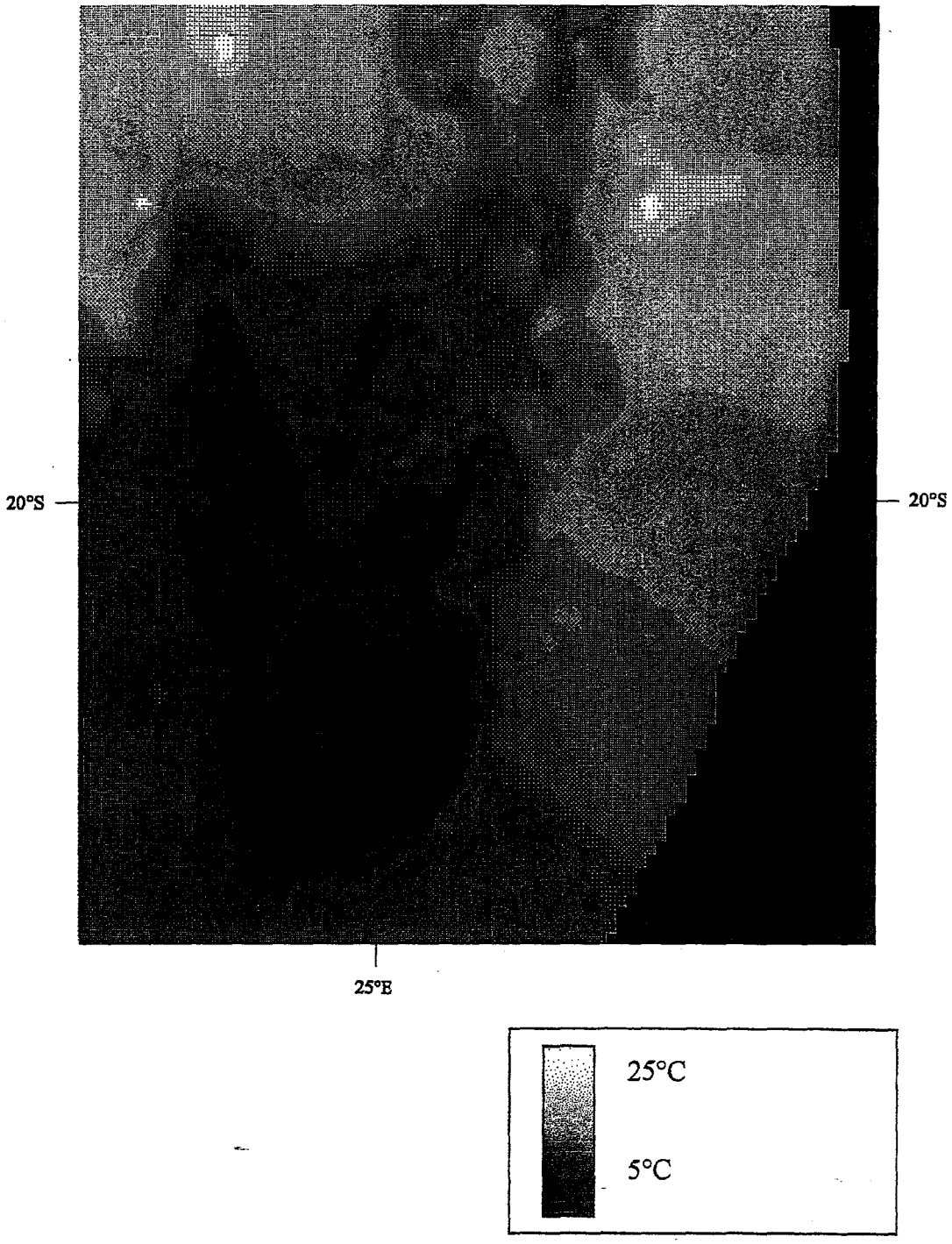


Figure E.194. Digital map layer **tmn_jun** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

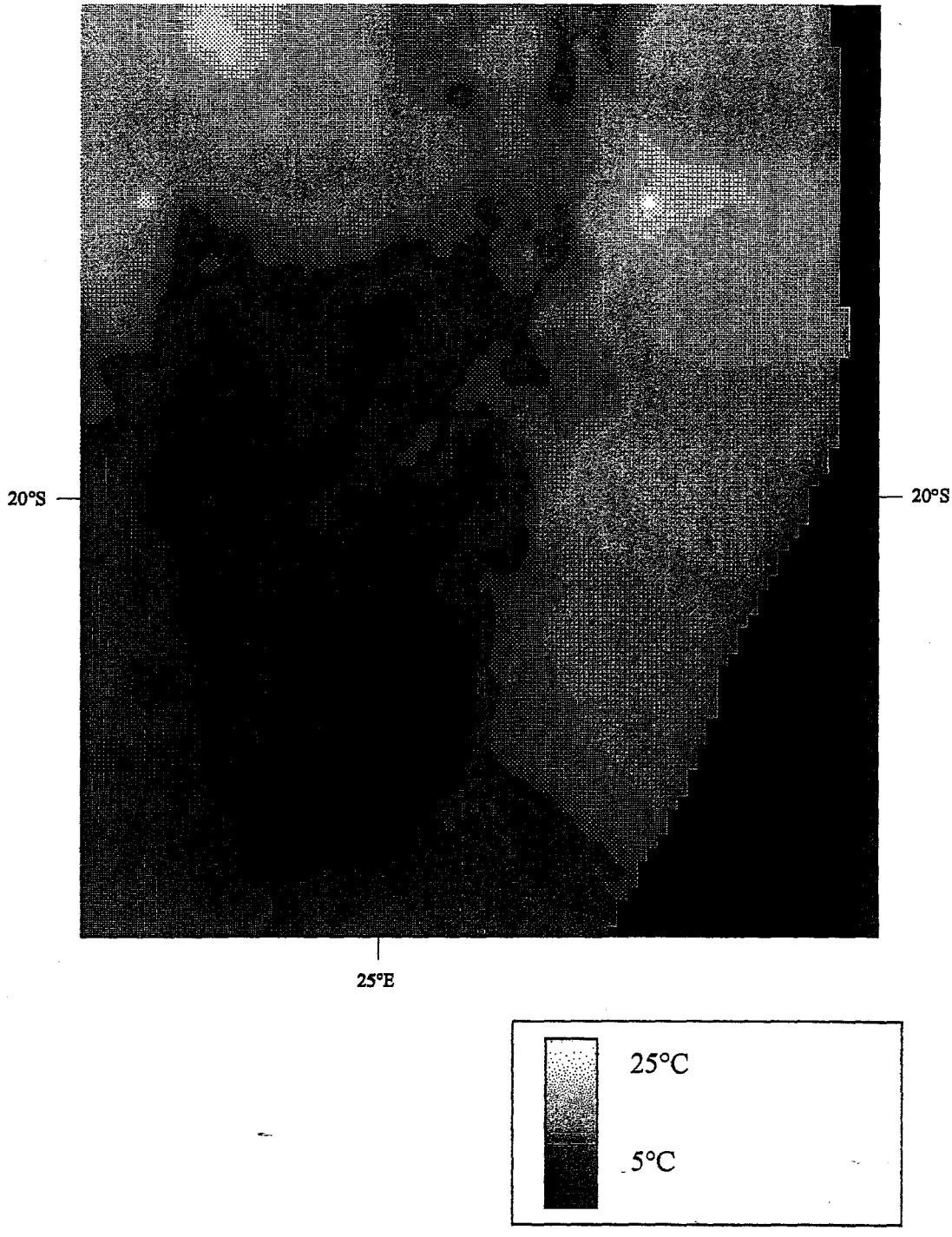


Figure E.195. Digital map layer **tmn_jul** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

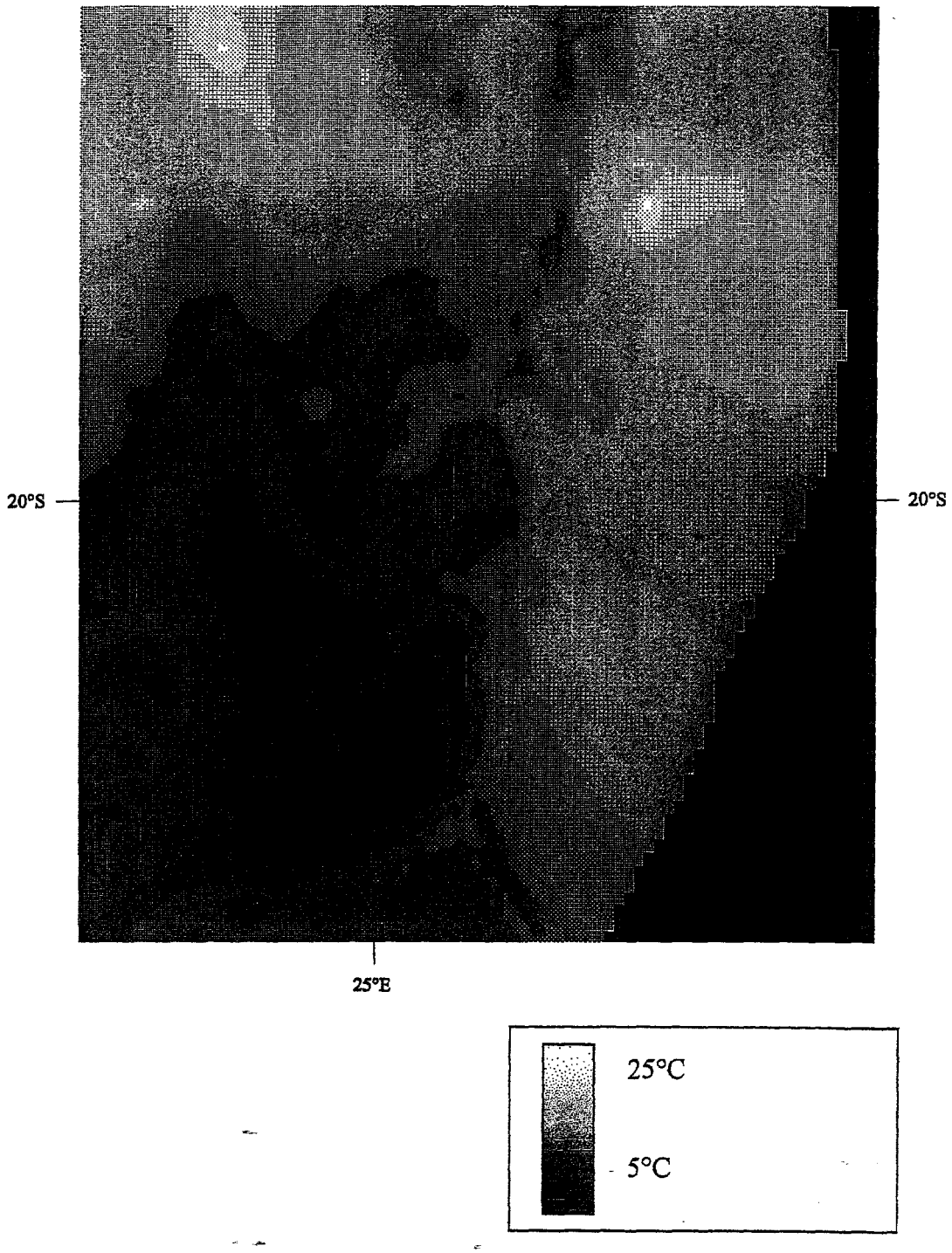


Figure E.196. Digital map layer **tmn_aug** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

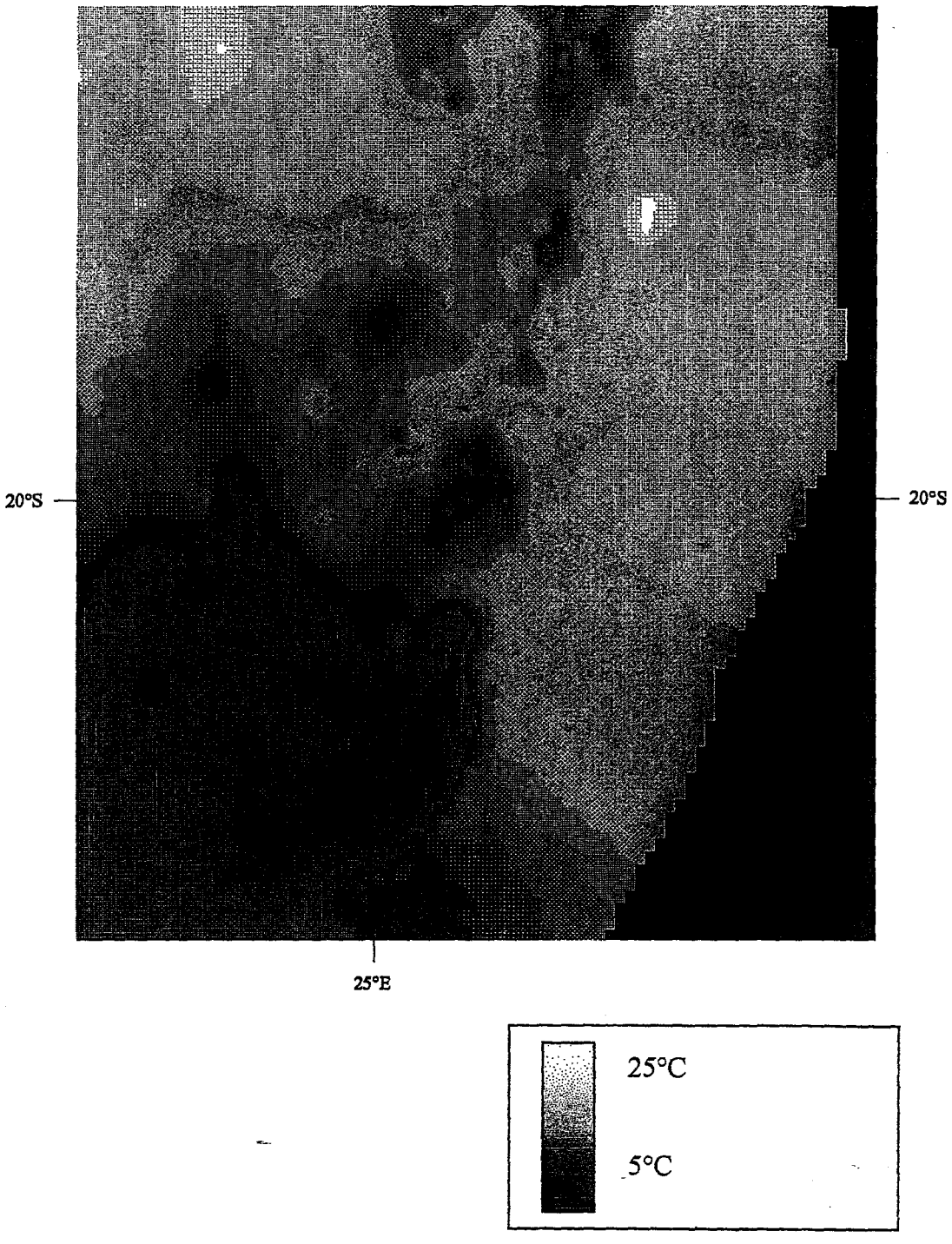


Figure E.197. Digital map layer **tmn_sep** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

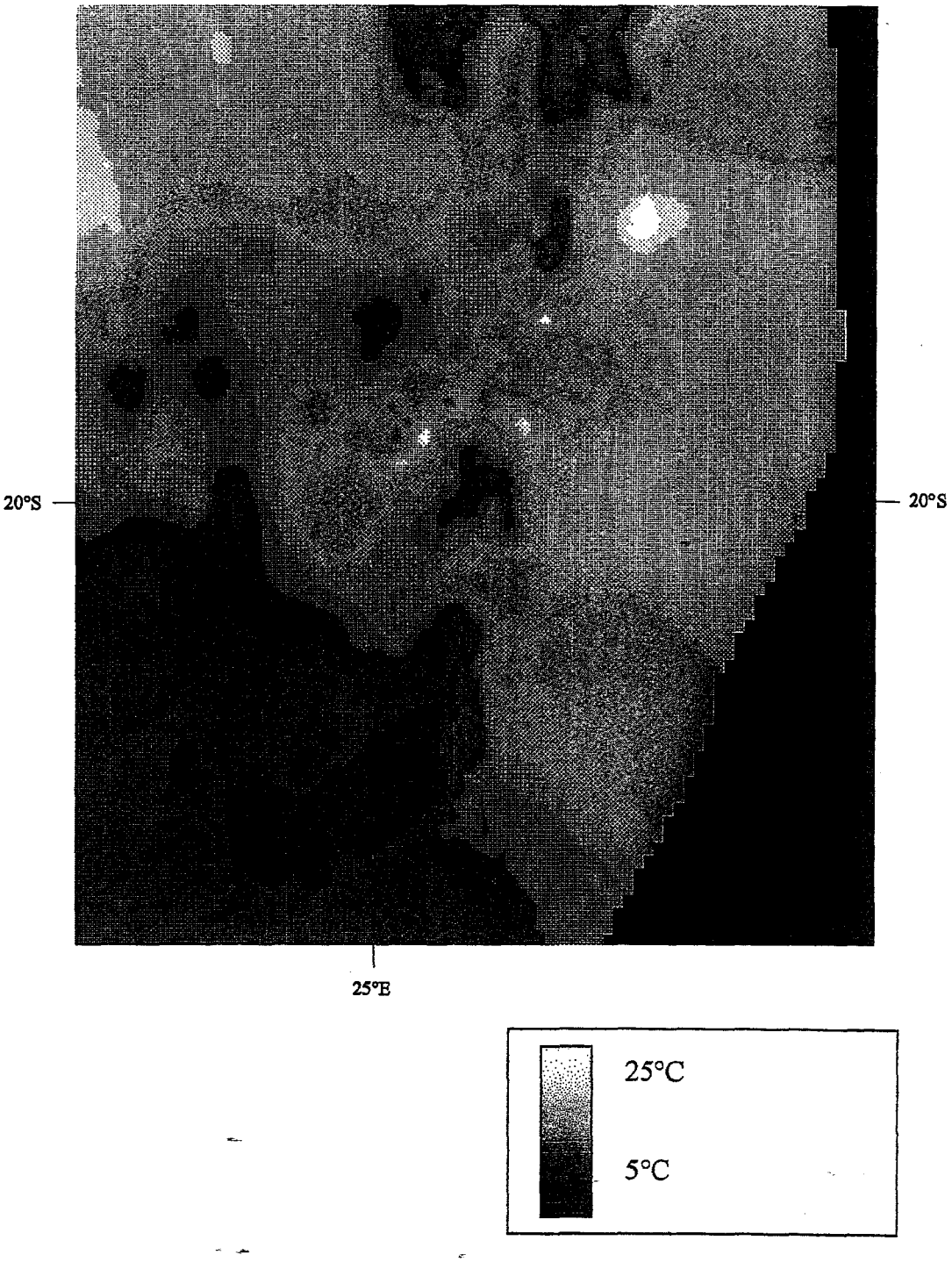


Figure E.198. Digital map layer **tmn_oct** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

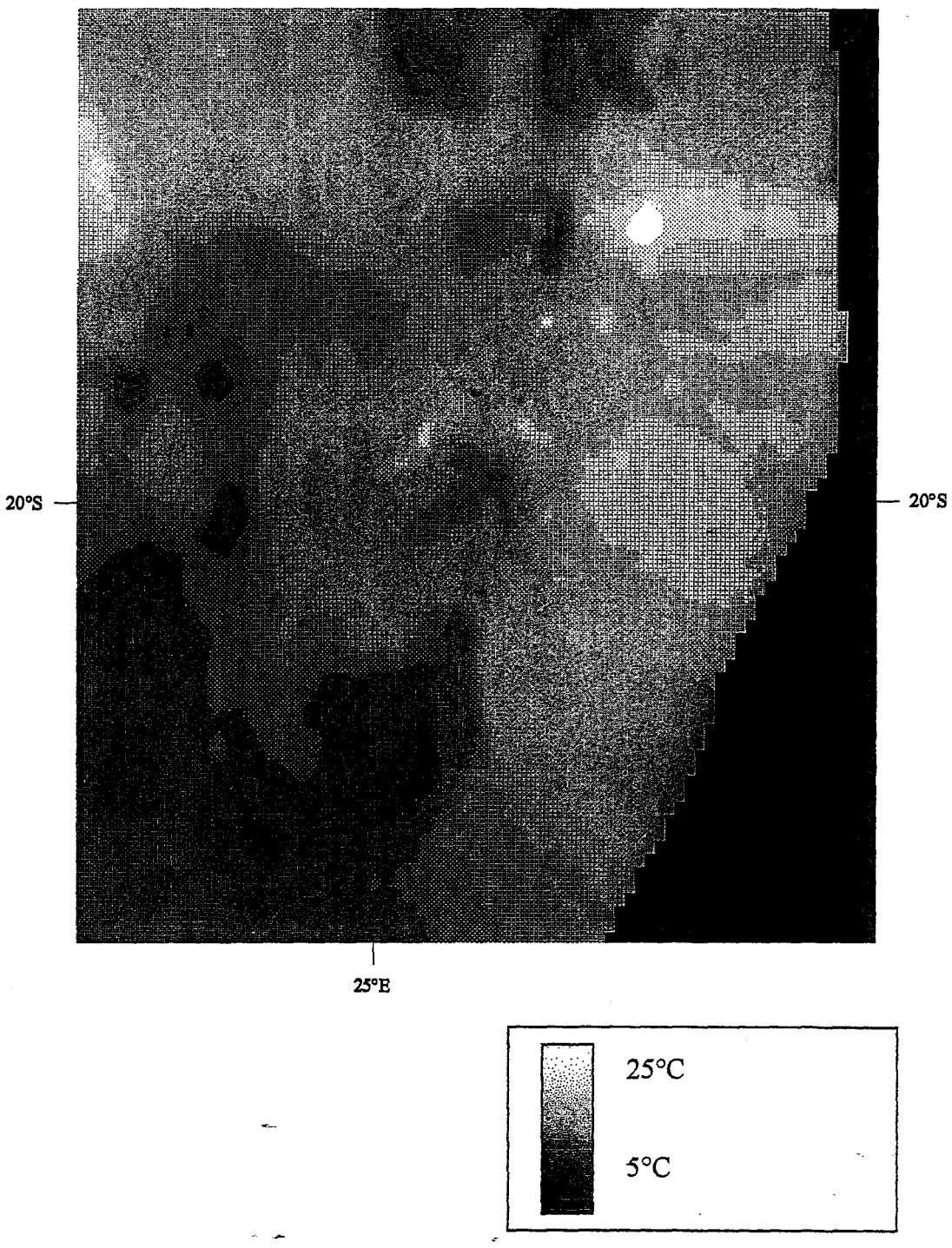


Figure E.199. Digital map layer **tmn_nov** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

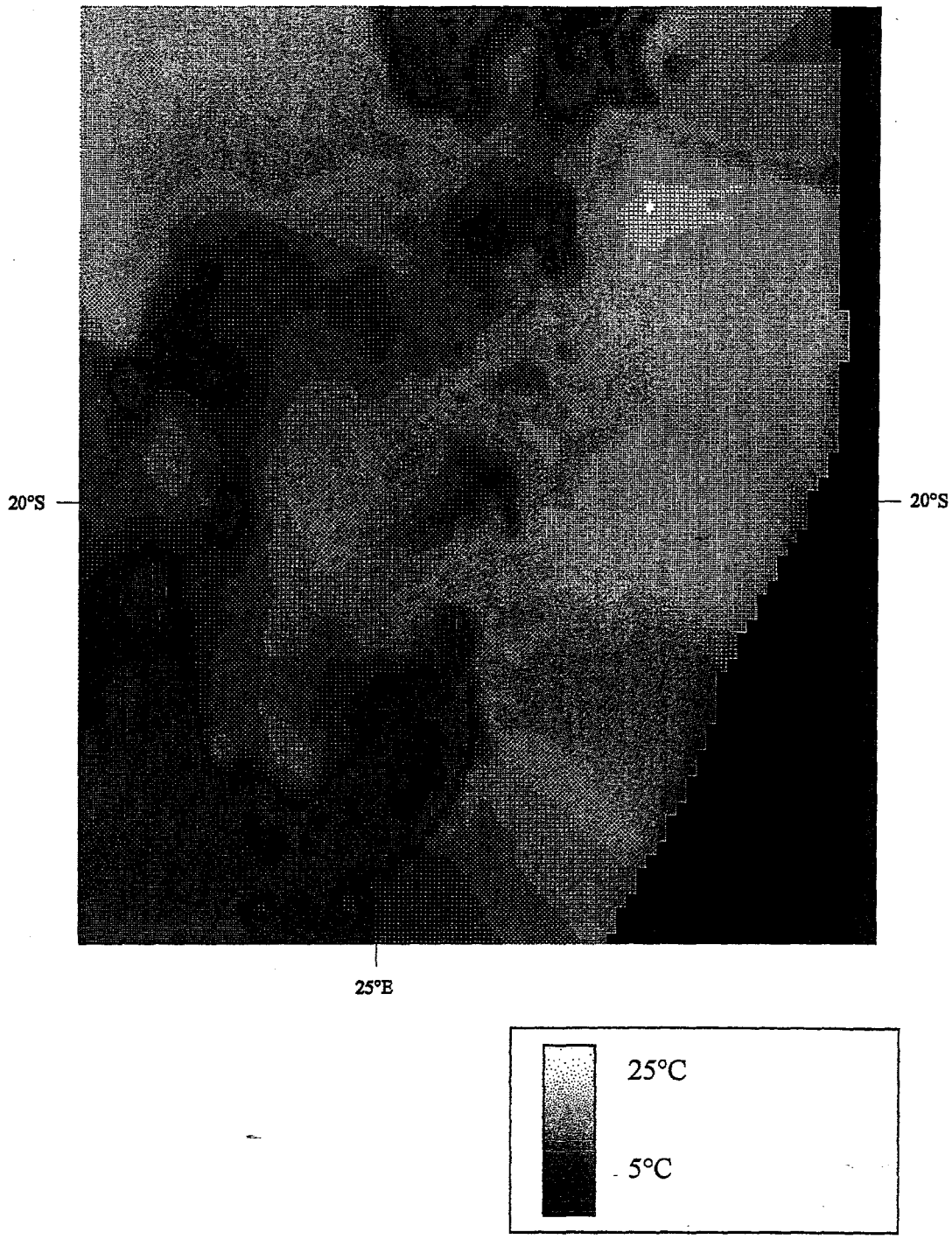


Figure E.200. Digital map layer **tmn_dec** (SADC region, normal minimum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

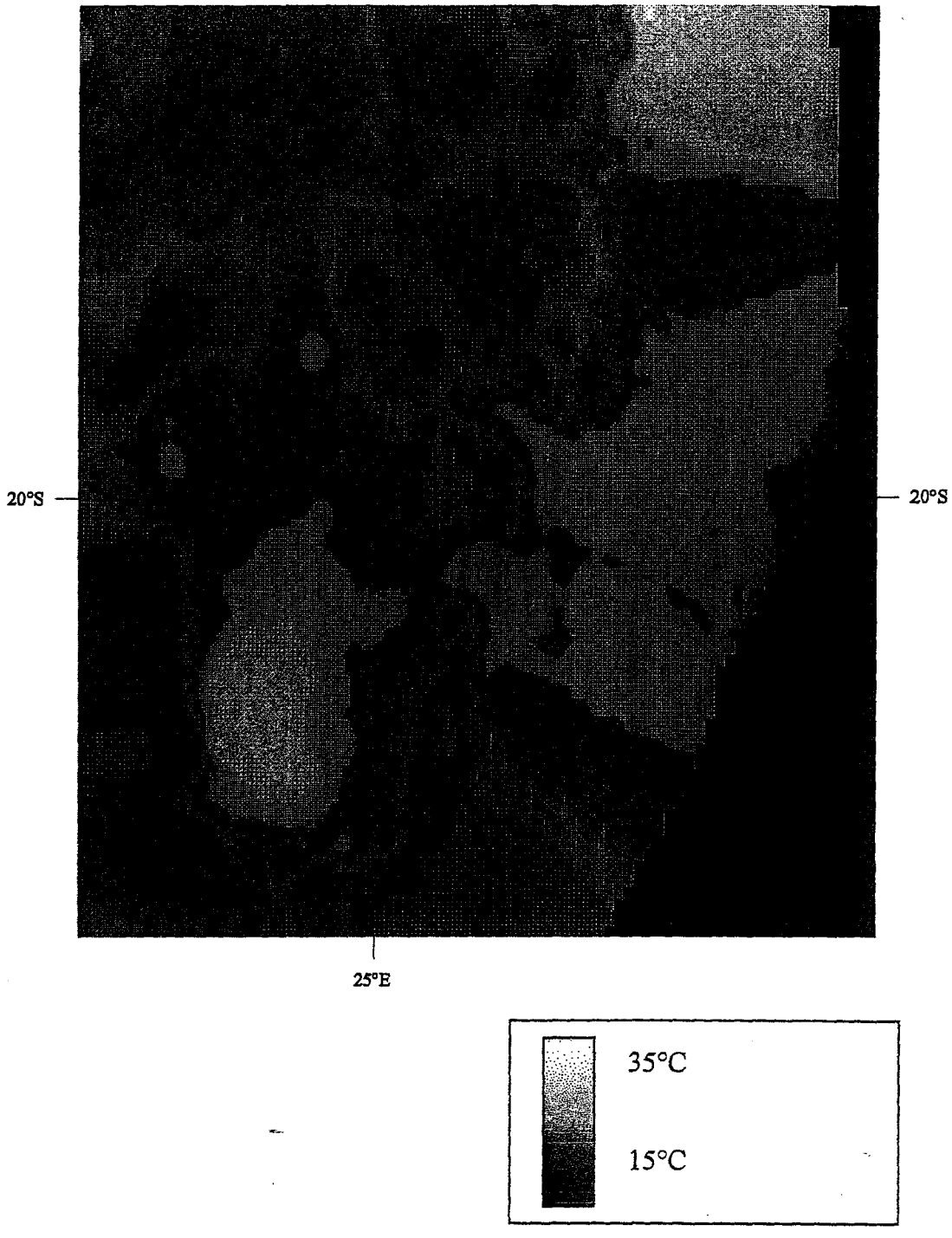


Figure E.201. Digital map layer **tmx_jan** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

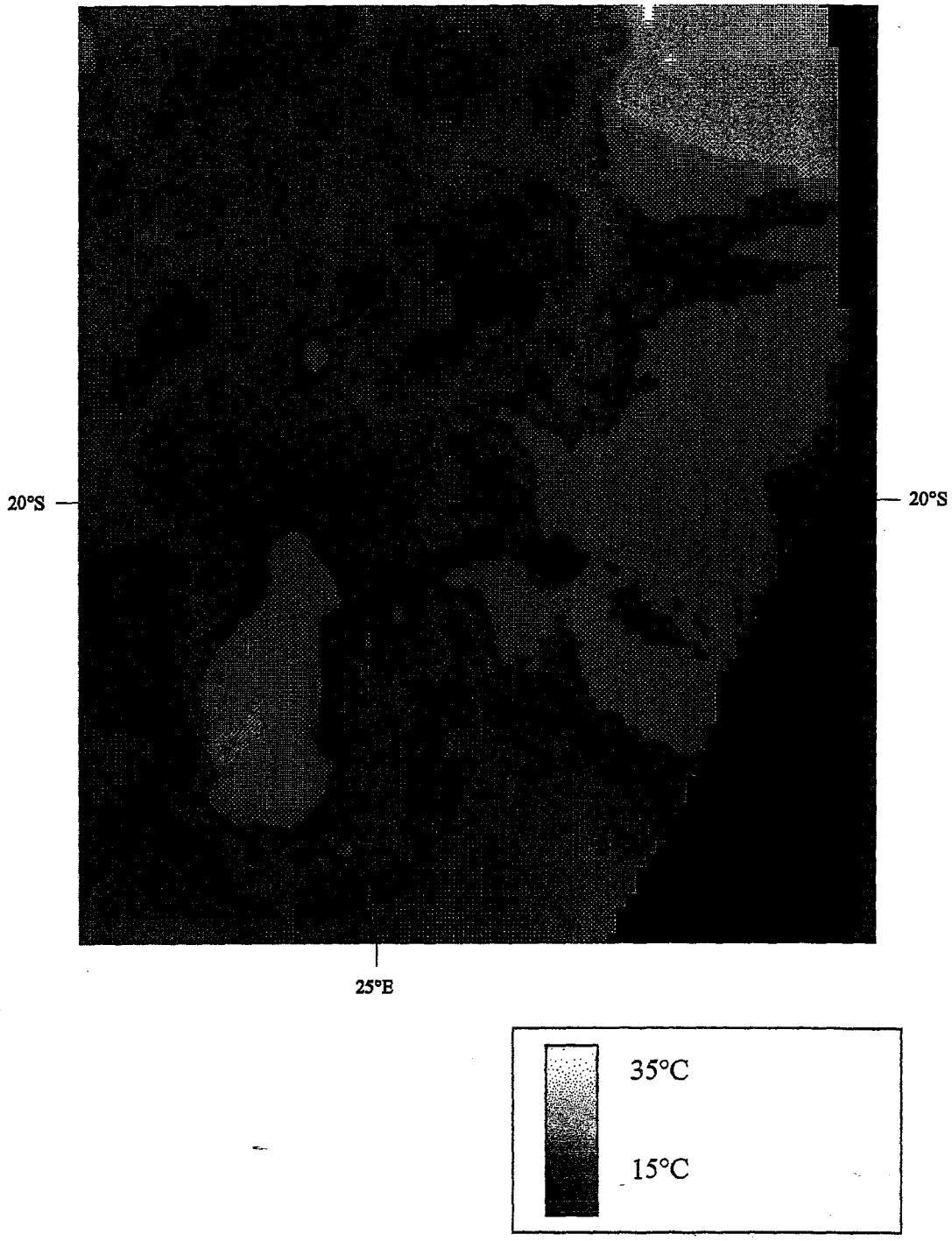


Figure E.202. Digital map layer **tmx_feb** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

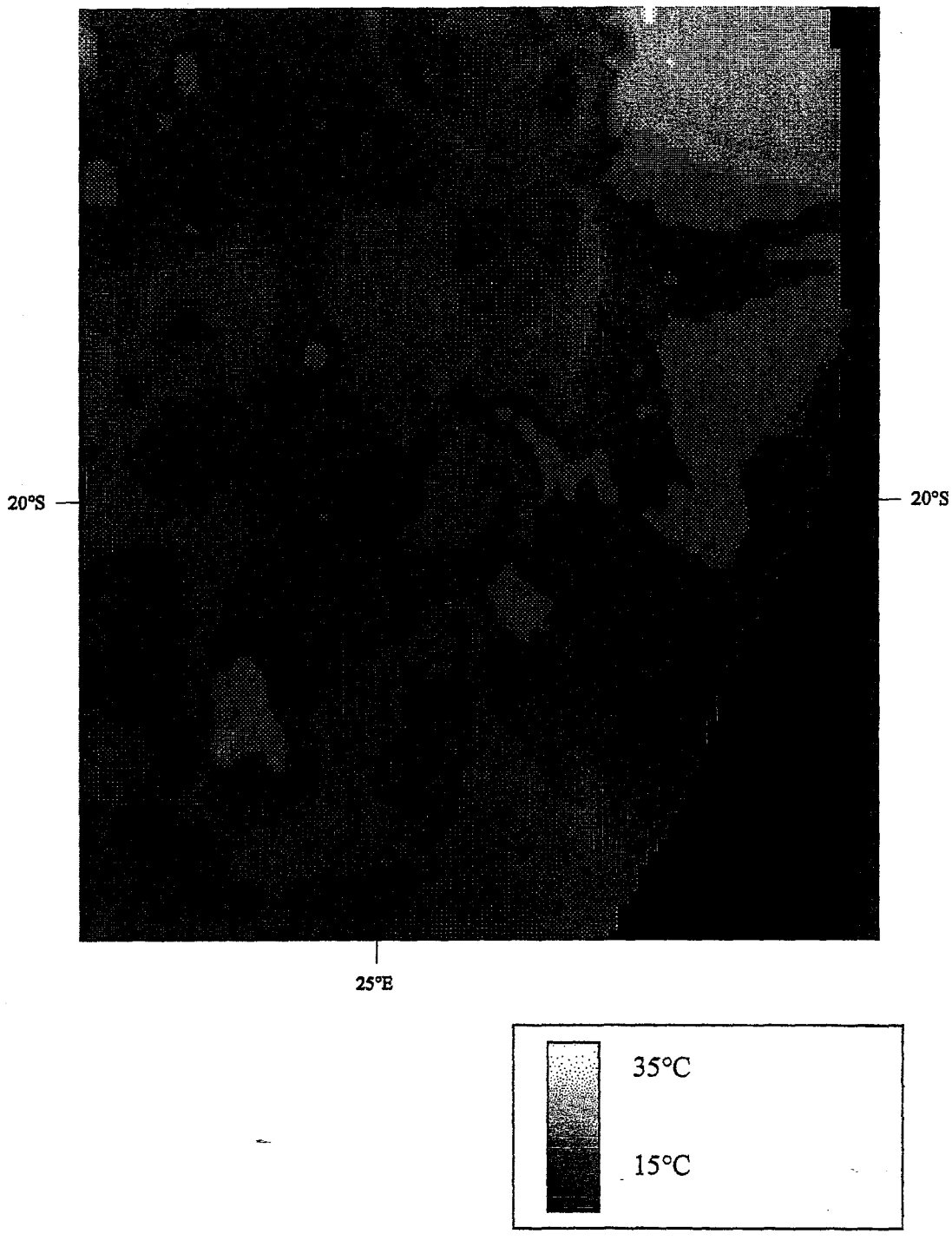


Figure E.203. Digital map layer **tmx_mar** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

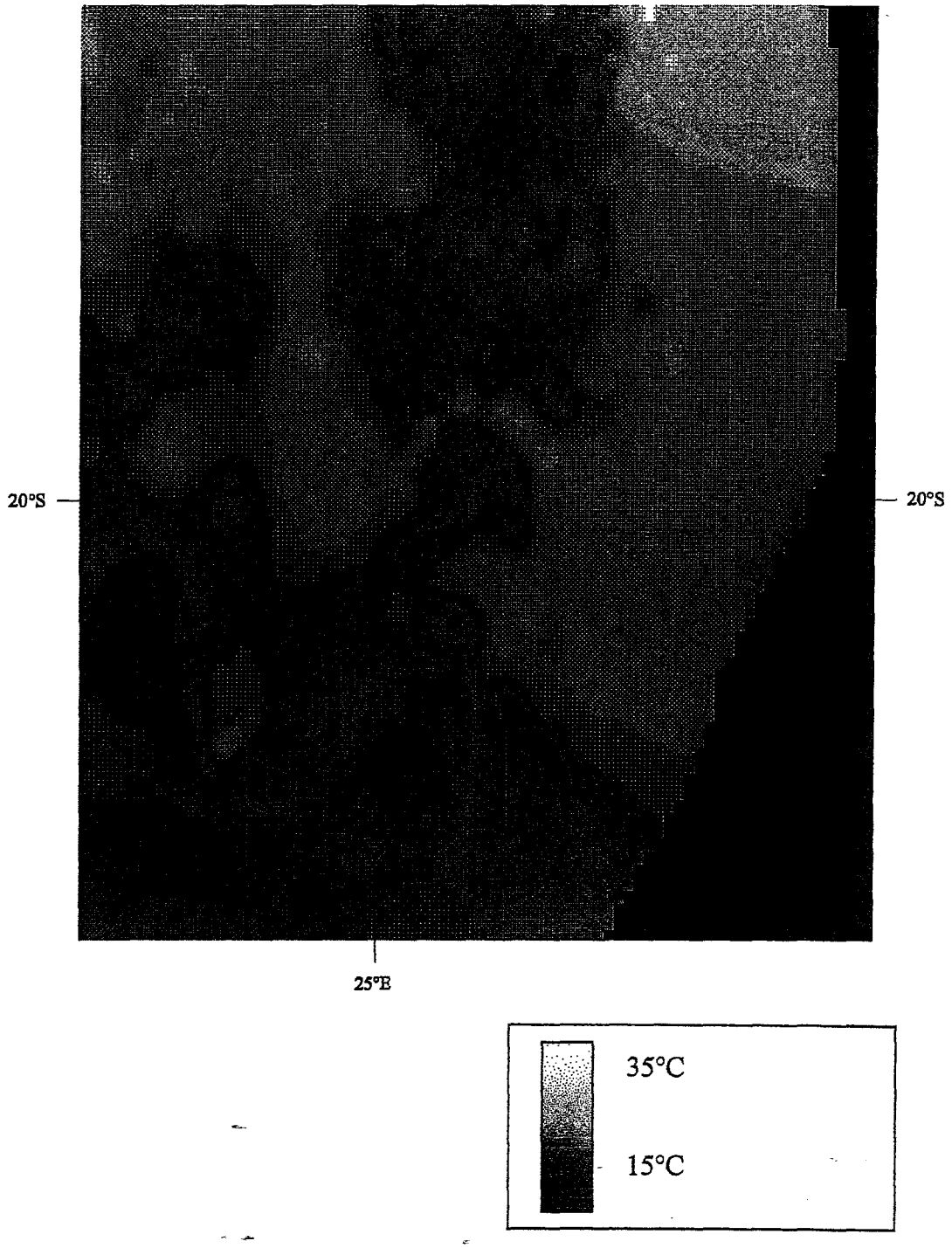


Figure E.204. Digital map layer **tmx_apr** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

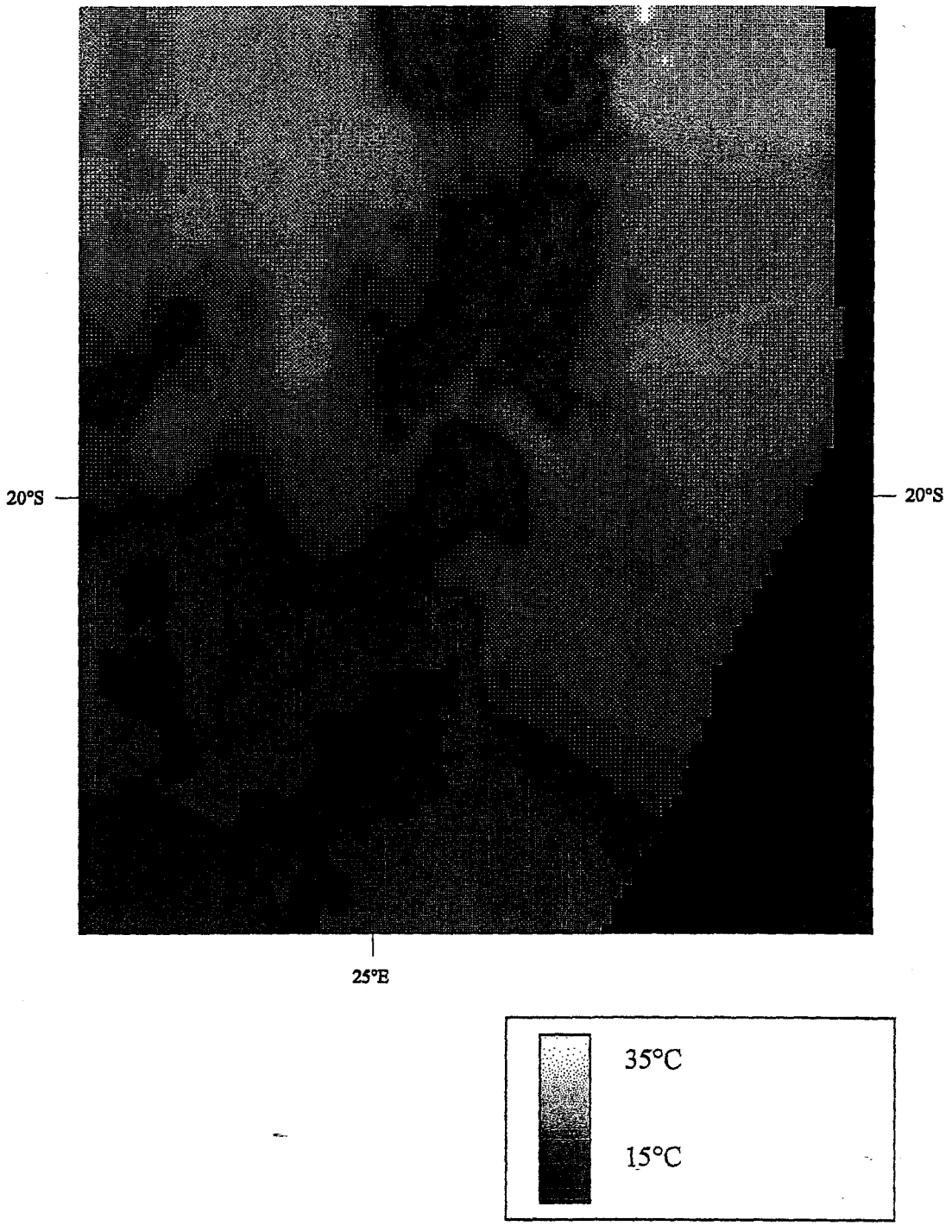


Figure E.205. Digital map layer **tmx_may** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

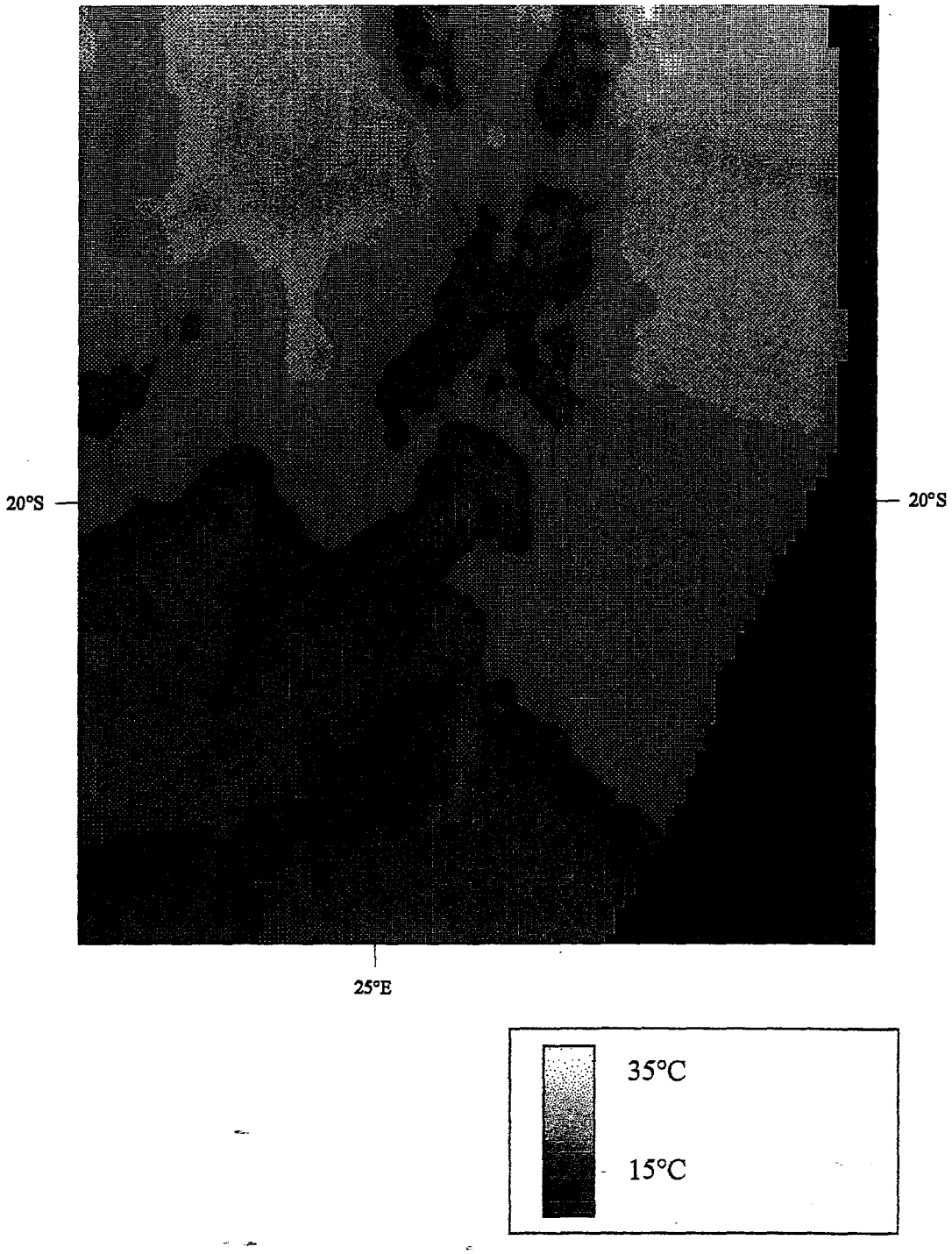


Figure E.206. Digital map layer **tmx_jun** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

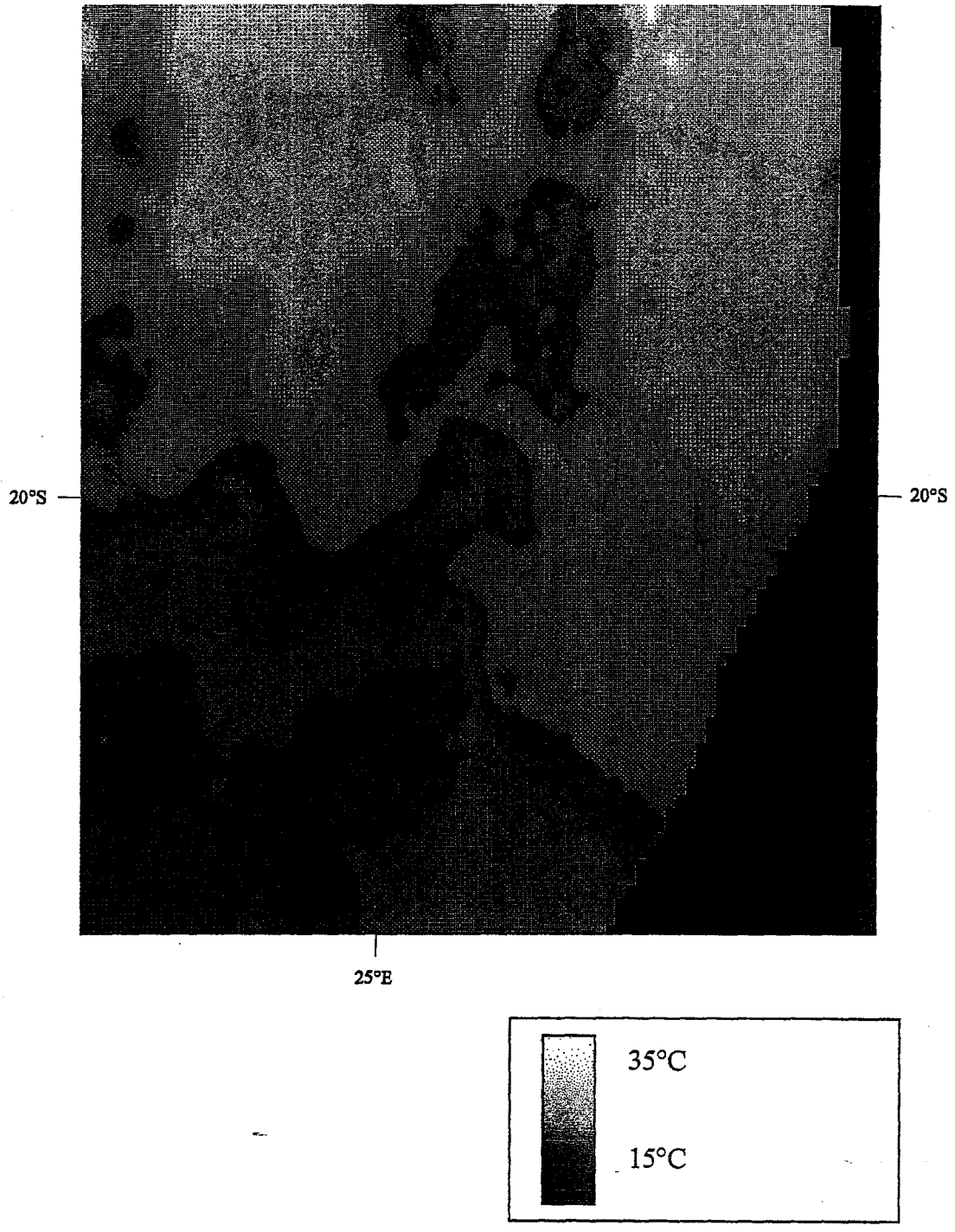


Figure E.207. Digital map layer **tmx_jul** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

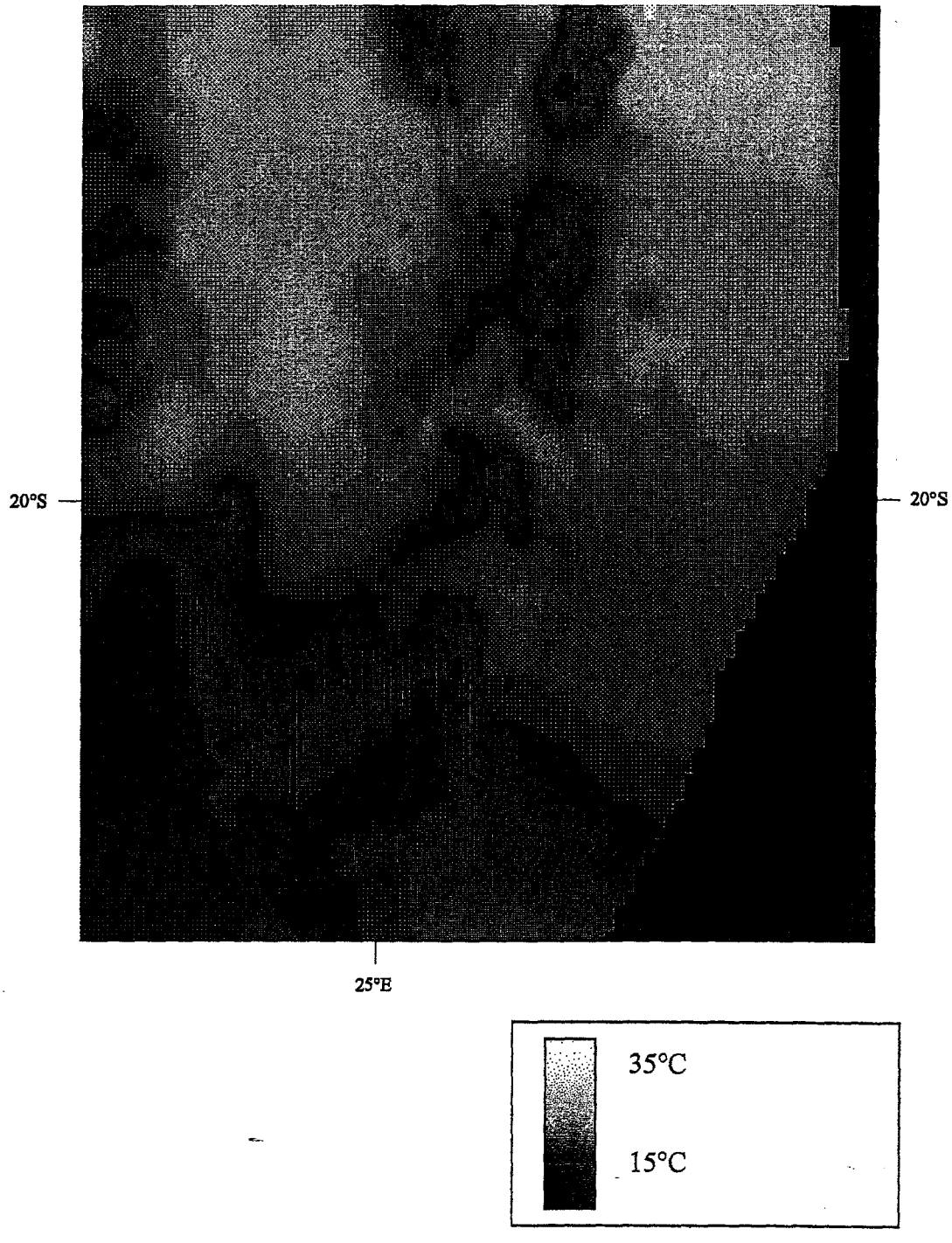


Figure E.208. Digital map layer **tmx_aug** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

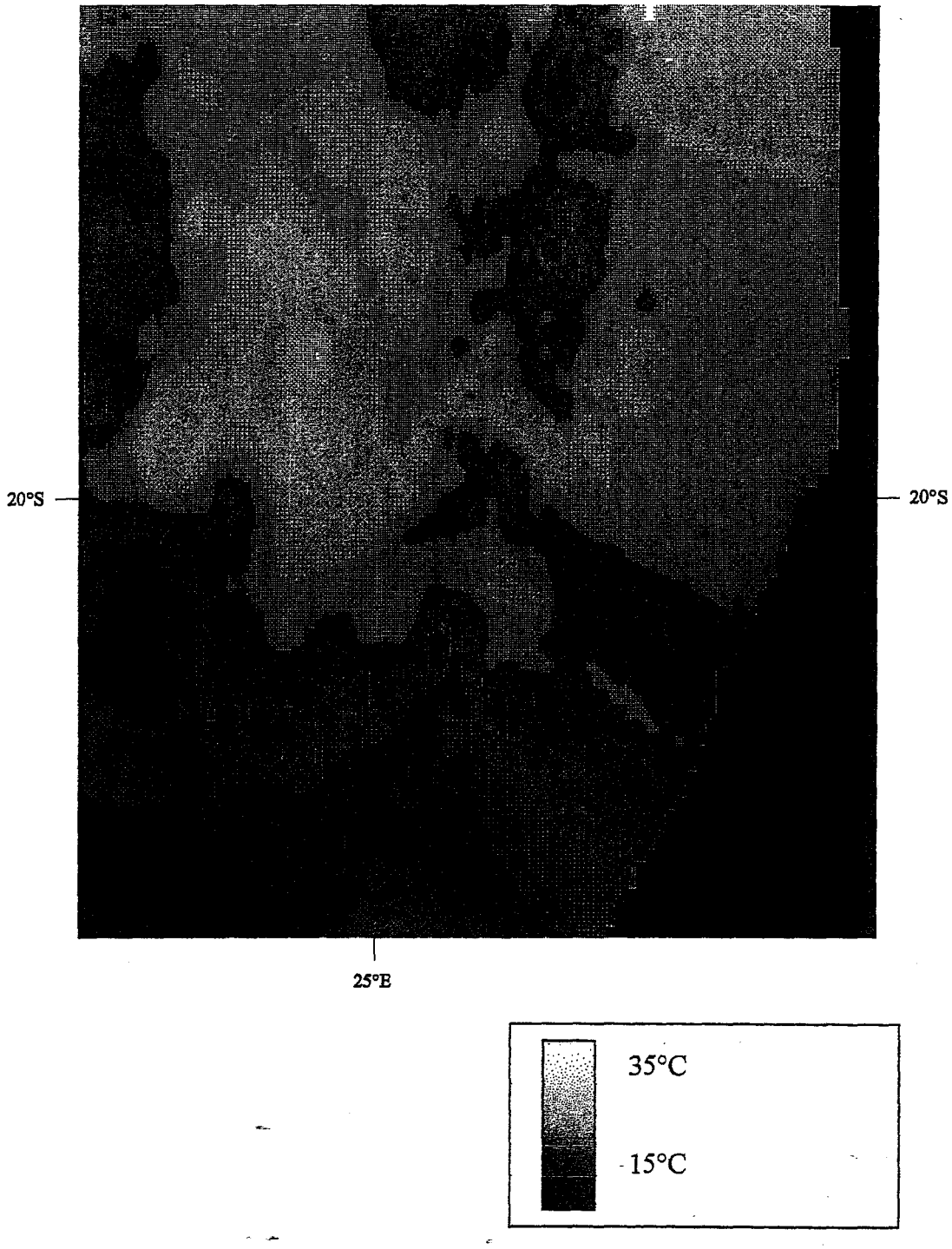


Figure E.209. Digital map layer **tmx_sep** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

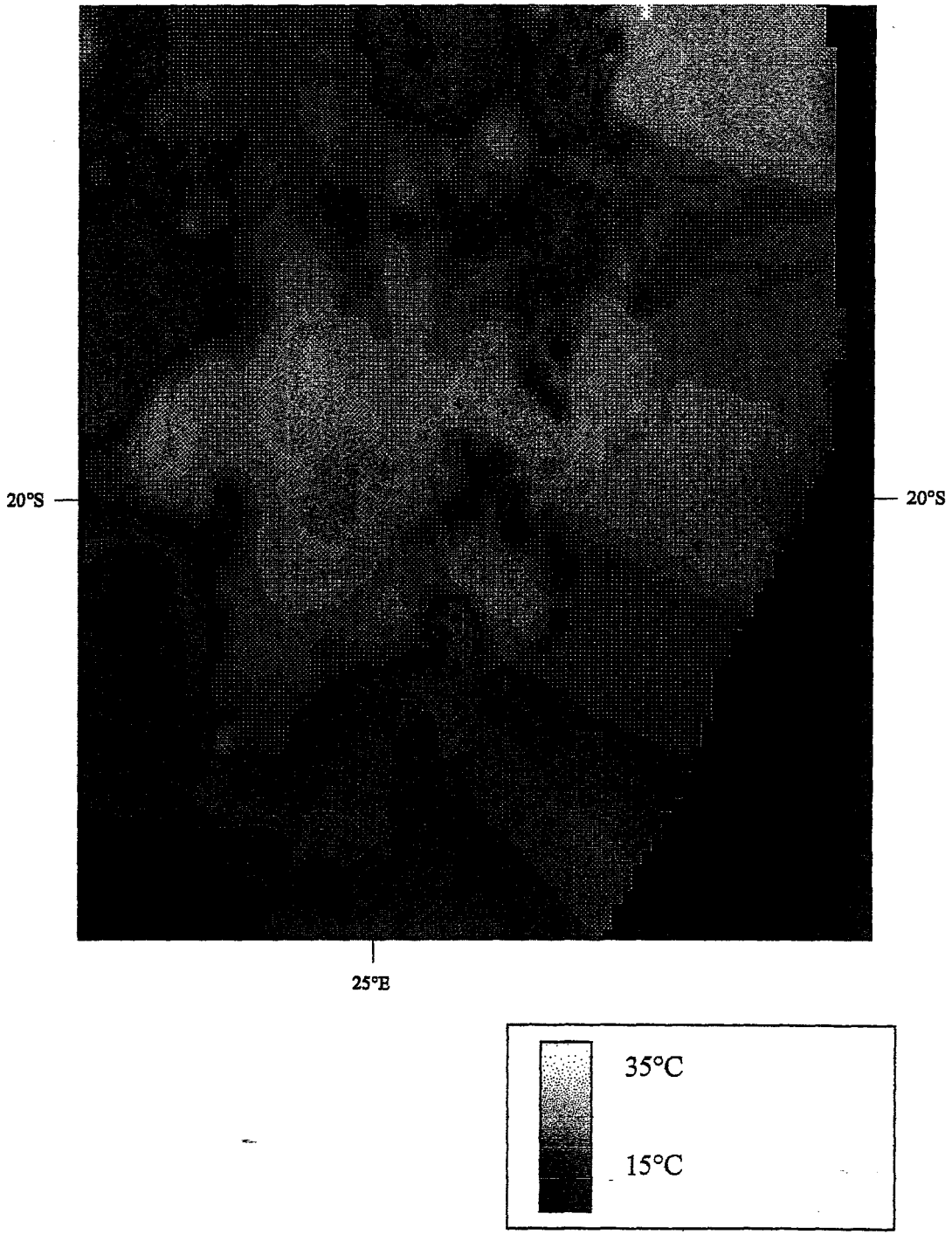


Figure E.210. Digital map layer **tmx_oct** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

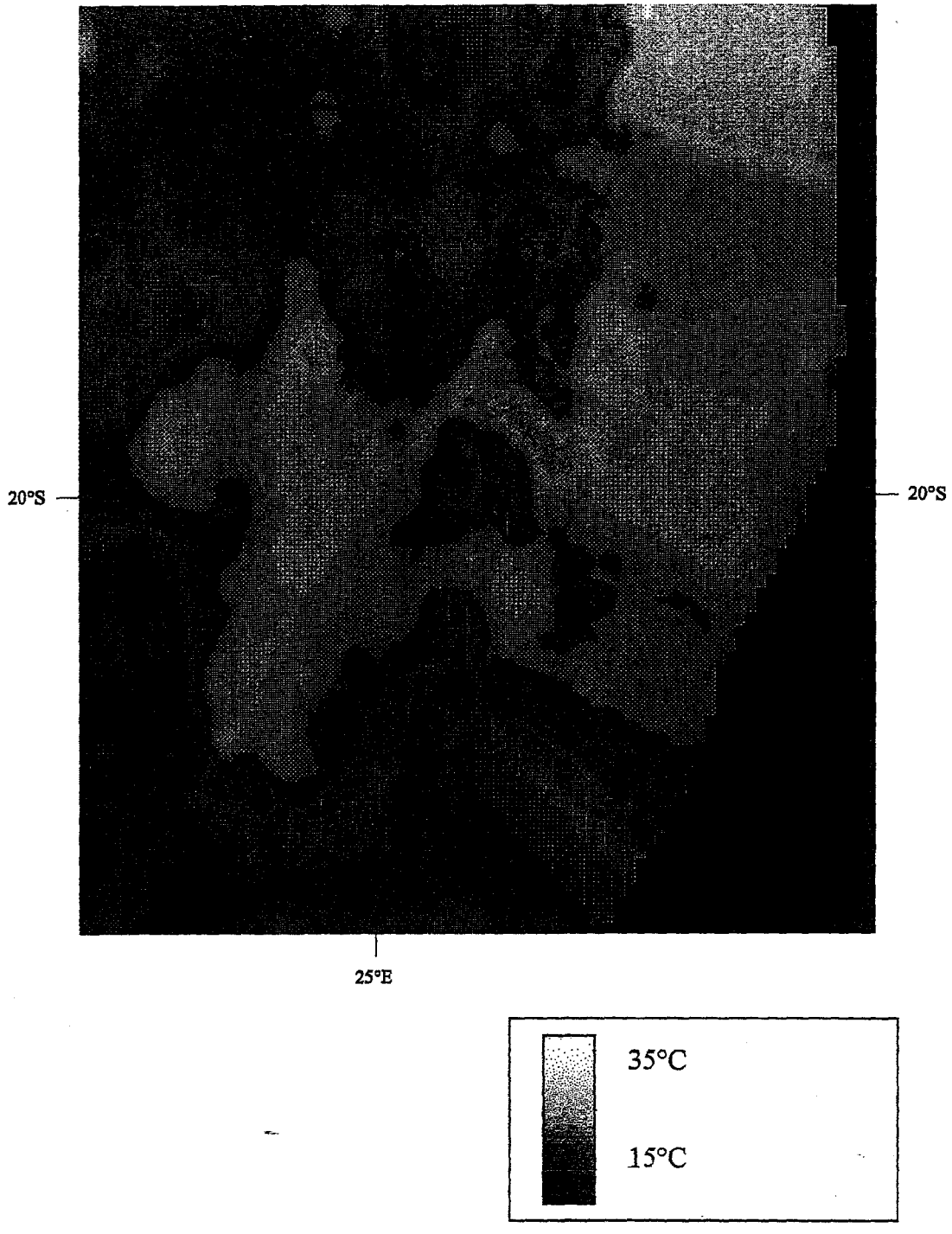


Figure E.211. Digital map layer **tmx_nov** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

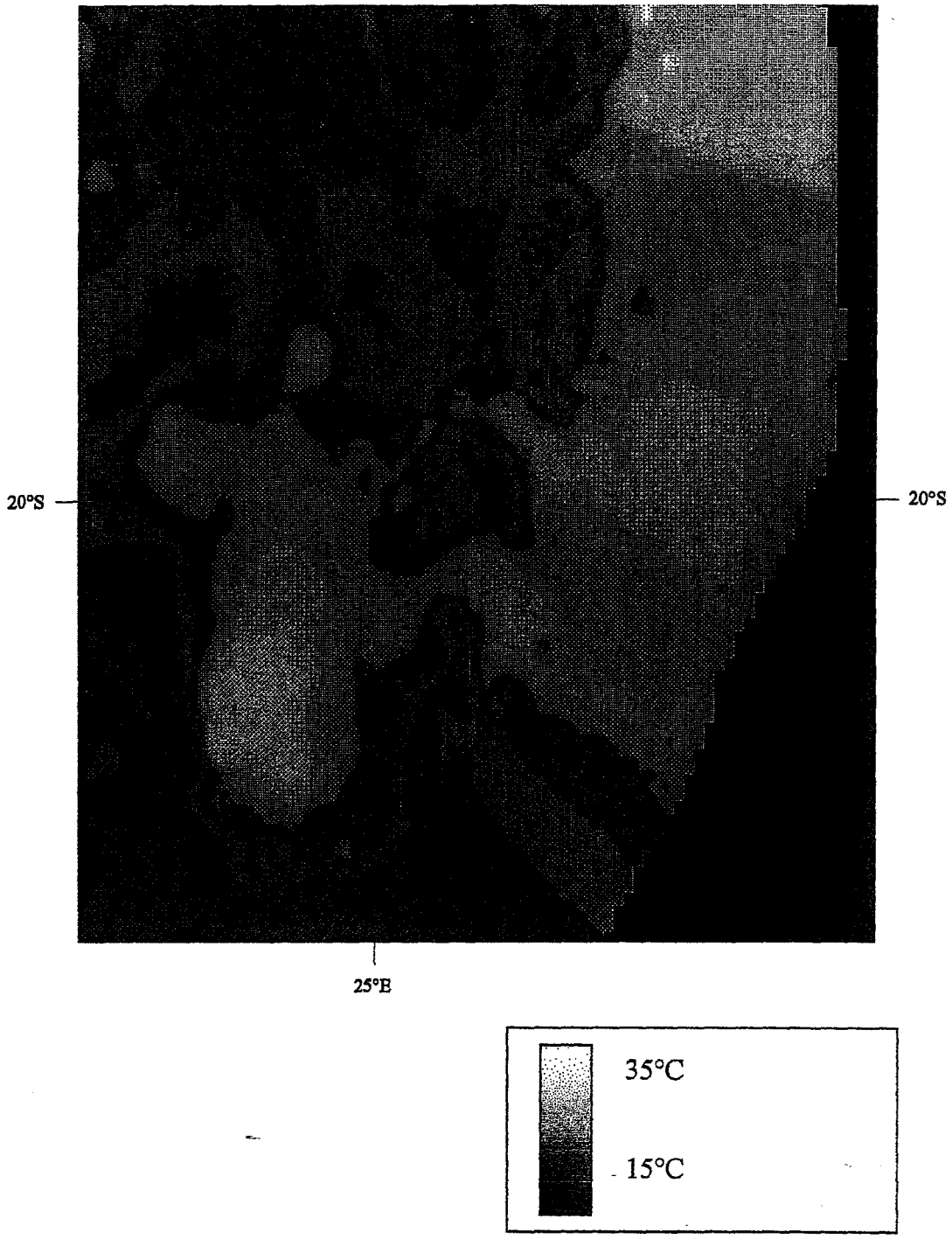
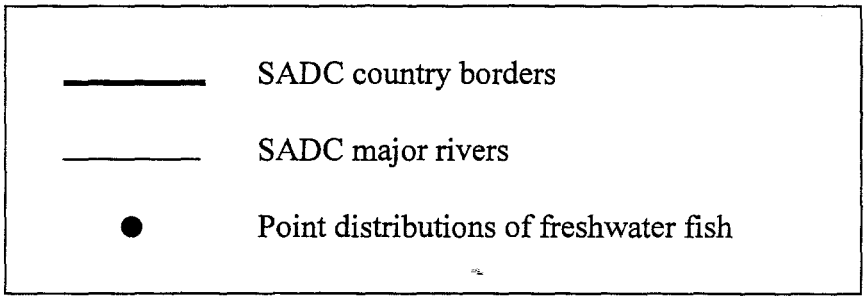


Figure E.212. Digital map layer **tmx_dec** (SADC region, normal maximum temperature surfaces) from the atlas of southern African freshwater fish. Scale approximately 1:30 000 000

APPENDIX F

FRESHWATER FISH POINT DISTRIBUTIONS MAPPED WITH THE ATLAS

The national borders and major rivers of all SADC countries are included in each figure to give a frame of reference to the freshwater fish point distributions. The positions of the points on the maps may represent multiple collections.



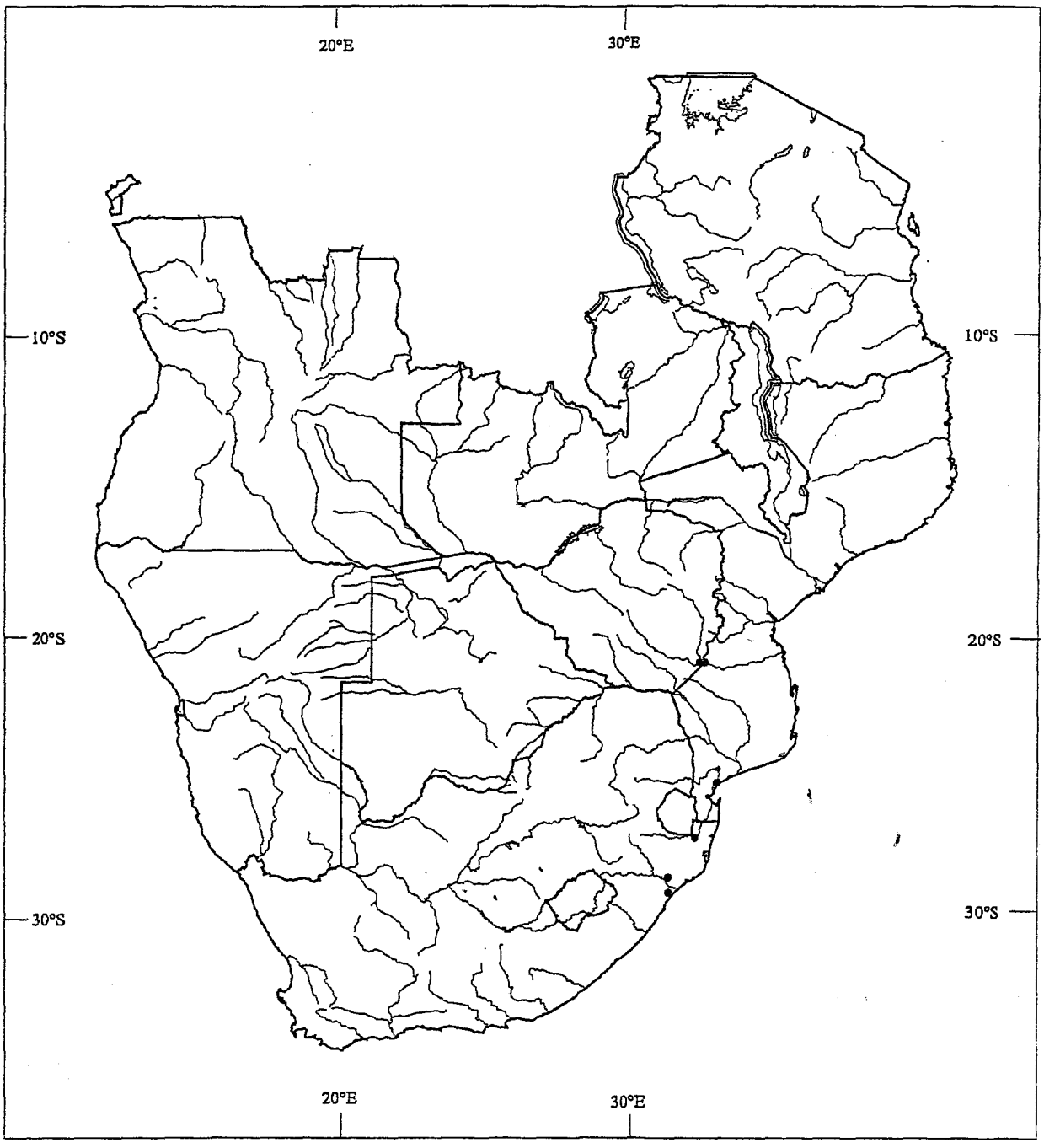


Figure F.1. Point distribution of *Acanthopagrus berda*. Scale approximately 1:25 000 000

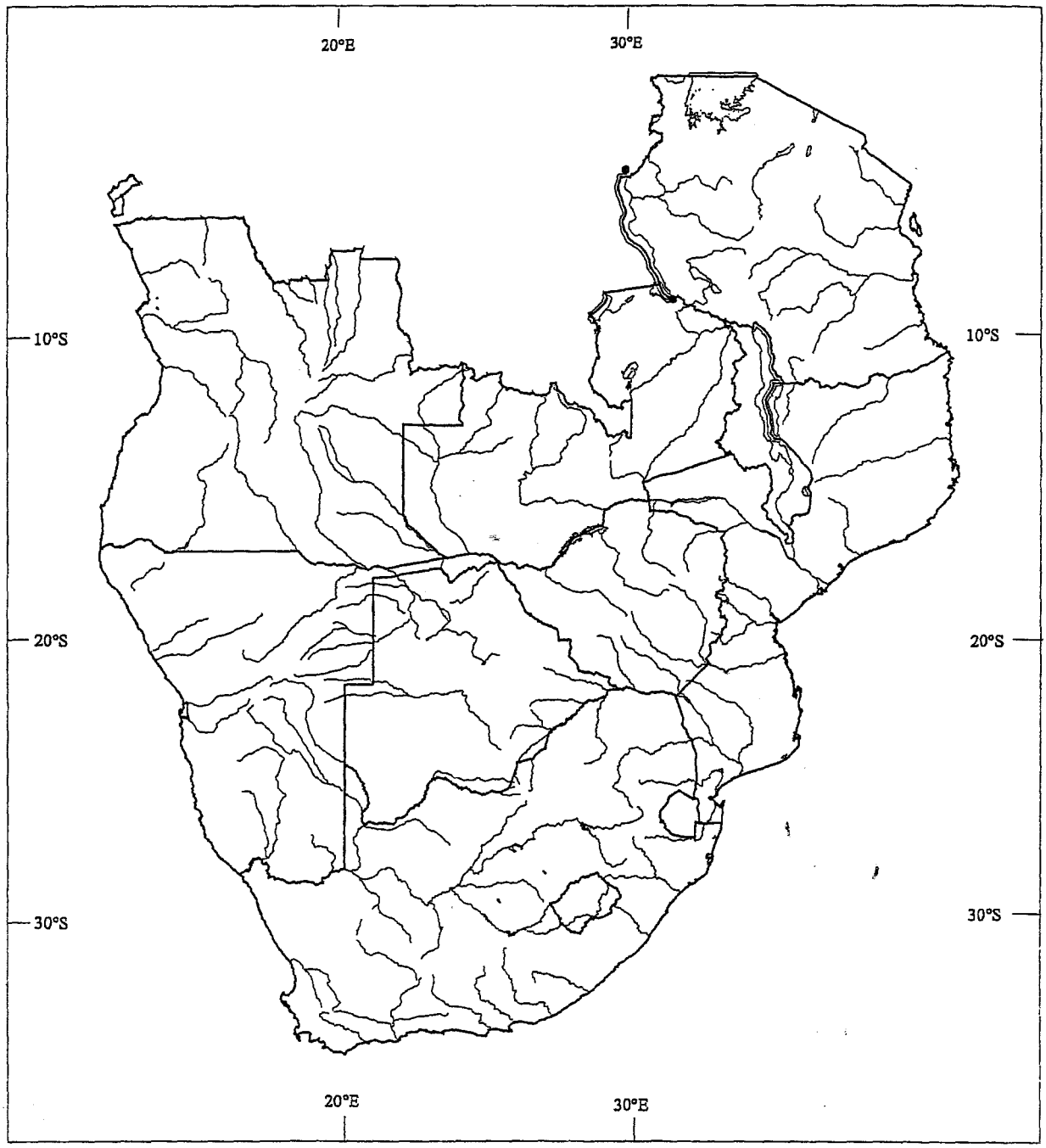


Figure F.2. Point distribution of *Acapoeta tanganicae*. Scale approximately 1:25 000 000

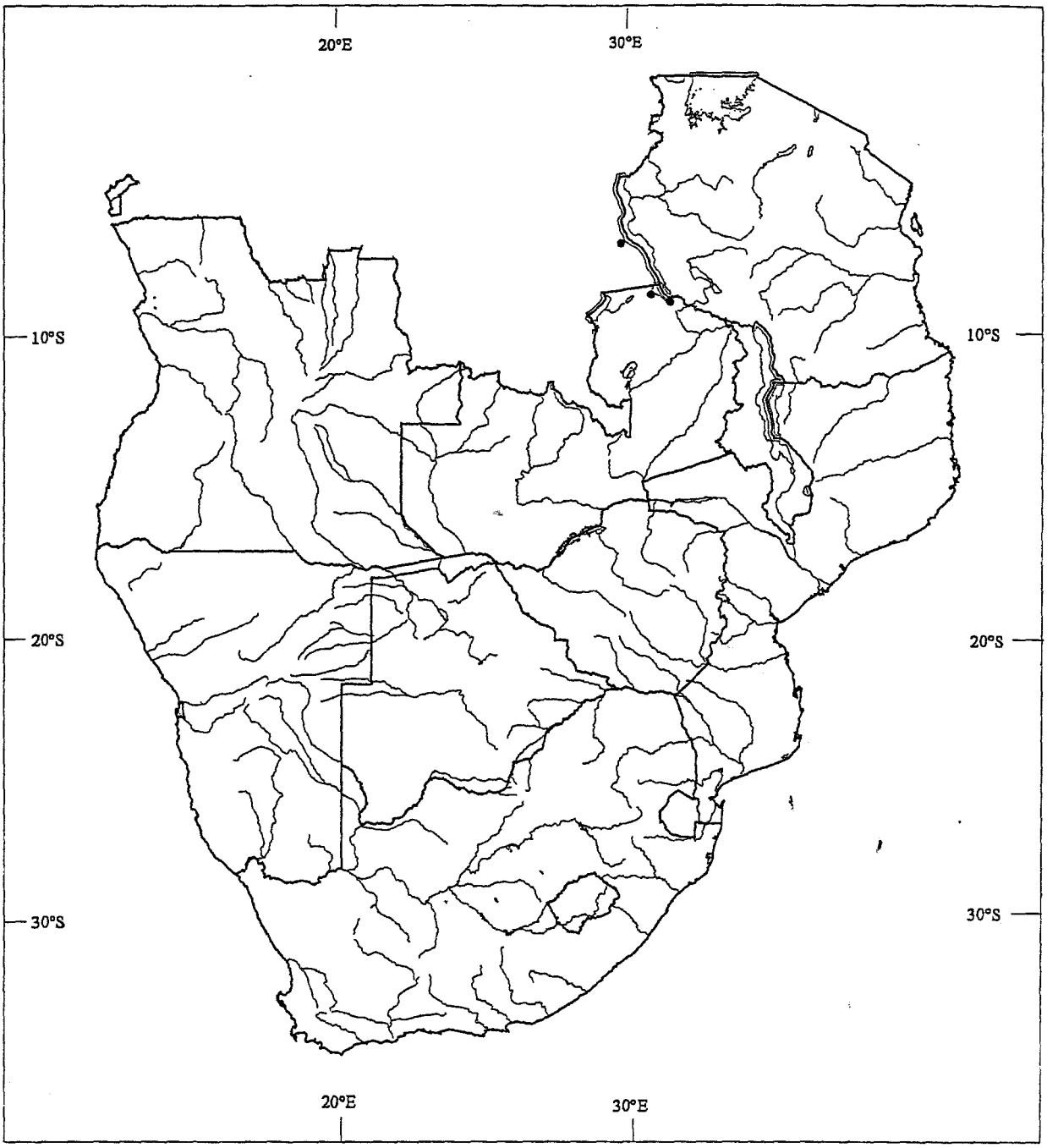


Figure F.3. Point distribution of *Aethiomastacembelus albomaculatus*. Scale approximately 1:25 000 000

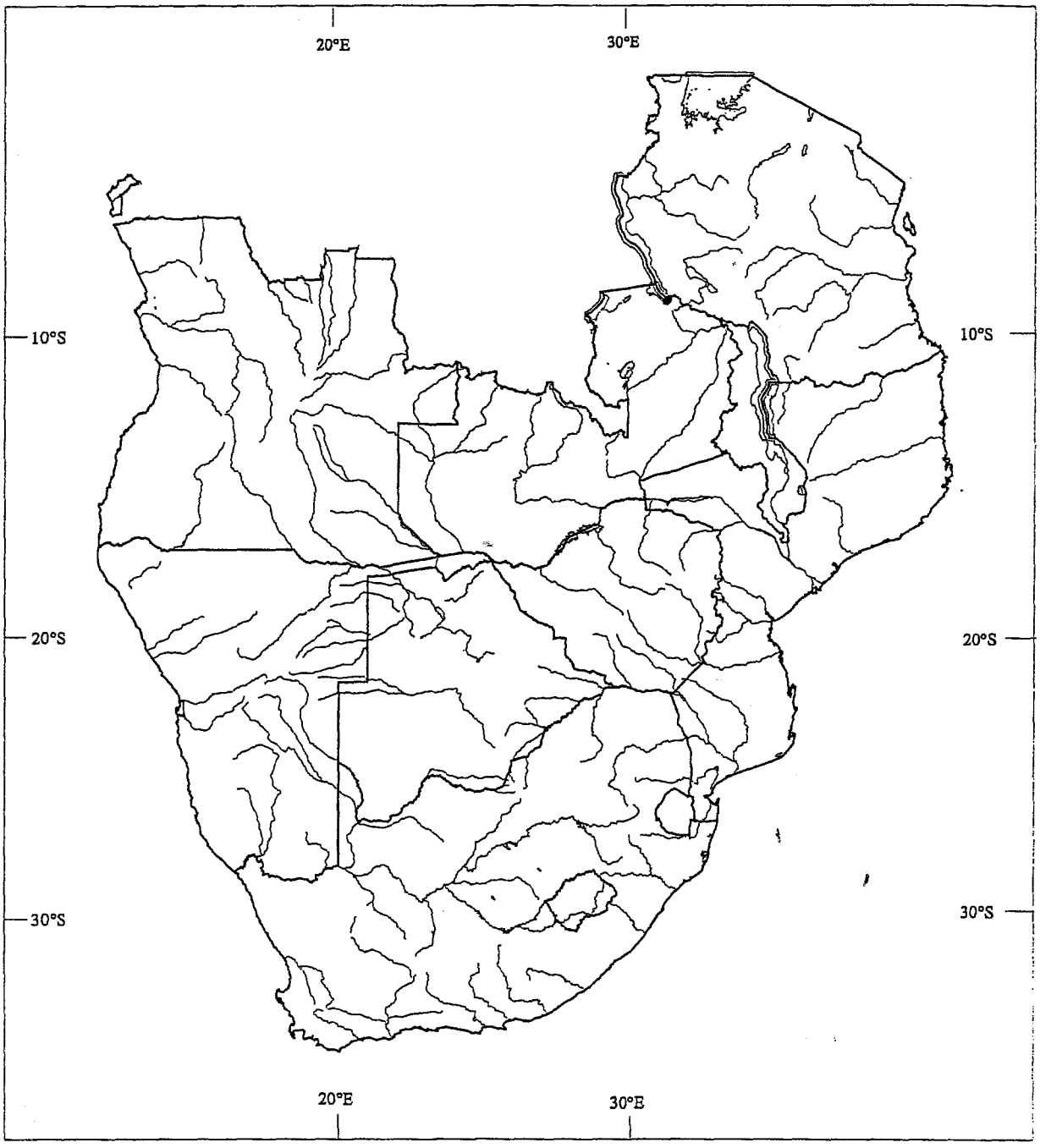


Figure F.4. Point distribution of *Aethiomastacembelus cunningtoni*. Scale approximately 1:25 000 000

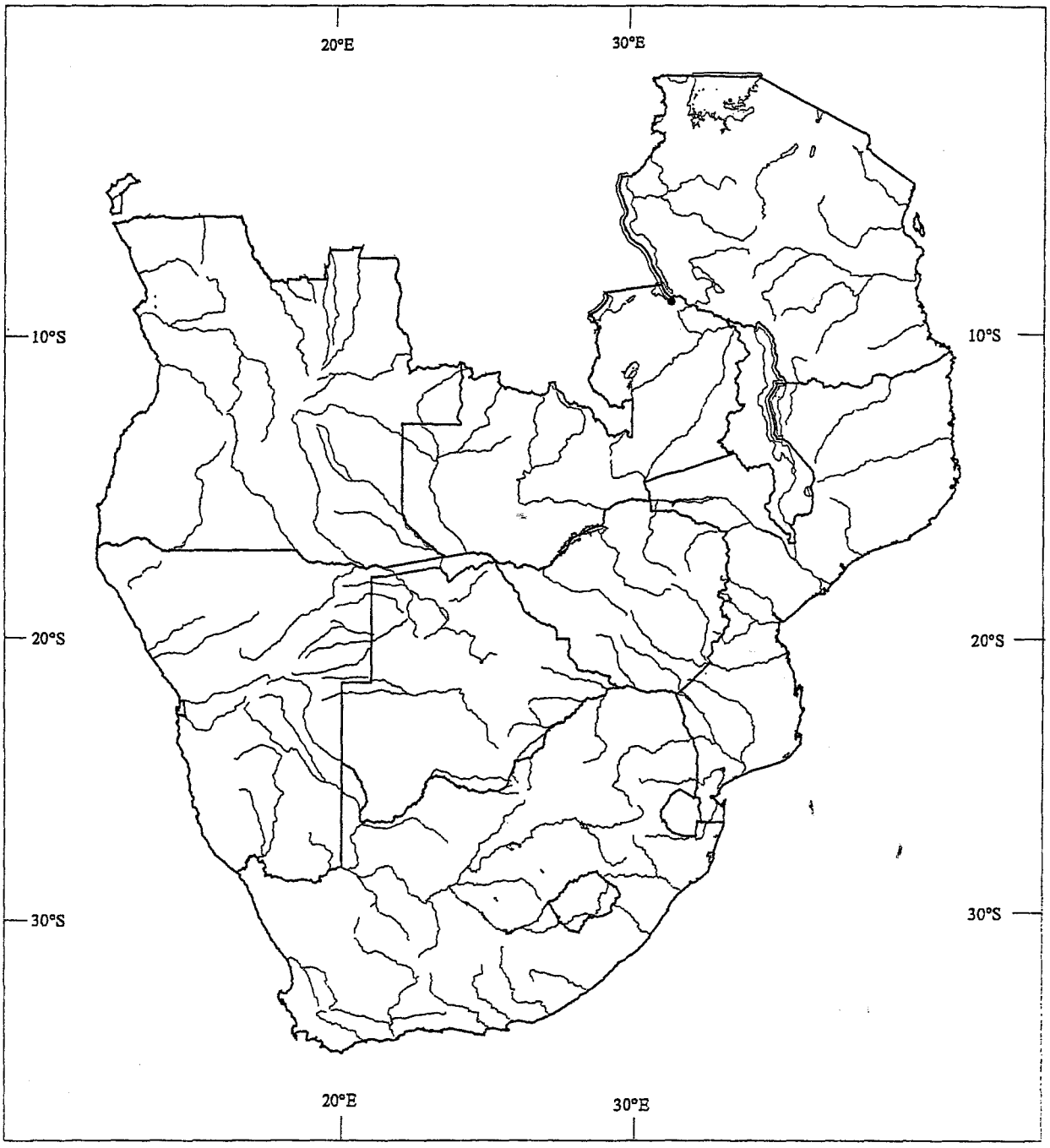


Figure F.5. Point distribution of *Aethiomastacembelus ellipsifer*. Scale approximately 1:25 000 000

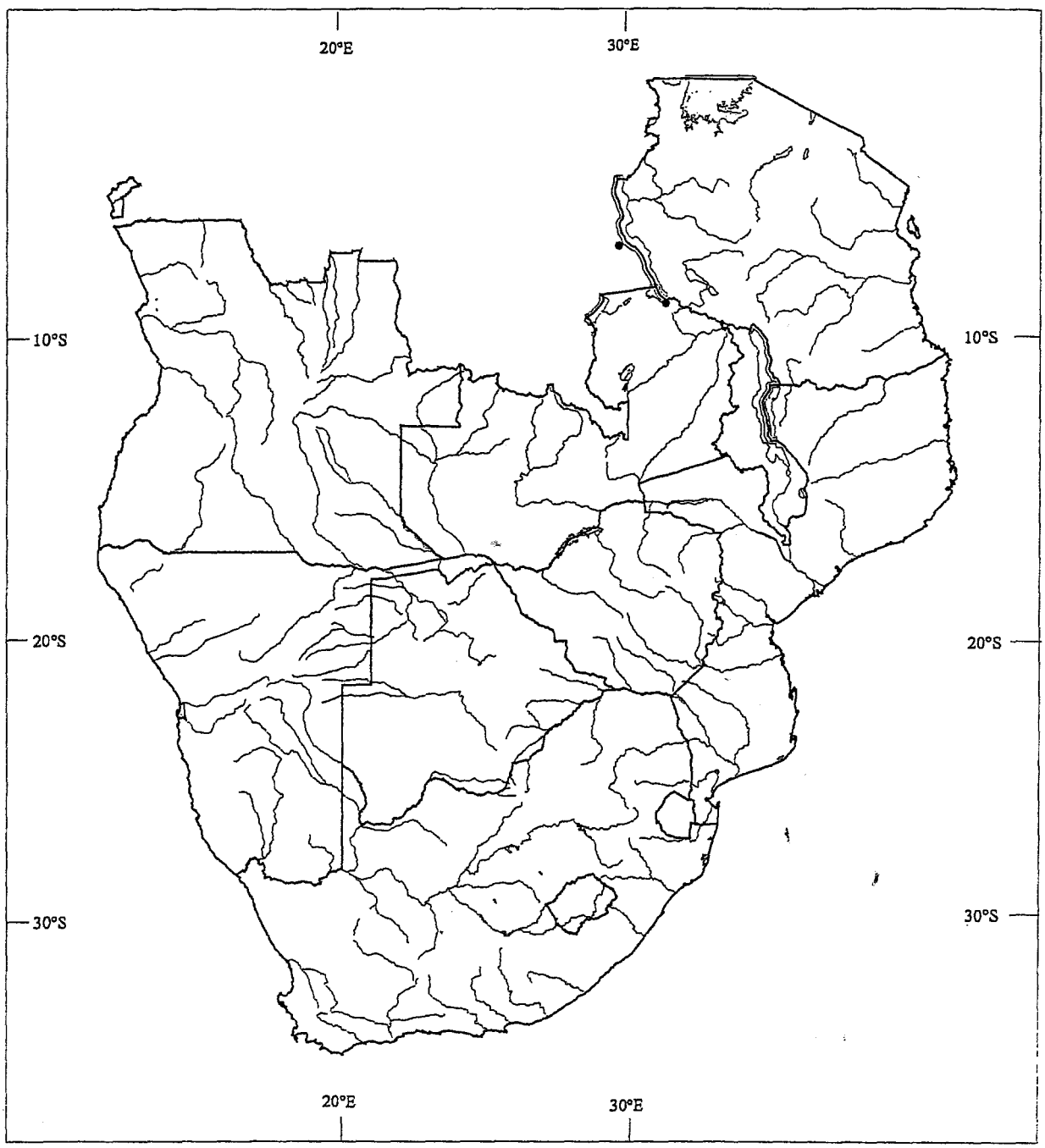


Figure F.6. Point distribution of *Aethiomastacembelus flavidus*. Scale approximately 1:25 000 000

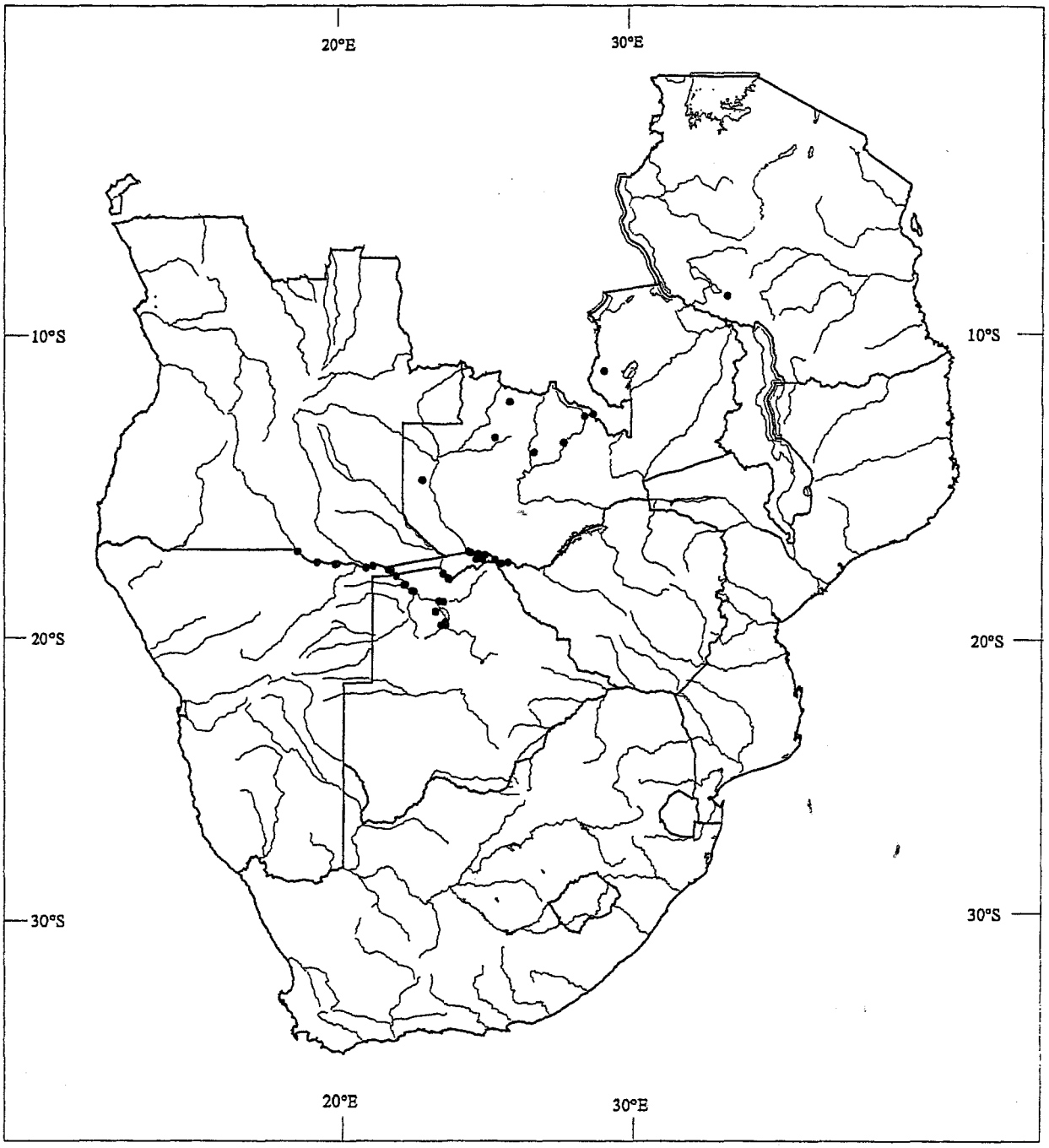


Figure F.7. Point distribution of *Aethiomastacembelus frenatus*. Scale approximately 1:25 000 000

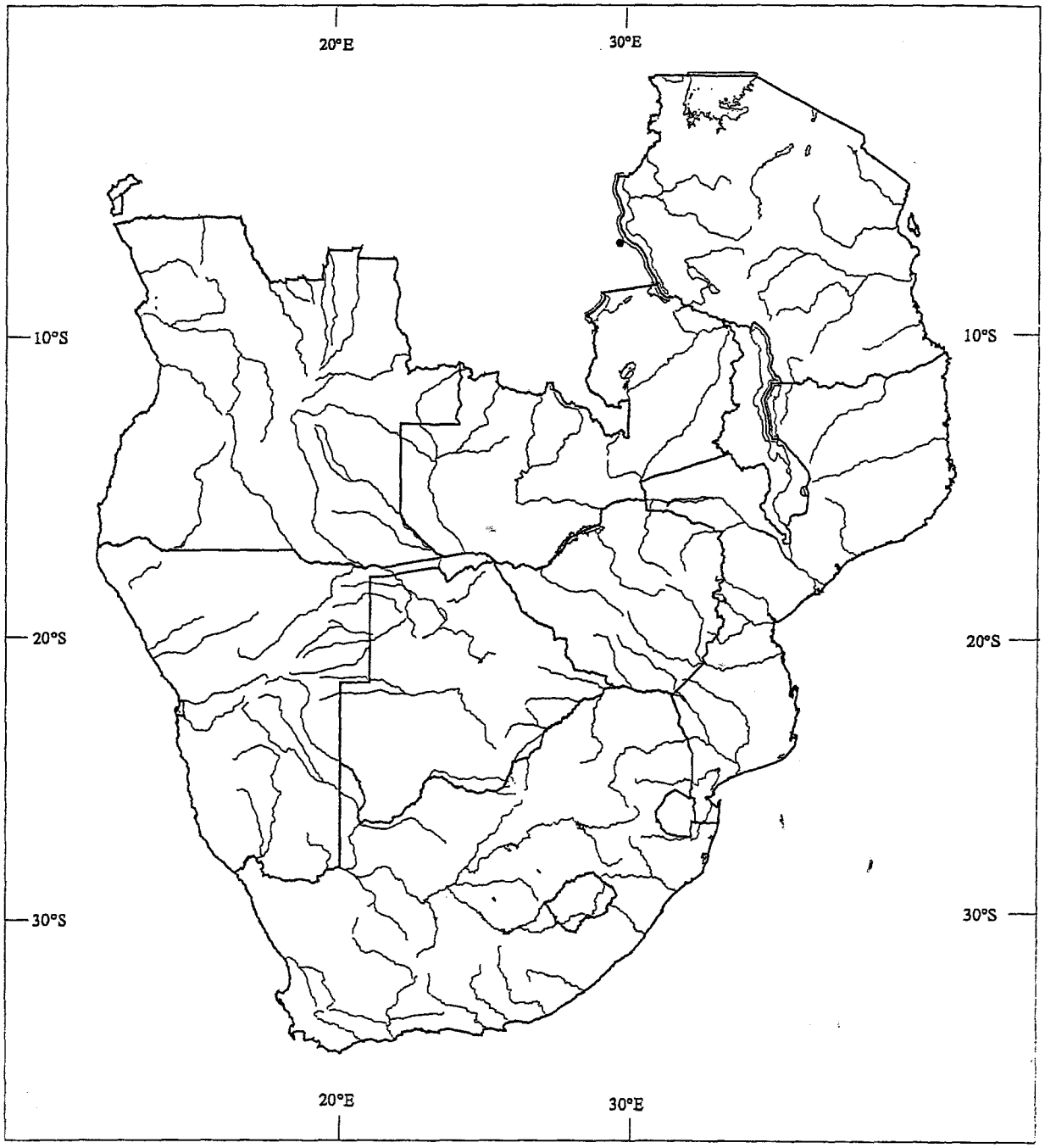


Figure F.8. Point distribution of *Aethiomastacembelus micropectus*. Scale approximately 1:25 000 000

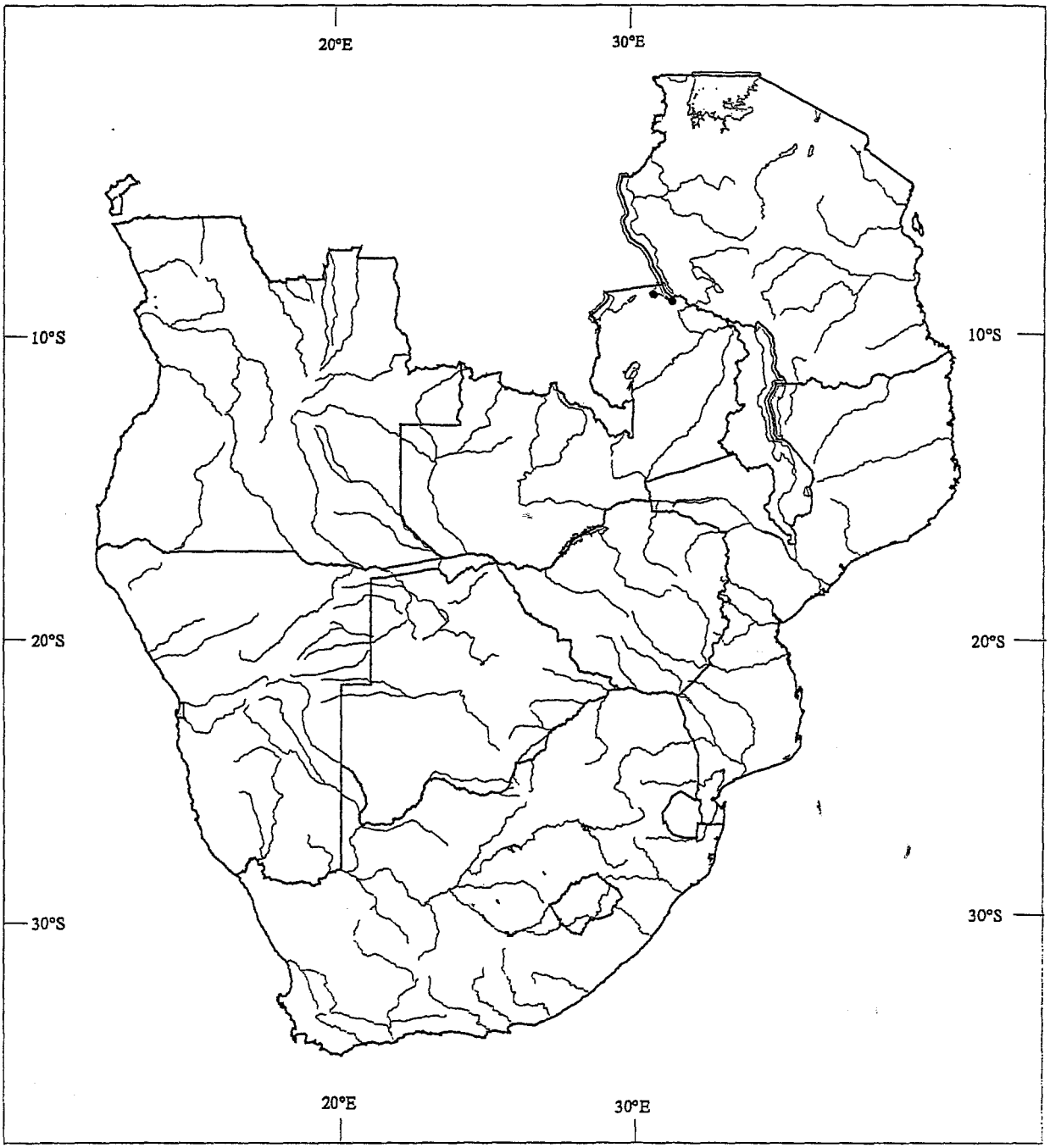


Figure F.9. Point distribution of *Aethiomastacembelus moorii*. Scale approximately 1:25 000 000

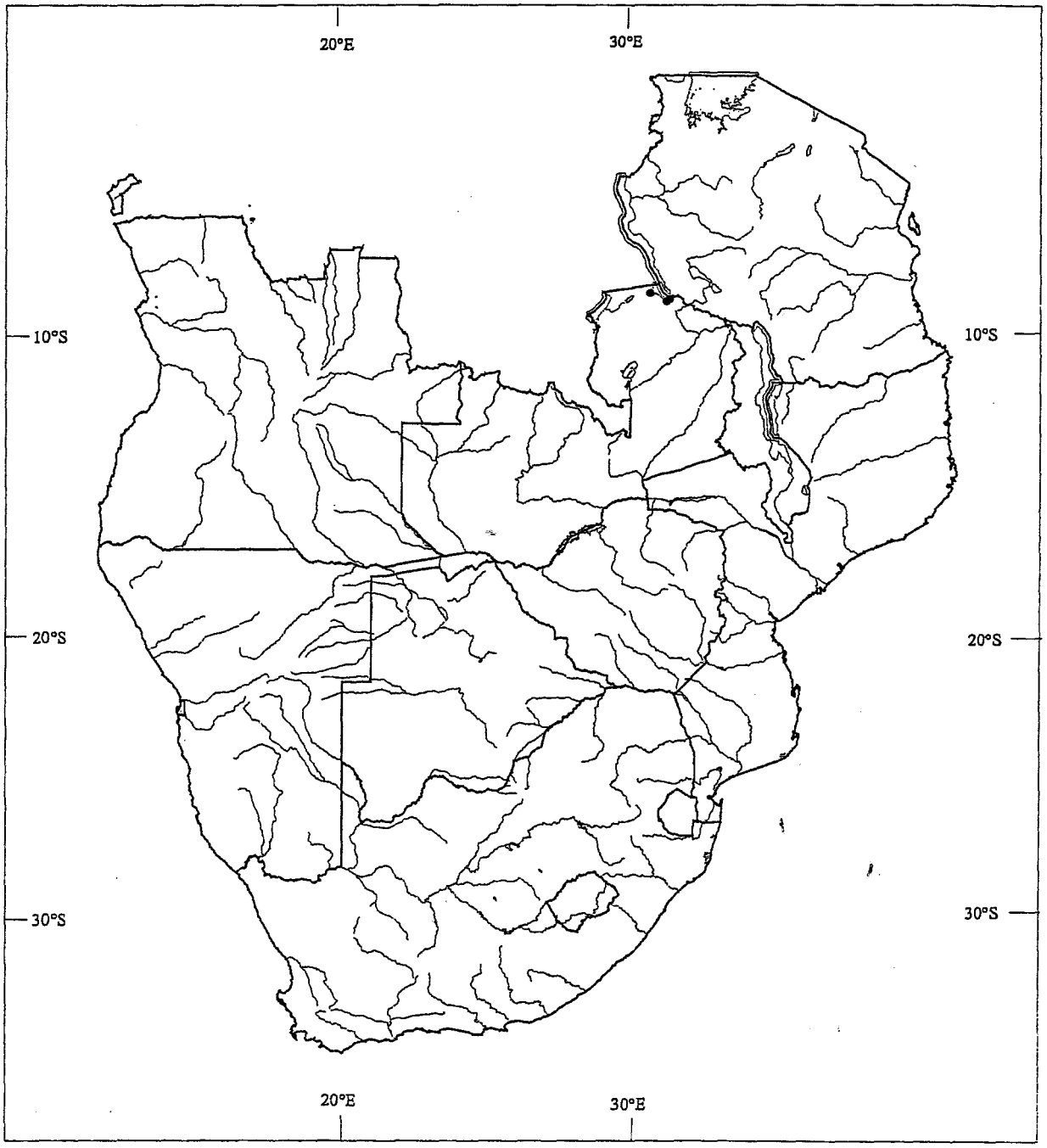


Figure F.10. Point distribution of *Aethiomastacembelus ophidium*. Scale approximately 1:25 000 000

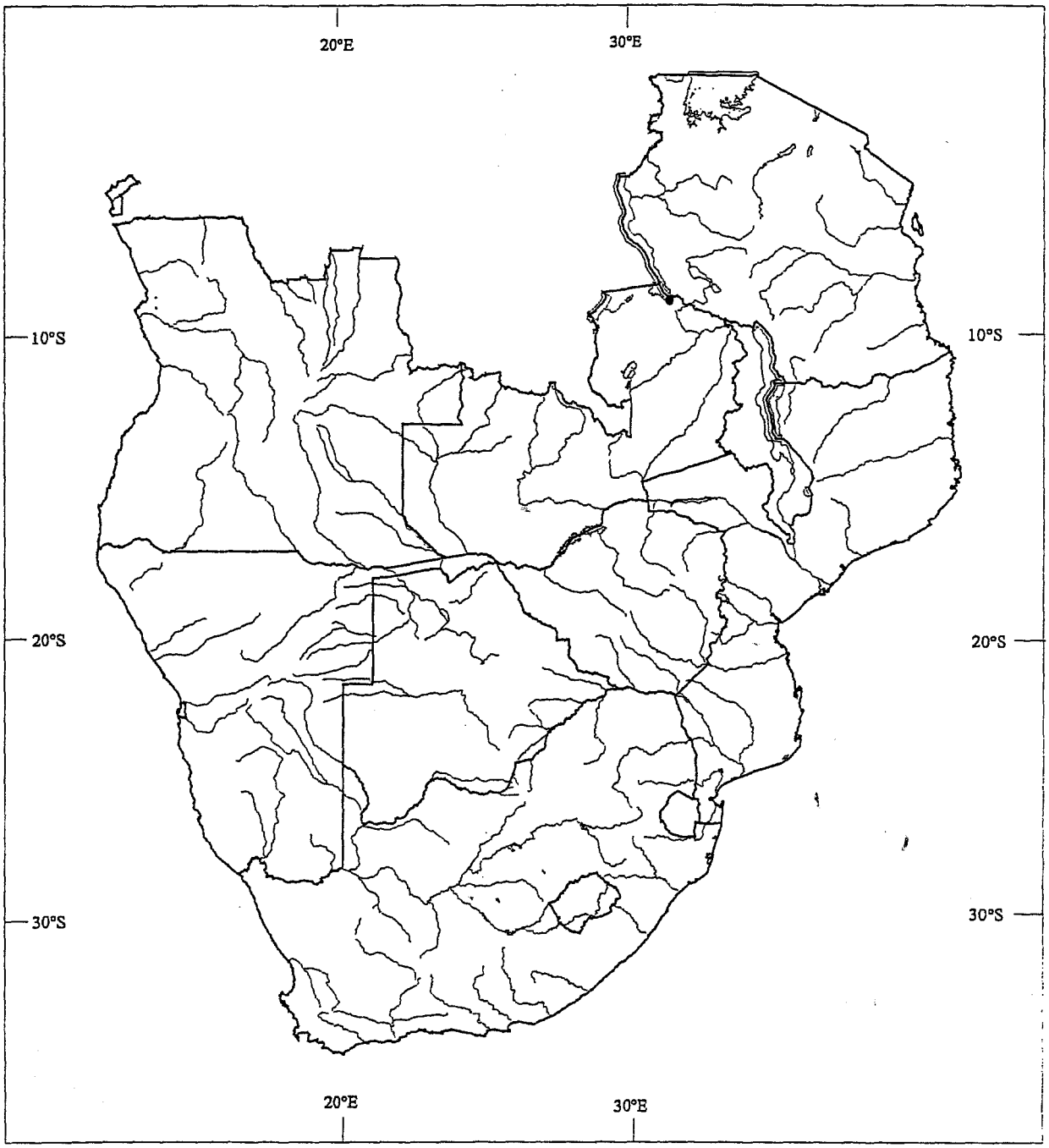


Figure F.11. Point distribution of *Aethiomastacembelus plagiostomus*. Scale approximately 1:25 000 000

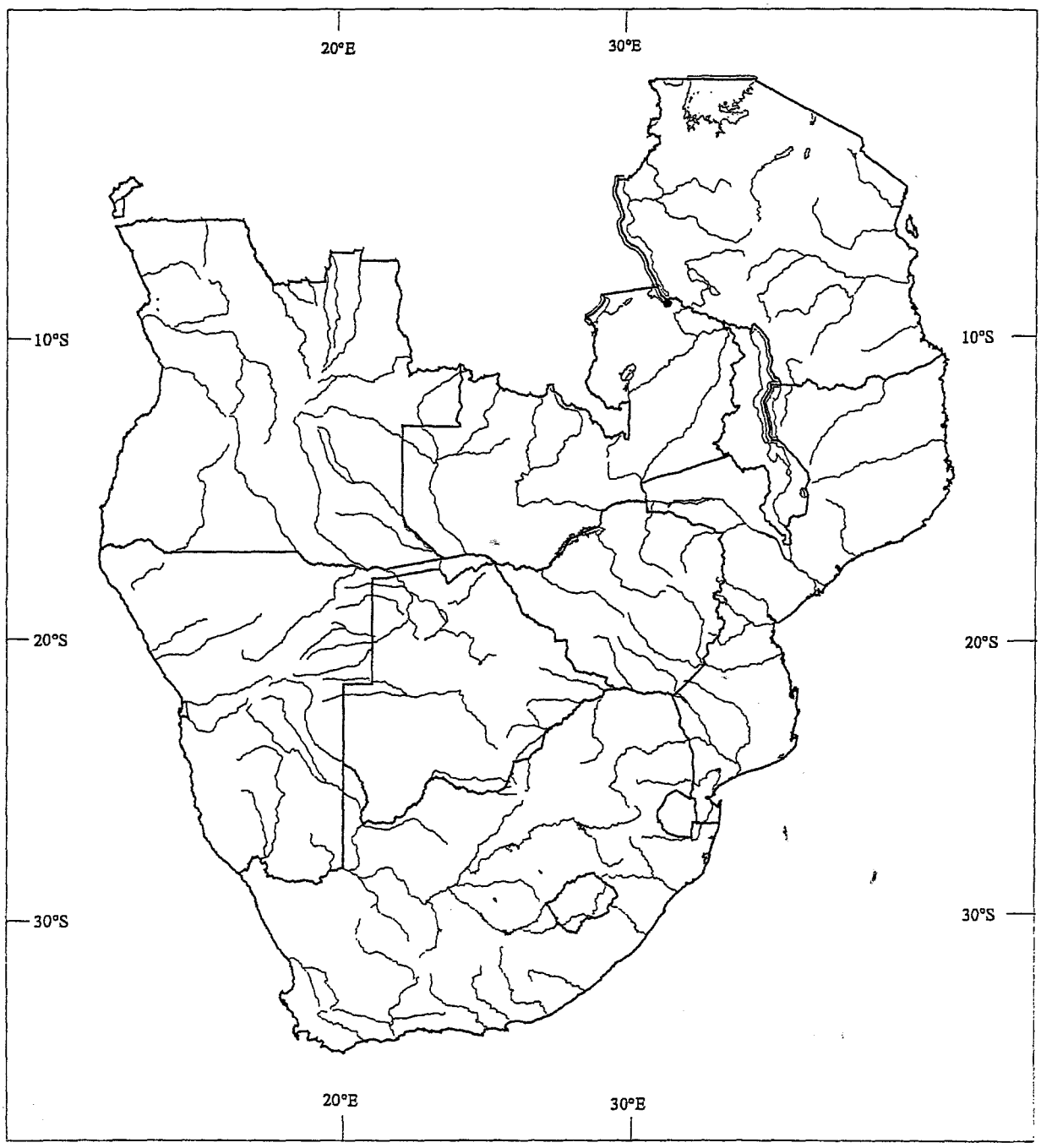


Figure F.12. Point distribution of *Aethiomastacembelus platysoma*. Scale approximately 1:25 000 000

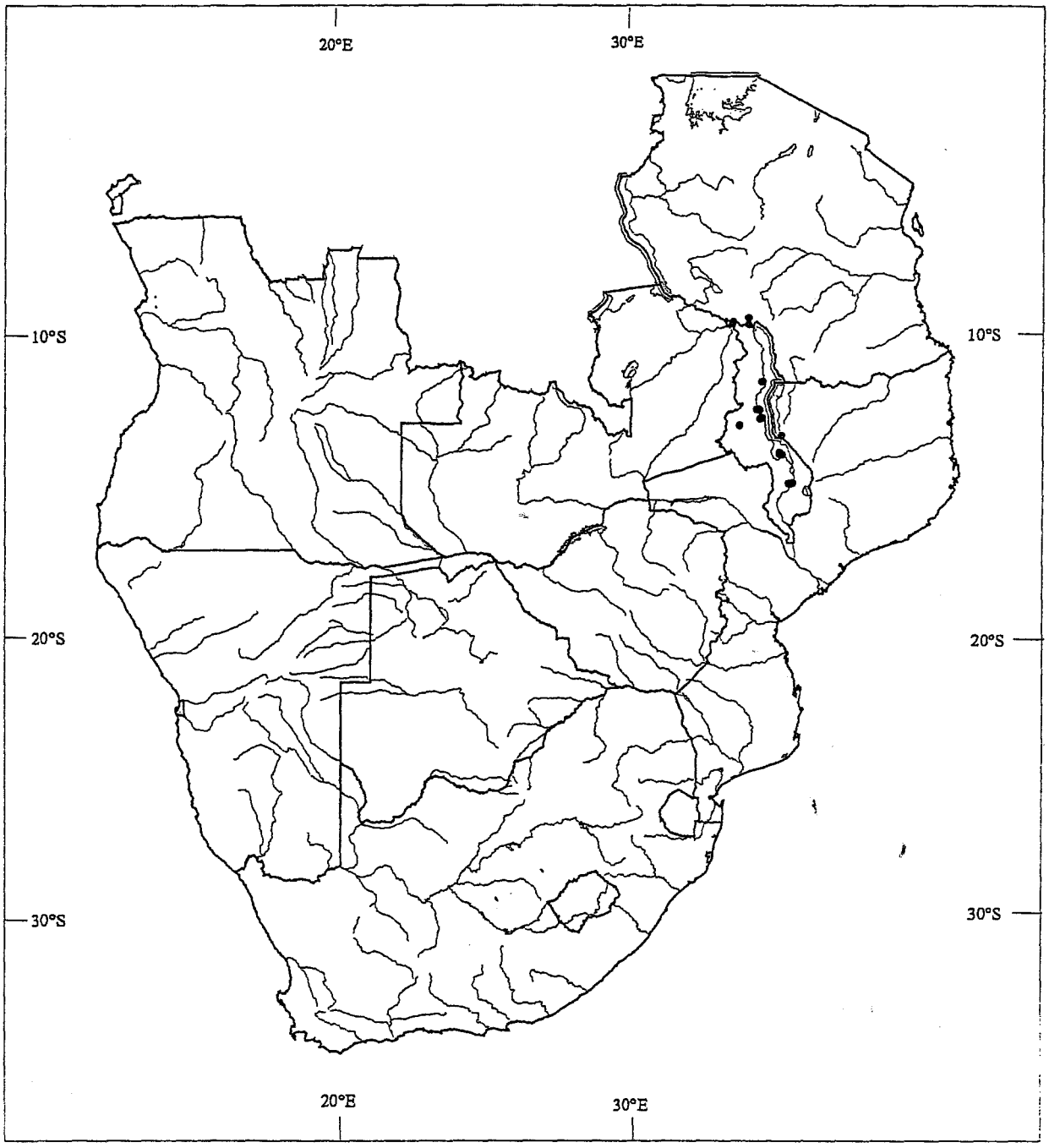


Figure F.13. Point distribution of *Aethiomastacembelus shiranus*. Scale approximately 1:25 000 000

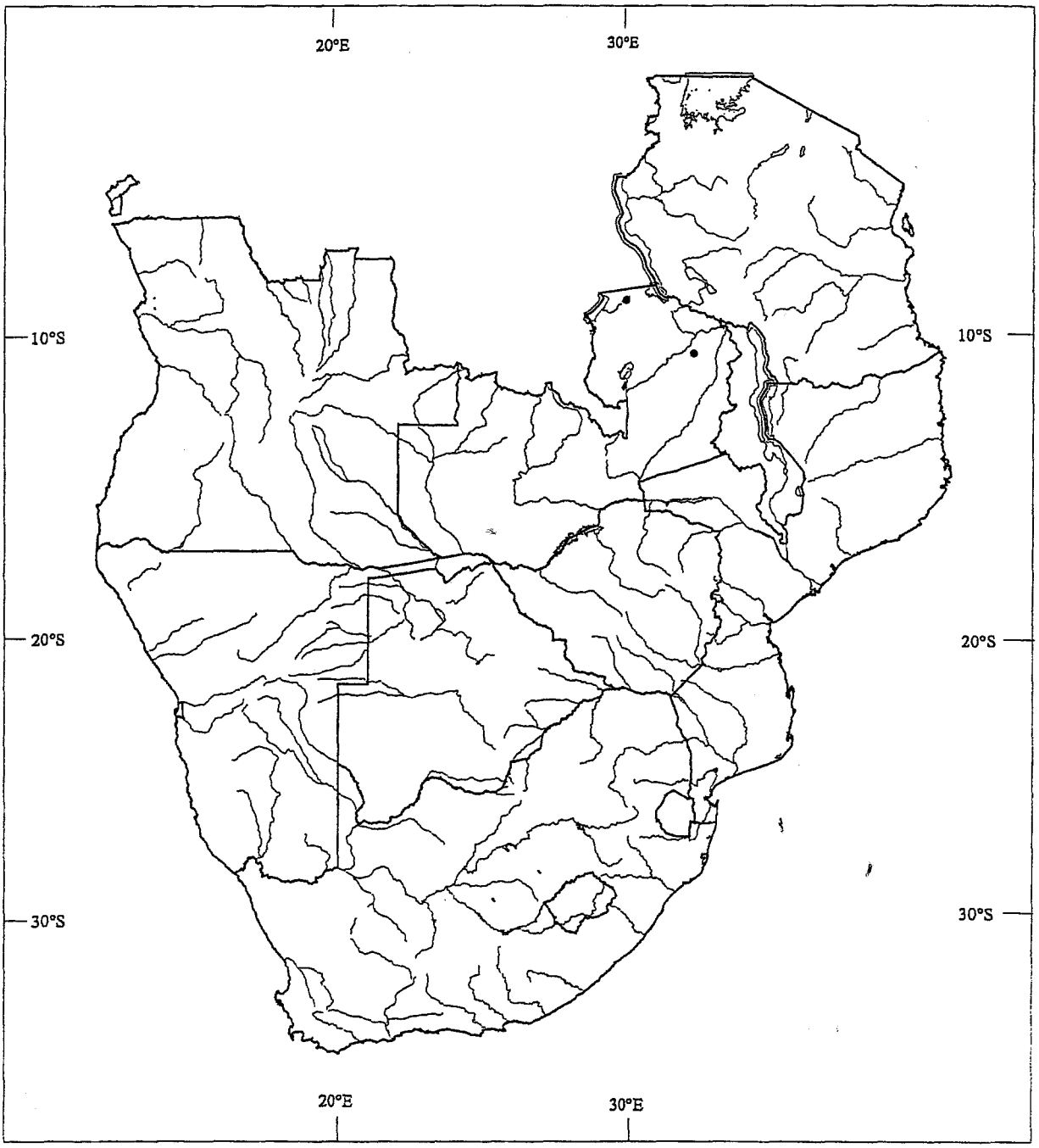


Figure F.14. Point distribution of *Aethiomastacembelus signatus*. Scale approximately 1:25 000 000

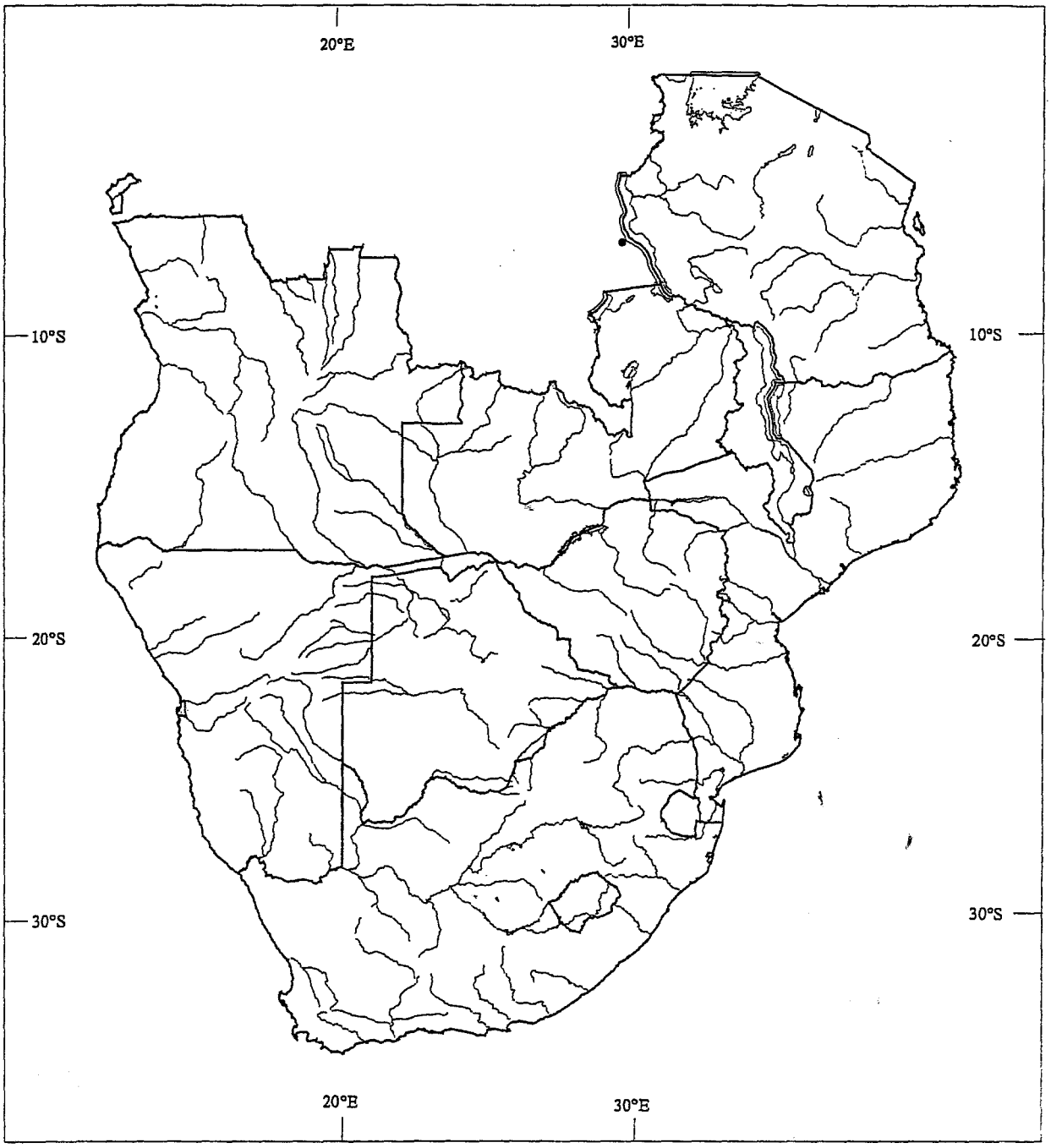


Figure F.15. Point distribution of *Aethiomastacembelus tanganicae*. Scale approximately 1:25 000 000

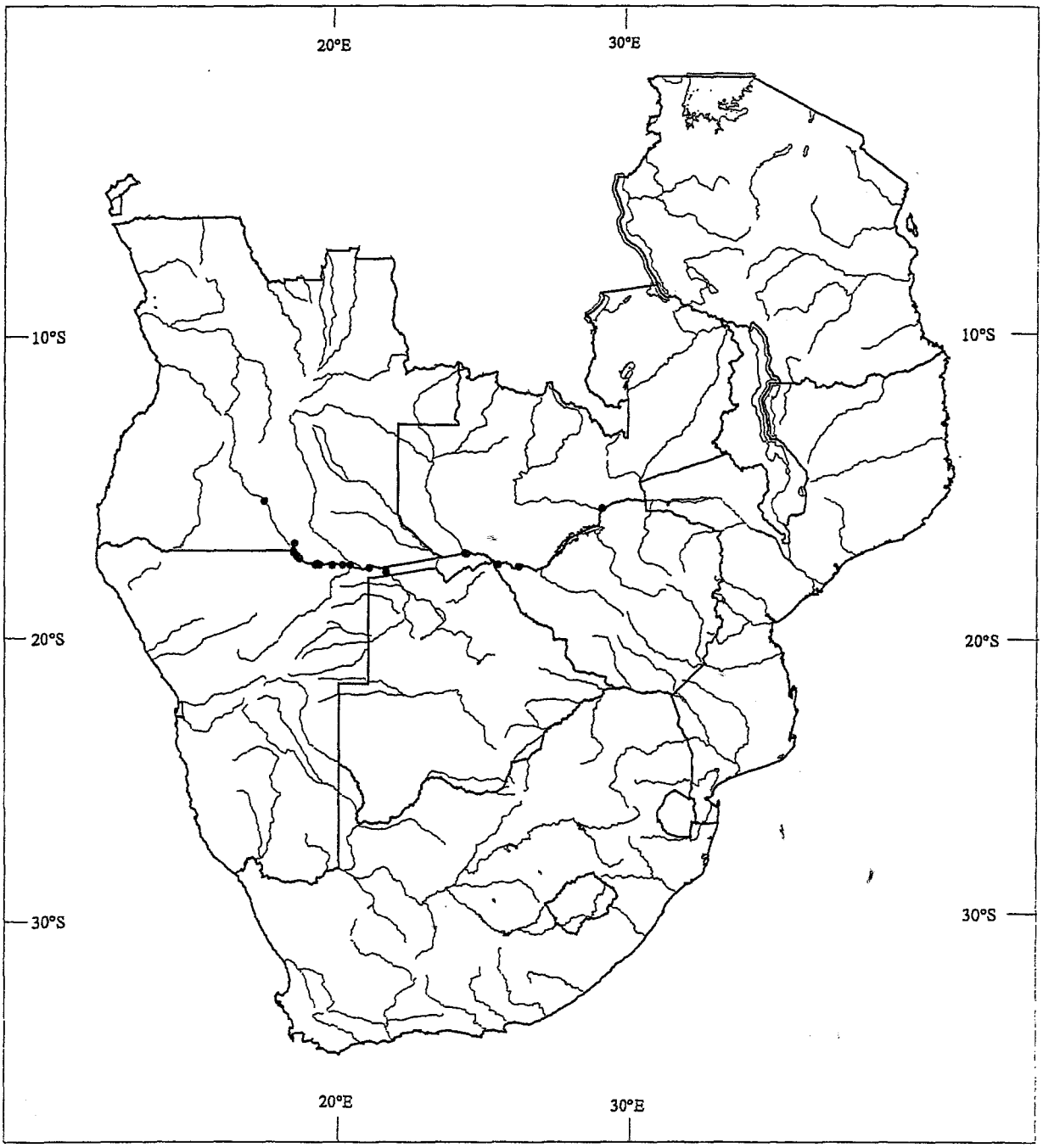


Figure F.16. Point distribution of *Aethiomastacembelus vanderwaali*. Scale approximately 1:25 000 000

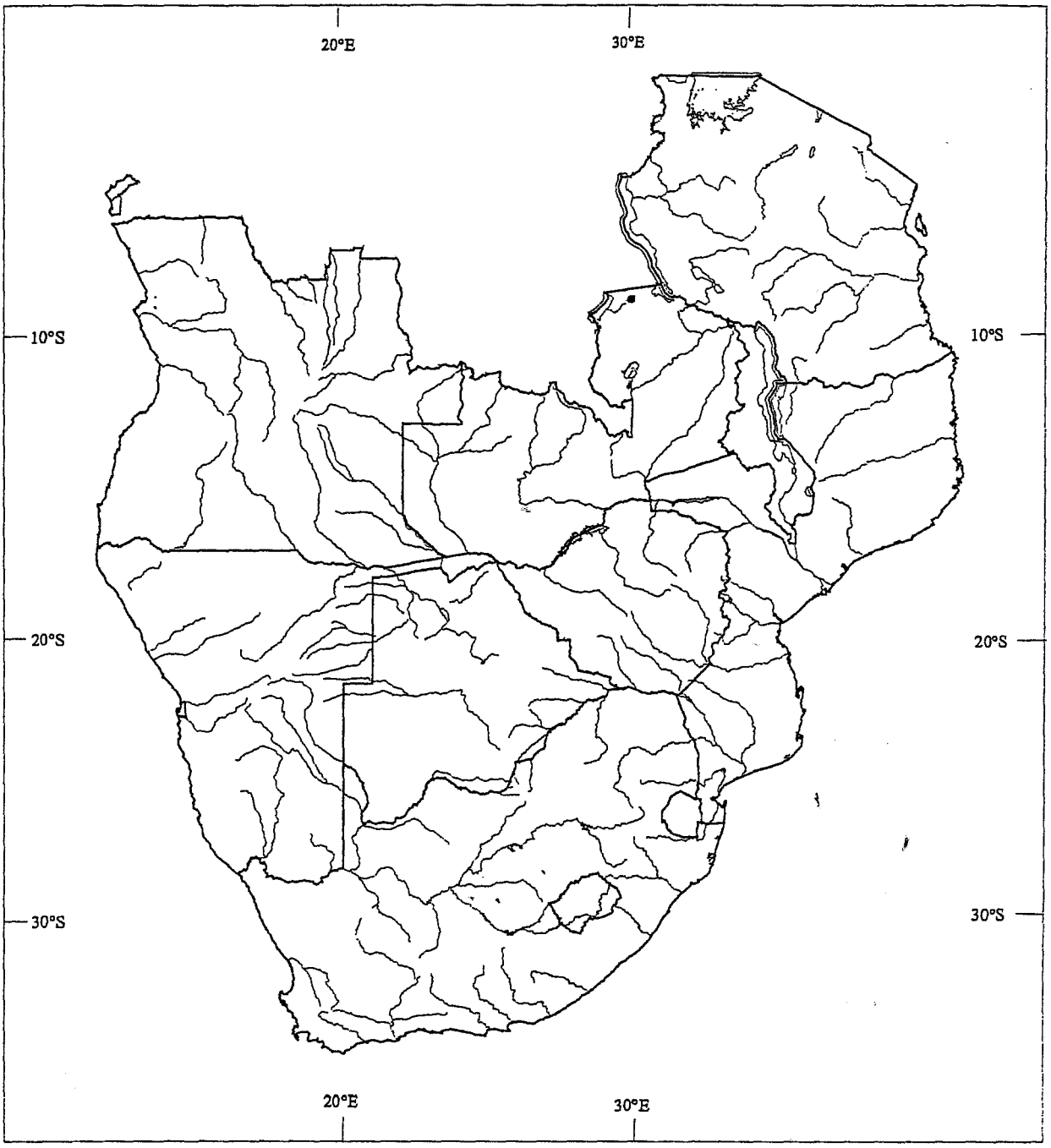


Figure F.17. Point distribution of *Alestes grandisquamis*. Scale approximately 1:25 000 000

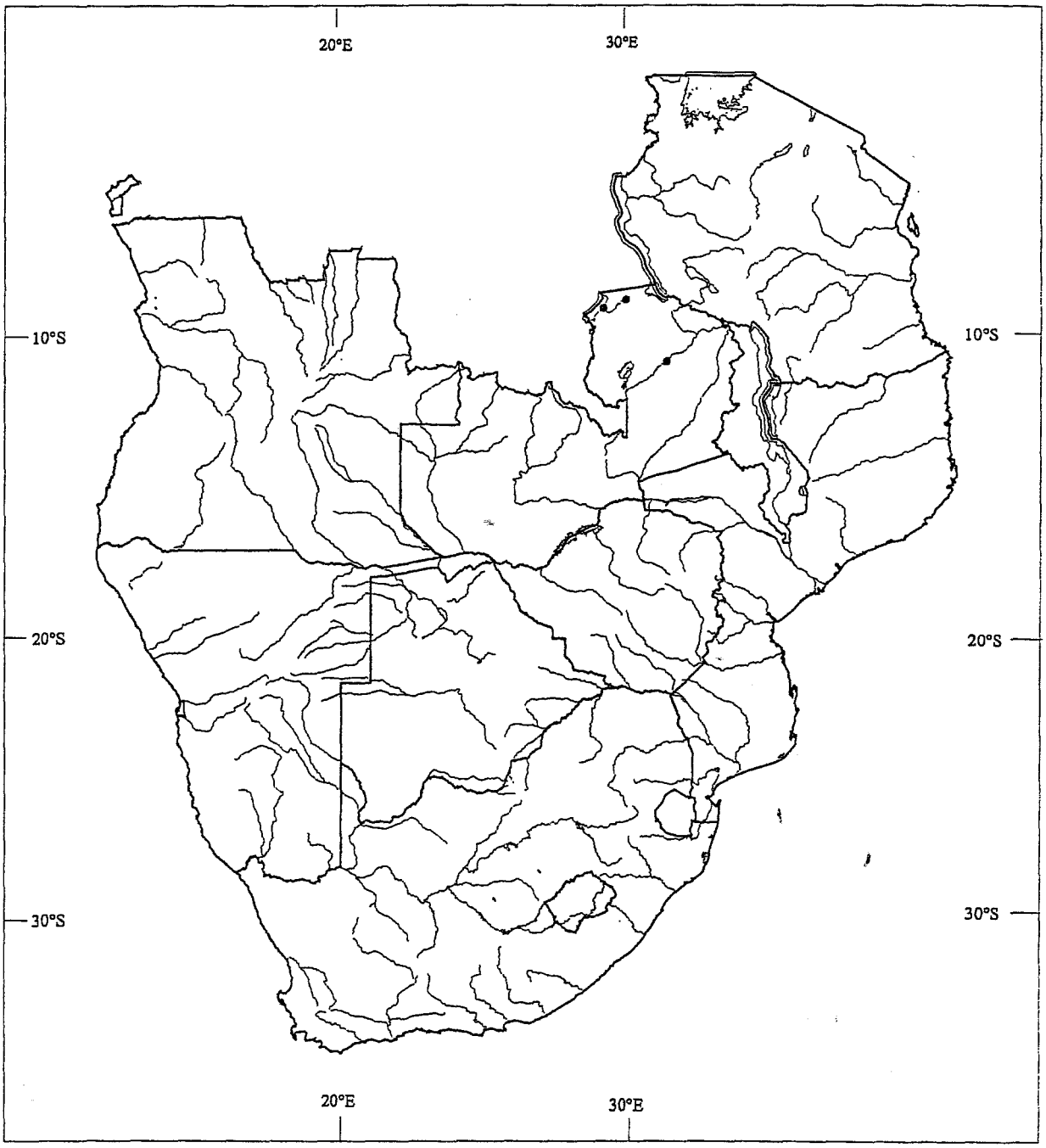


Figure F.18. Point distribution of *Alestes macropthalmus*. Scale approximately 1:25 000 000

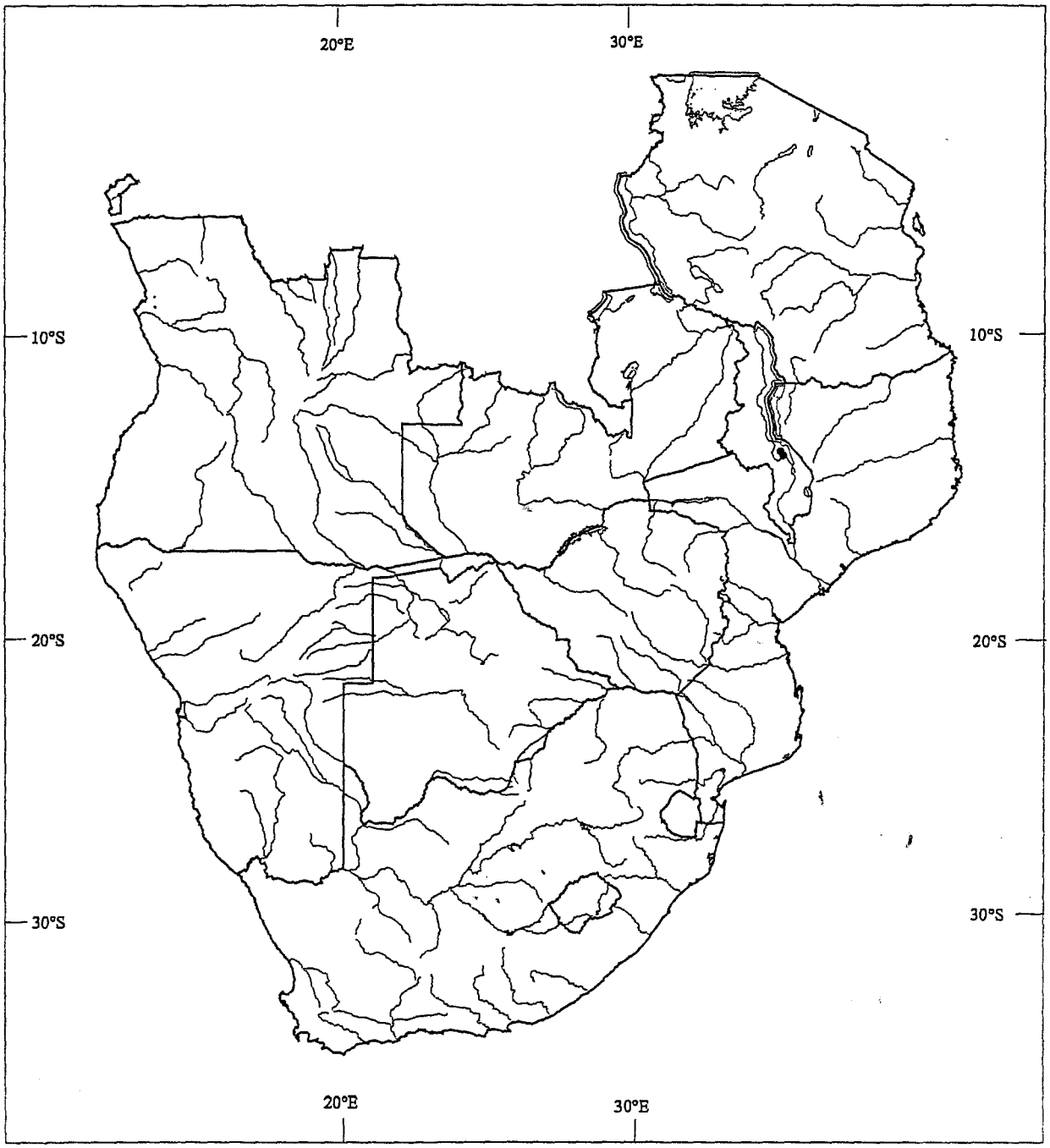


Figure F.19. Point distribution of *Alticorpus macroleithrum*. Scale approximately 1:25 000 000

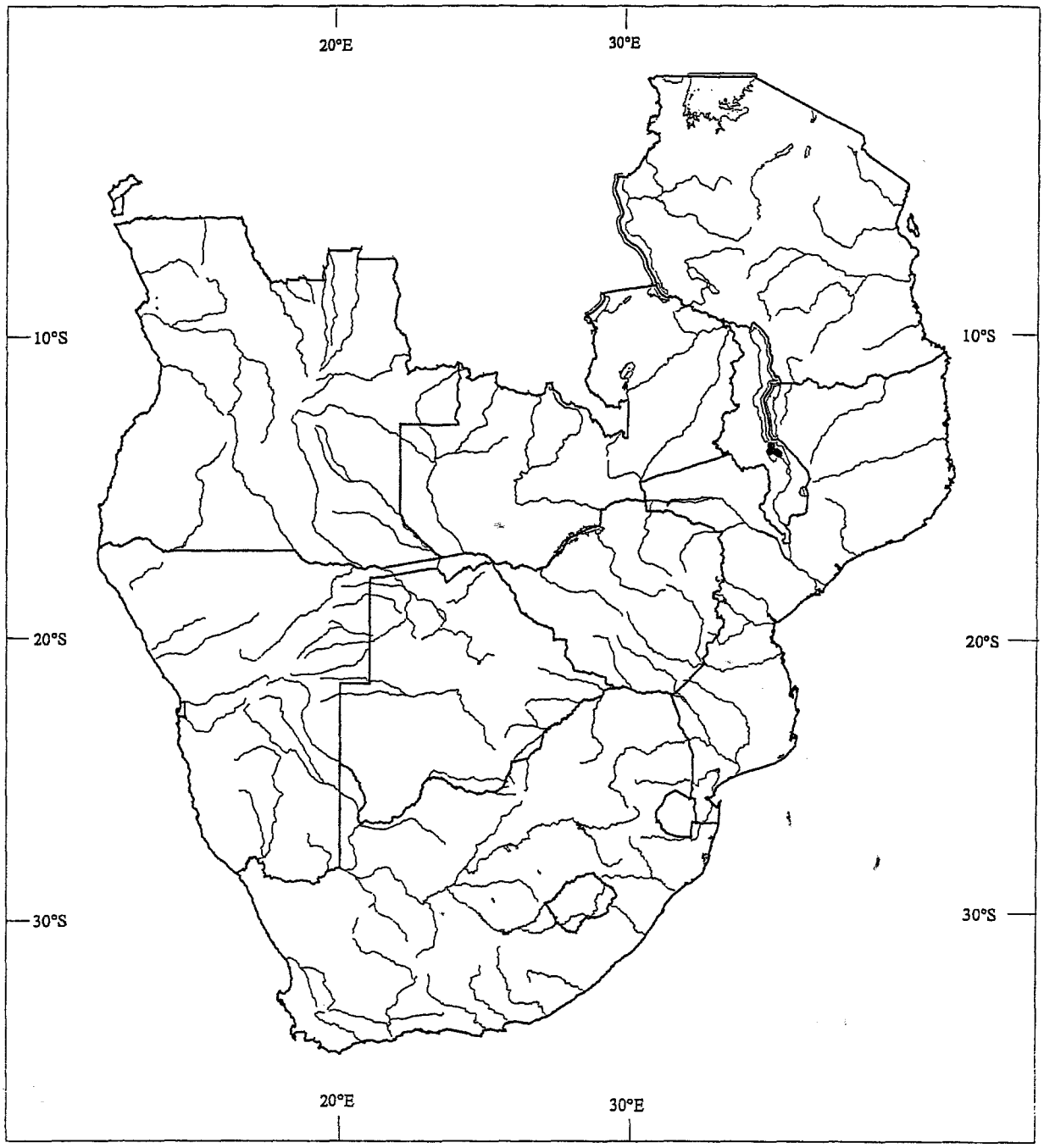


Figure F.20. Point distribution of *Alticorpus mentale*. Scale approximately 1:25 000 000

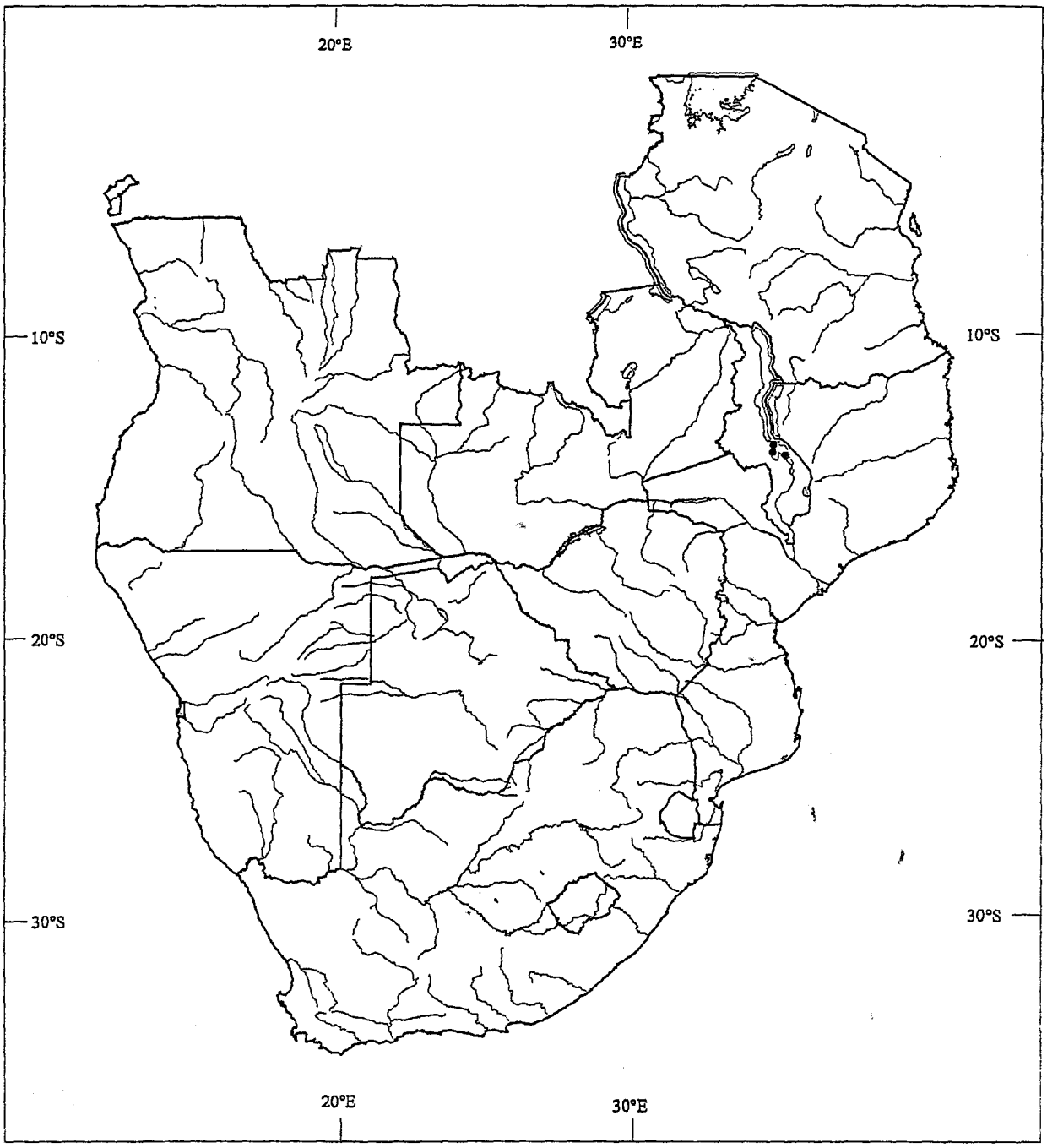


Figure F.21. Point distribution of *Alticorpus pectinatum*. Scale approximately 1:25 000 000

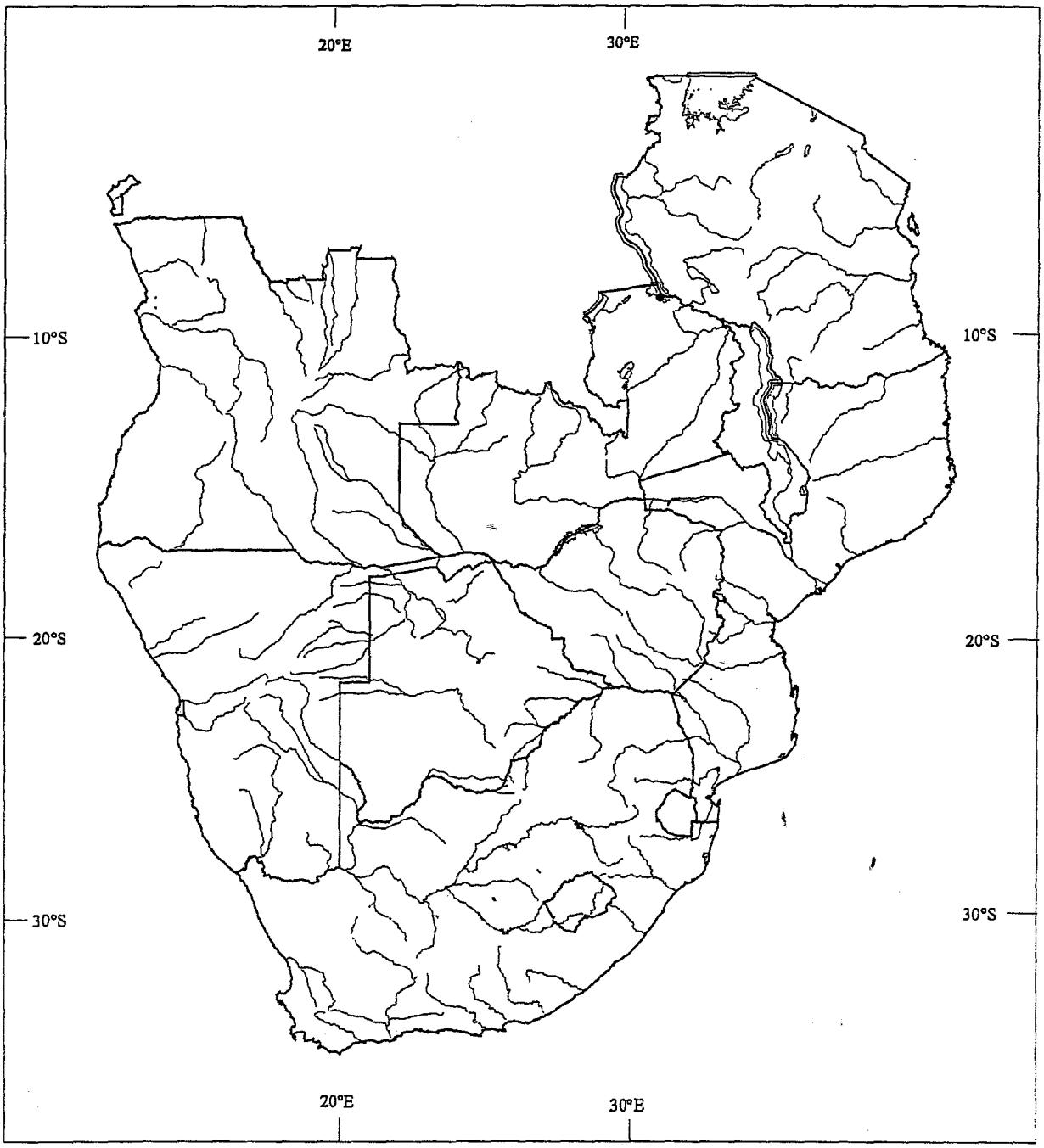


Figure F.22. Point distribution of *Altolamprologus calvus*. Scale approximately 1:25 000 000

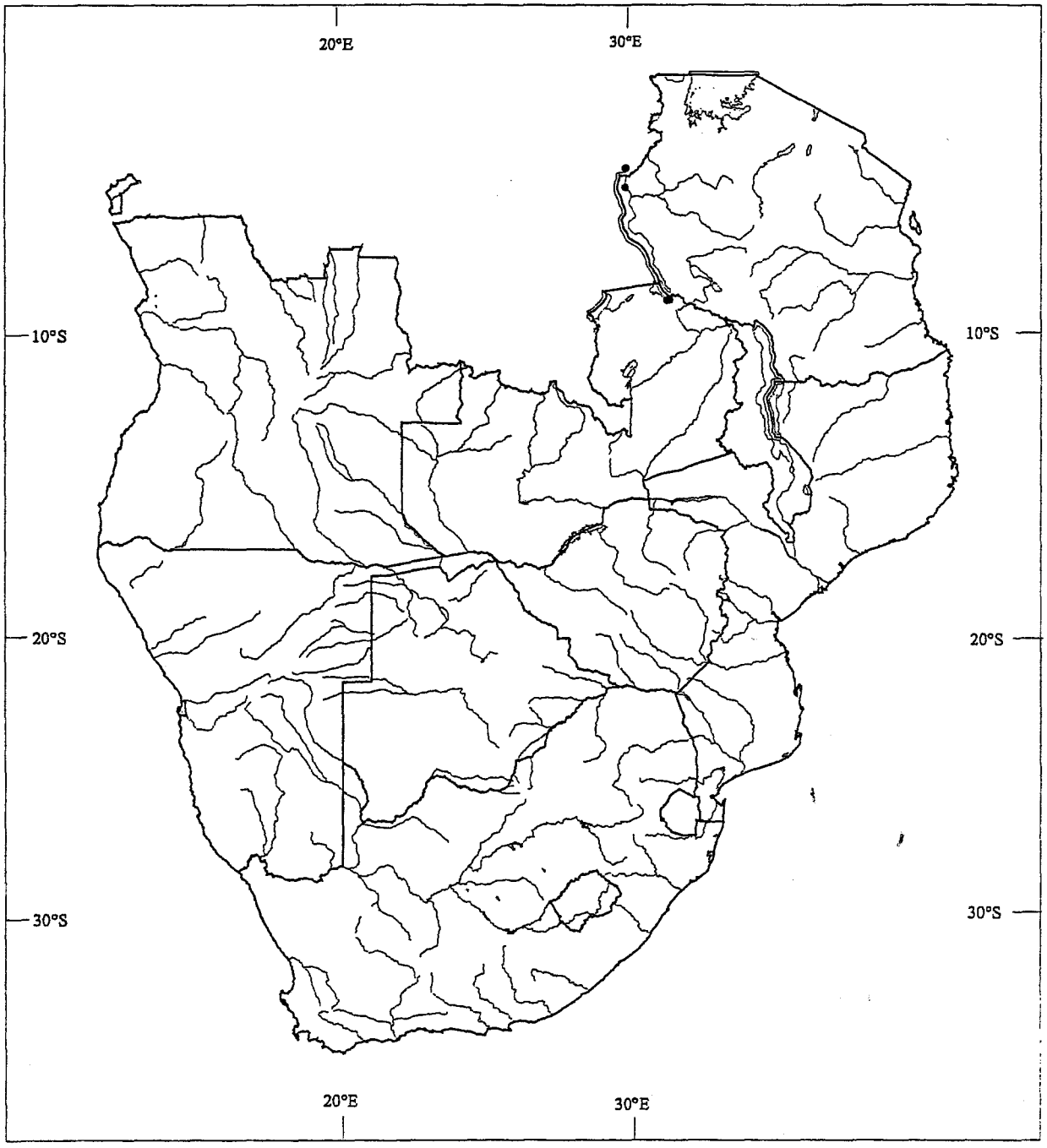


Figure F.23. Point distribution of *Altolamprologus compressiceps*. Scale approximately 1:25 000 000

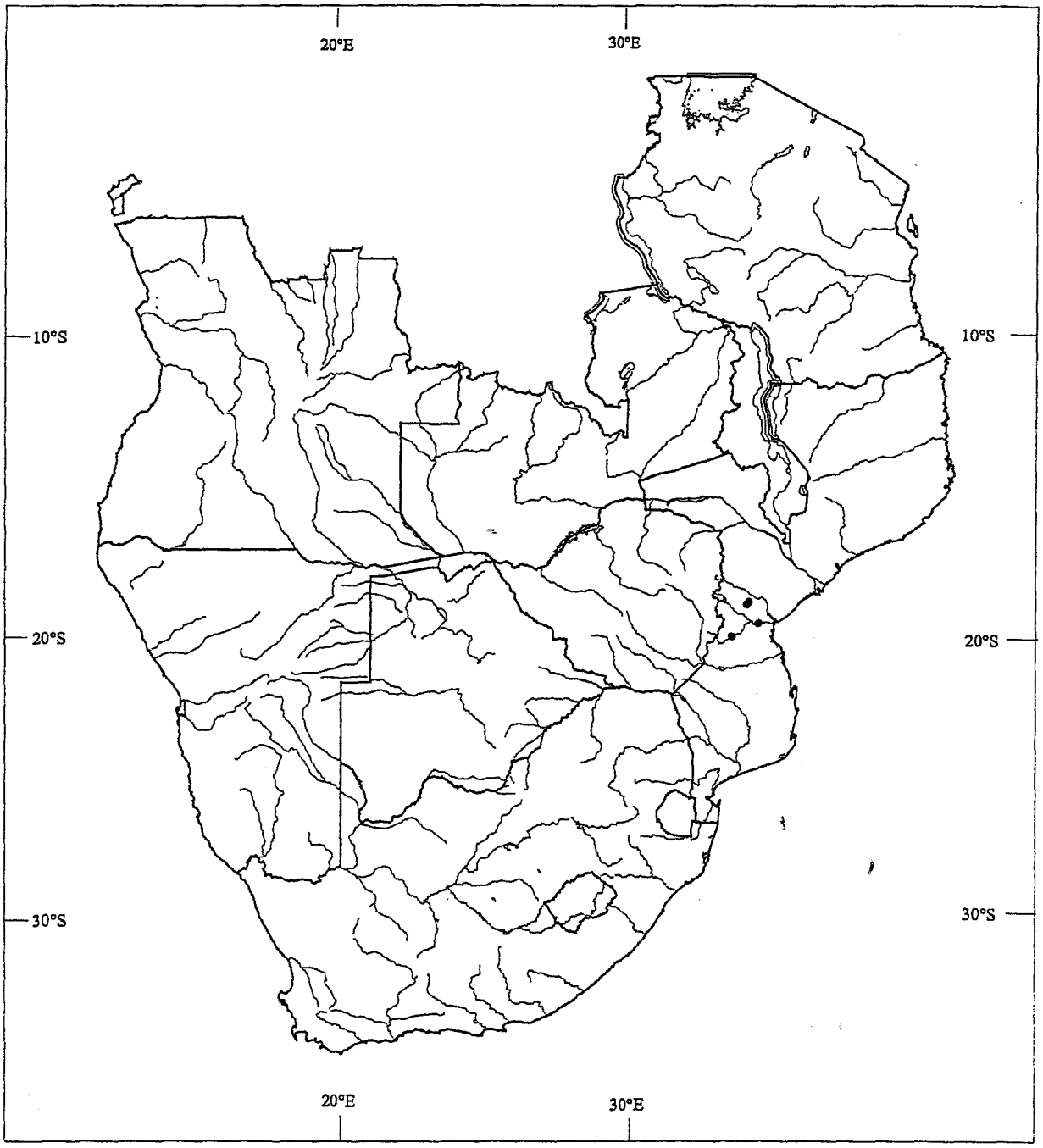


Figure F.24. Point distribution of *Amarginops hildae*. Scale approximately 1:25 000 000

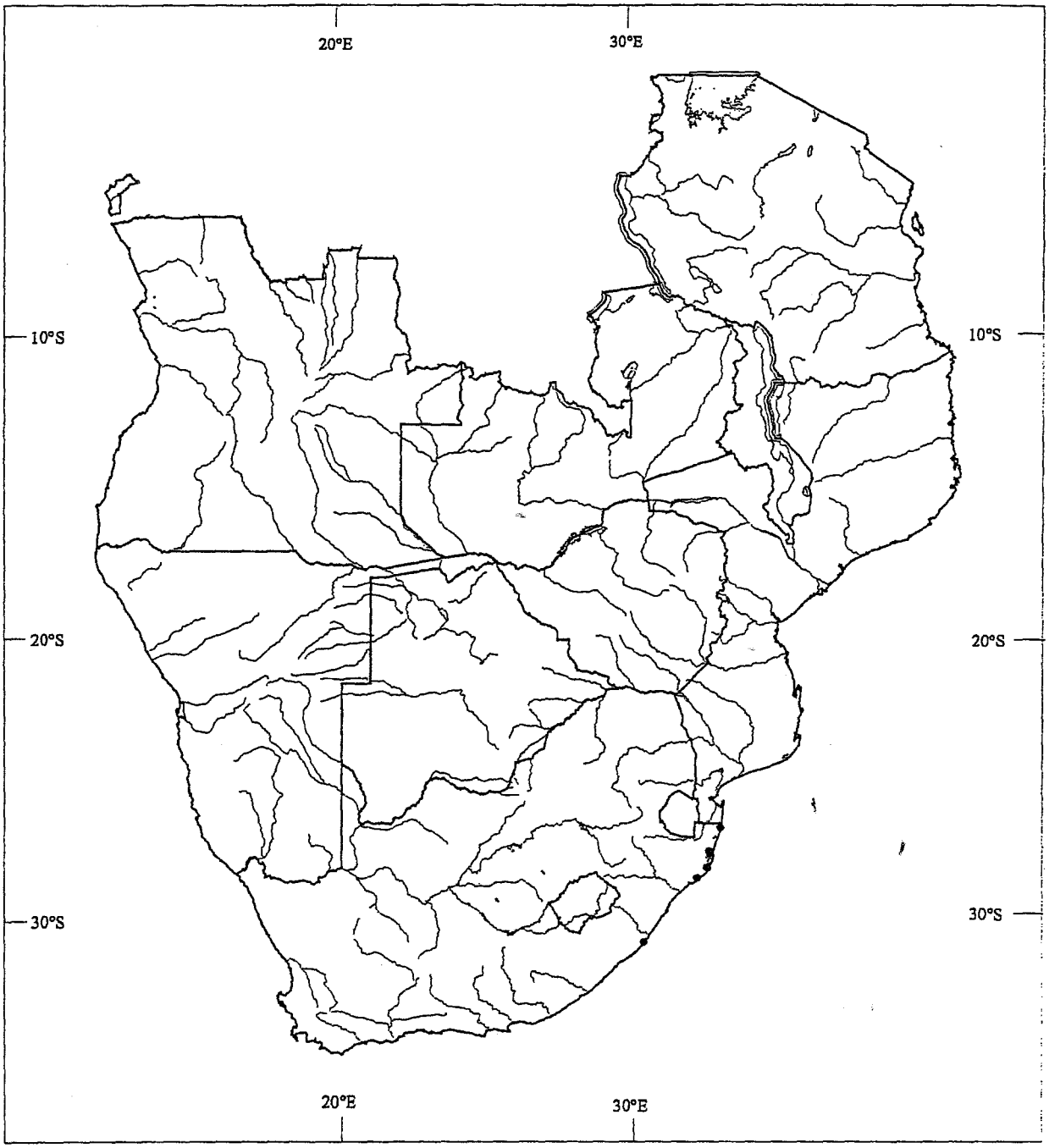


Figure F.25. Point distribution of *Ambassis natalensis*. Scale approximately 1:25 000 000

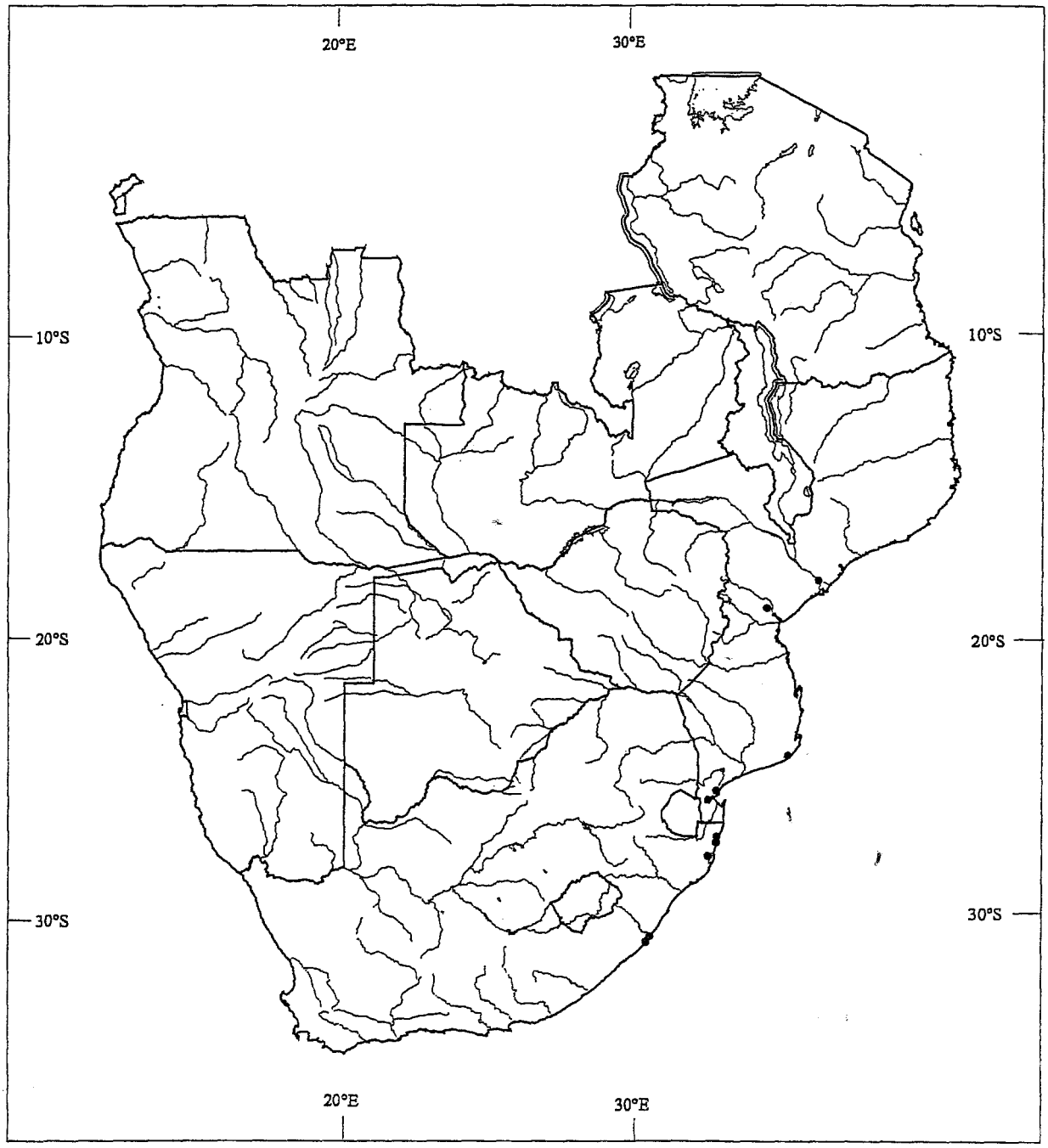


Figure F.26. Point distribution of *Ambassis productus*. Scale approximately 1:25 000 000

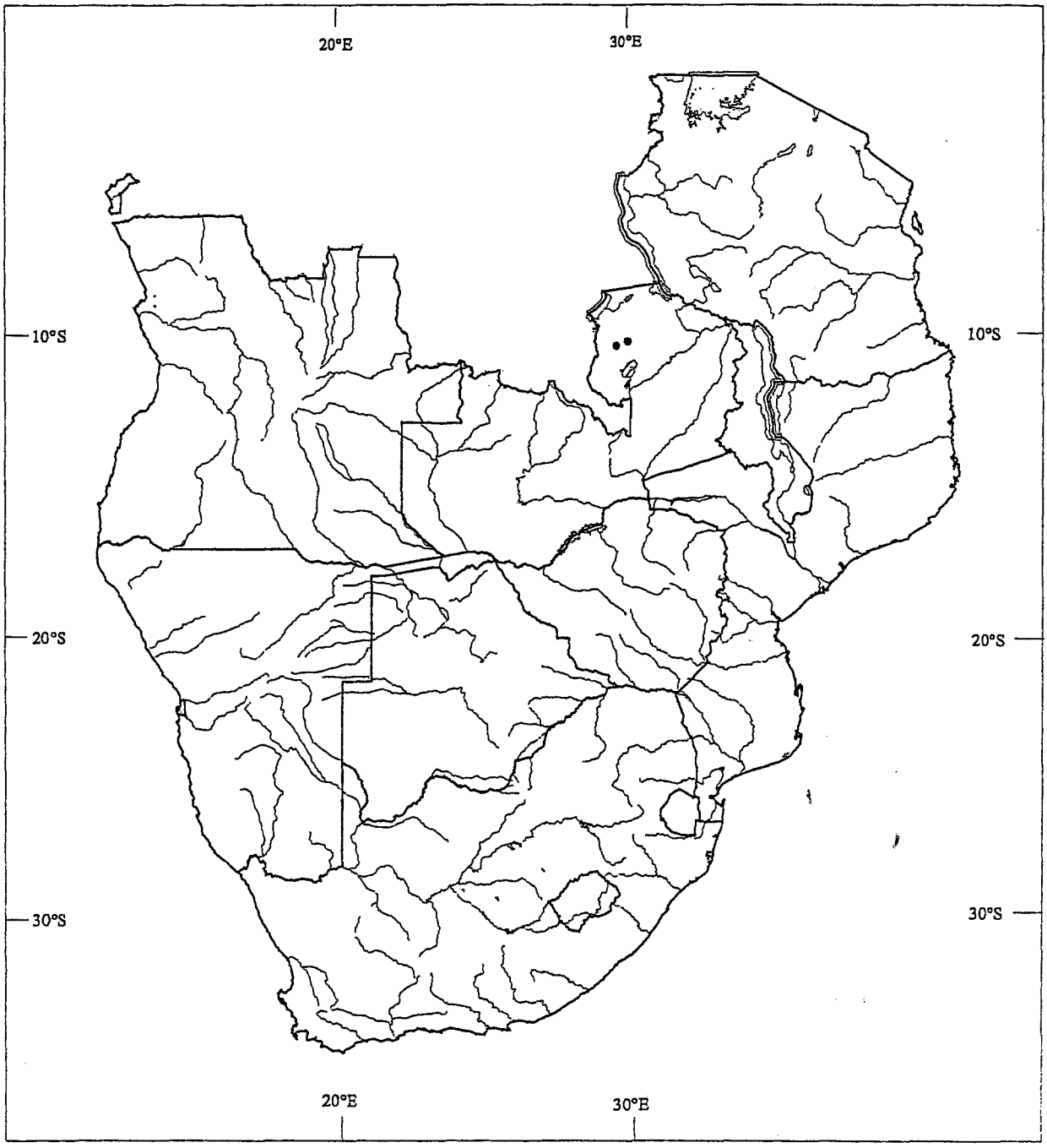


Figure F.27. Point distribution of *Amphilius cryptobullatus*. Scale approximately 1:25 000 000

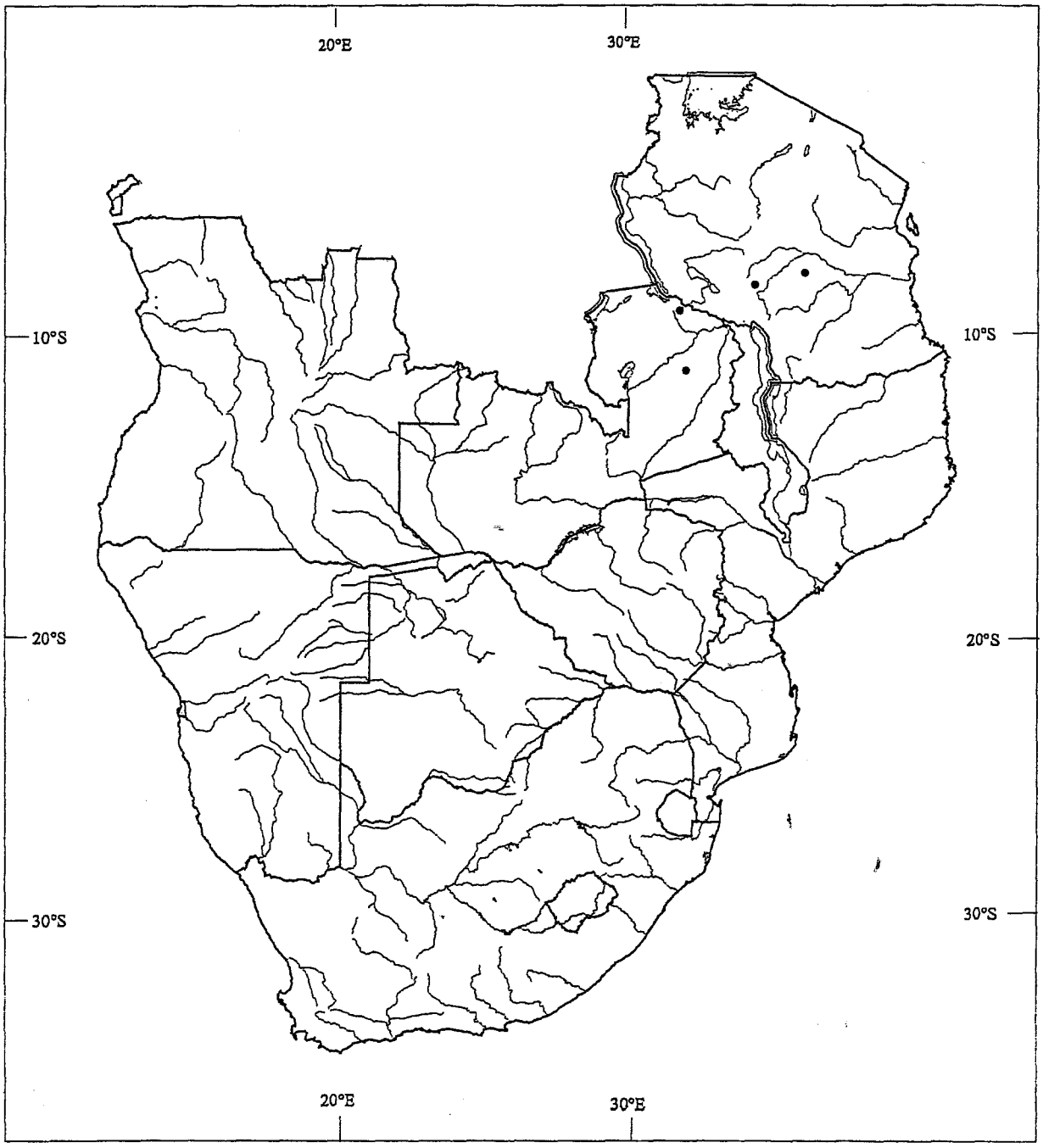


Figure F.28. Point distribution of *Amphilius jacksonii*. Scale approximately 1:25 000 000

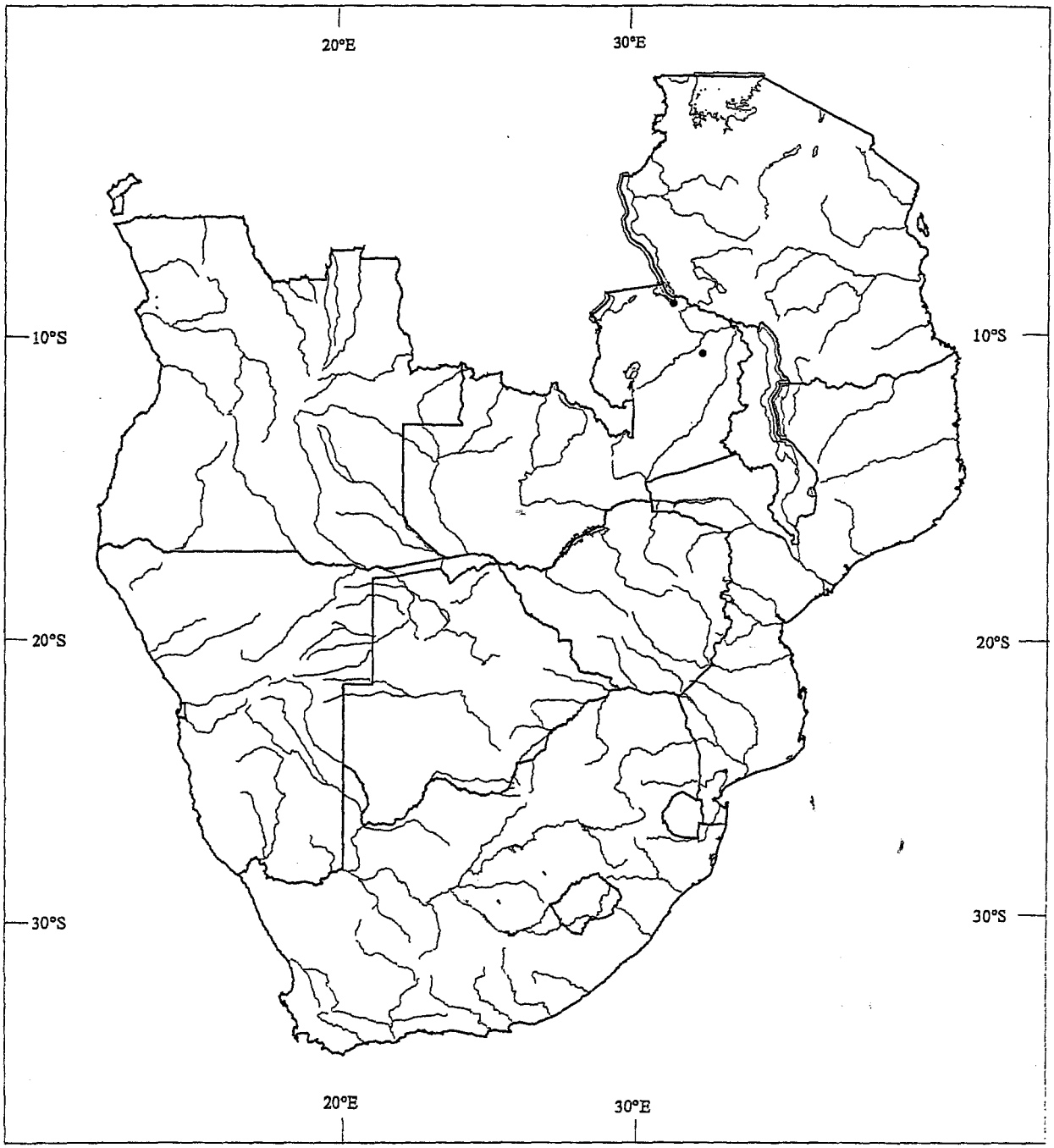


Figure F.29. Point distribution of *Amphilius kivuensis*. Scale approximately 1:25 000 000

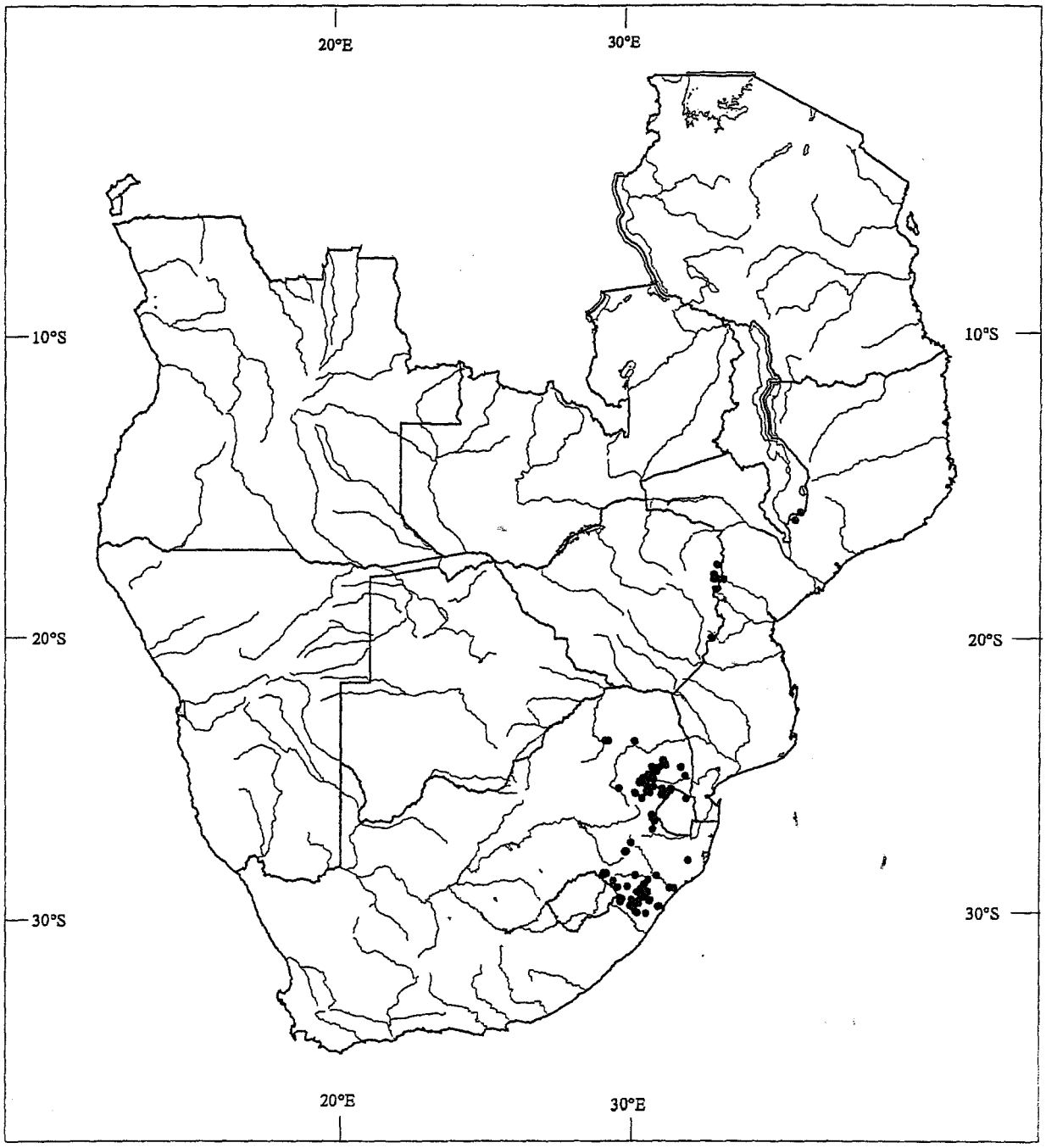


Figure F.30. Point distribution of *Amphilius natalensis*. Scale approximately 1:25 000 000

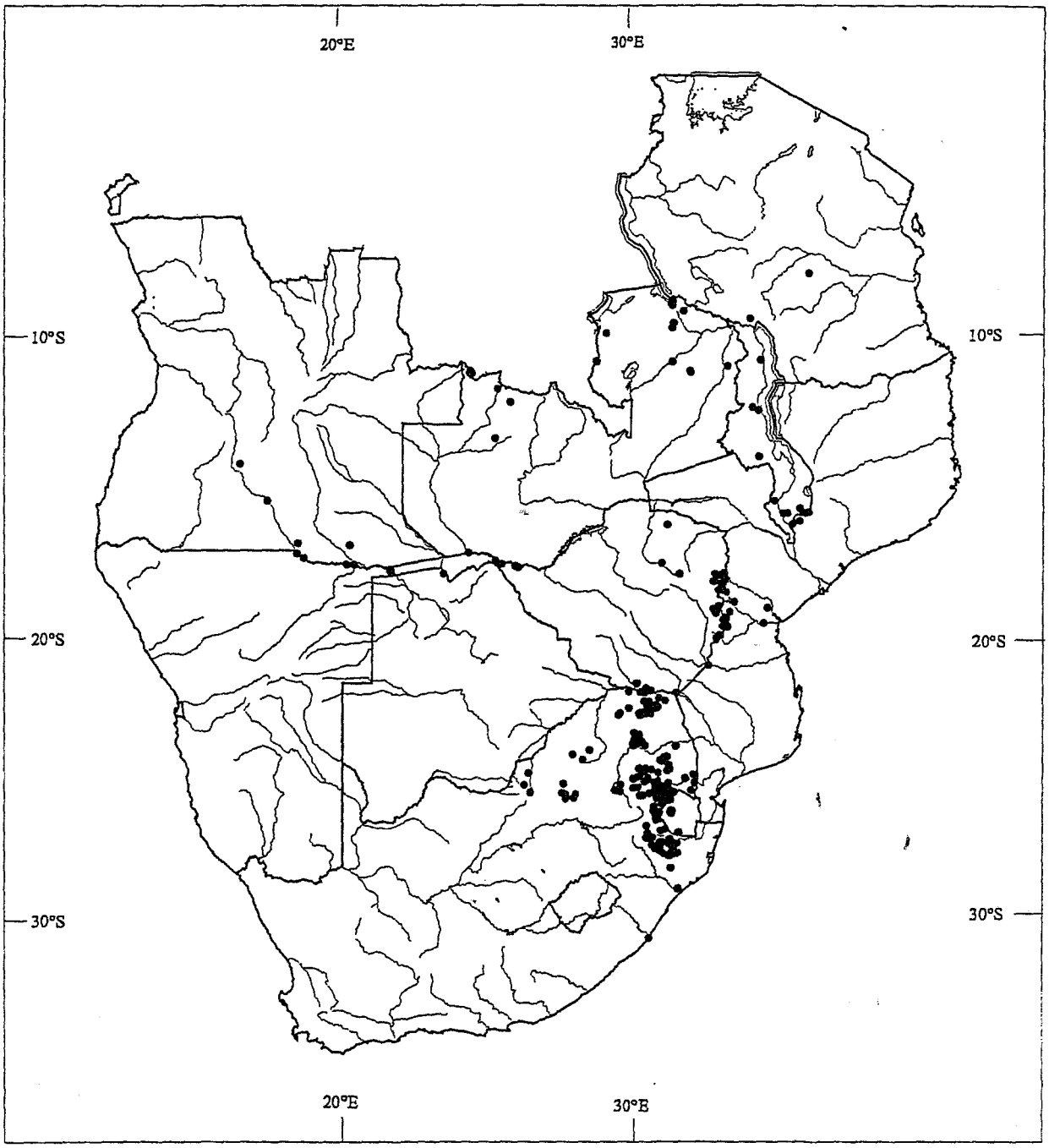


Figure F.31. Point distribution of *Amphilius uranoscopus*. Scale approximately 1:25 000 000

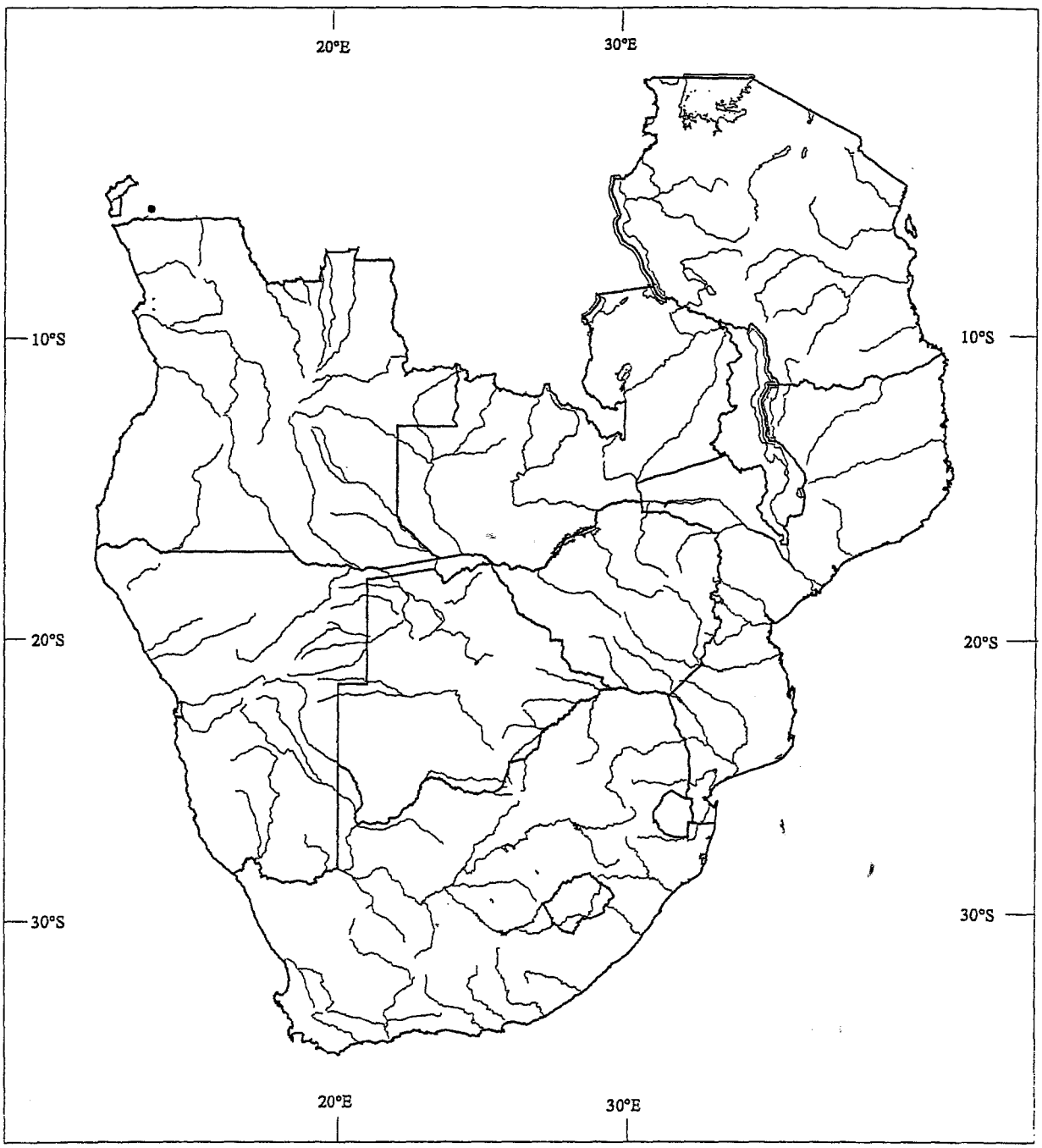


Figure F.32. Point distribution of *Amphilius zairensis*. Scale approximately 1:25 000 000

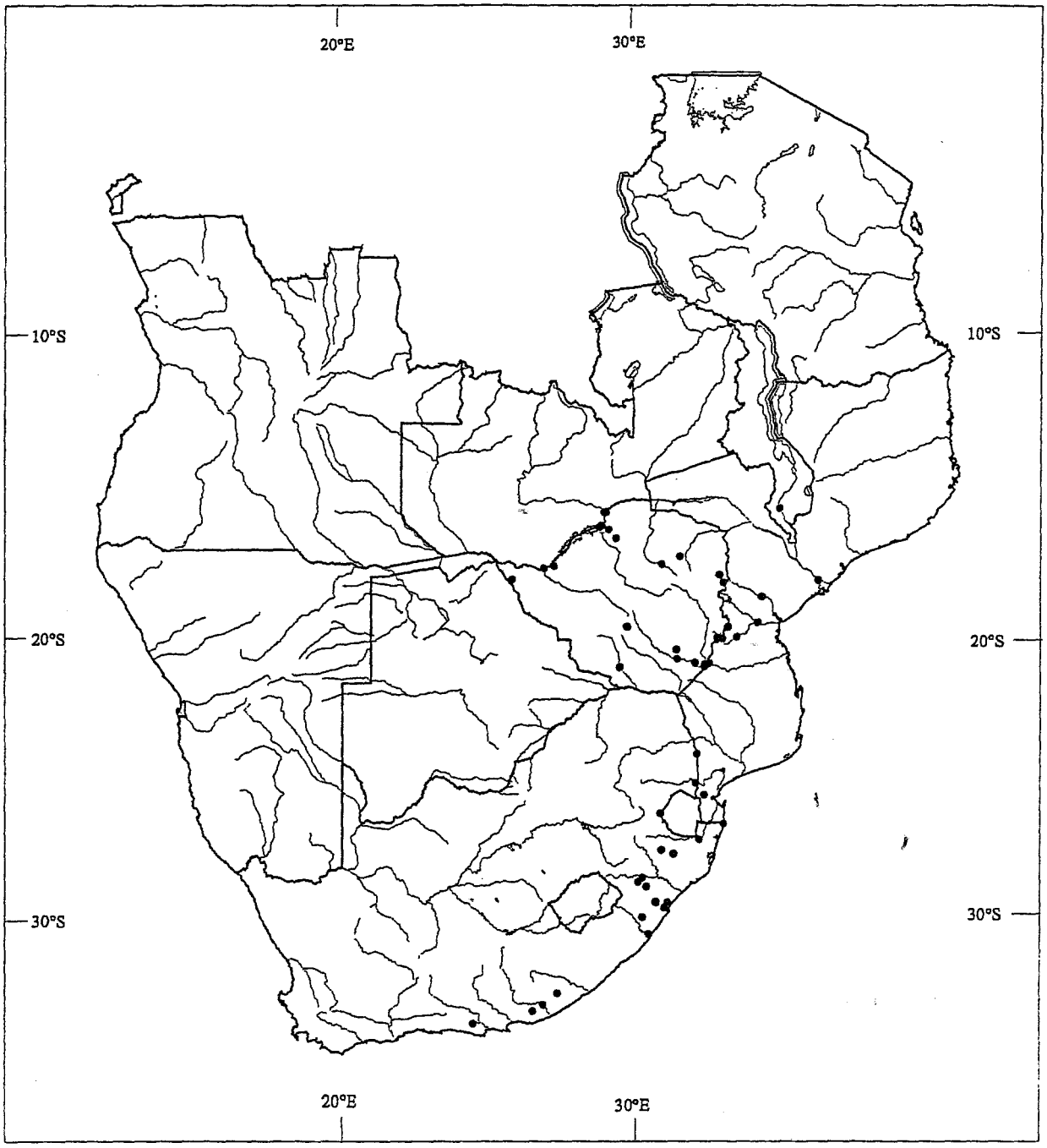


Figure F.33. Point distribution of *Anguilla bengalensis labiata*. Scale approximately 1:25 000 000

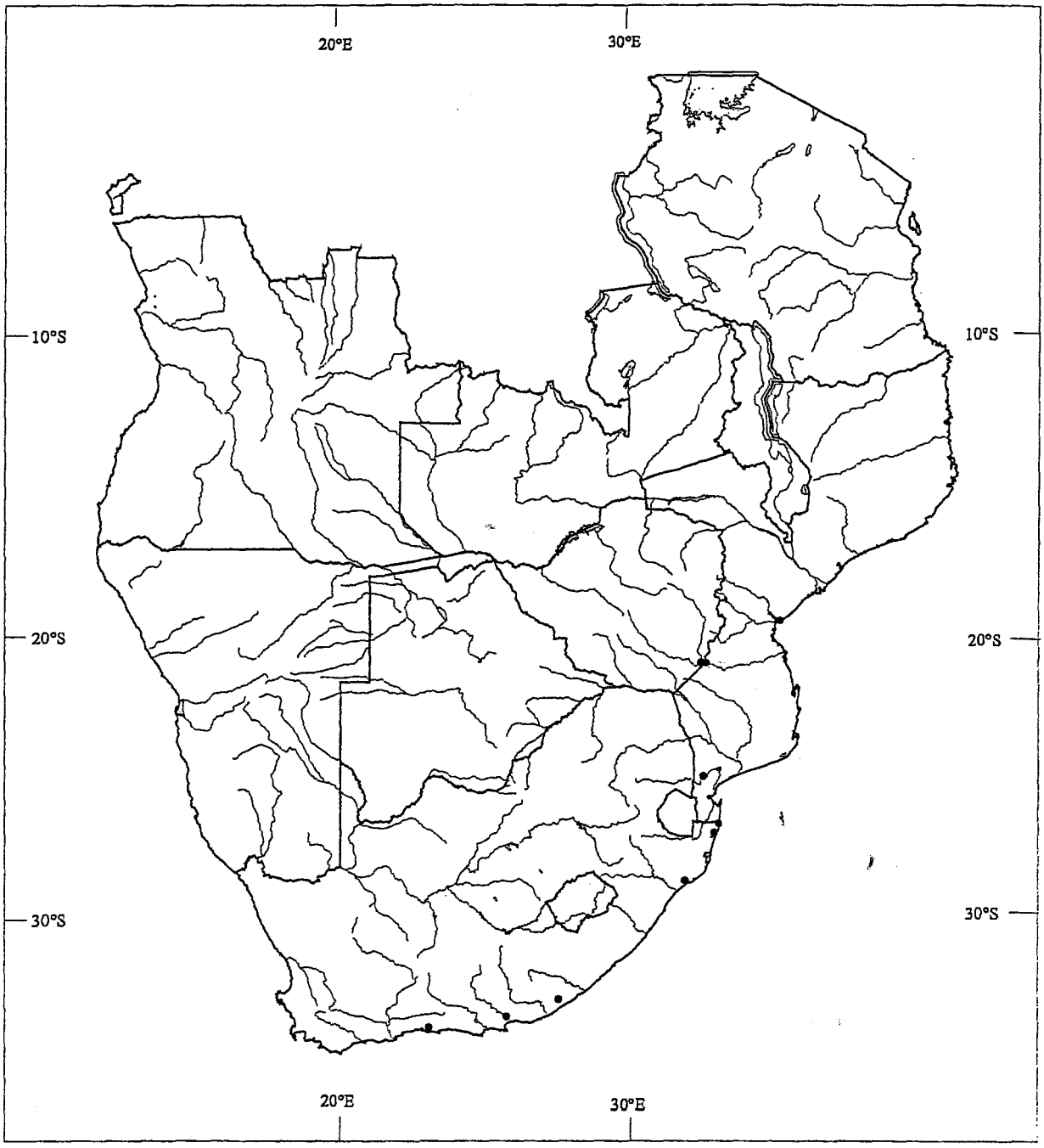


Figure F.34. Point distribution of *Anguilla bicolor bicolor*. Scale approximately 1:25 000 000

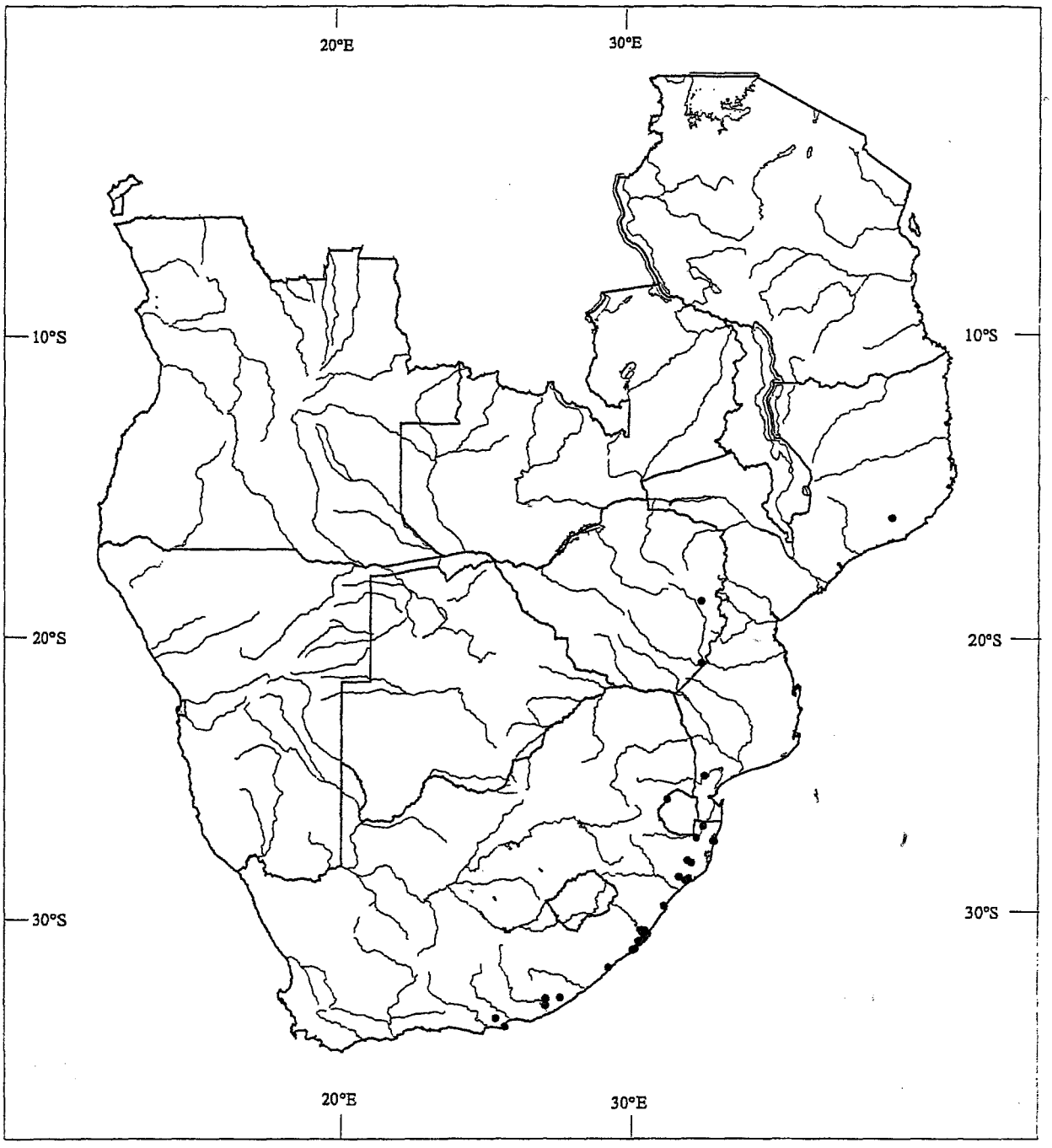


Figure F.35. Point distribution of *Anguilla marmorata*. Scale approximately 1:25 000 000

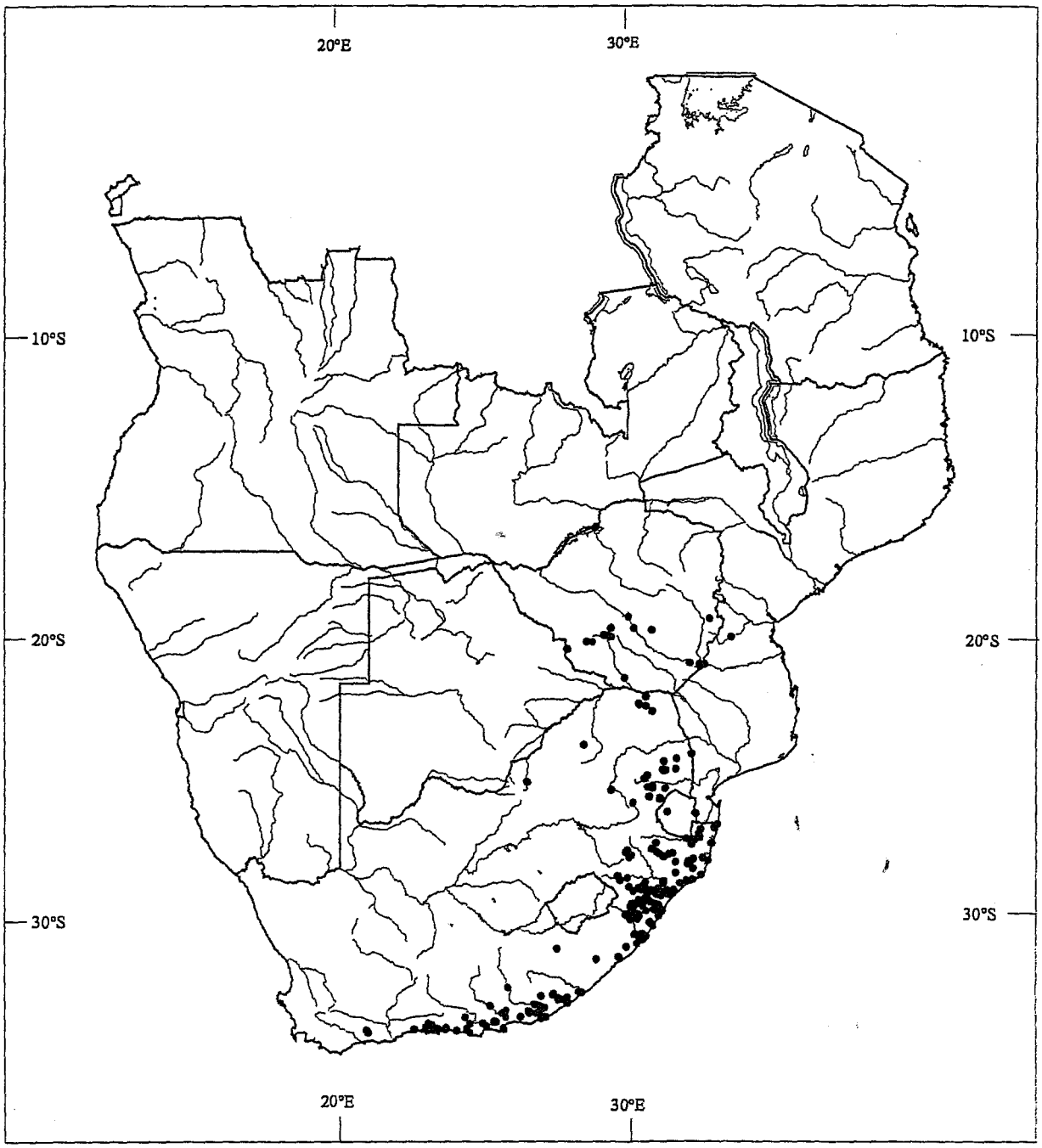


Figure F.36. Point distribution of *Anguilla mossambica*. Scale approximately 1:25 000 000

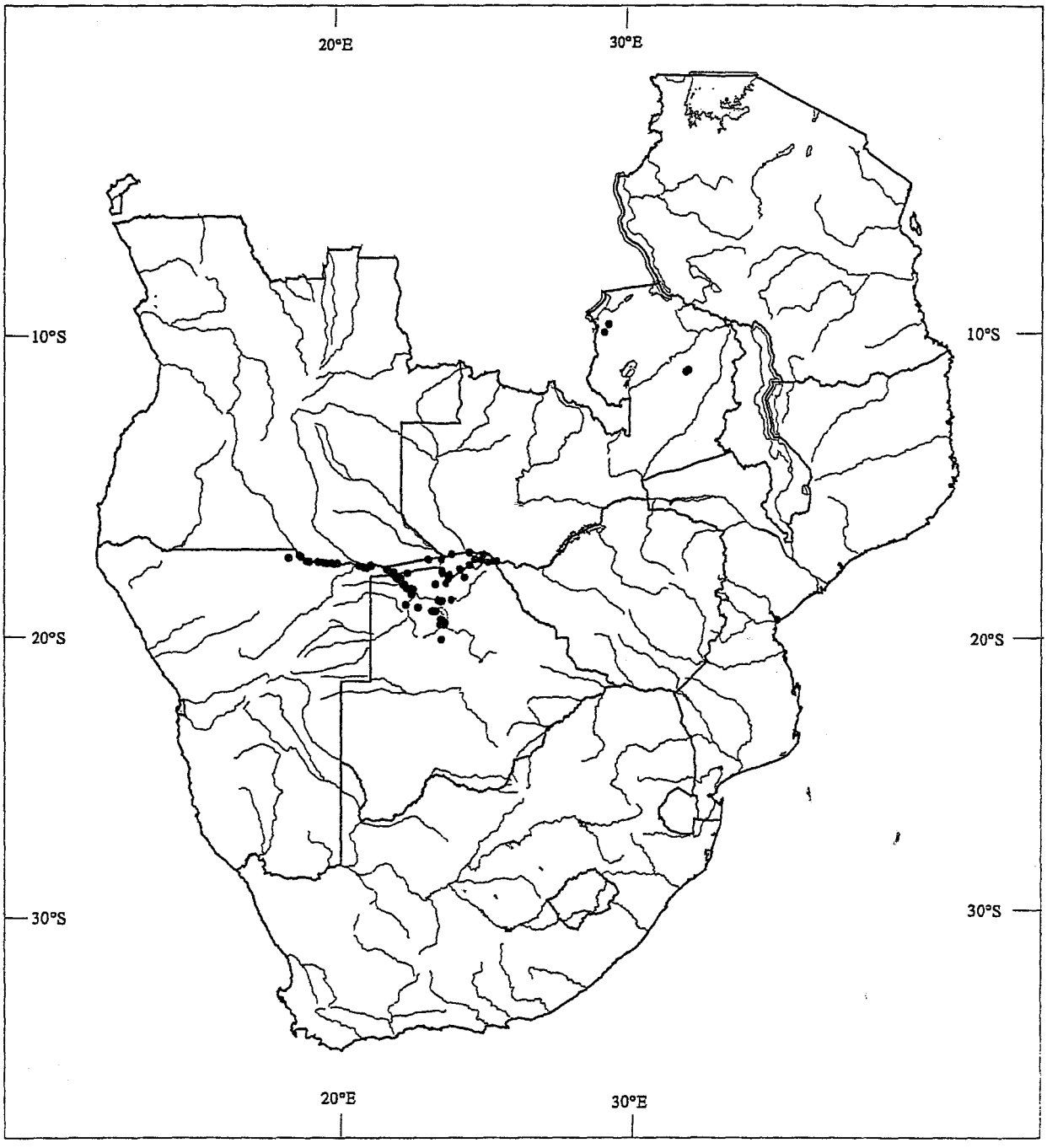


Figure F.37. Point distribution of *Aplocheilichthys hutereaui*. Scale approximately 1:25 000 000

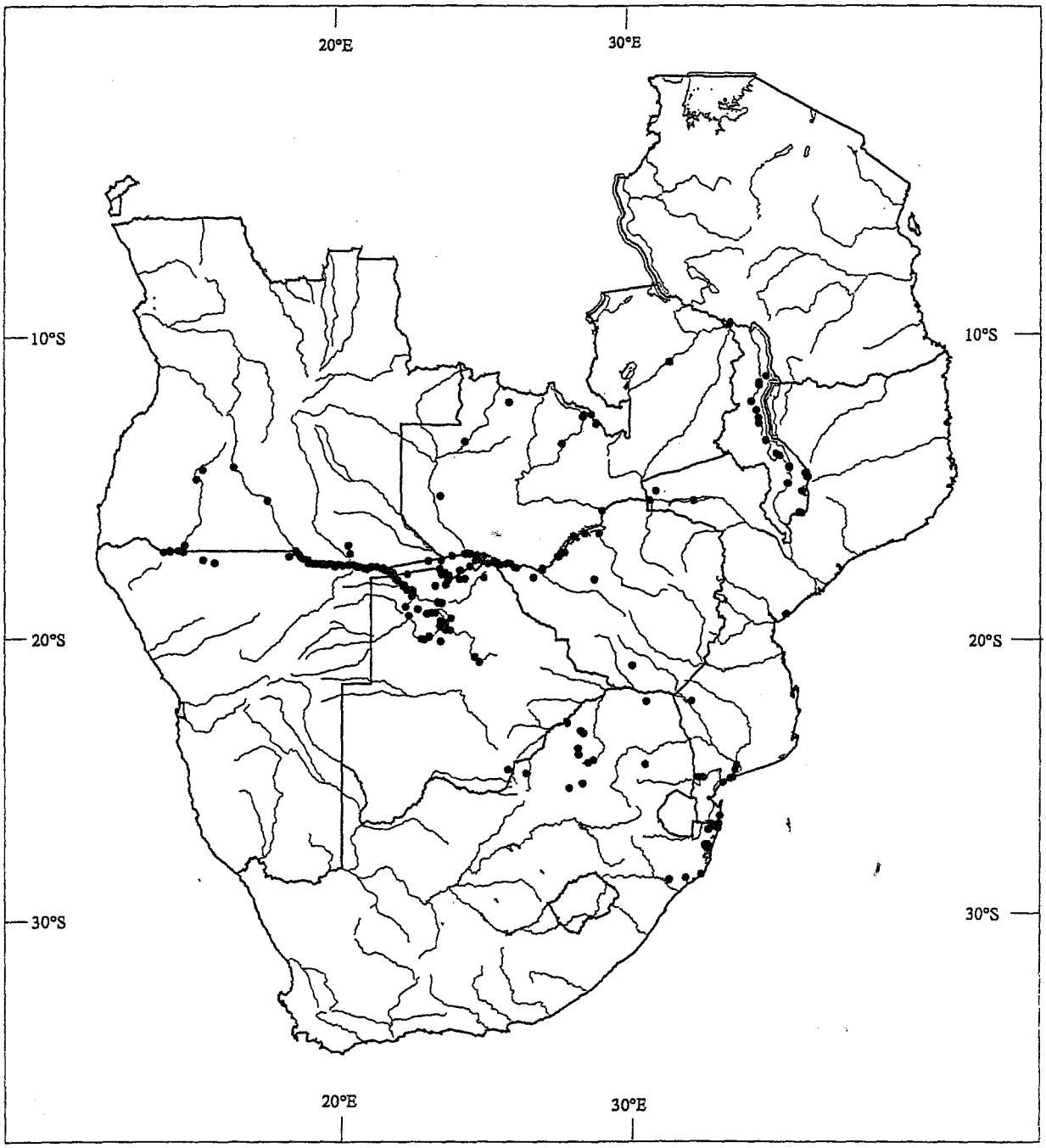


Figure F.38. Point distribution of *Aplocheilichthys johnstoni*. Scale approximately 1:25 000 000

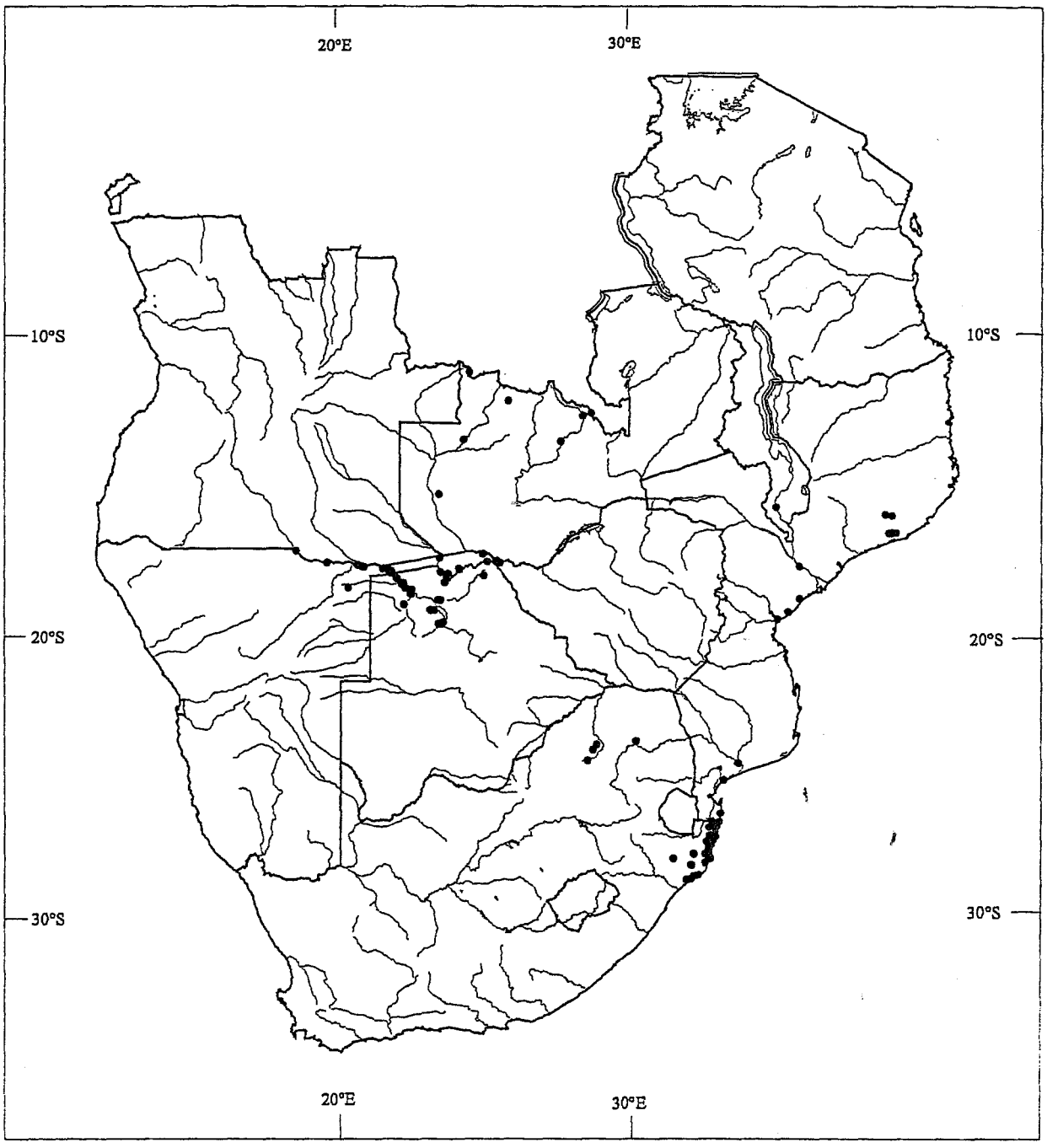


Figure F.39. Point distribution of *Aplocheilichthys katangae*. Scale approximately 1:25 000 000

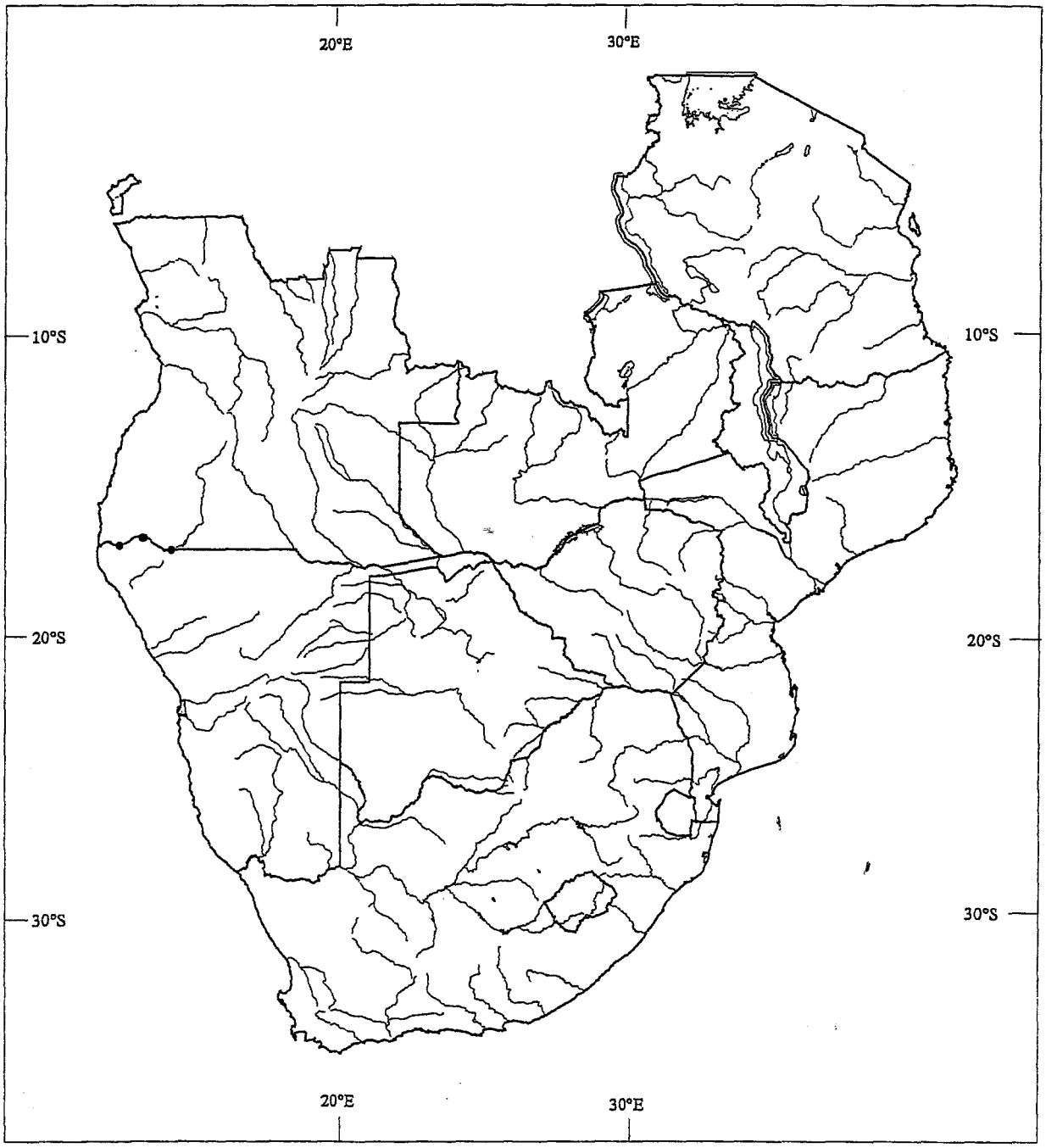


Figure F.40. Point distribution of *Aplocheilichthys macrurus*. Scale approximately 1:25 000 000

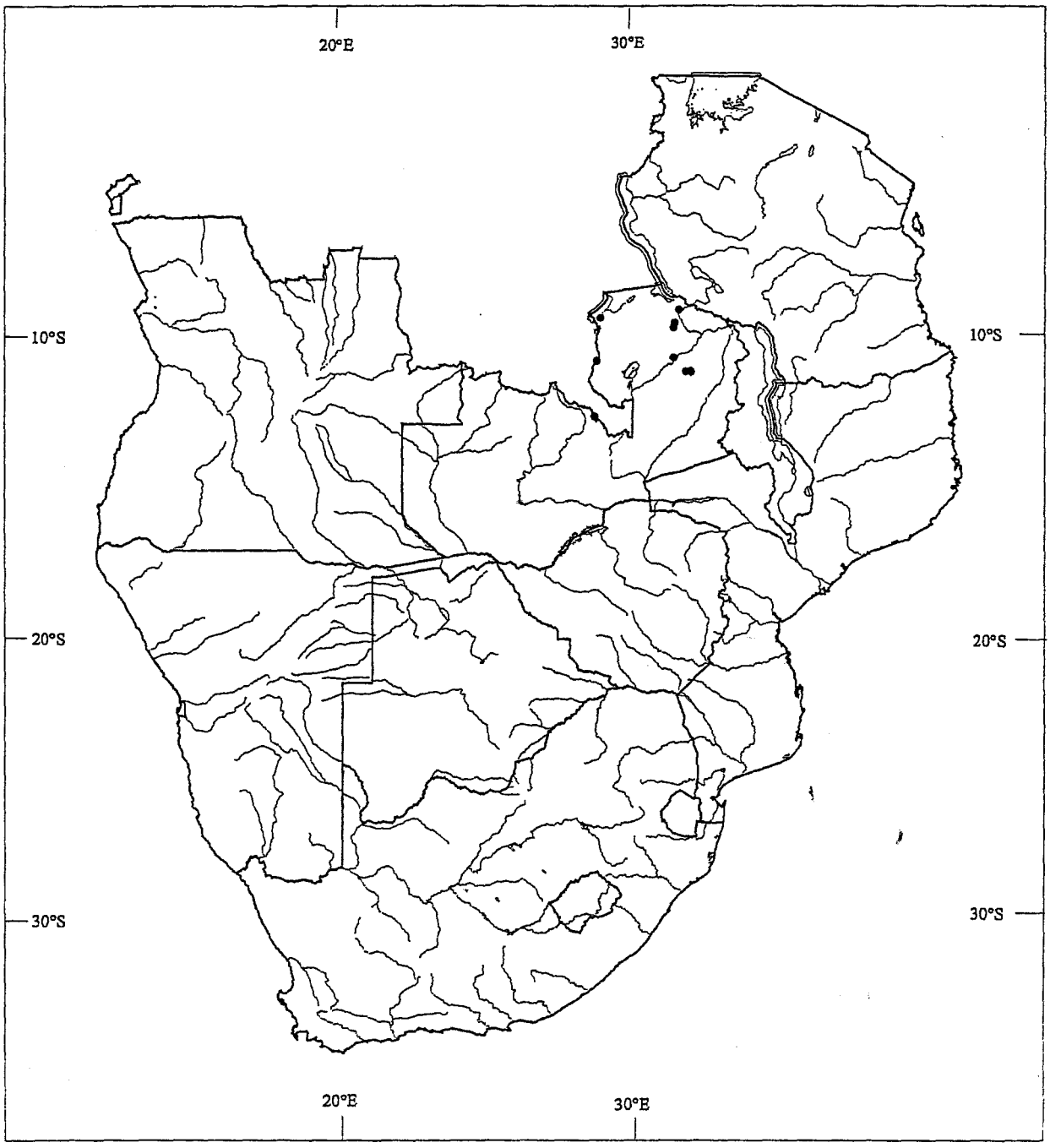


Figure F.41. Point distribution of *Aplocheilichthys moeruensis*. Scale approximately 1:25 000 000

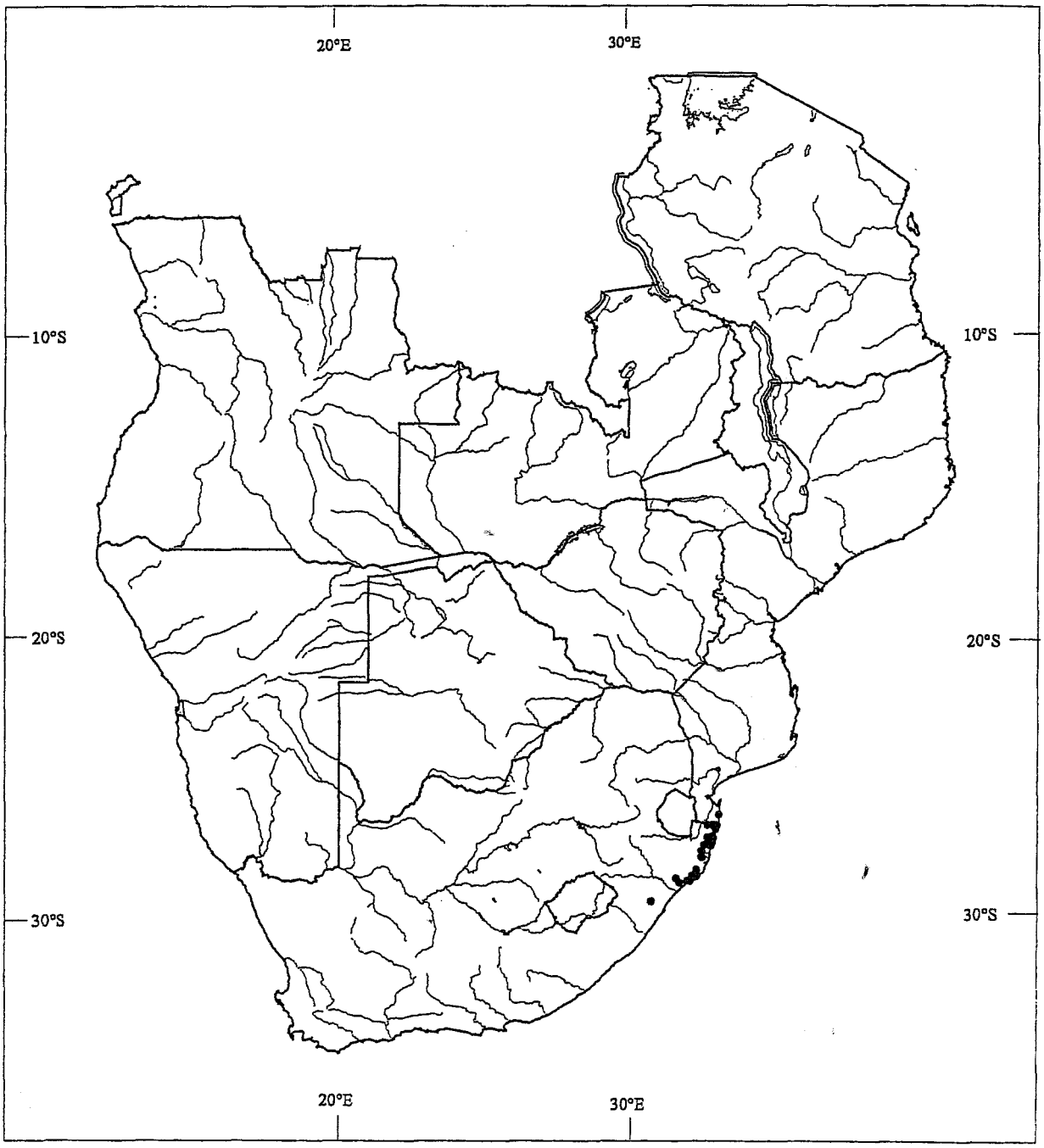


Figure F.42. Point distribution of *Aplocheilichthys myaposae*. Scale approximately 1:25 000 000

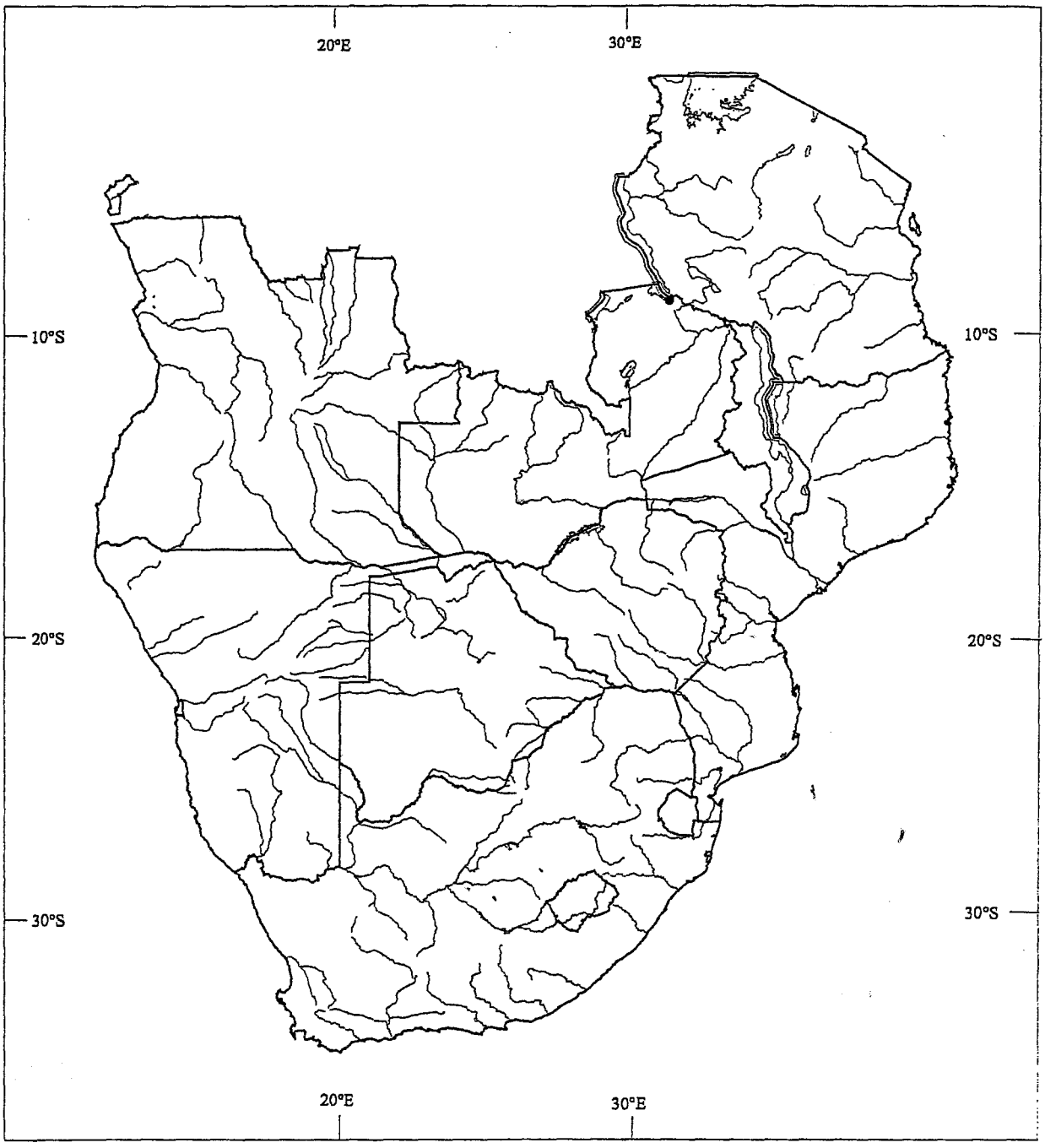


Figure F.43. Point distribution of *Aplocheilichthys pumilus*. Scale approximately 1:25 000 000

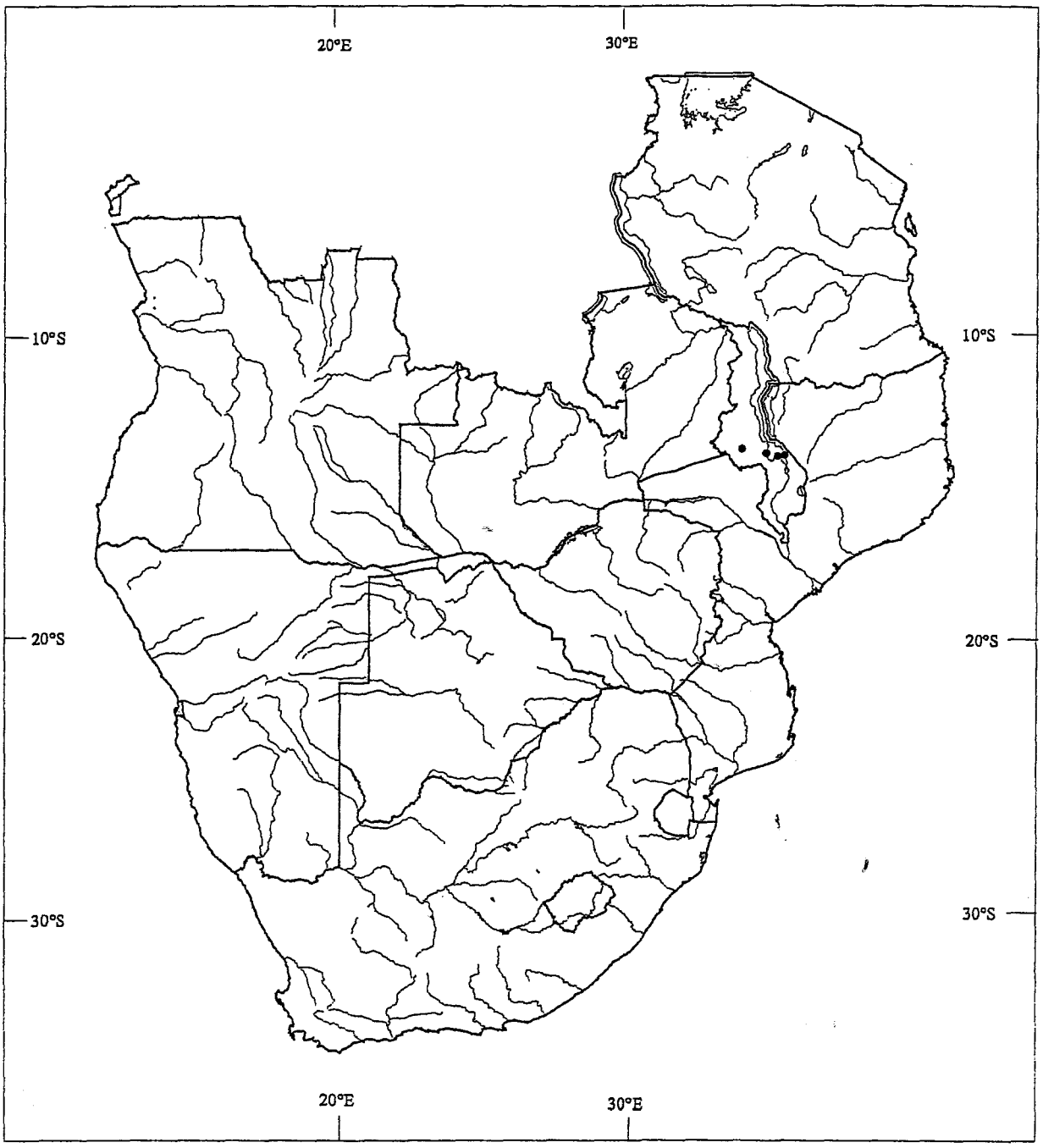


Figure F.44. Point distribution of *Aristochromis christyi*. Scale approximately 1:25 000 000

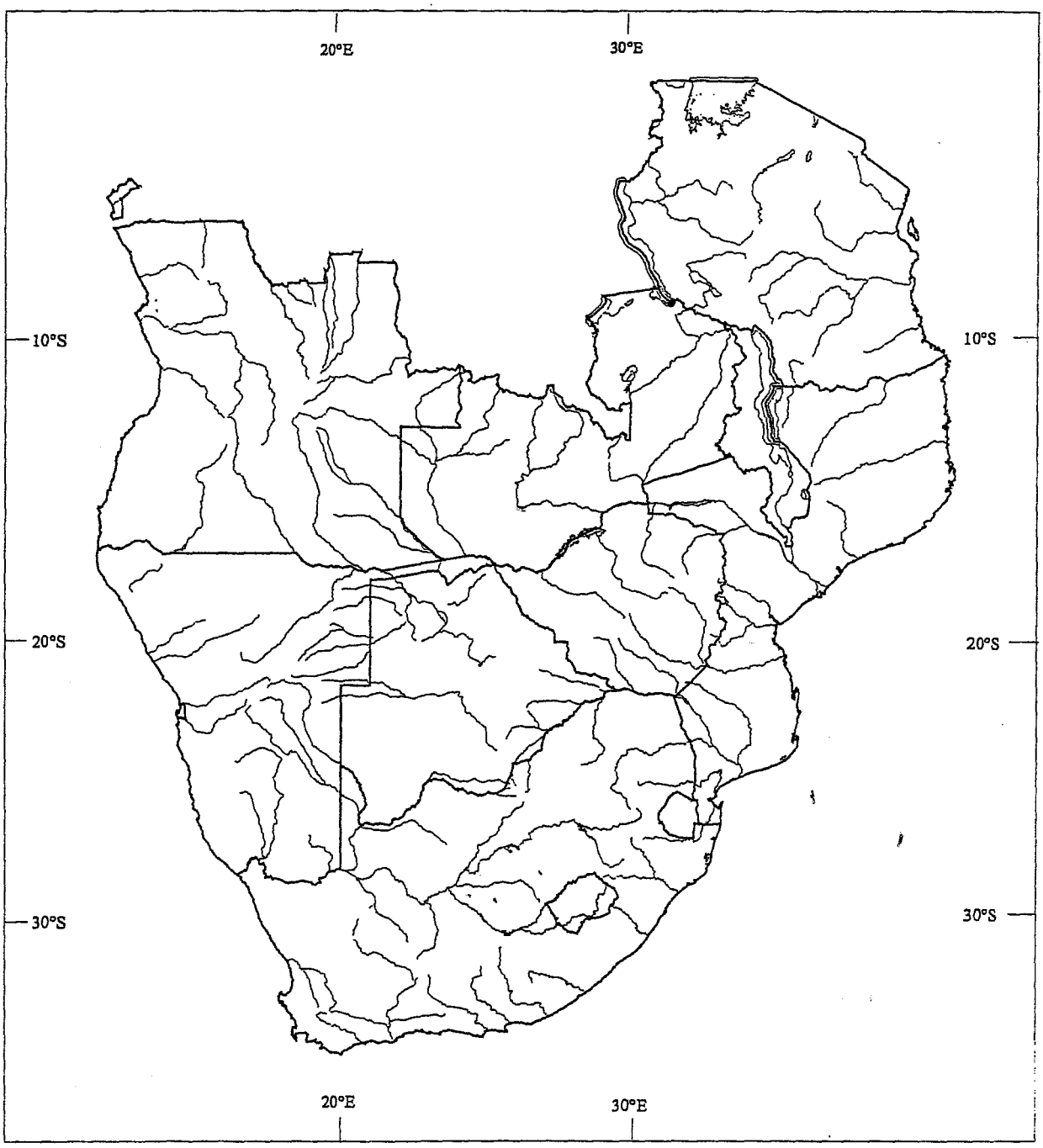


Figure F.45. Point distribution of *Asprotilapia leptura*. Scale approximately 1:25 000 000

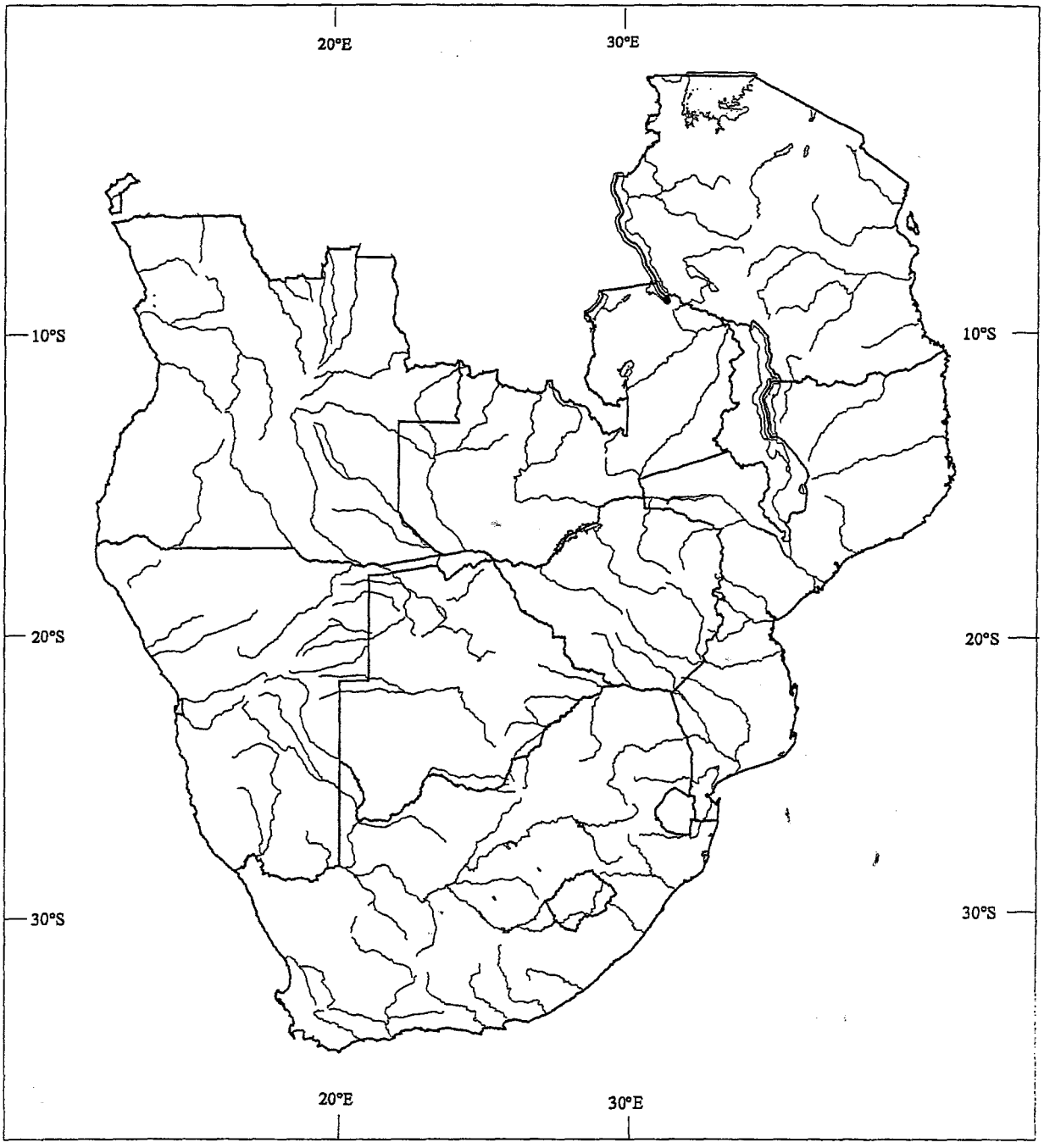


Figure F.46. Point distribution of *Astatotilapia burtoni*. Scale approximately 1:25 000 000

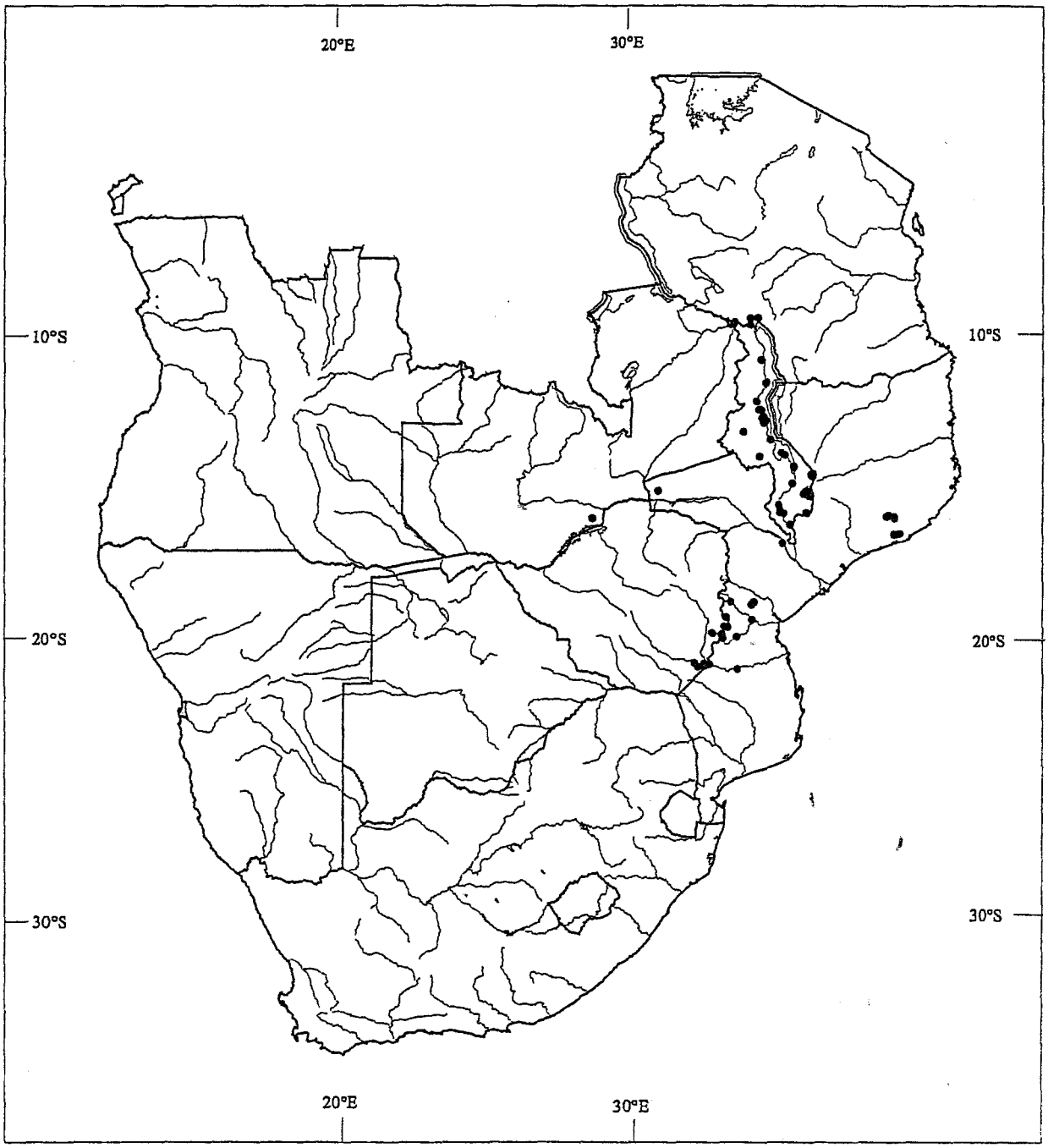


Figure F.47. Point distribution of *Astatotilapia calliptera*. Scale approximately 1:25 000 000

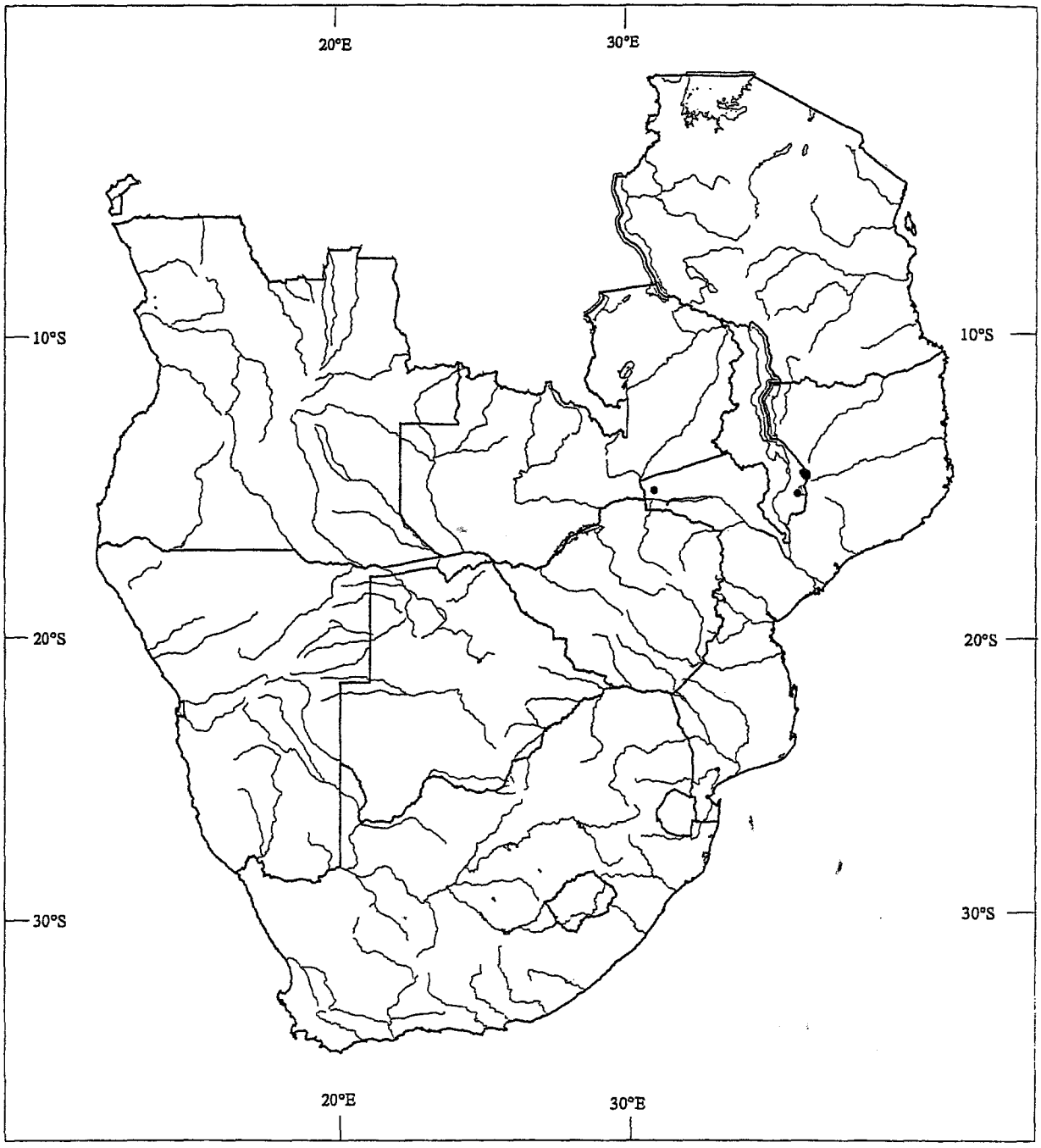


Figure F.48. Point distribution of *Astatotilapia tweddlei*. Scale approximately 1:25 000 000

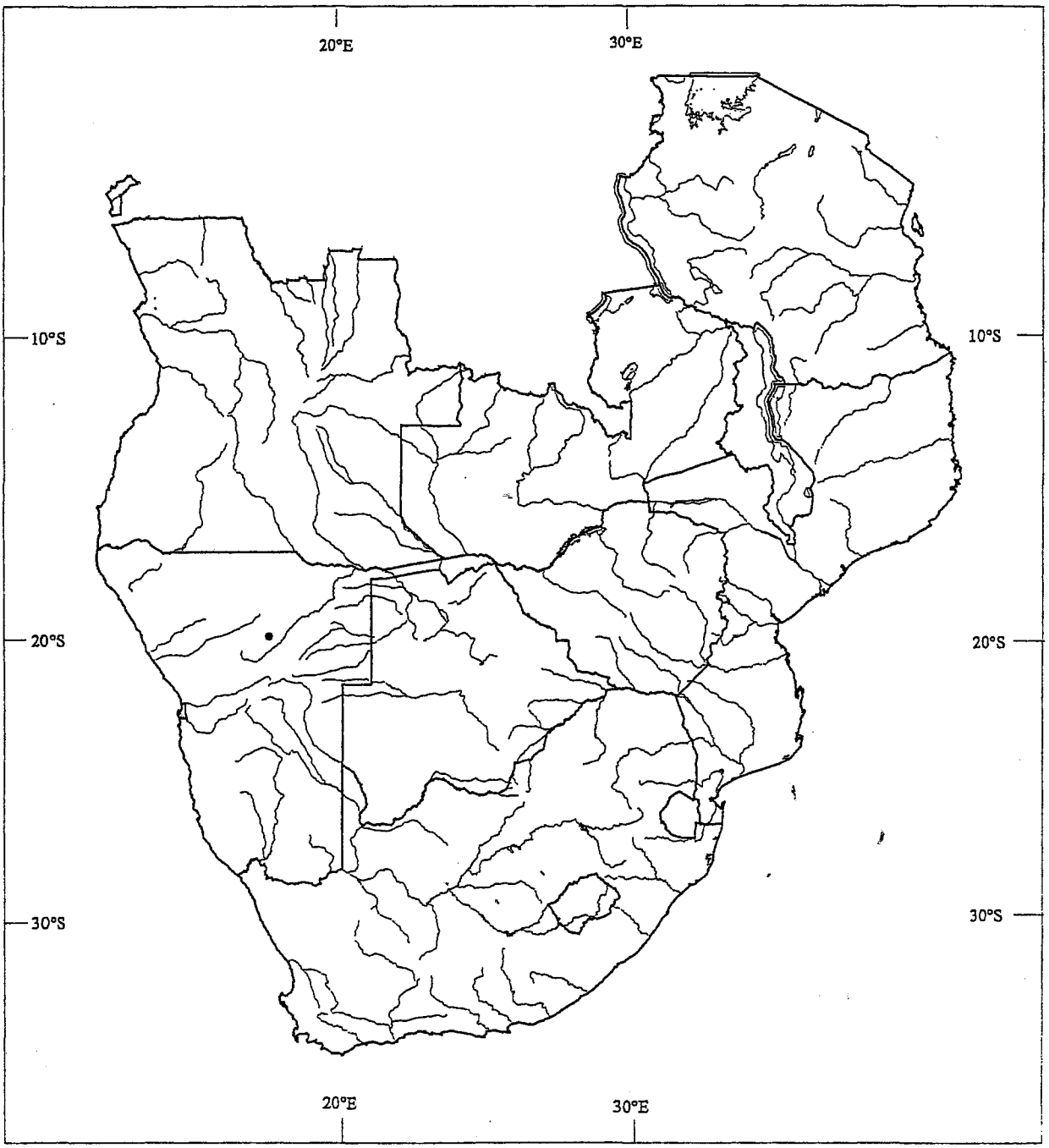


Figure F.49. Point distribution of *Astyanax orthodus*. Scale approximately 1:25 000 000

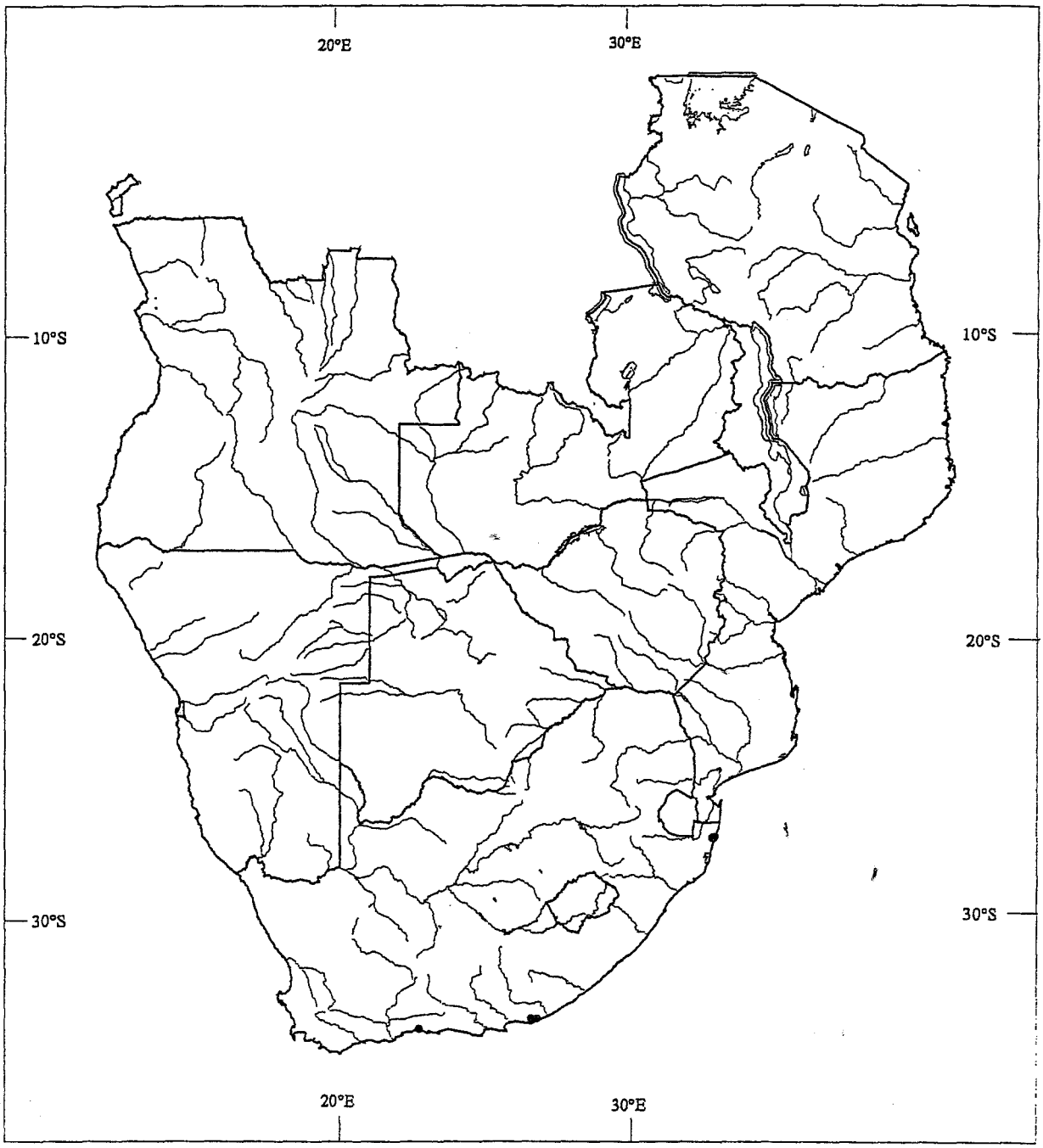


Figure F.50. Point distribution of *Atherina breviceps*. Scale approximately 1:25 000 000

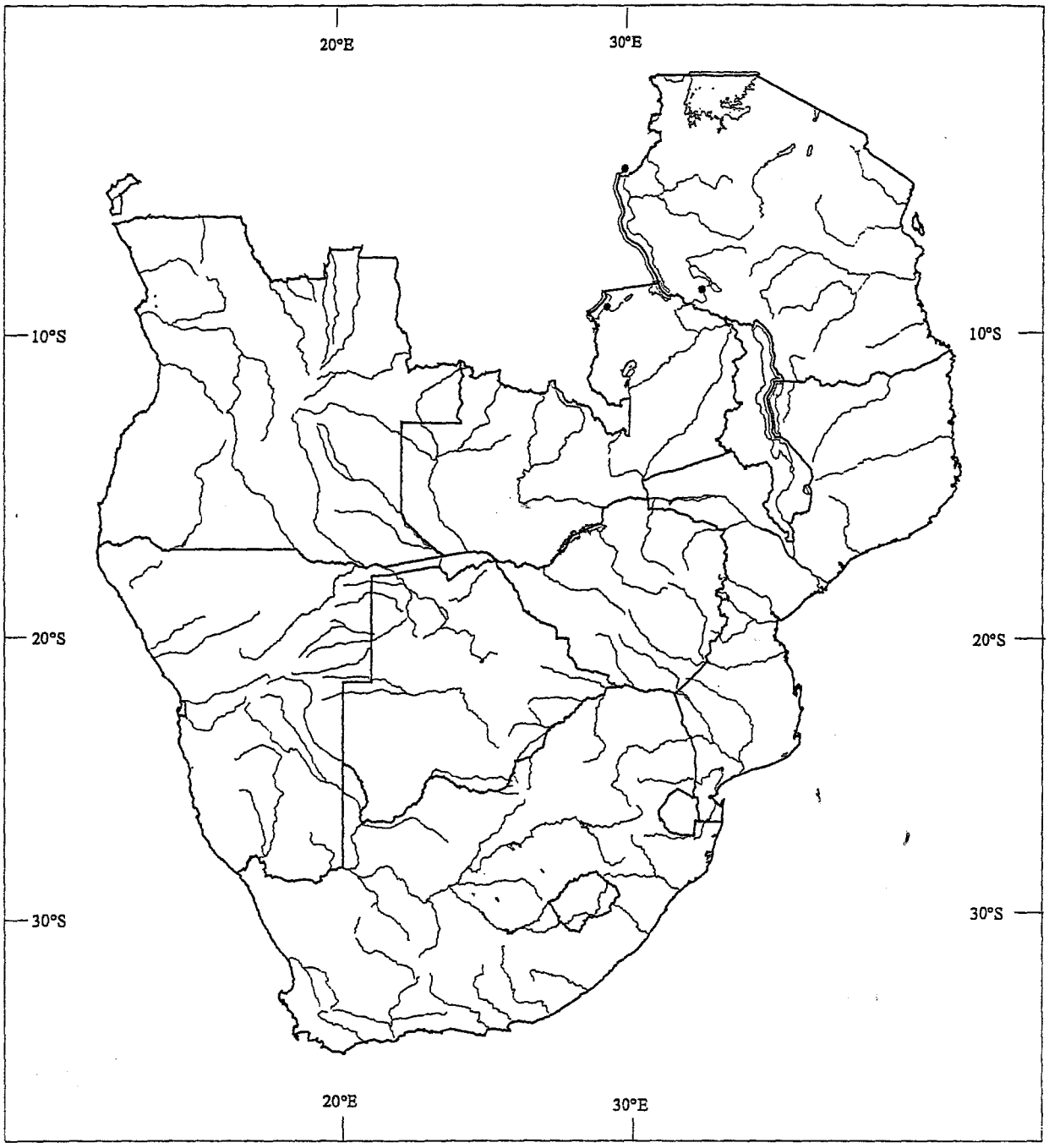


Figure F.51. Point distribution of *Auchenoglanis occidentalis*. Scale approximately 1:25 000 000

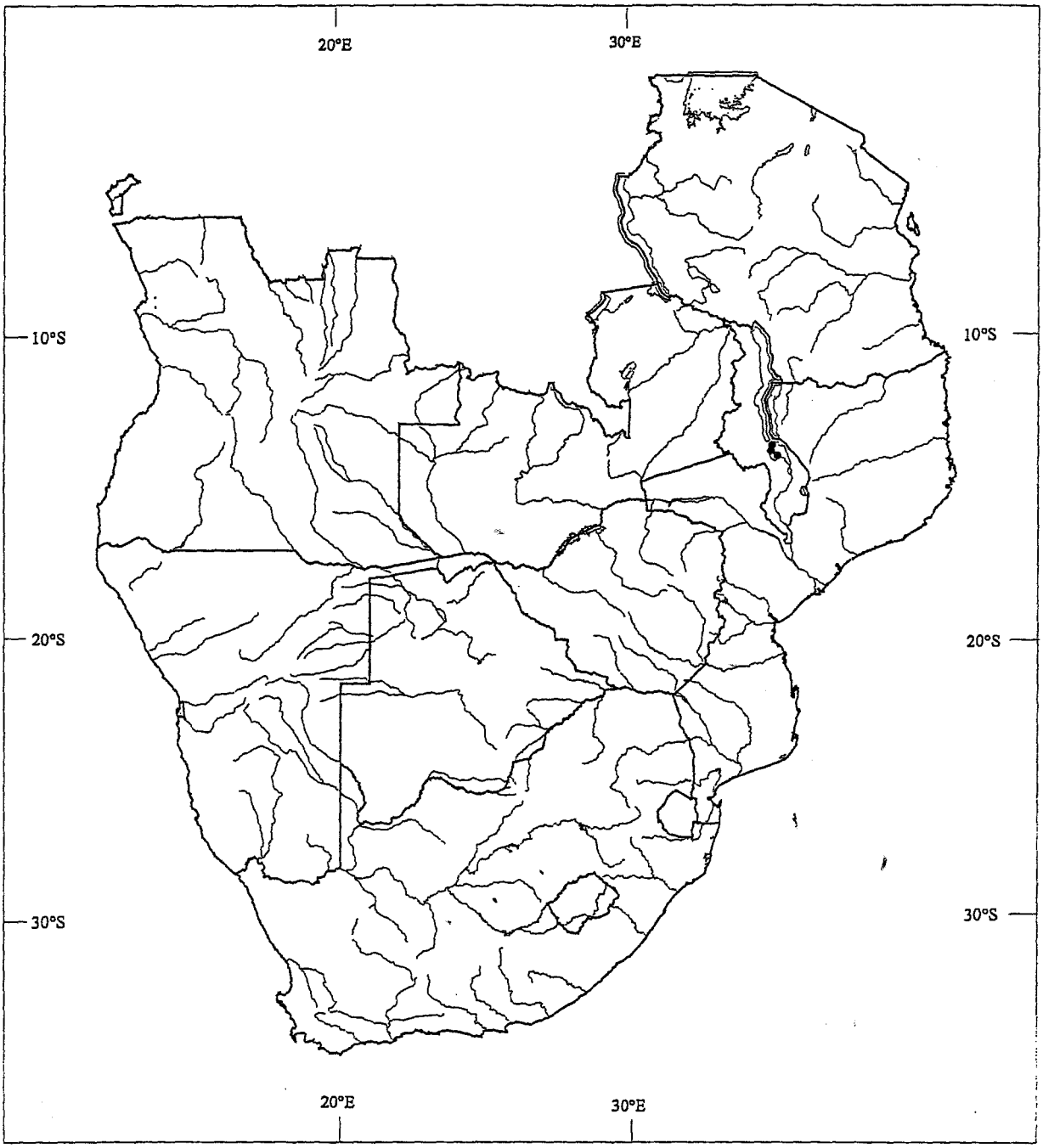


Figure F.52. Point distribution of *Aulonocara guentheri*. Scale approximately 1:25 000 000

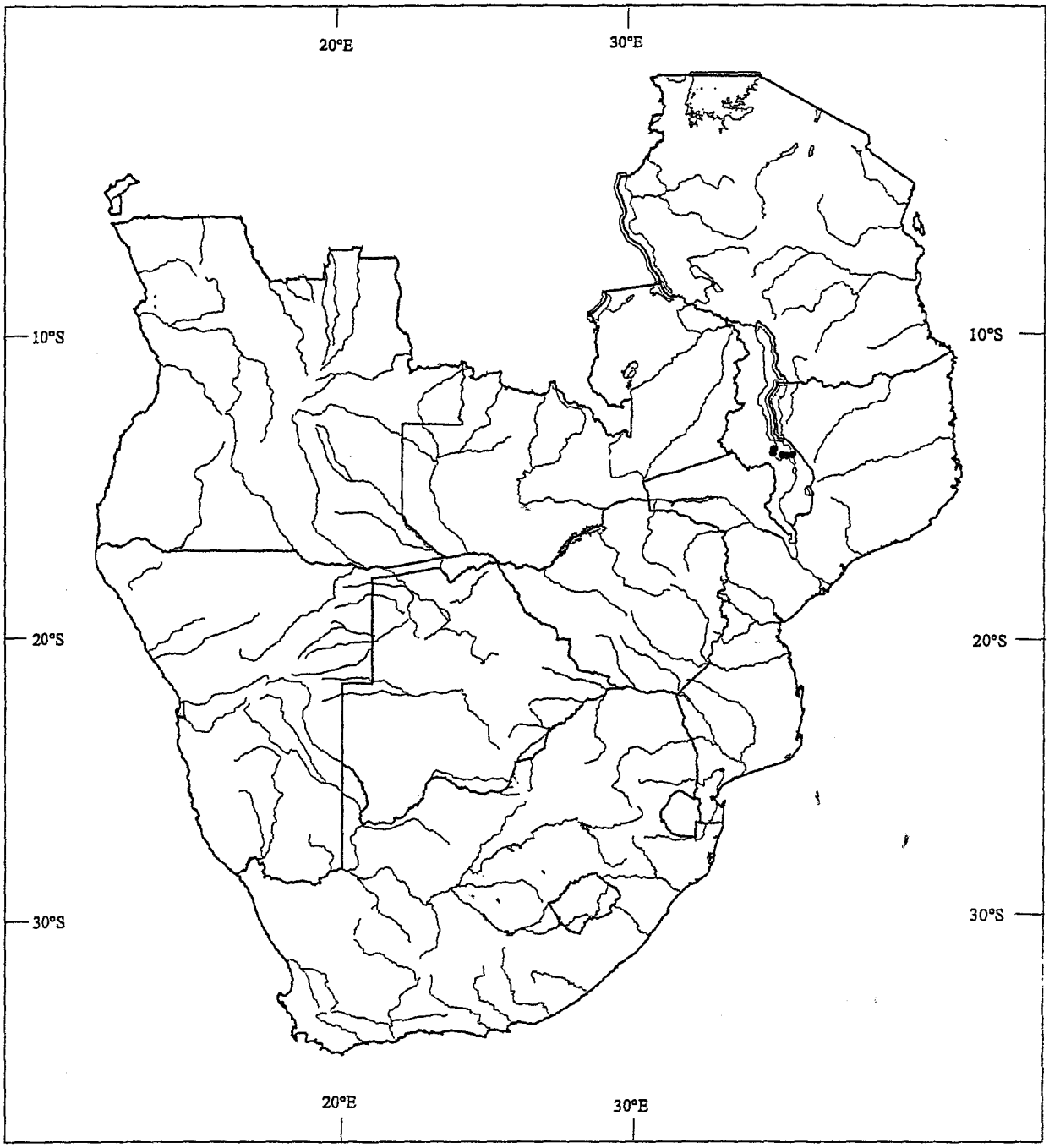


Figure F.53. Point distribution of *Aulonocara macrochir*. Scale approximately 1:25 000 000

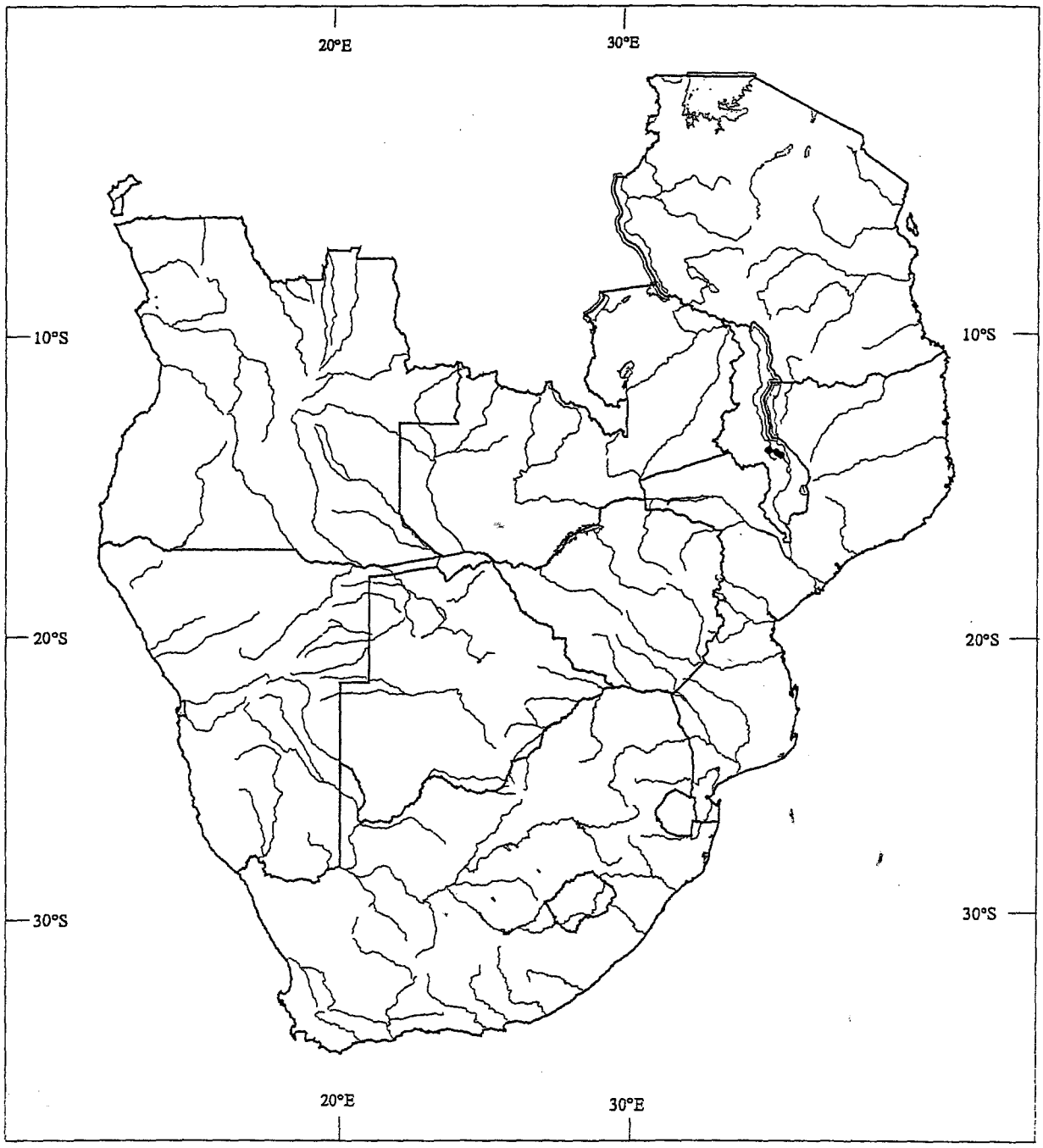


Figure F.54. Point distribution of *Aulonocara nyassae*. Scale approximately 1:25 000 000

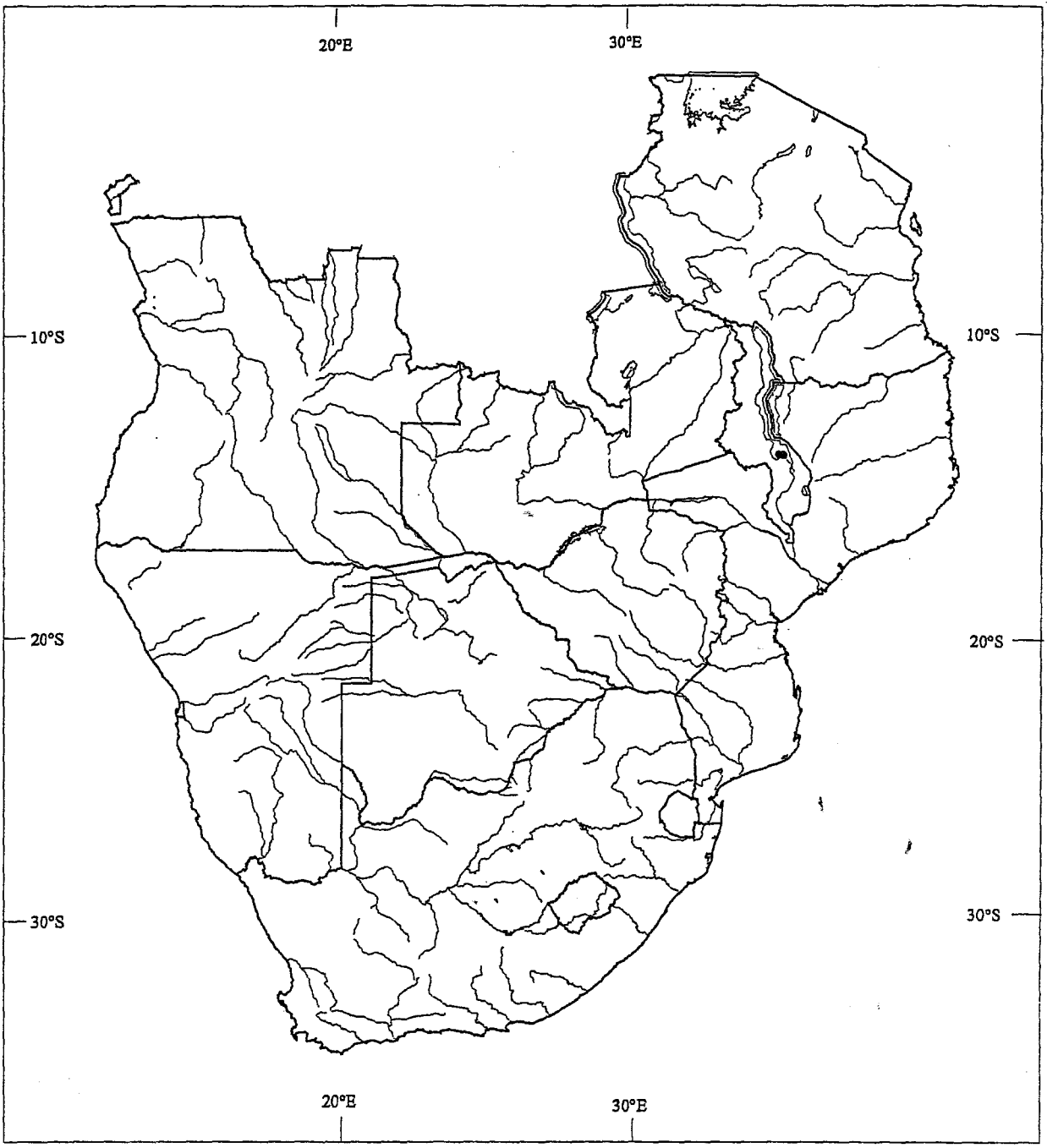


Figure F.55. Point distribution of *Aulonocara rostratum*. Scale approximately 1:25 000 000

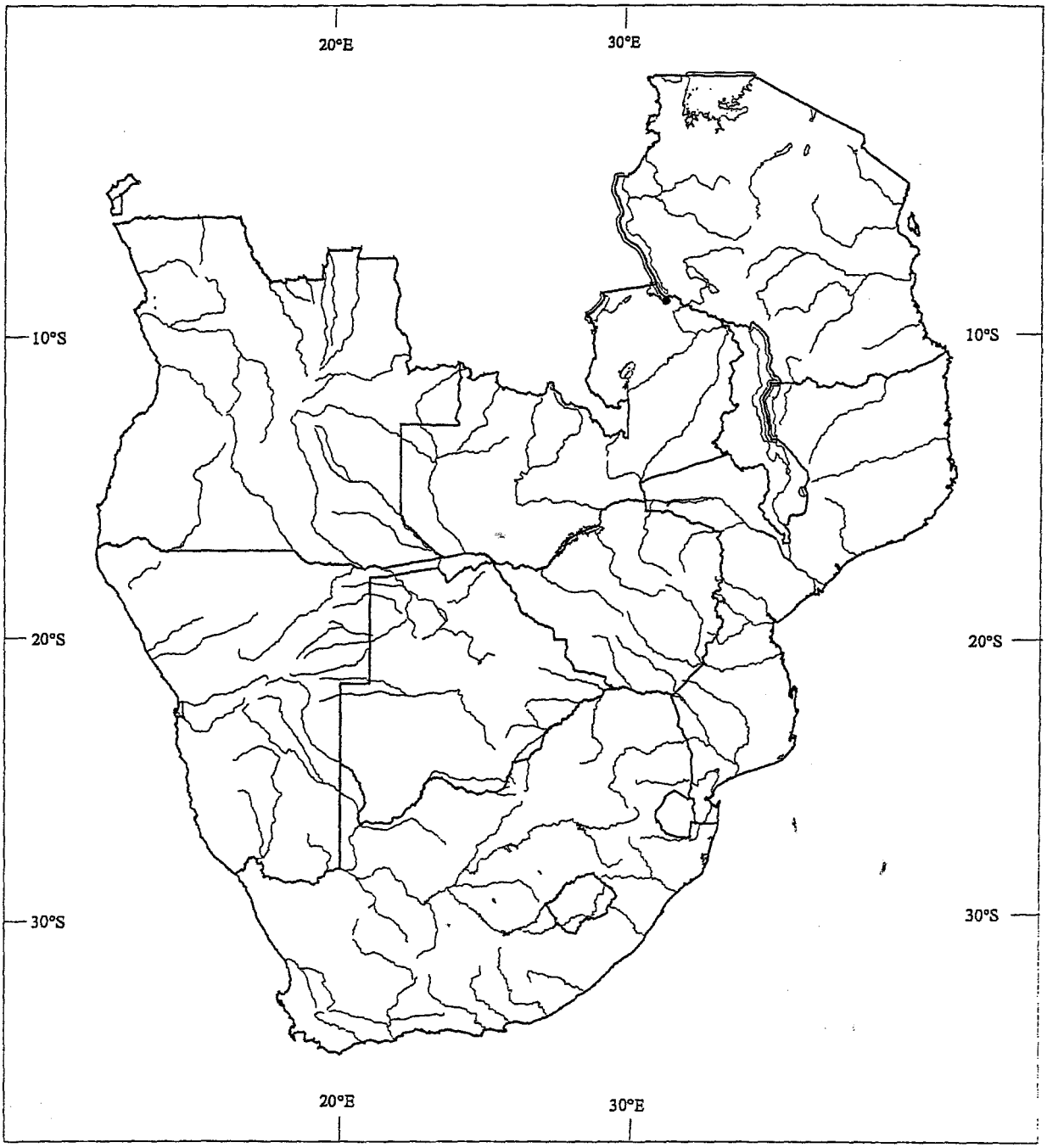


Figure F.56. Point distribution of *Aulonocranus dewindti*. Scale approximately 1:25 000 000

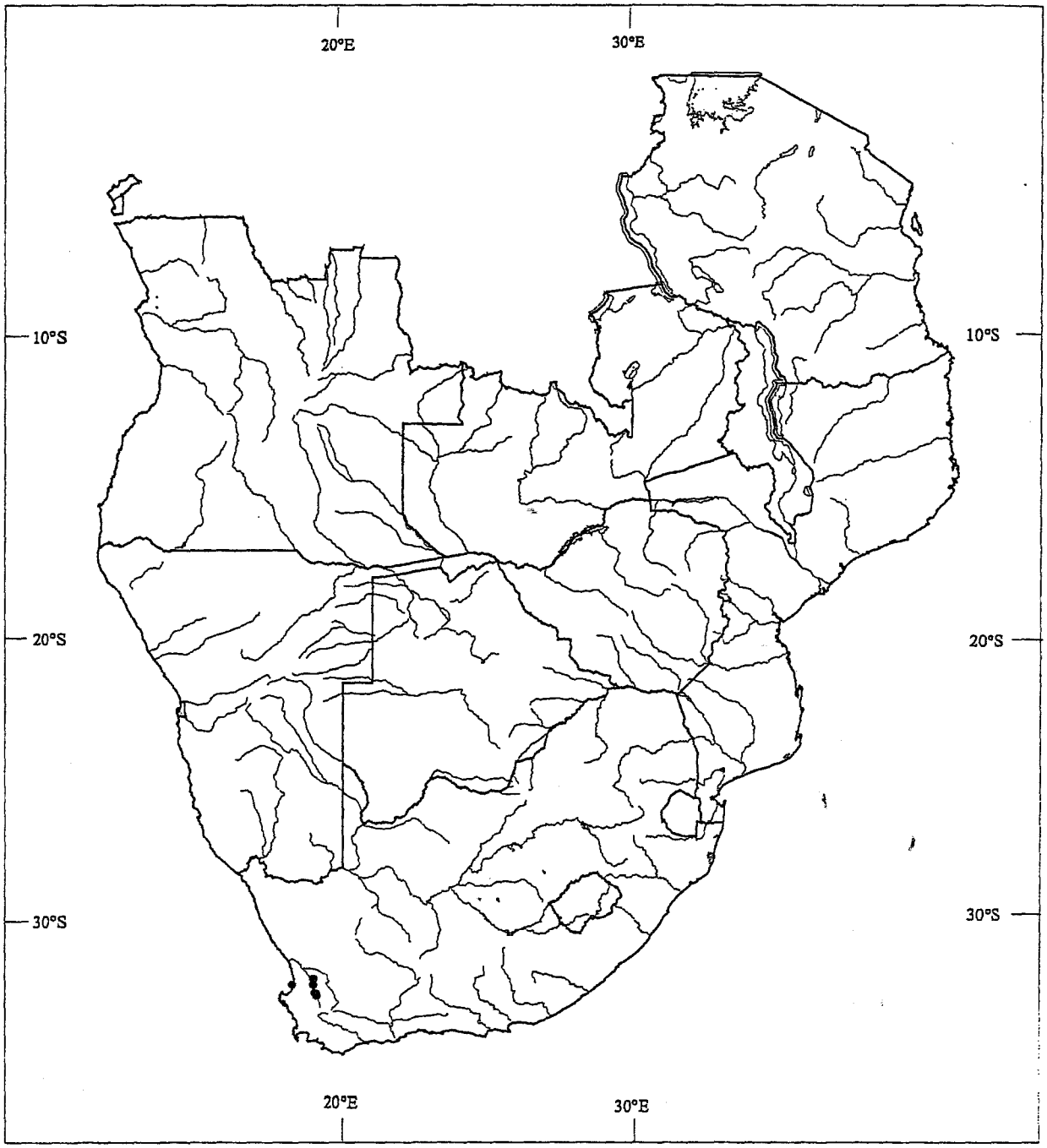


Figure F.57. Point distribution of *Austroglanis barnardi*. Scale approximately 1:25 000 000

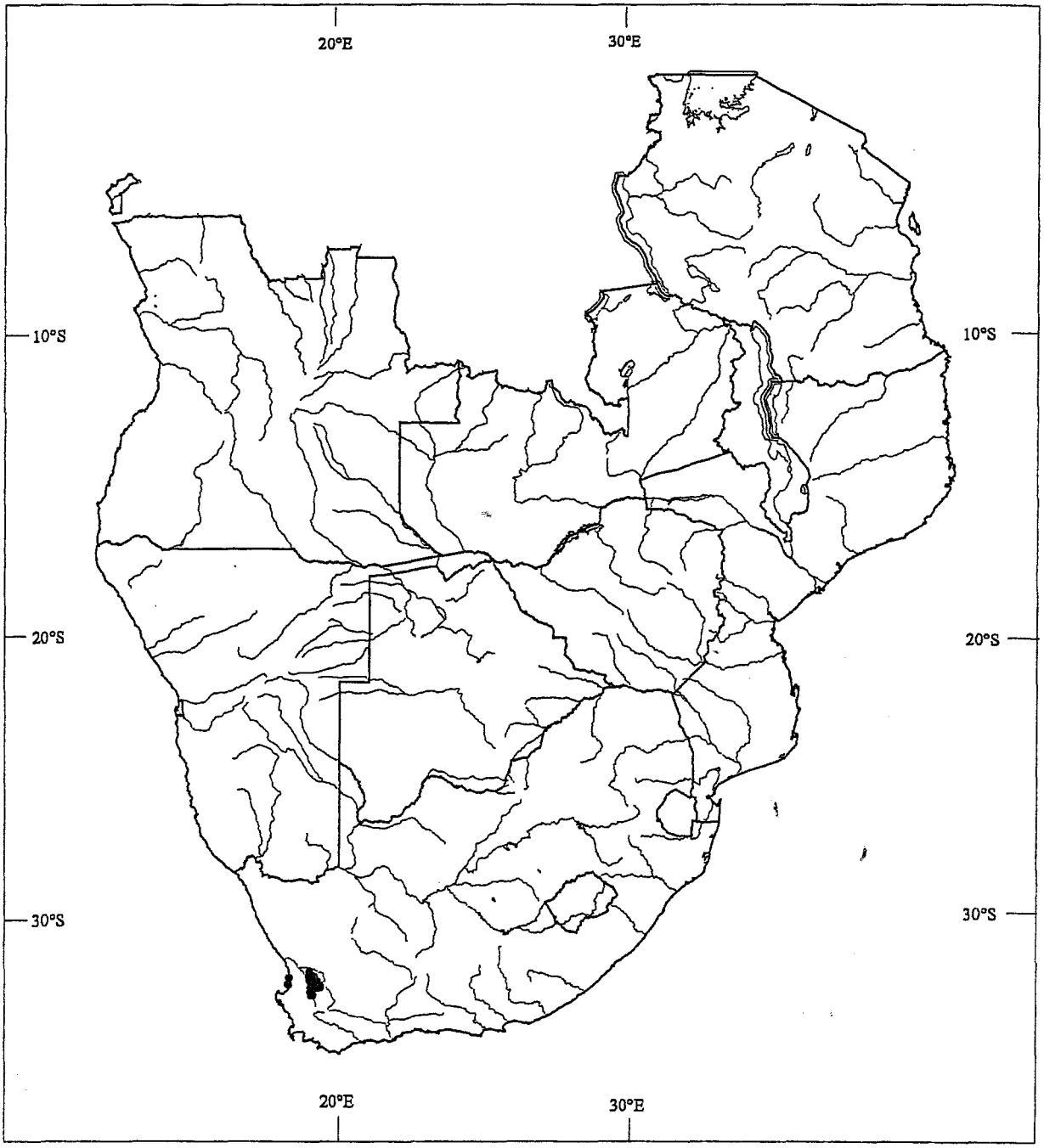


Figure F.58. Point distribution of *Austroglanis gilli*. Scale approximately 1:25 000 000

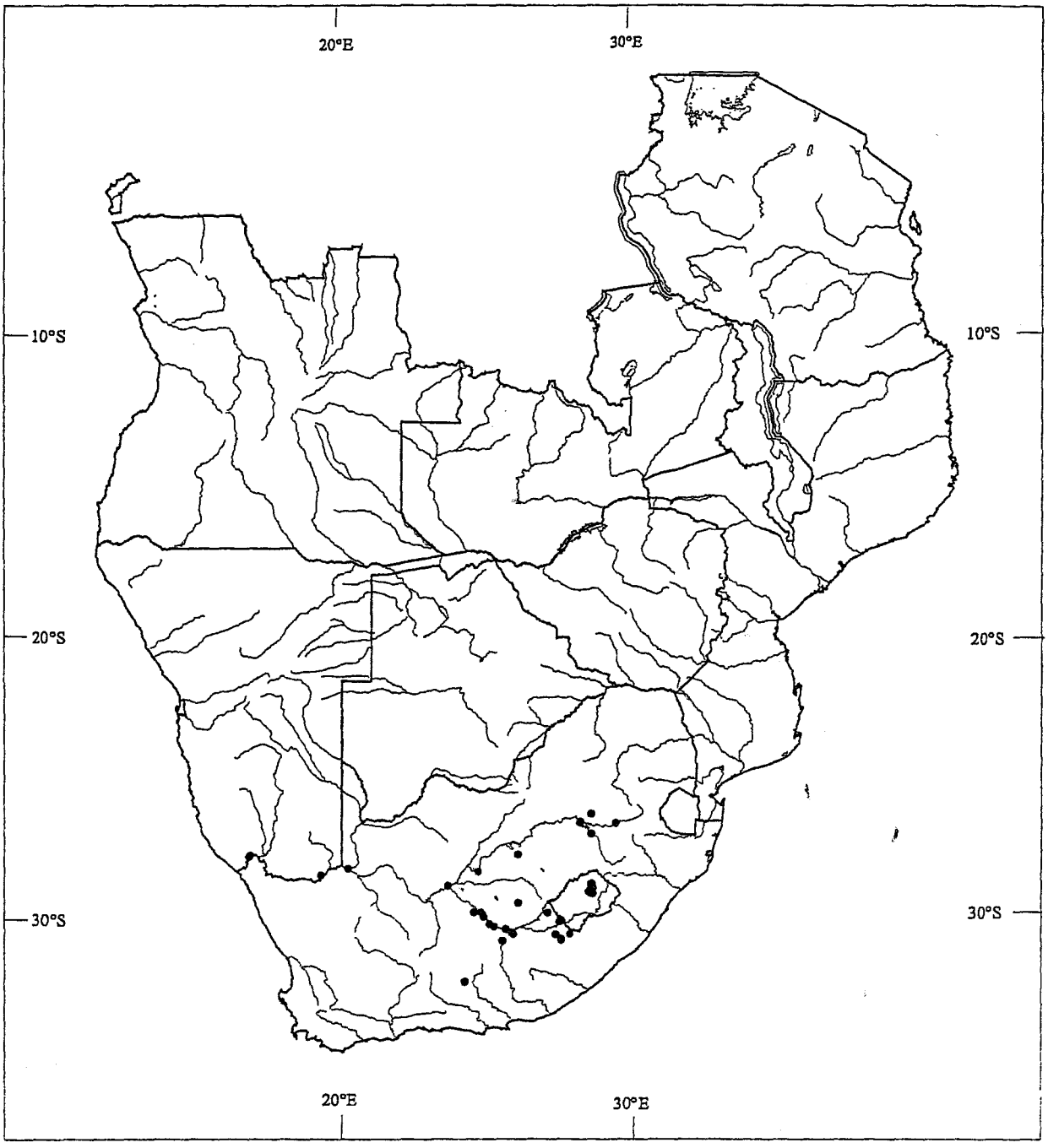


Figure F.59. Point distribution of *Austroglanis sclateri*. Scale approximately 1:25 000 000

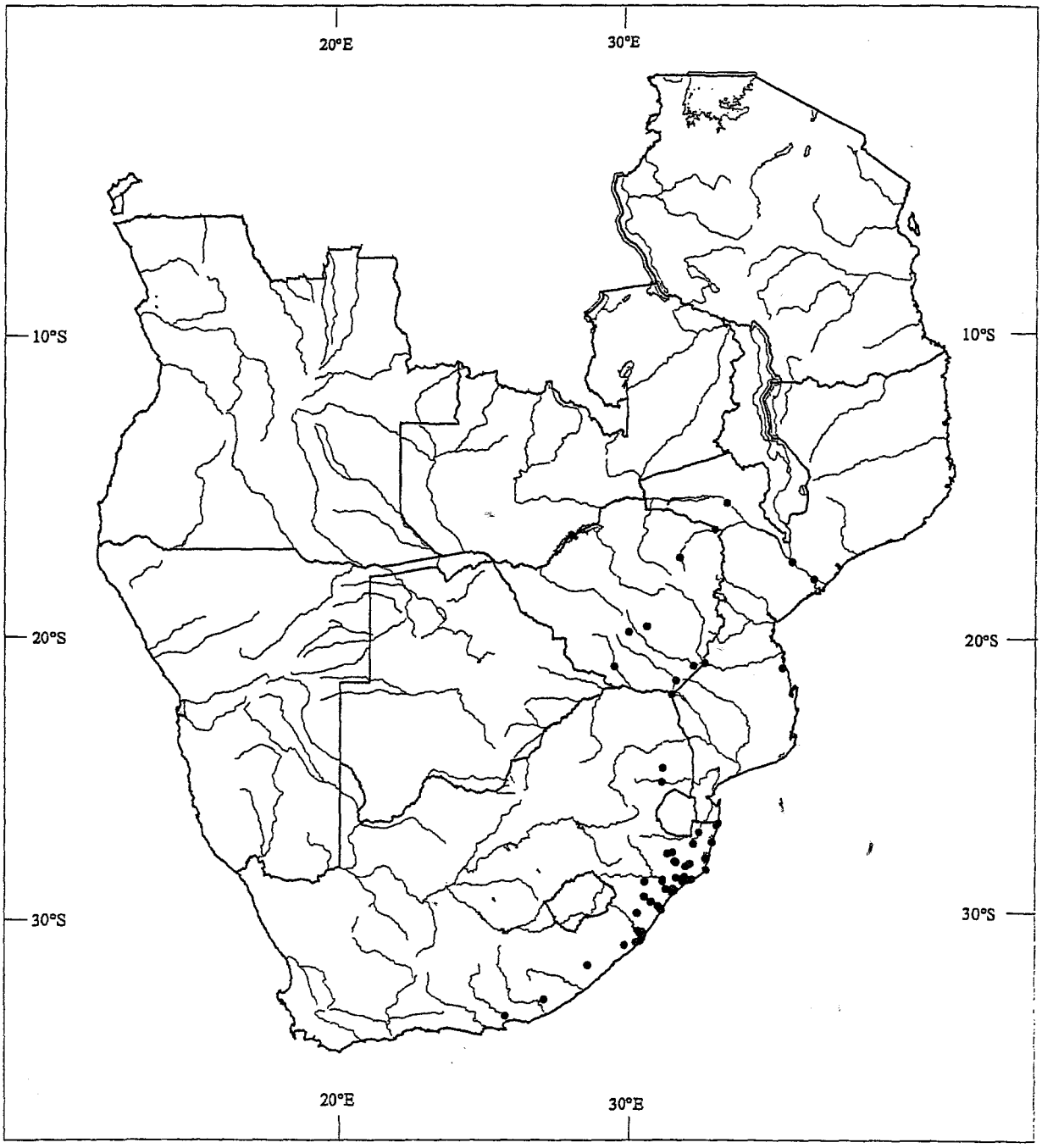


Figure F.60. Point distribution of *Awaous aeneofuscus*. Scale approximately 1:25 000 000

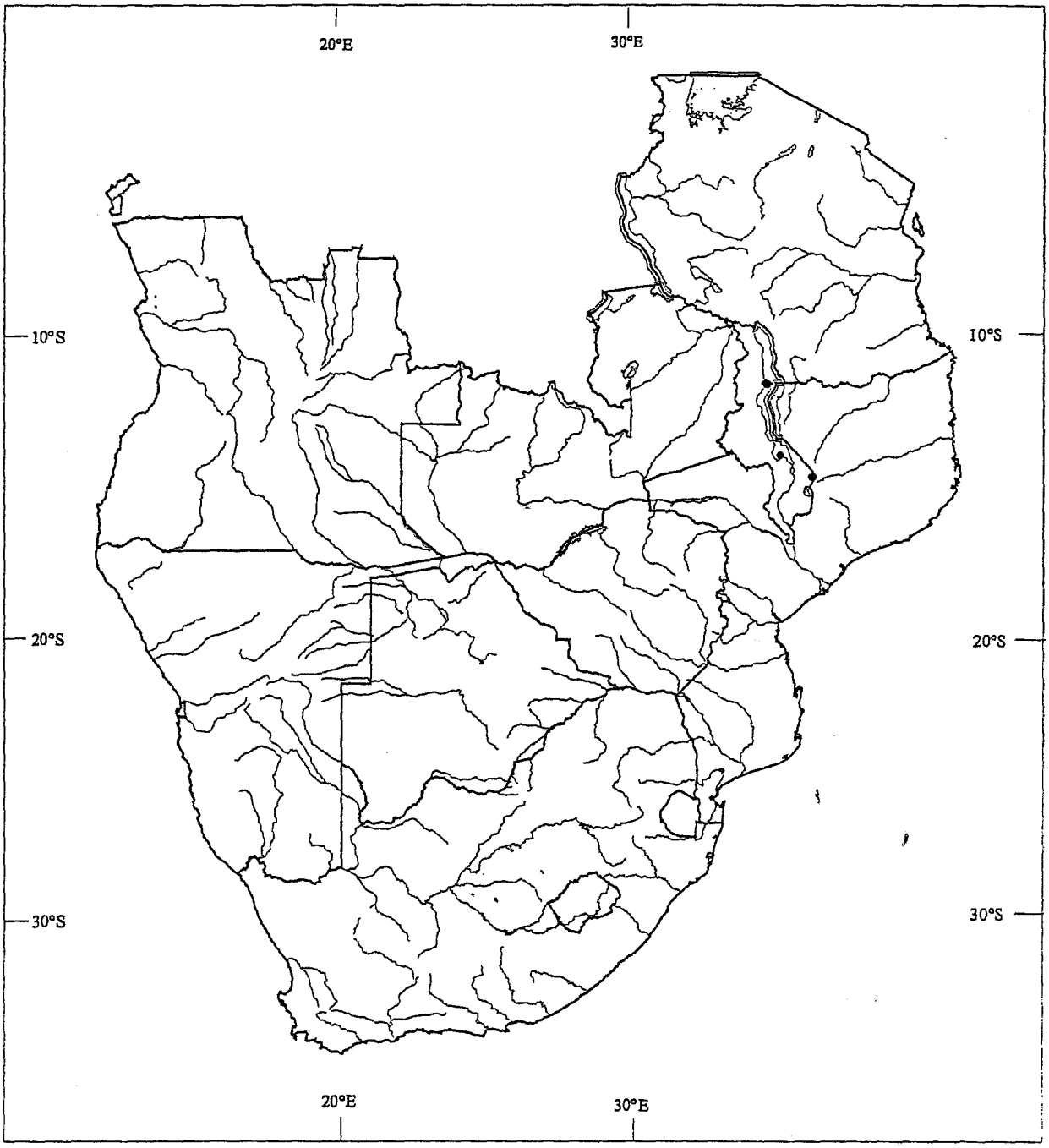


Figure F.61. Point distribution of *Bagrus meridionalis*. Scale approximately 1:25 000 000

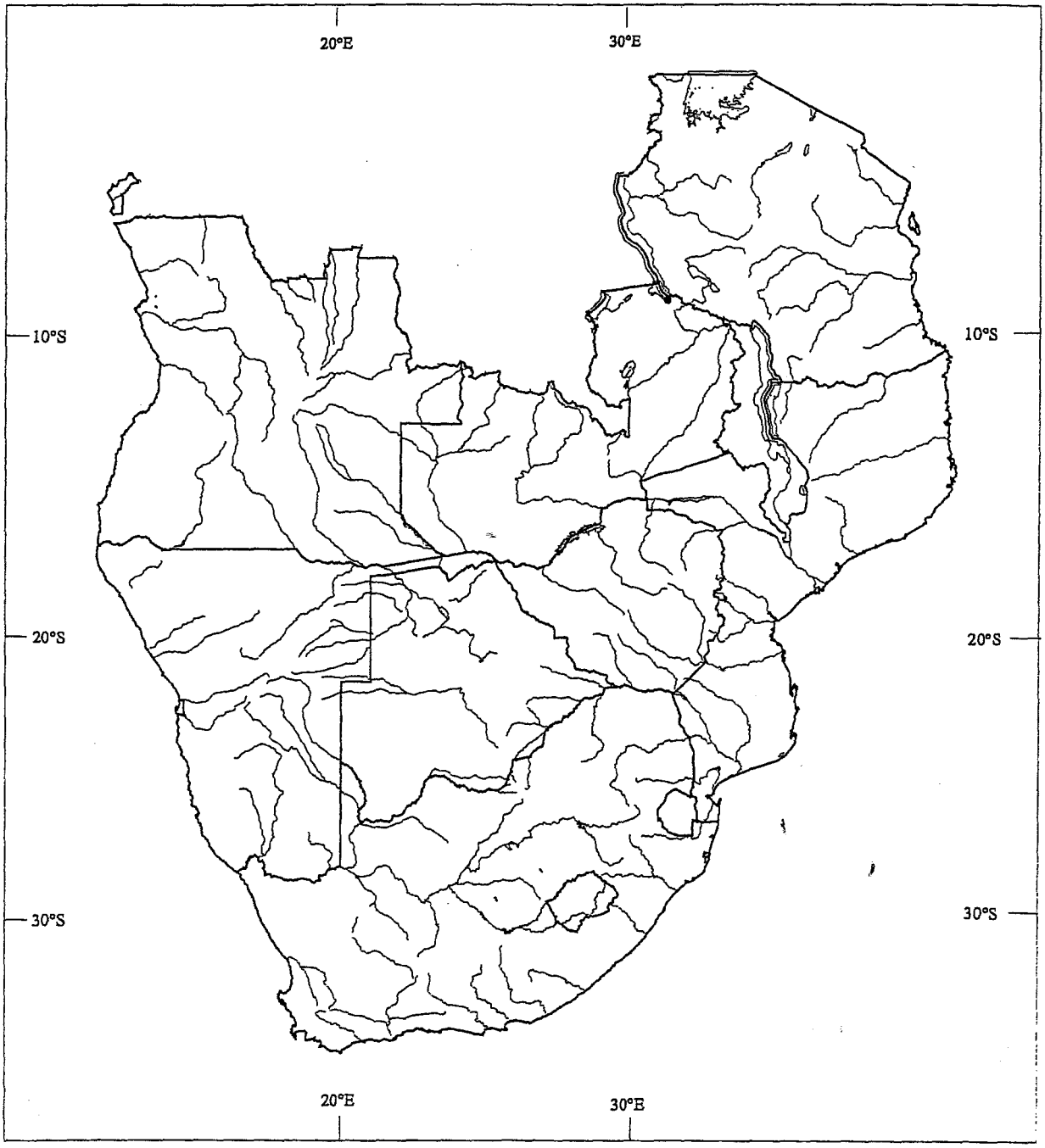


Figure F.62. Point distribution of *Baileychromis centropomoides*. Scale approximately 1:25 000 000

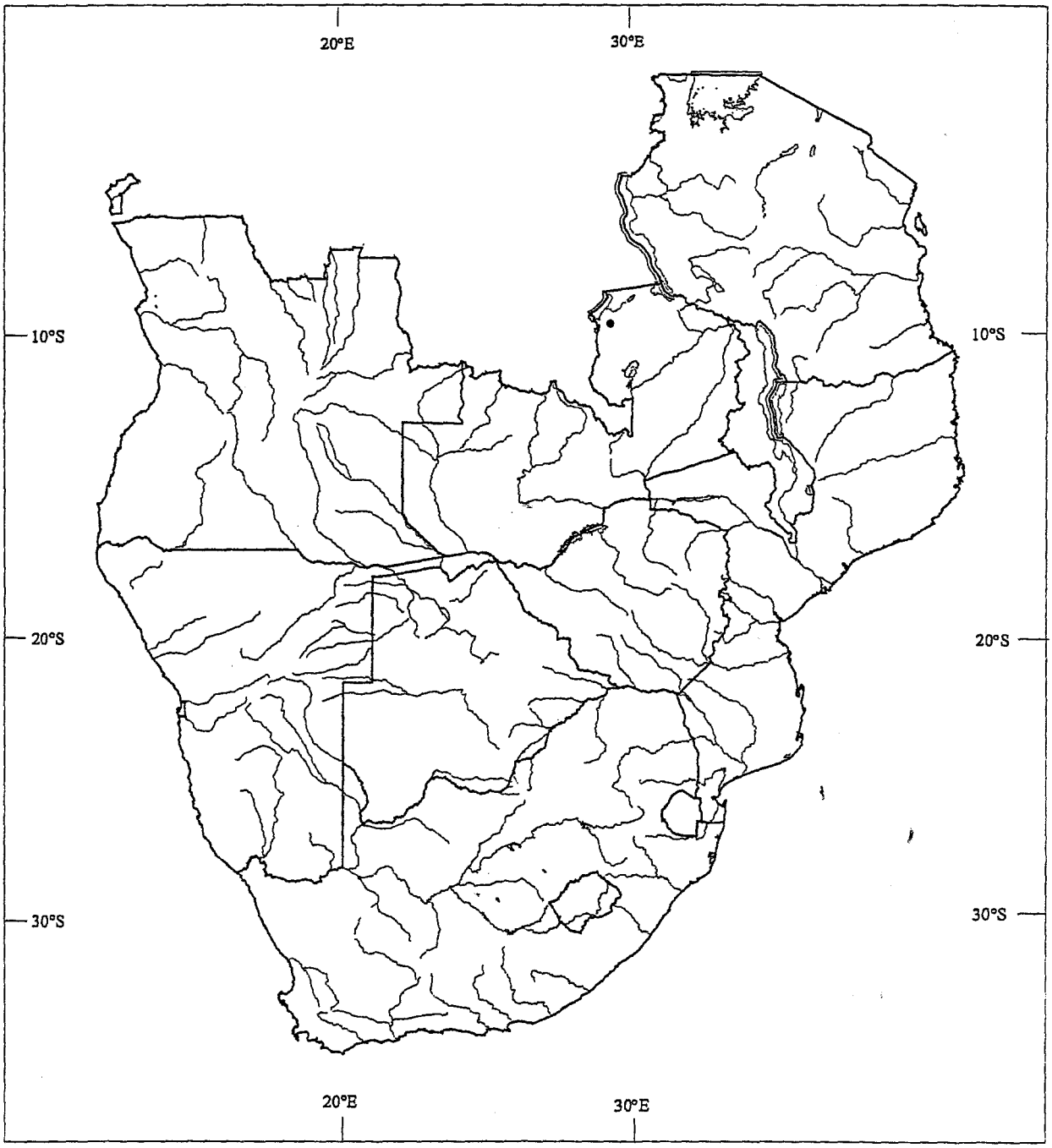


Figure F.63. Point distribution of *Barbus acuticeps*. Scale approximately 1:25 000 000

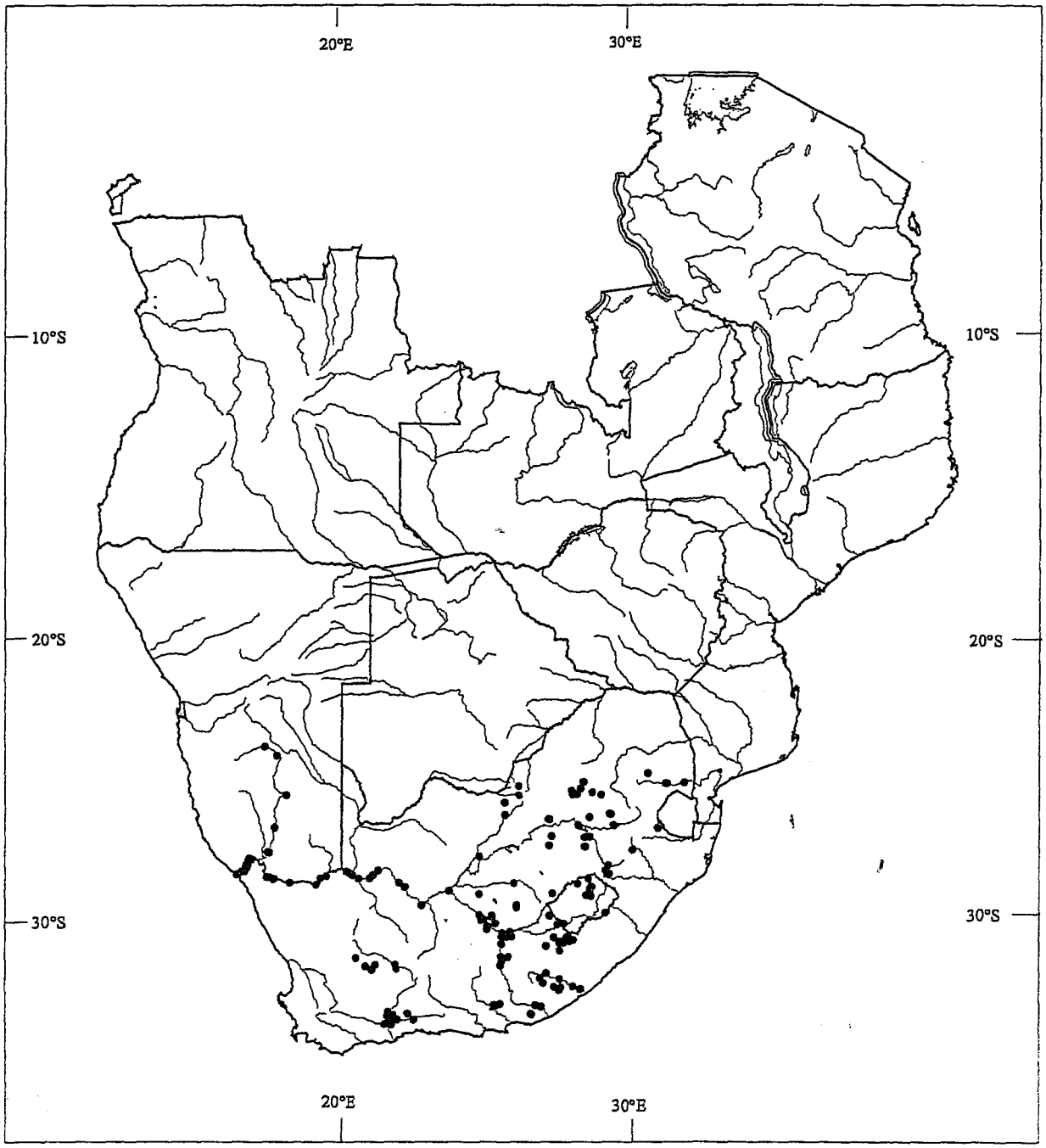


Figure F.64. Point distribution of *Barbus aeneus*. Scale approximately 1:25 000 000

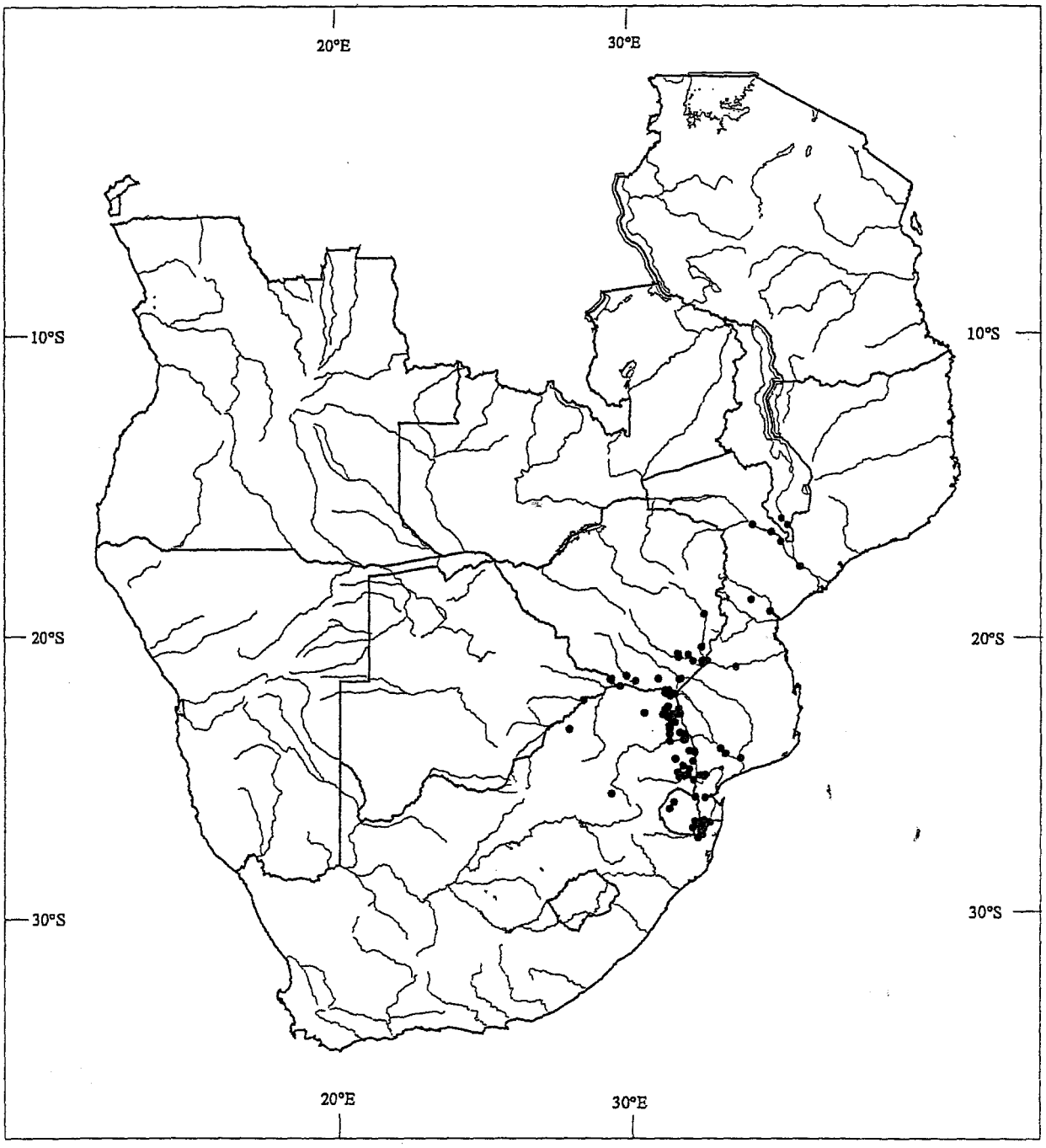


Figure F.65. Point distribution of *Barbus afrohamiltoni*. Scale approximately 1:25 000 000

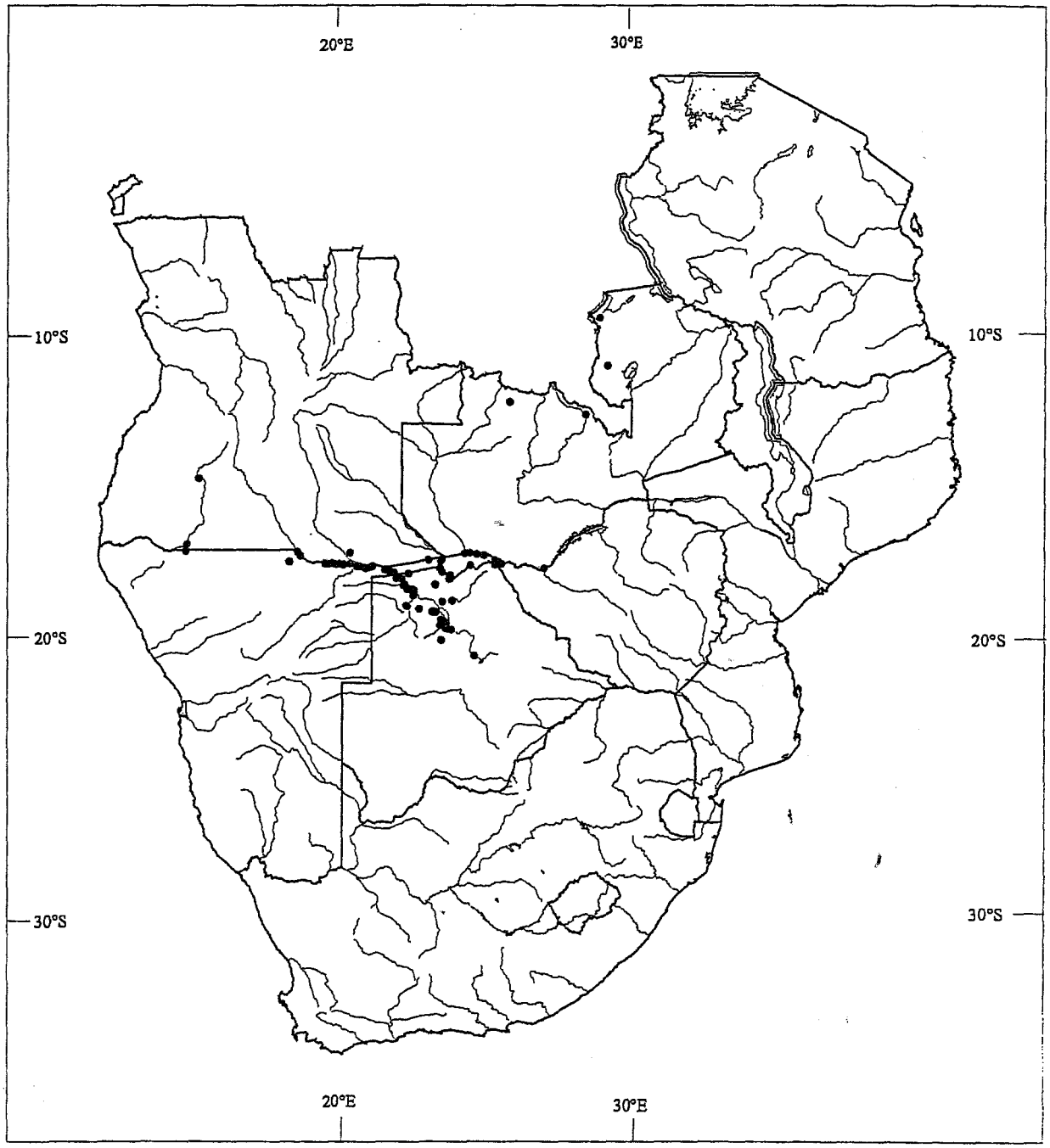


Figure F.66. Point distribution of *Barbus afrovernayi*. Scale approximately 1:25 000 000

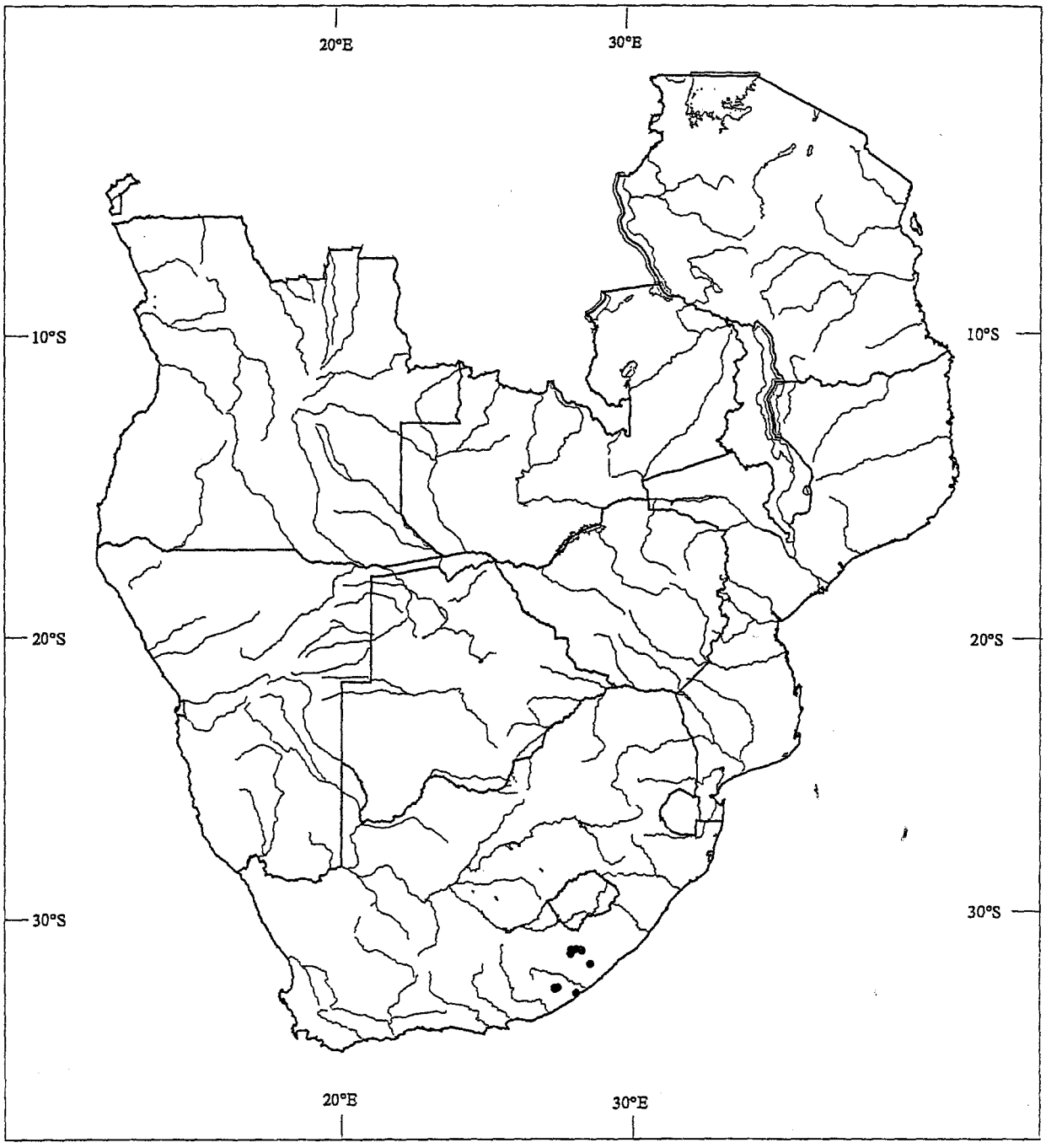


Figure F.67. Point distribution of *Barbus amatolicus*. Scale approximately 1:25 000 000

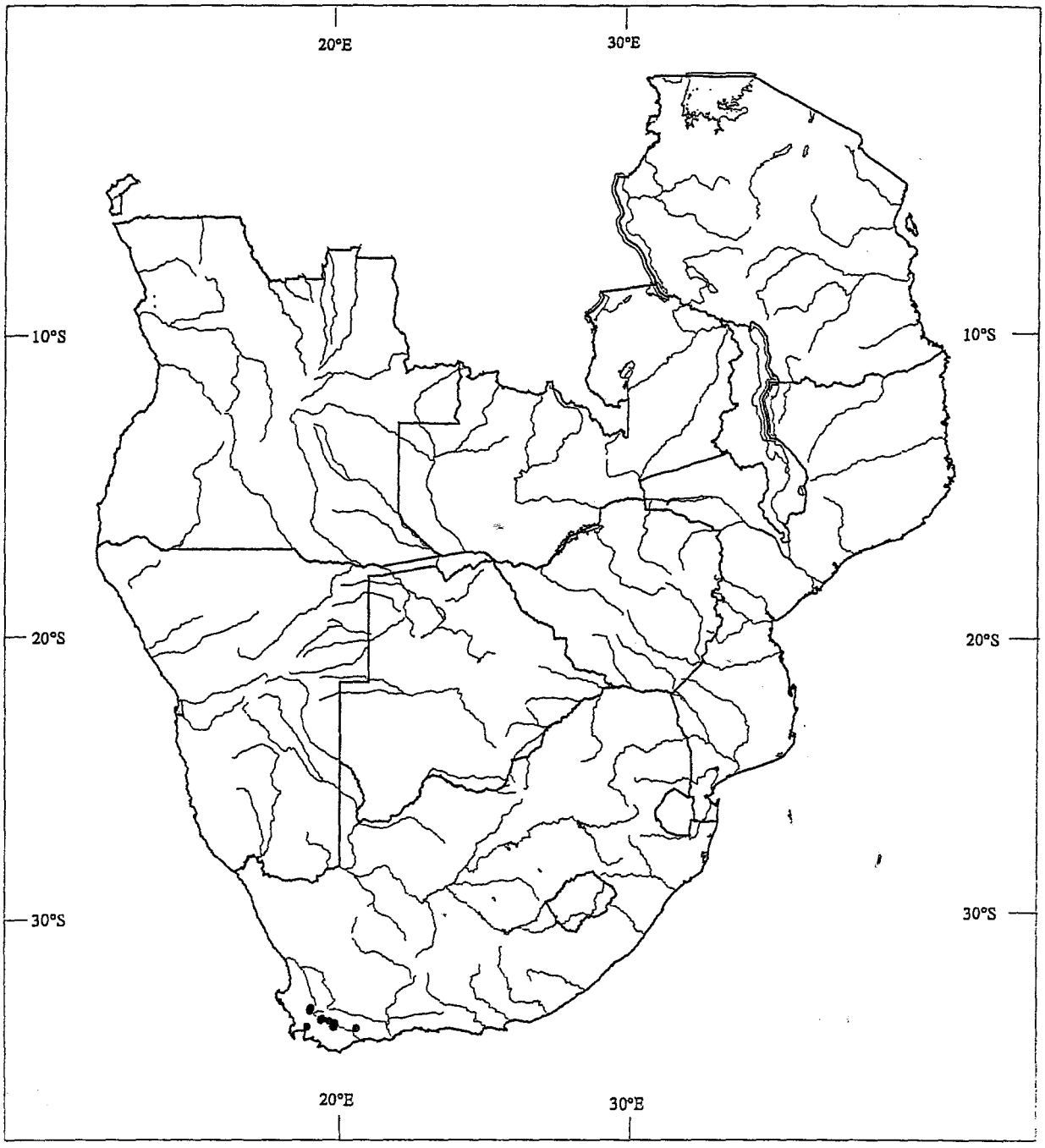


Figure F.68. Point distribution of *Barbus andrewi*. Scale approximately 1:25 000 000

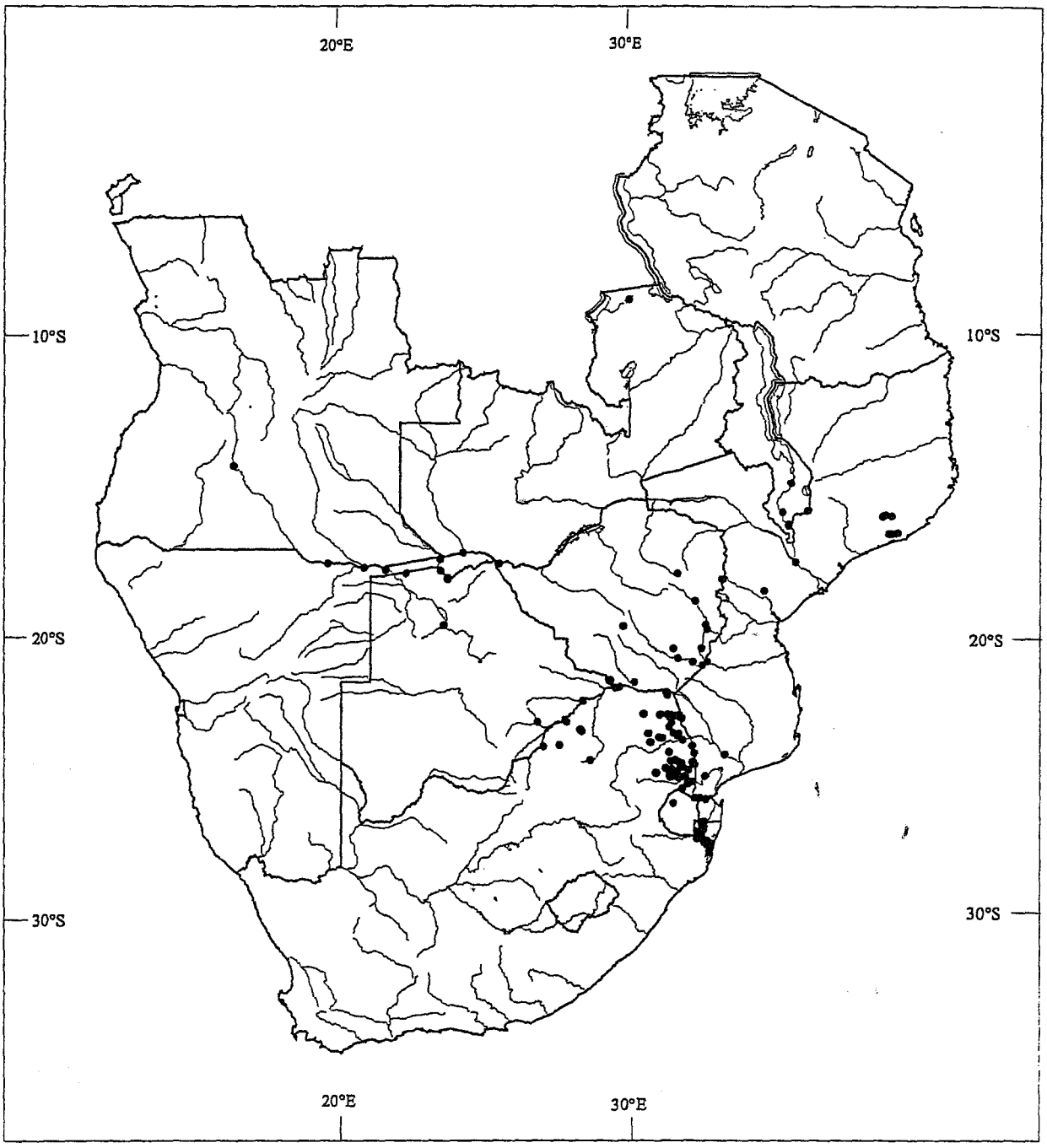


Figure F.69. Point distribution of *Barbus annectens*. Scale approximately 1:25 000 000

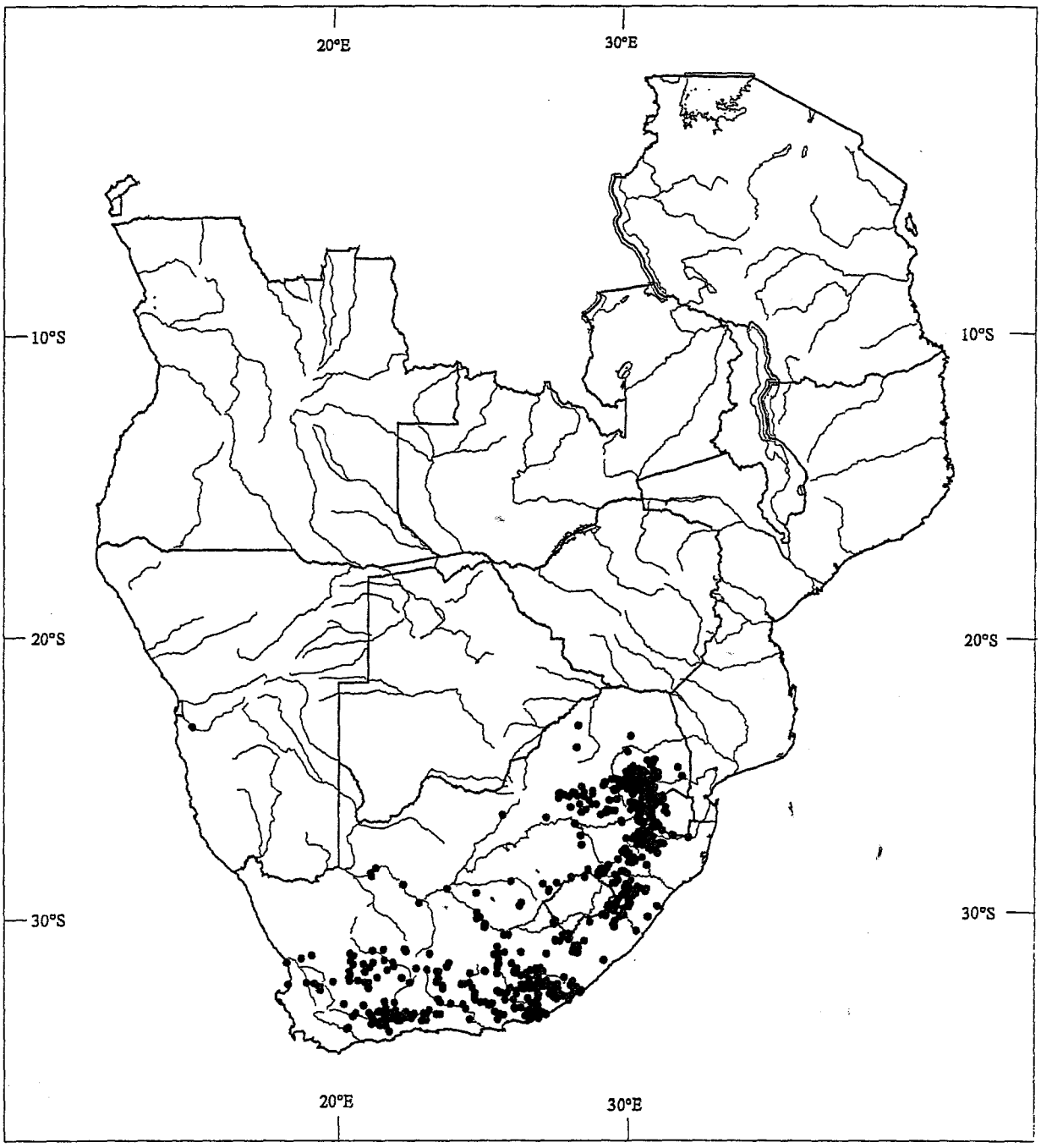


Figure F.70. Point distribution of *Barbus anoplus*. Scale approximately 1:25 000 000

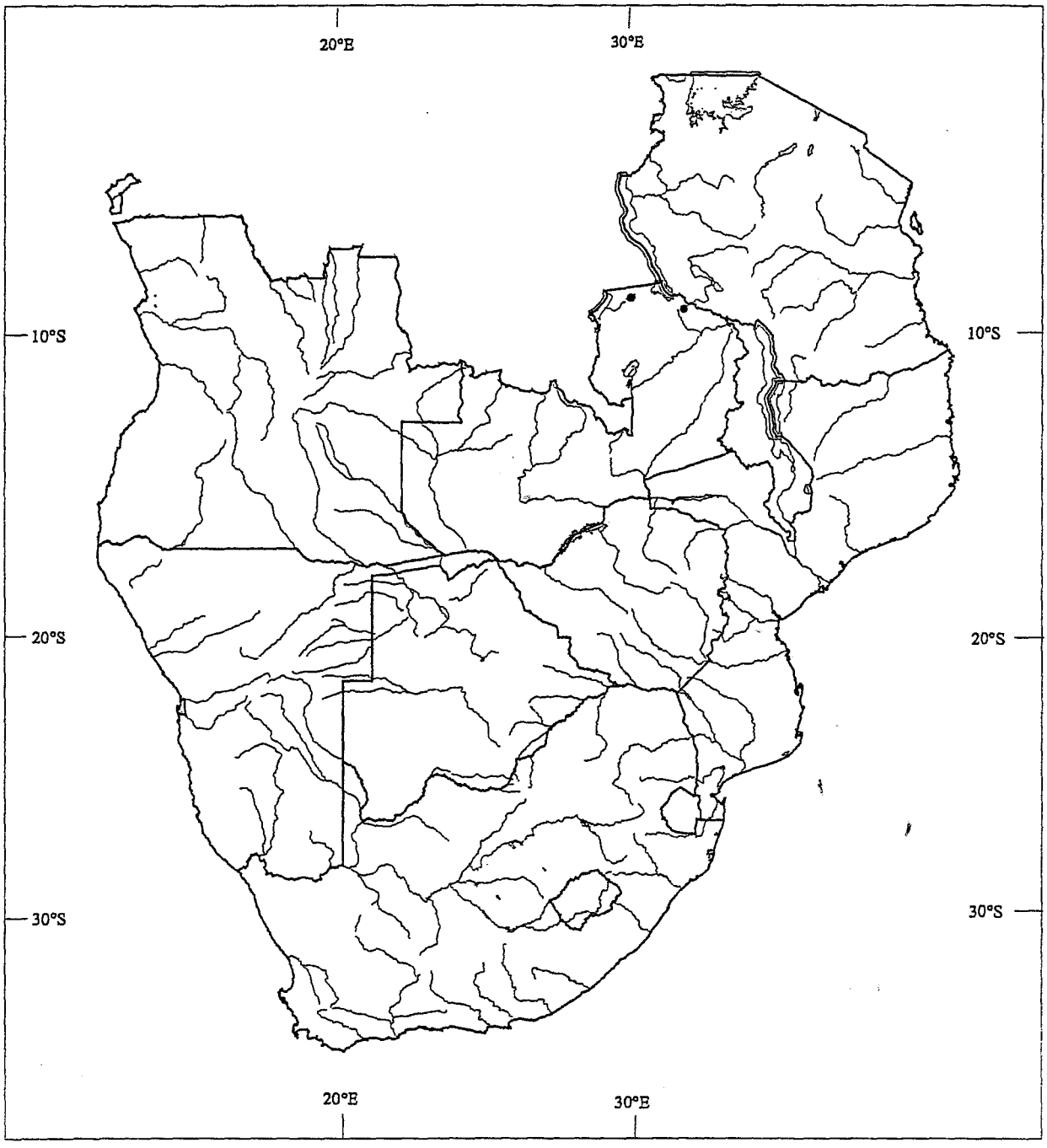


Figure F.71. Point distribution of *Barbus apleurogramma*. Scale approximately 1:25 000 000

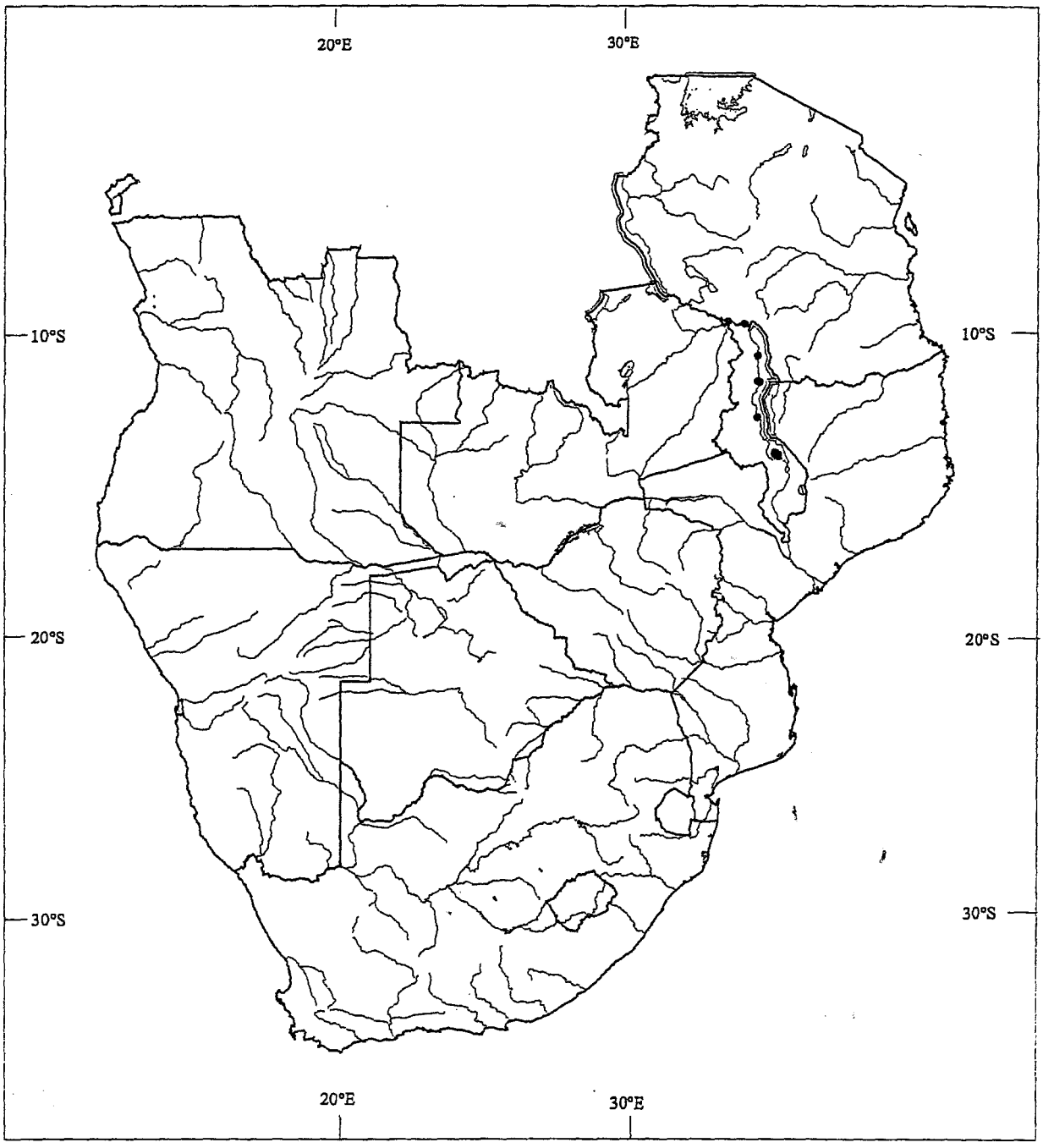


Figure F.72. Point distribution of *Barbus arcislongae*. Scale approximately 1:25 000 000

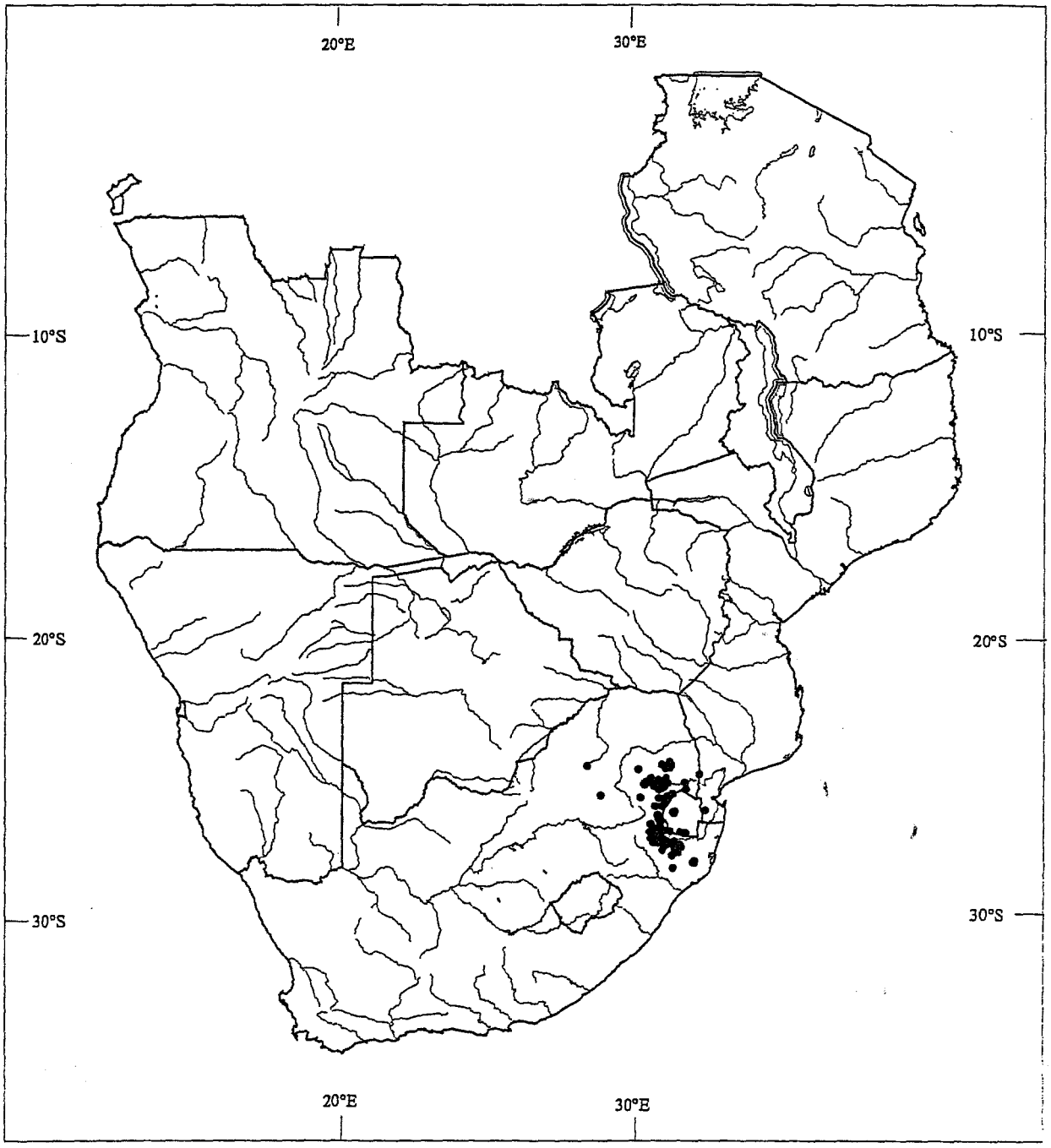


Figure F.73. Point distribution of *Barbus argenteus*. Scale approximately 1:25 000 000

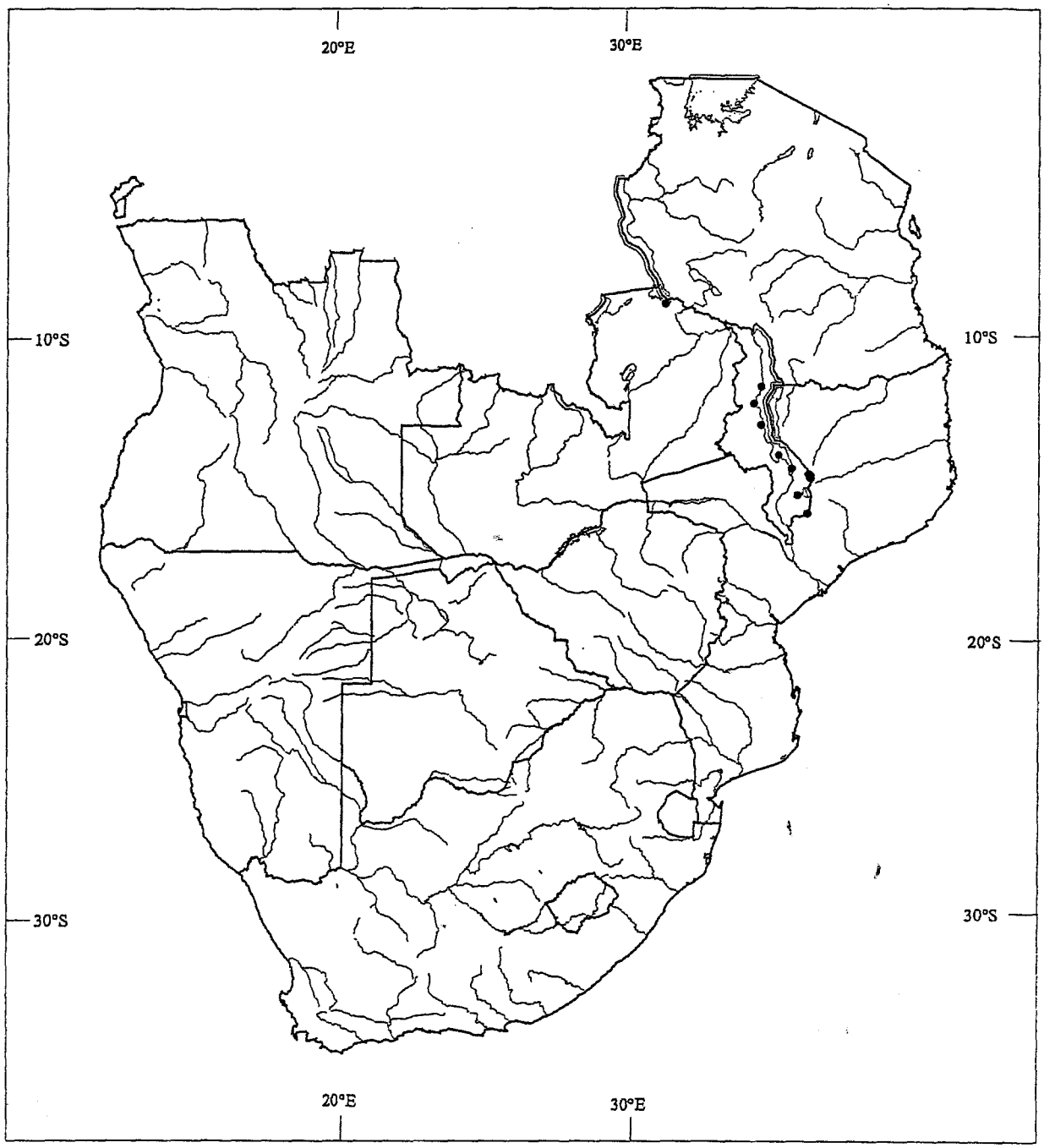


Figure F.74. Point distribution of *Barbus atkinsoni*. Scale approximately 1:25 000 000

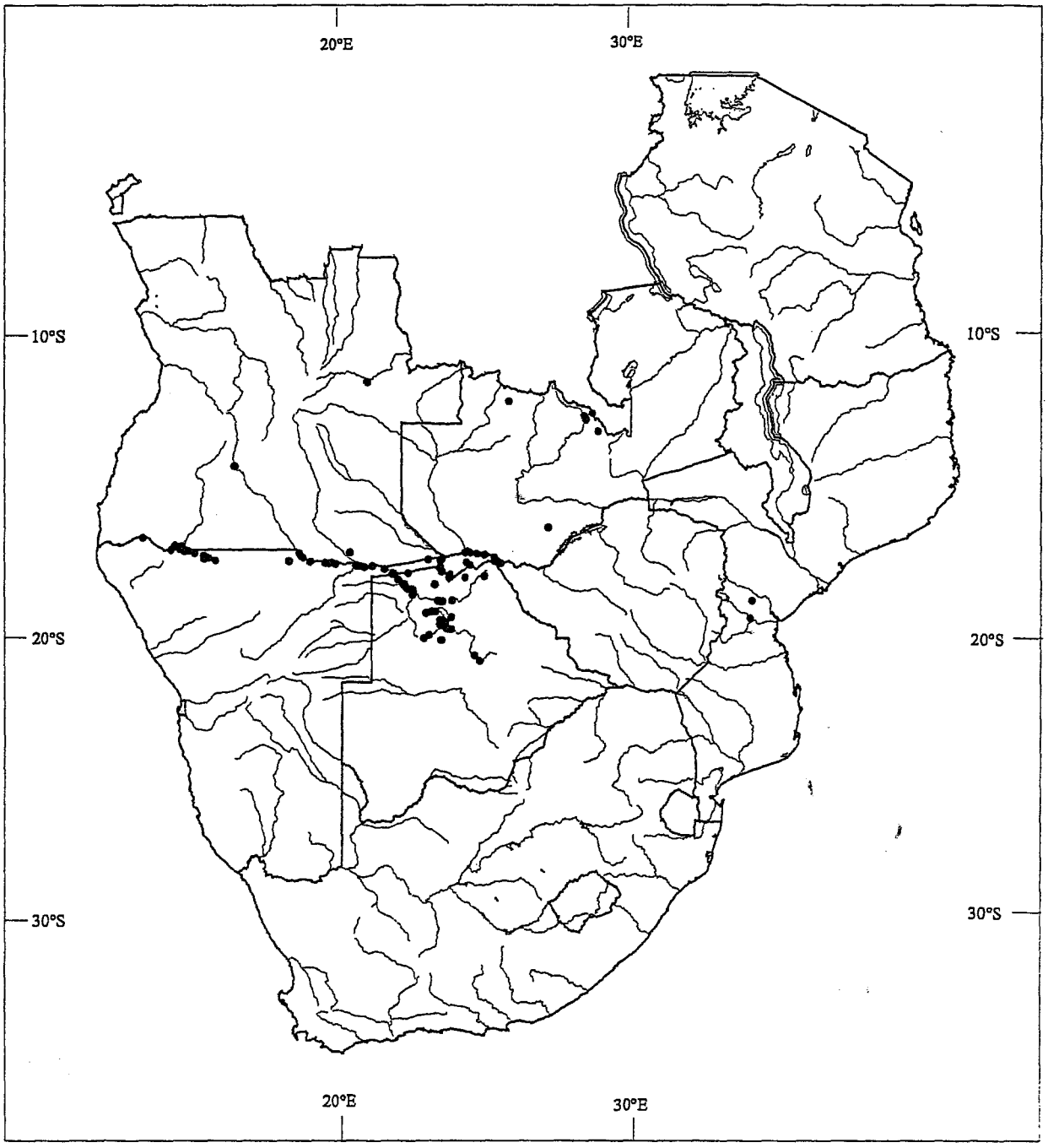


Figure F.75. Point distribution of *Barbus barnardi*. Scale approximately 1:25 000 000

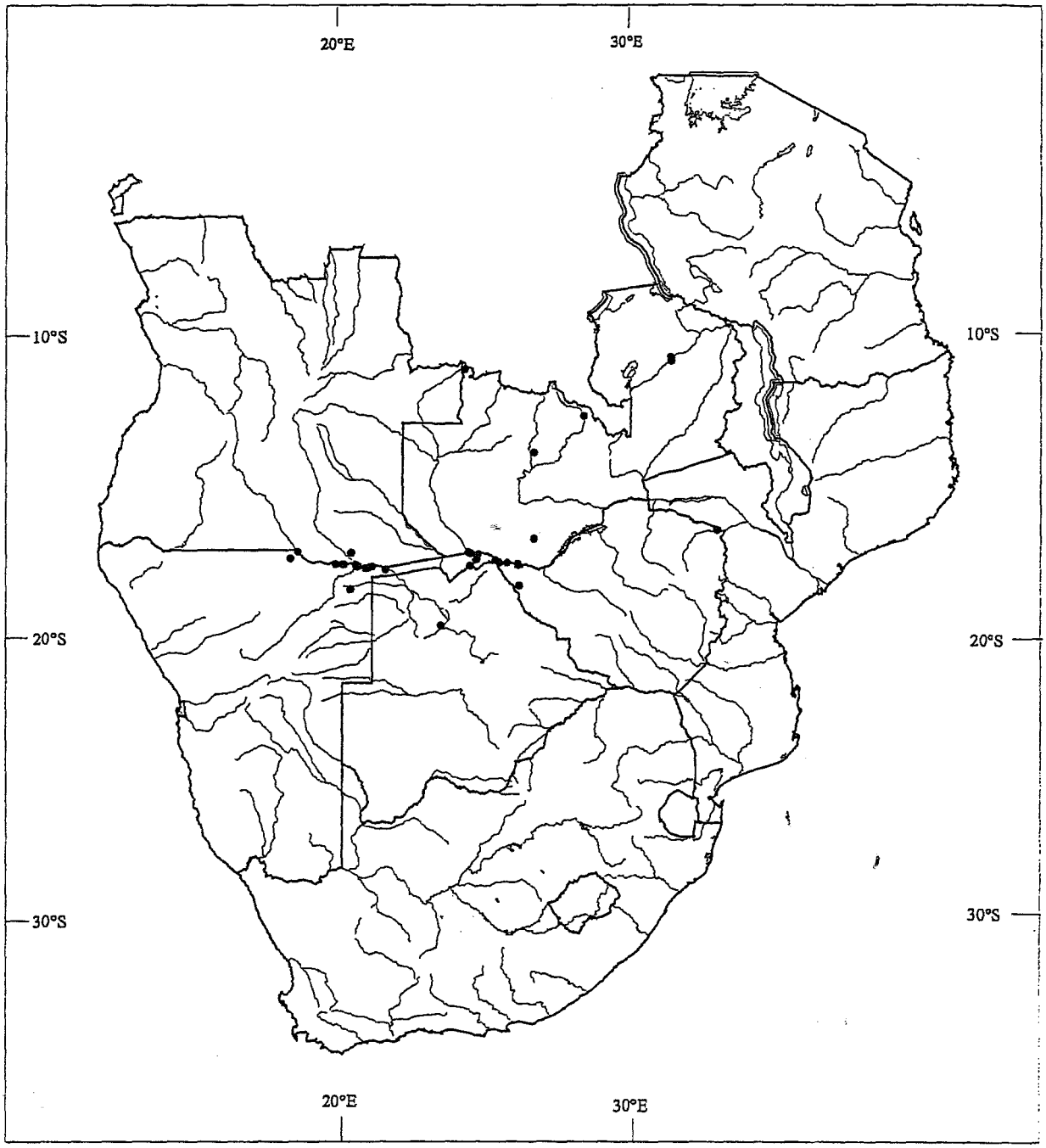


Figure F.76. Point distribution of *Barbus barotseensis*. Scale approximately 1:25 000 000

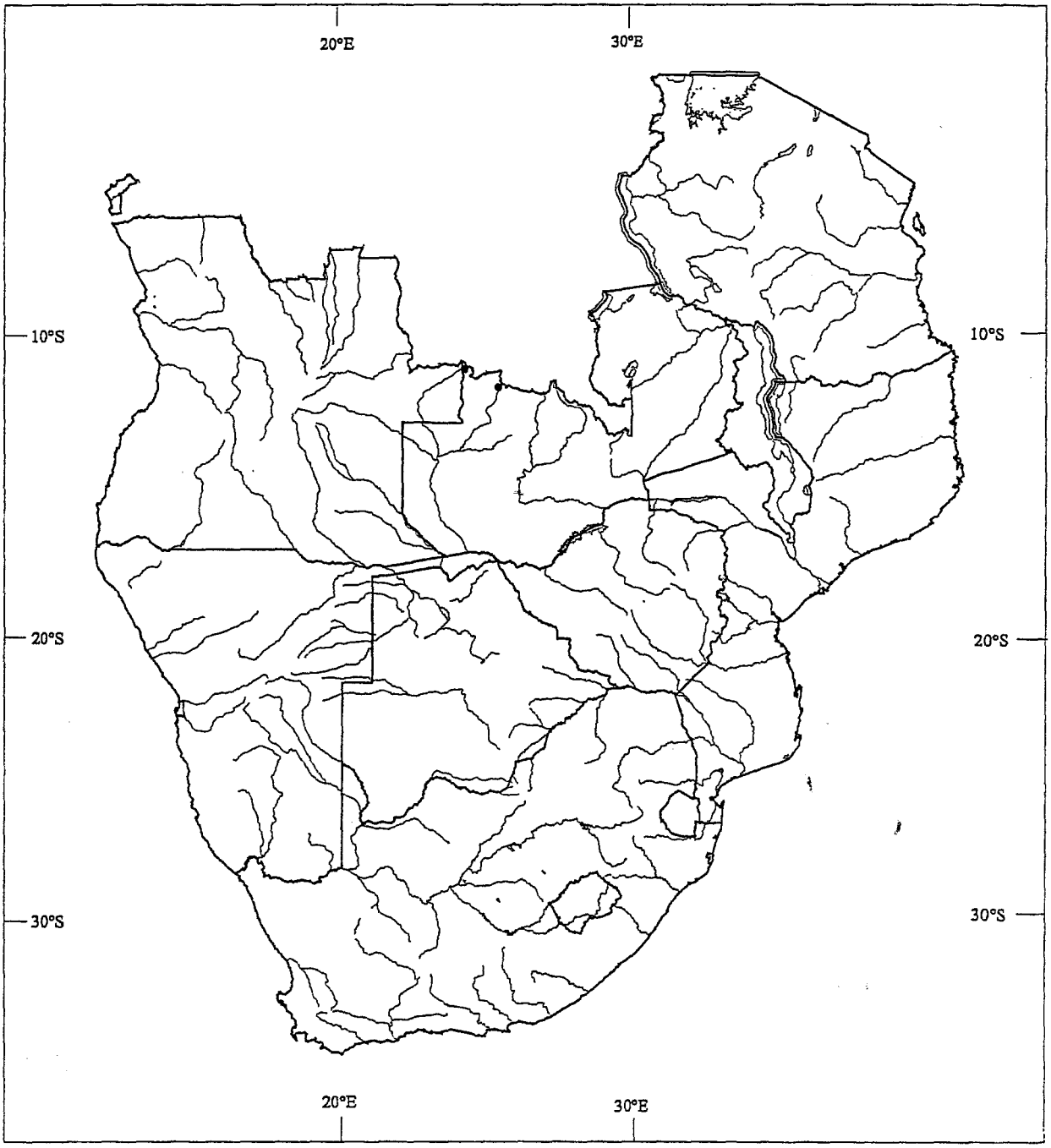


Figure F.77. Point distribution of *Barbus bellcrossi*. Scale approximately 1:25 000 000

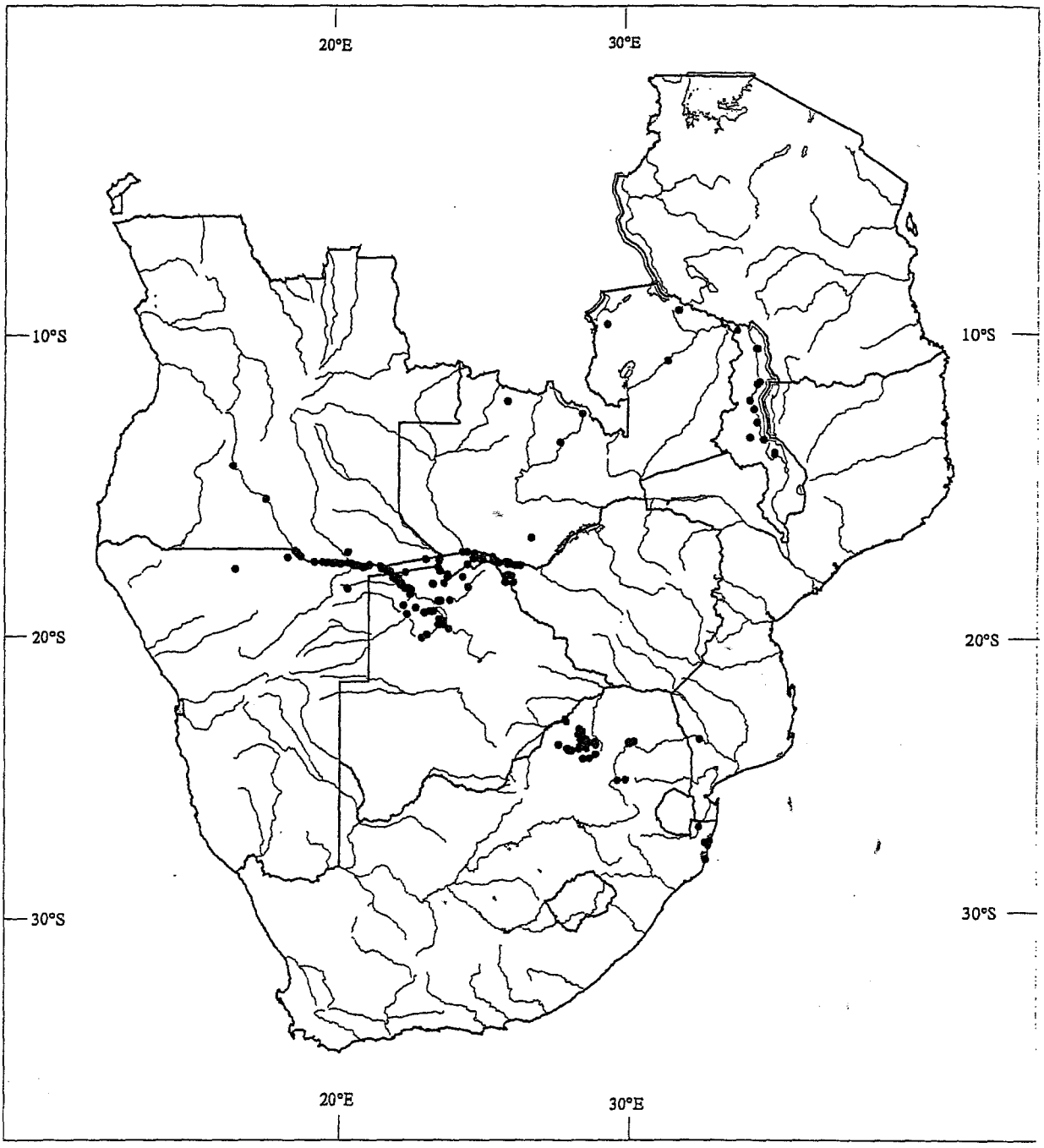


Figure F.78. Point distribution of *Barbus bifrenatus*. Scale approximately 1:25 000 000

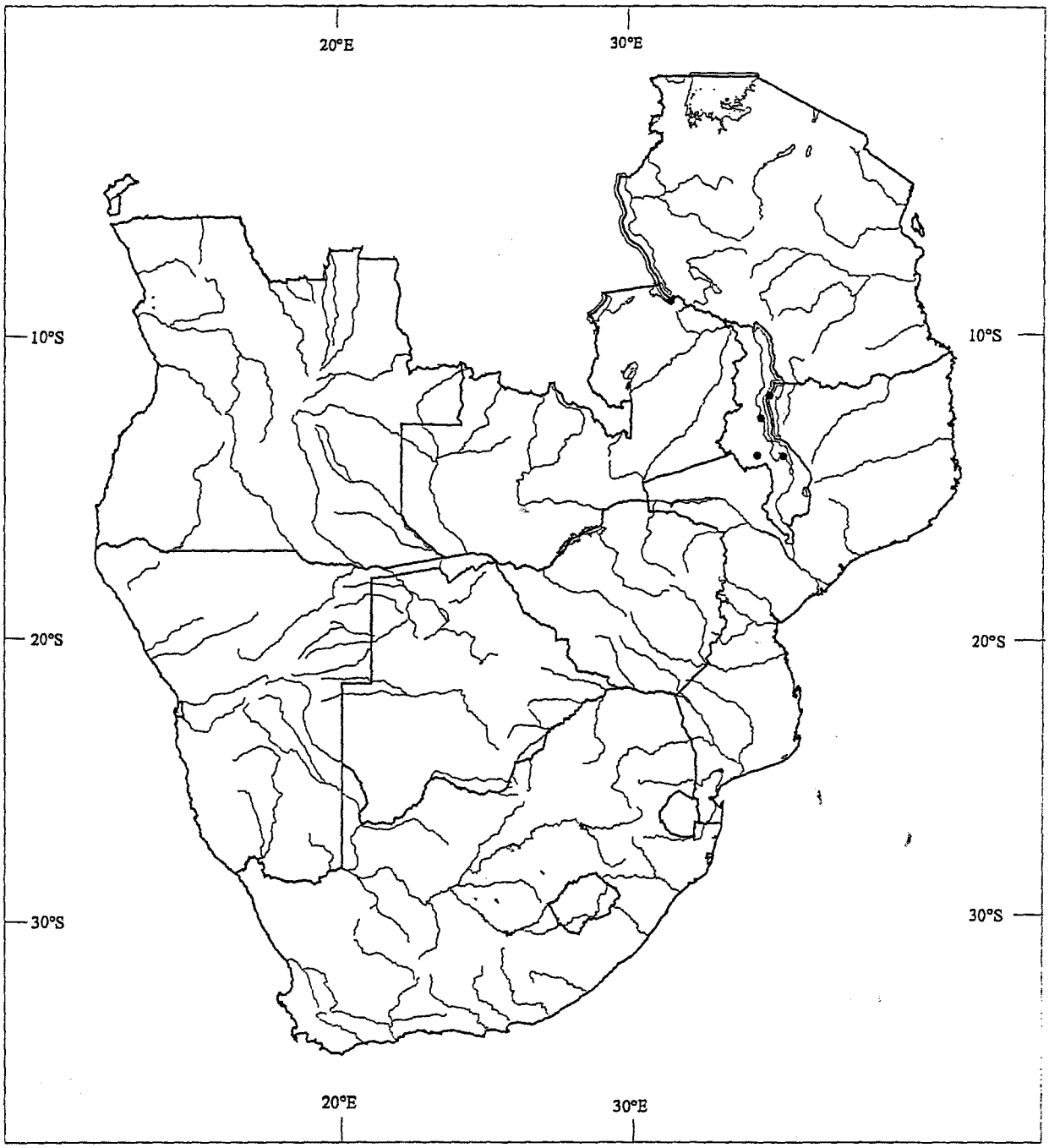


Figure F.79. Point distribution of *Barbus brevicauda*. Scale approximately 1:25 000 000

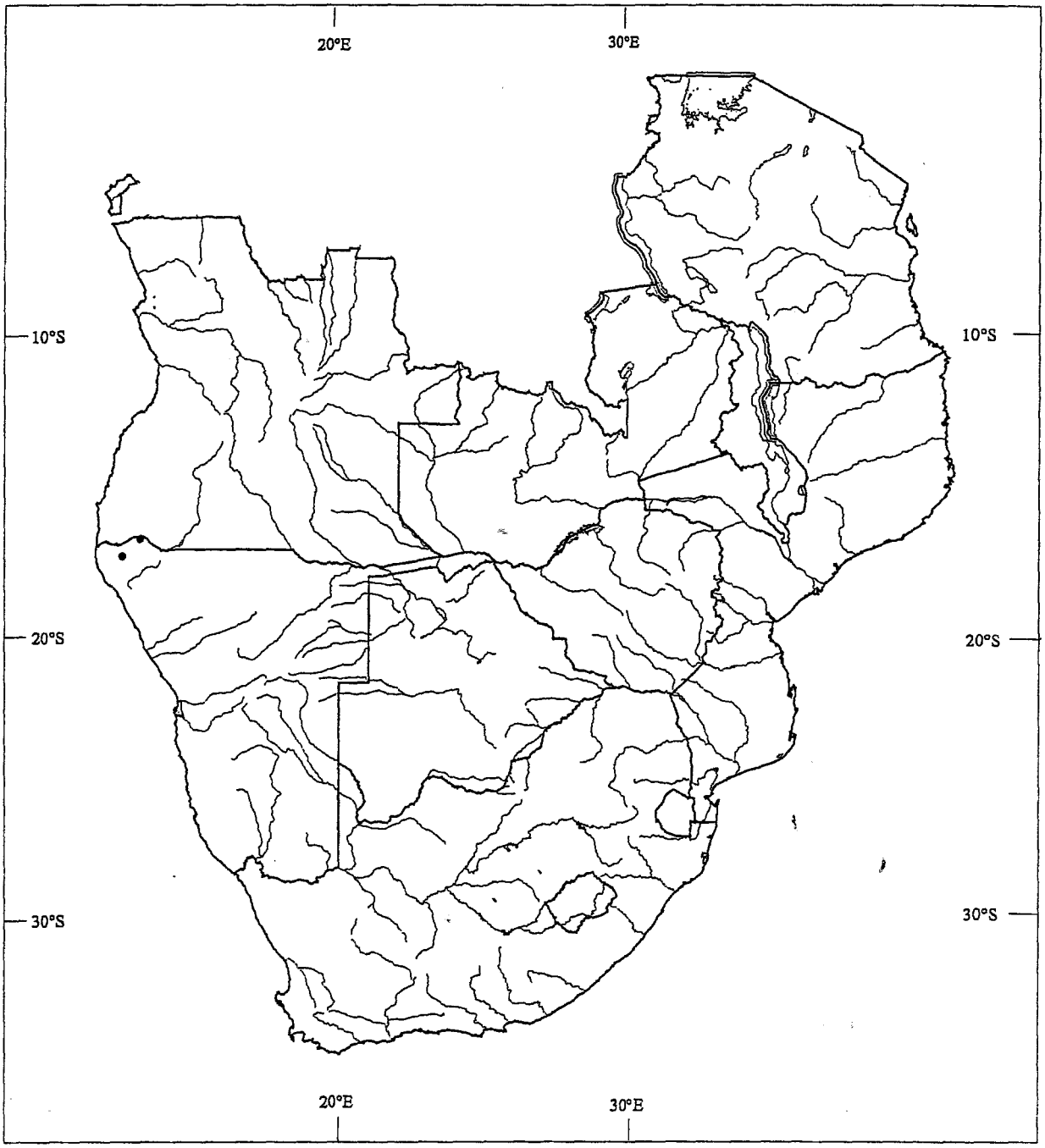


Figure F.80. Point distribution of *Barbus breviceps*. Scale approximately 1:25 000 000

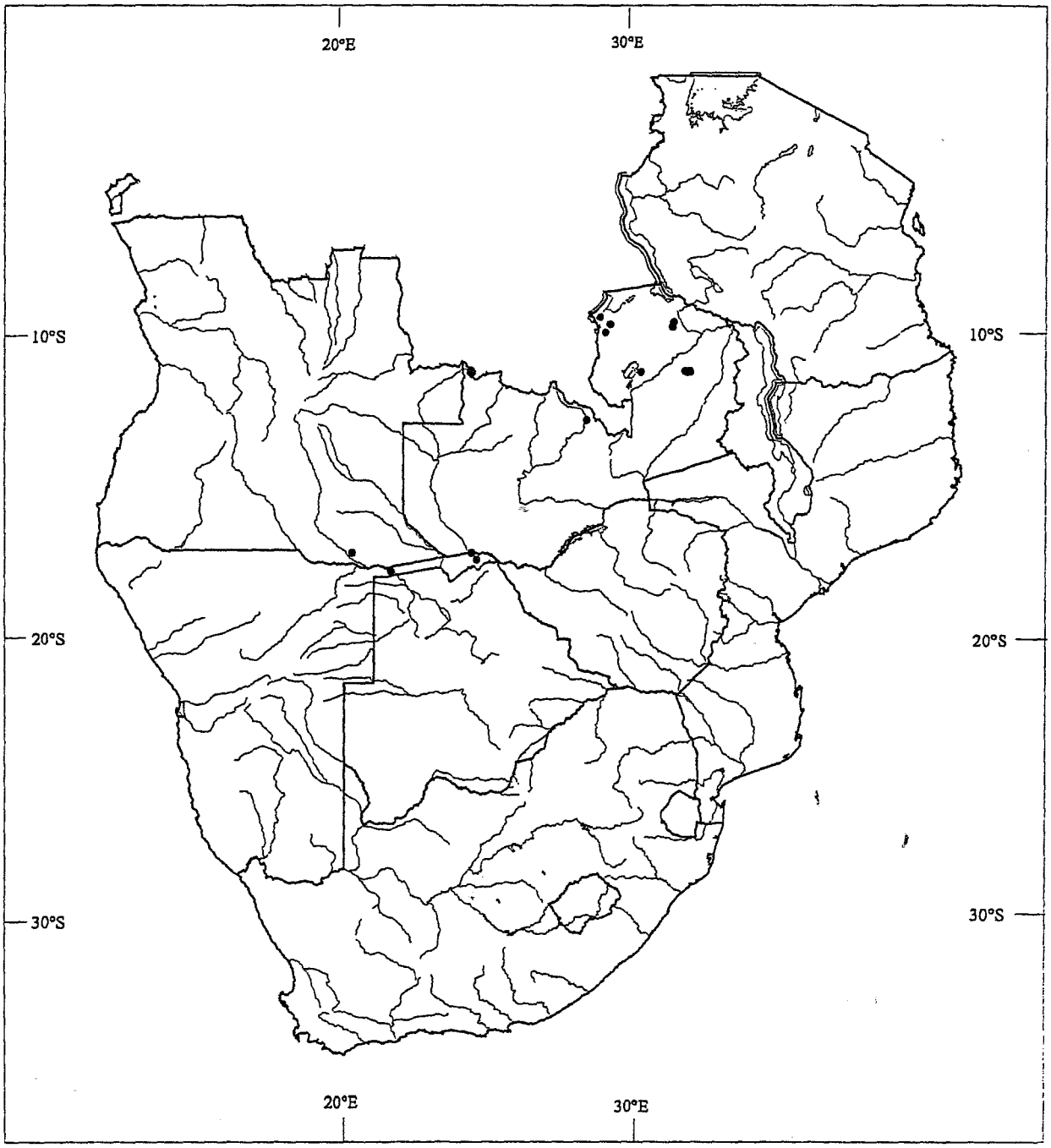


Figure F.81. Point distribution of *Barbus brevidorsalis*. Scale approximately 1:25 000 000

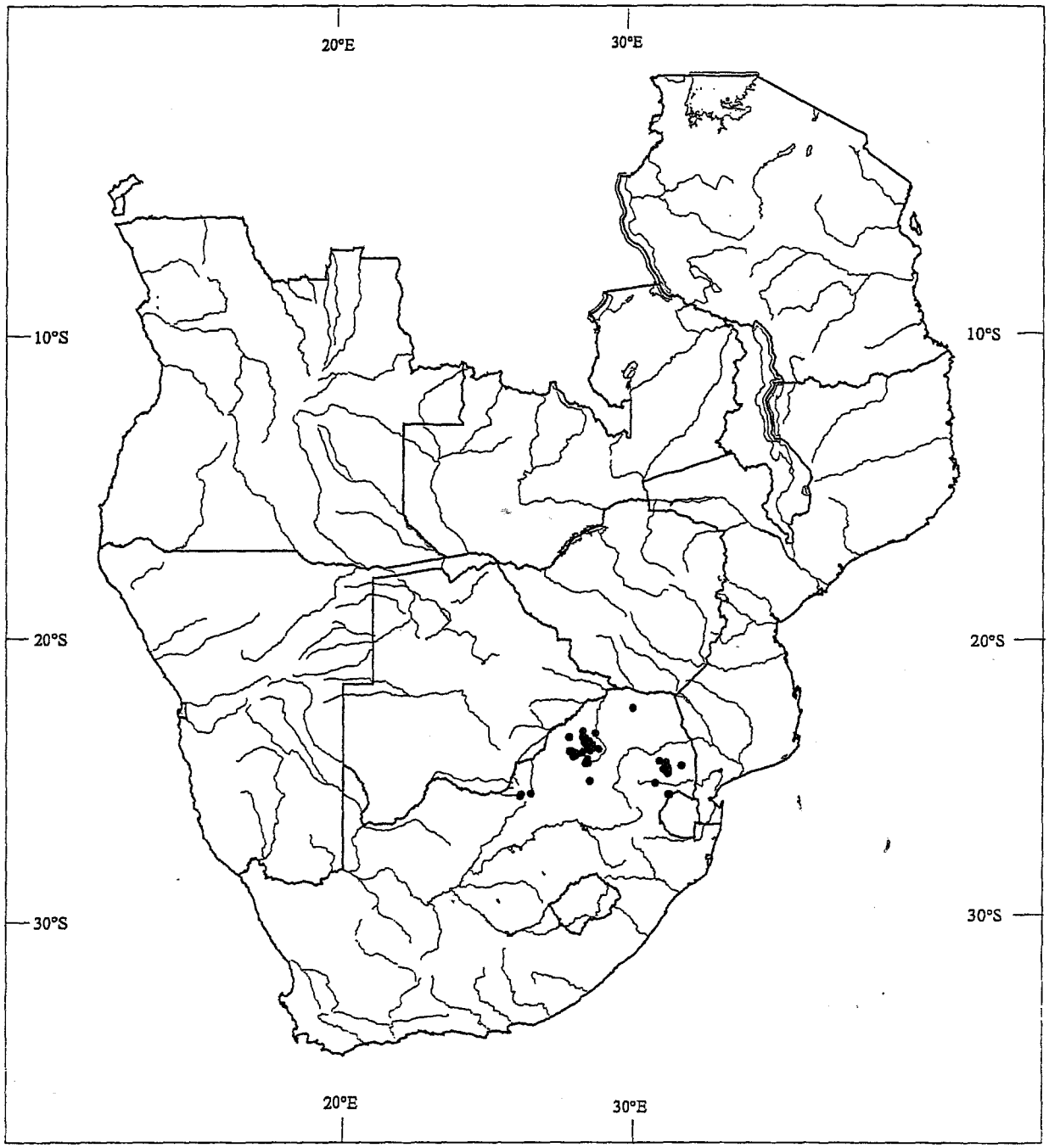


Figure F.82. Point distribution of *Barbus brevipinnis*. Scale approximately 1:25 000 000

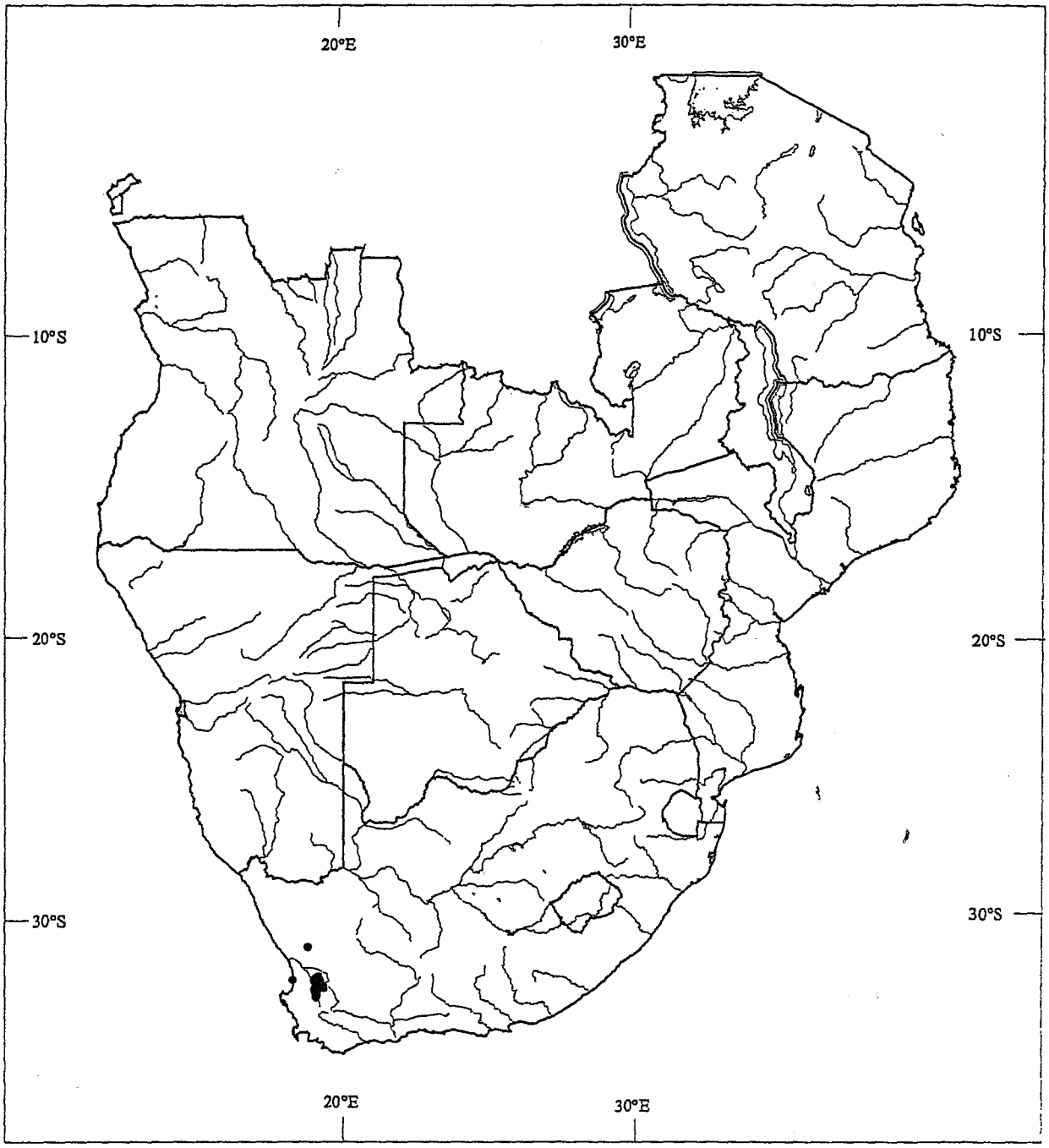


Figure F.83. Point distribution of *Barbus calidus*. Scale approximately 1:25 000 000

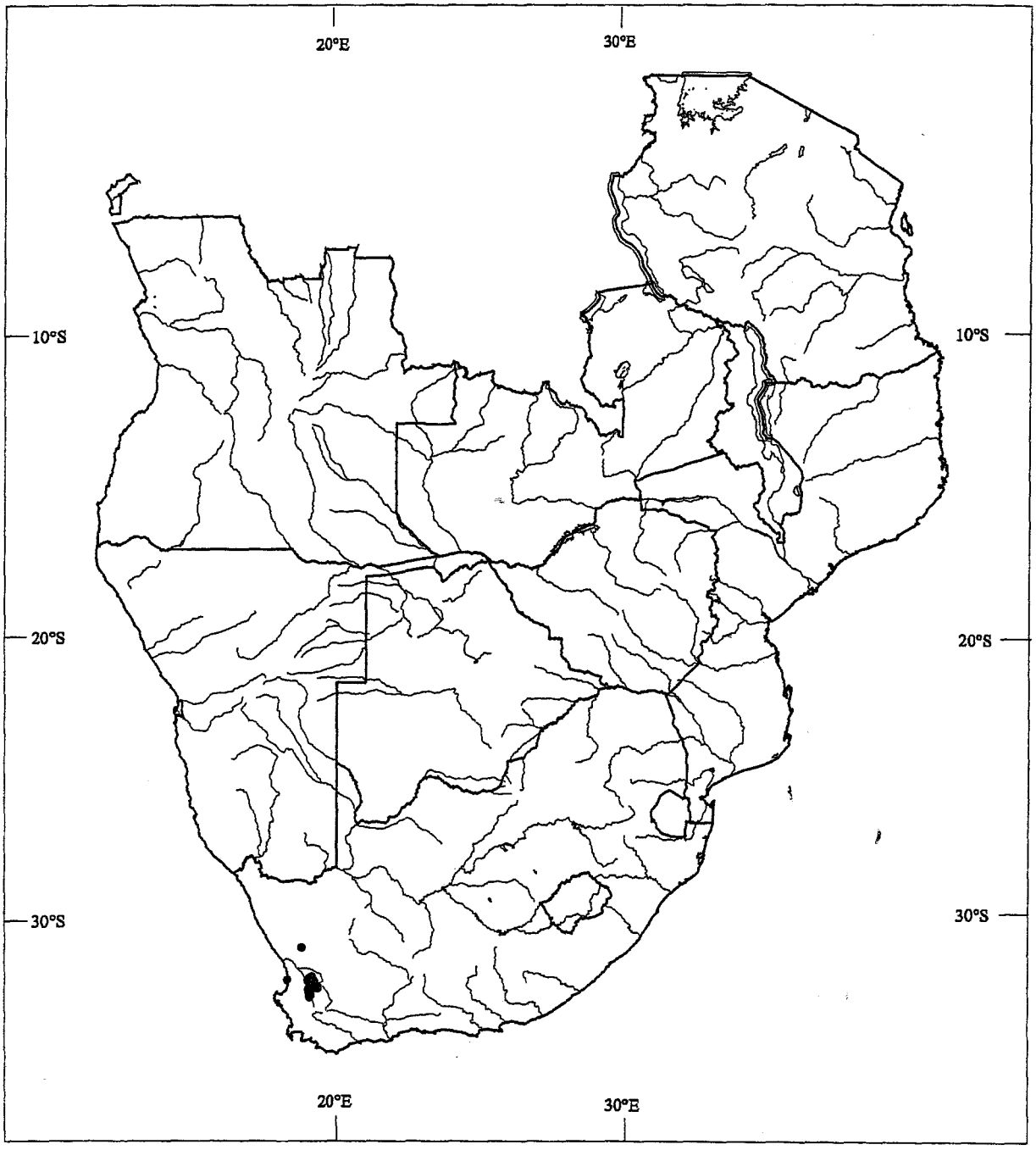


Figure F.84. Point distribution of *Barbus capensis*. Scale approximately 1:25 000 000

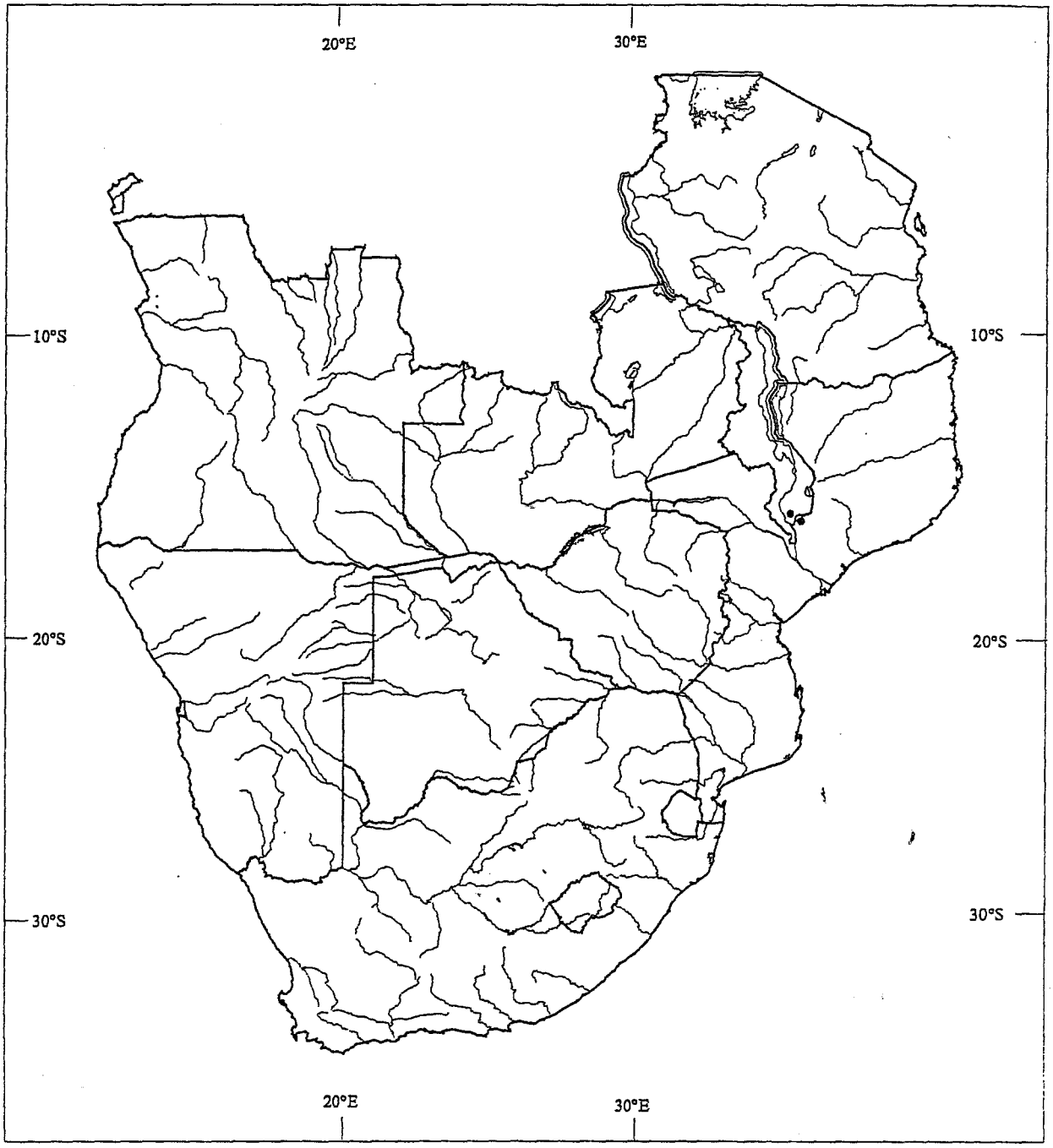


Figure F.85. Point distribution of *Barbus choloensis*. Scale approximately 1:25 000 000

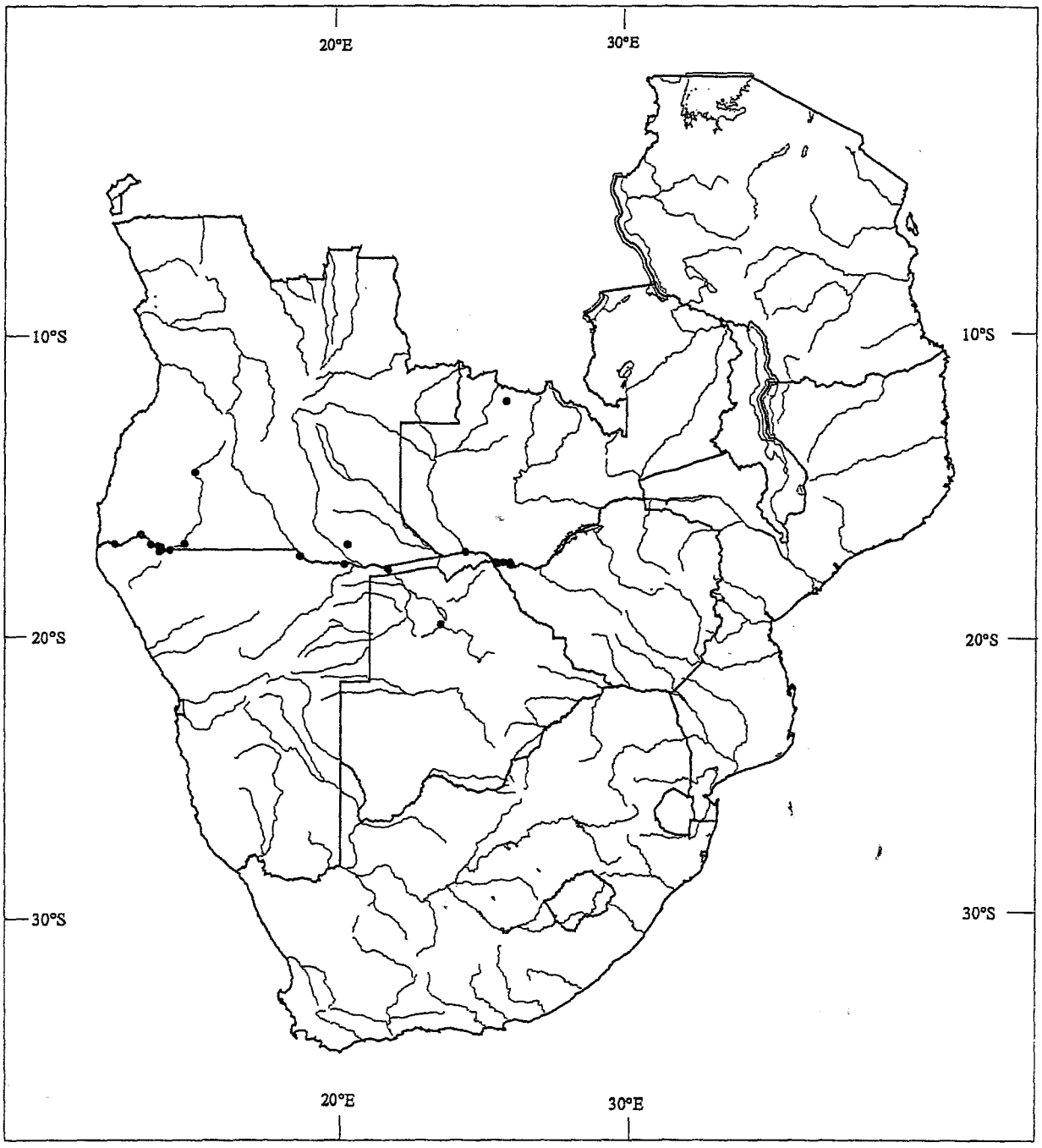


Figure F.86. Point distribution of *Barbus codringtonii*. Scale approximately 1:25 000 000

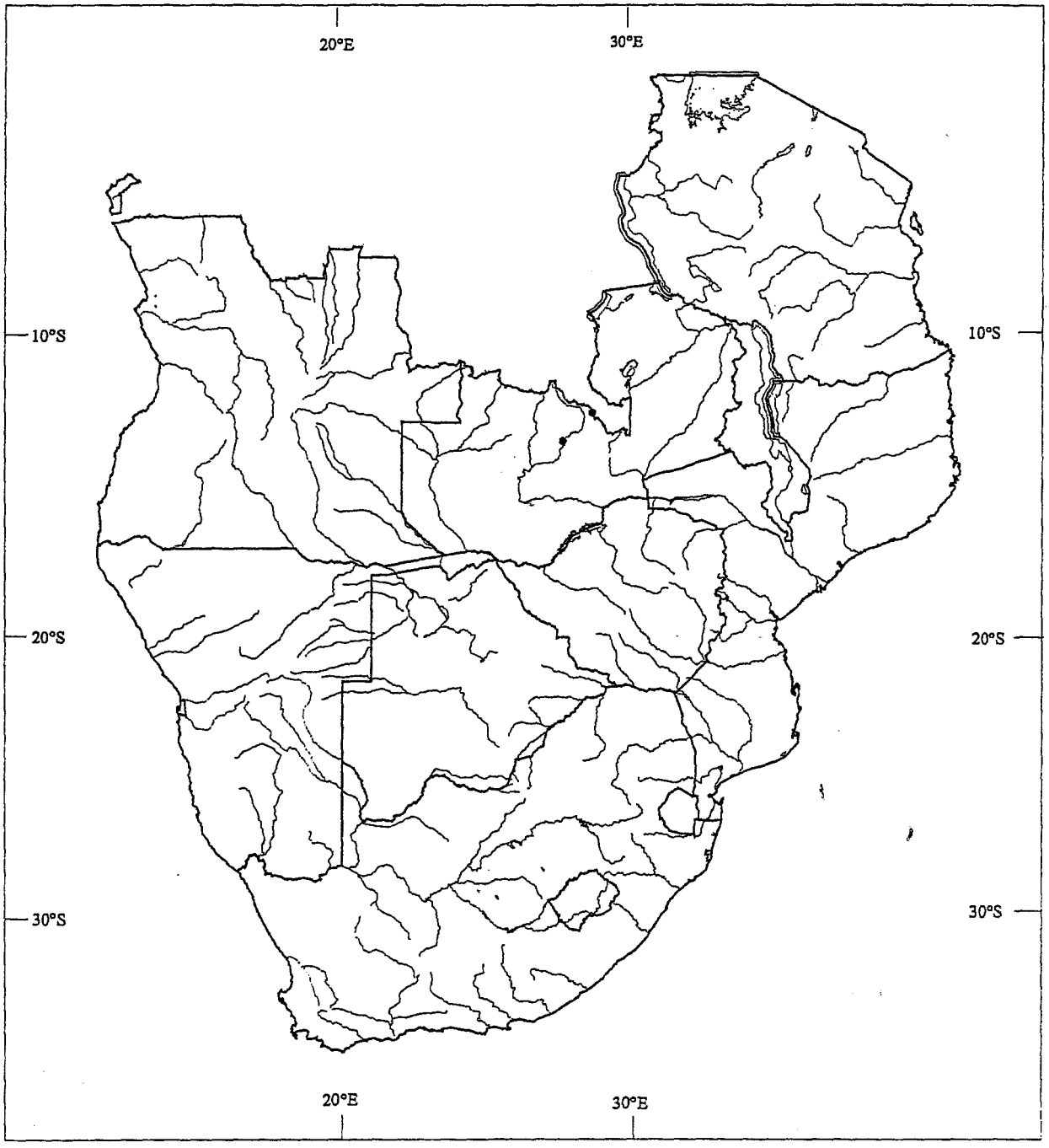


Figure F.87. Point distribution of *Barbus dorsolineatus*. Scale approximately 1:25 000 000

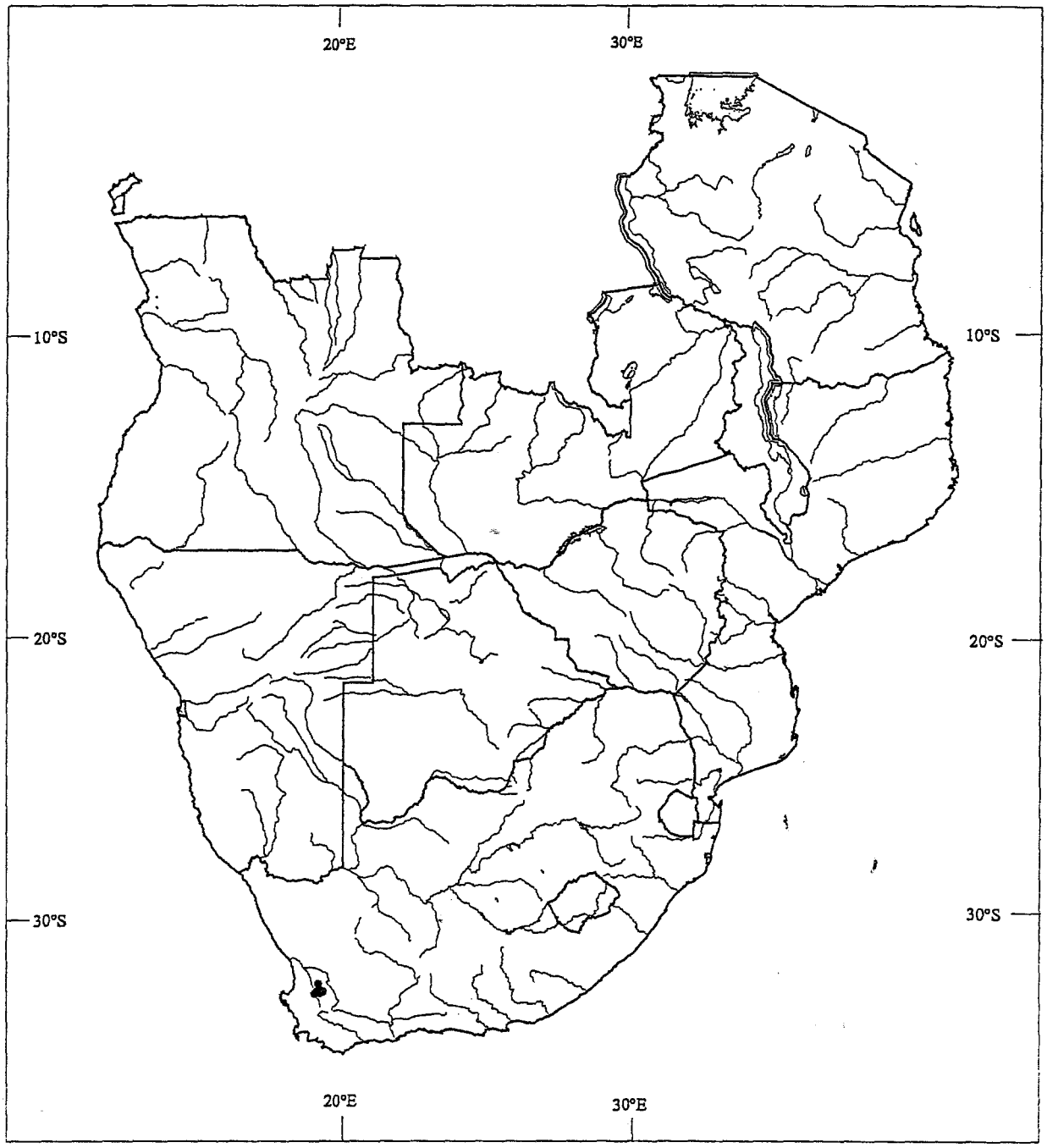


Figure F.88. Point distribution of *Barbus erubescens*. Scale approximately 1:25 000 000

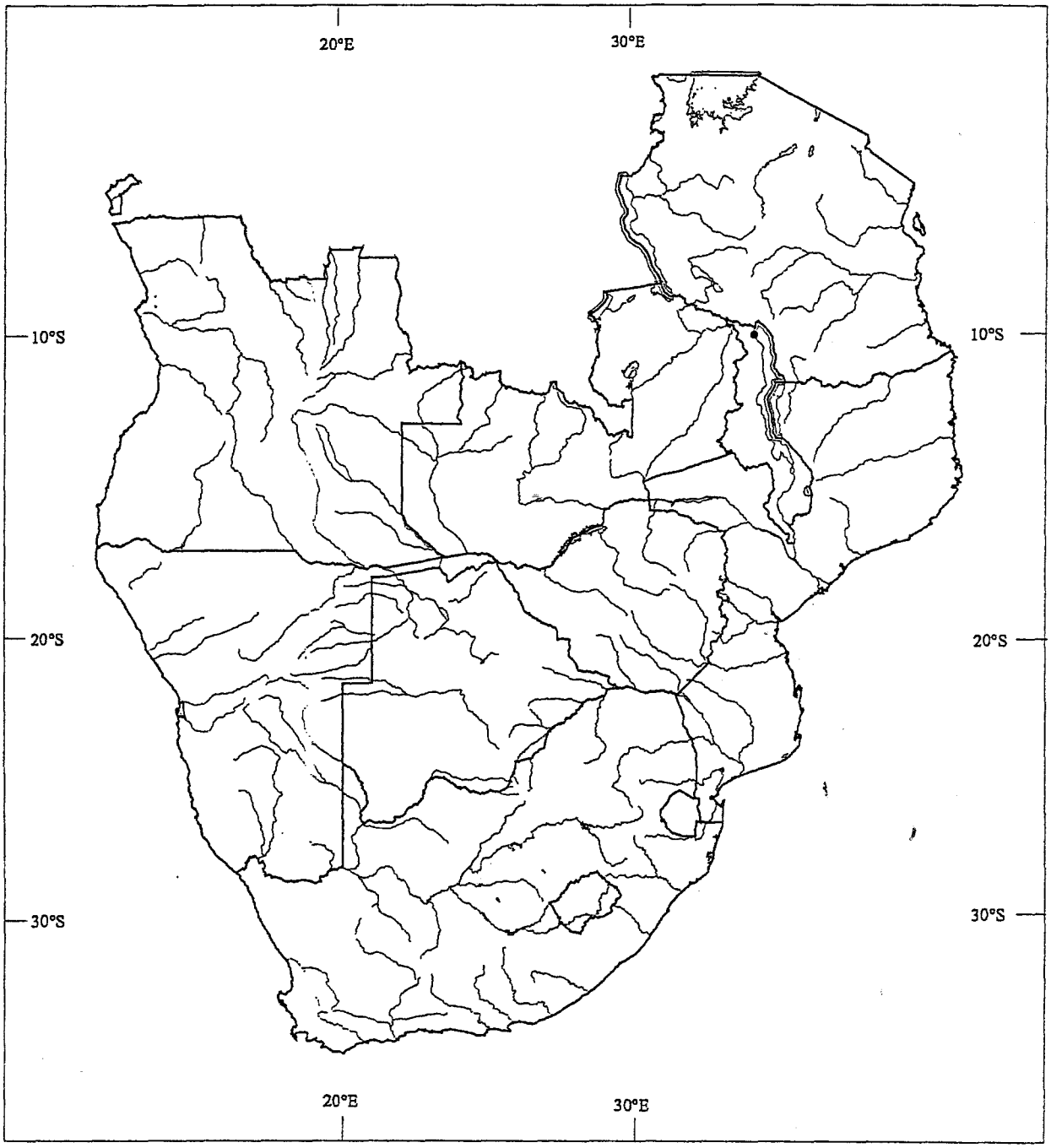


Figure F.89. Point distribution of *Barbus eurystomus*. Scale approximately 1:25 000 000

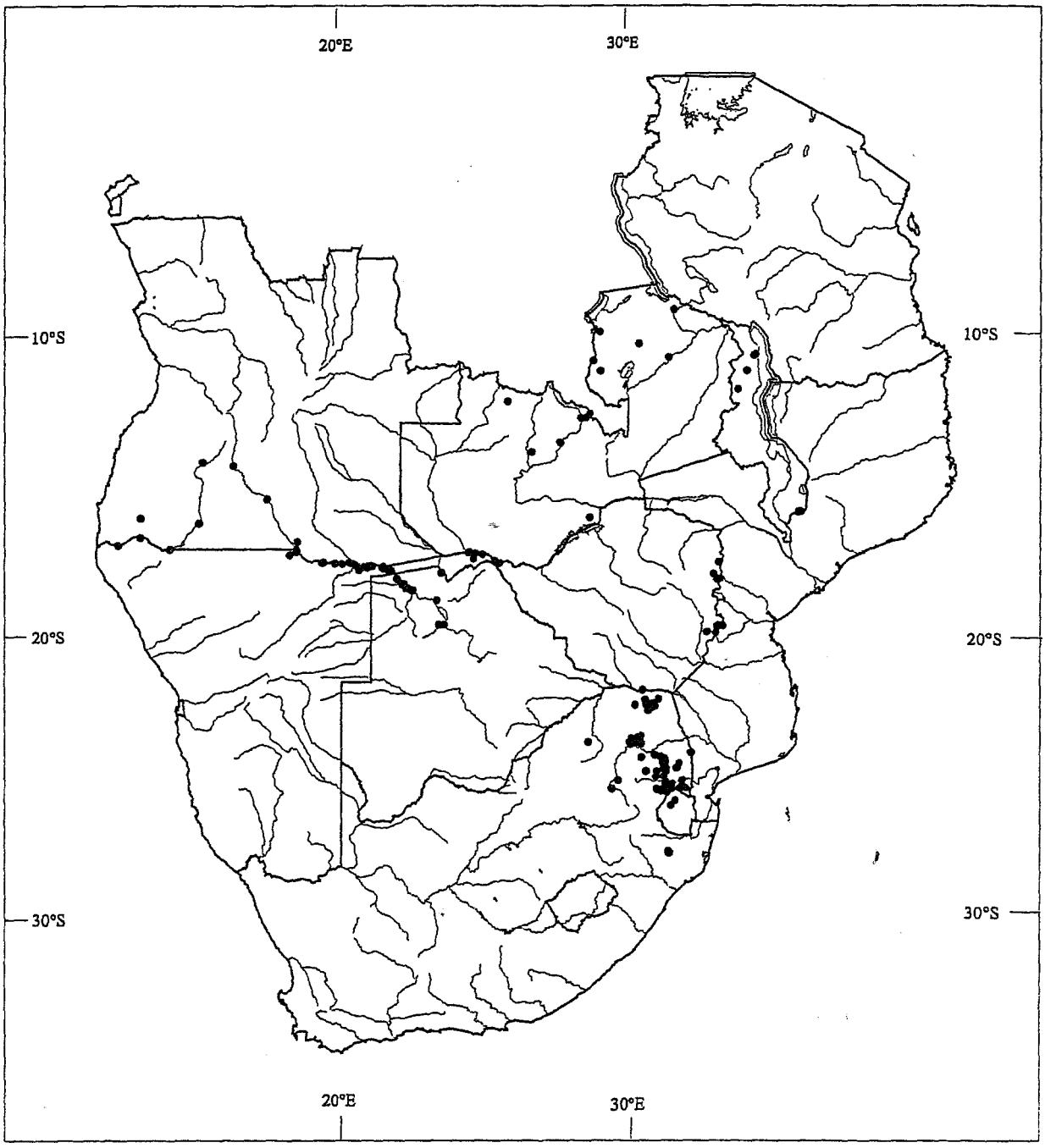


Figure F.90. Point distribution of *Barbus eutaenia*. Scale approximately 1:25 000 000

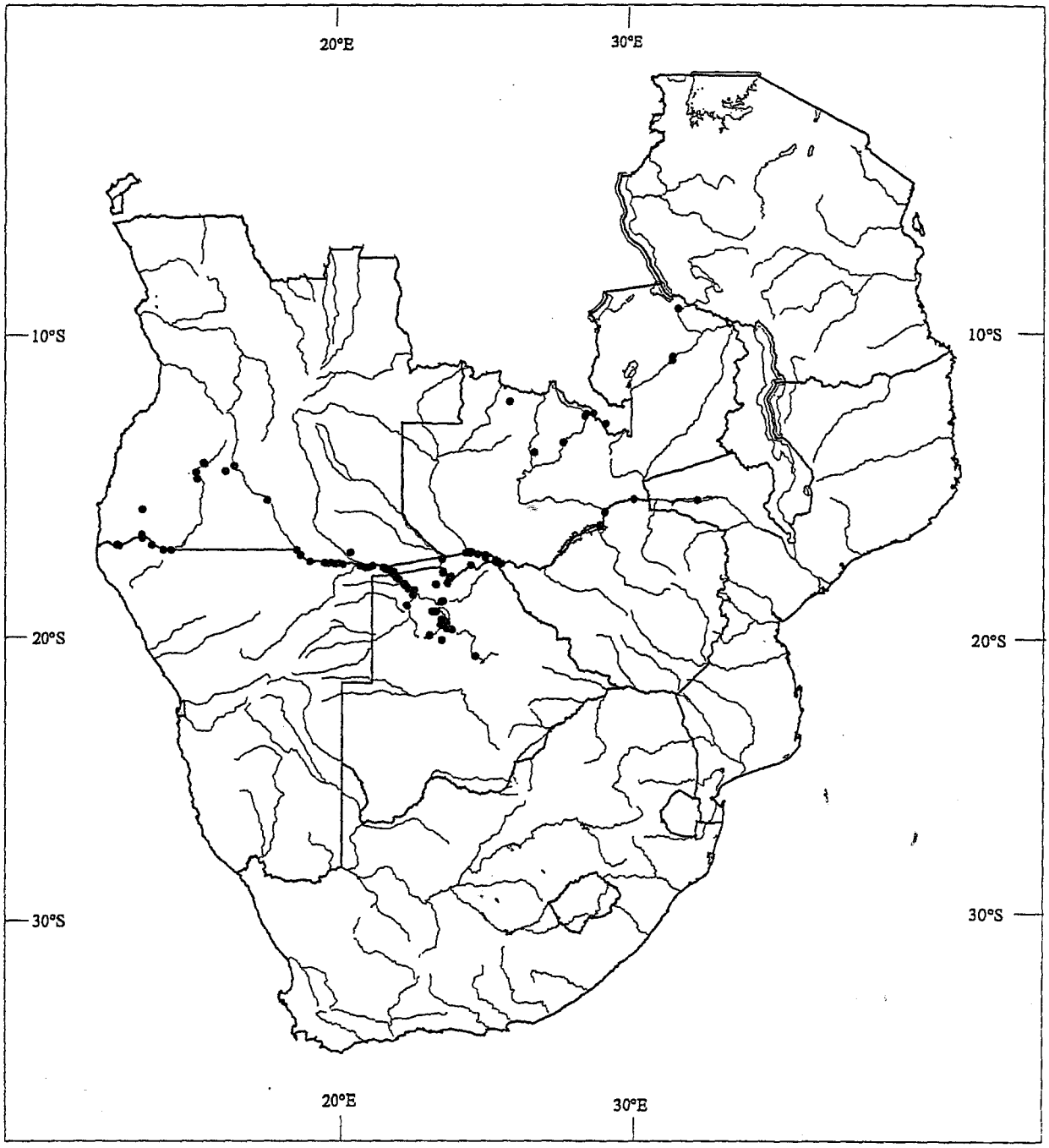


Figure F.91. Point distribution of *Barbus fasciolatus*. Scale approximately 1:25 000 000

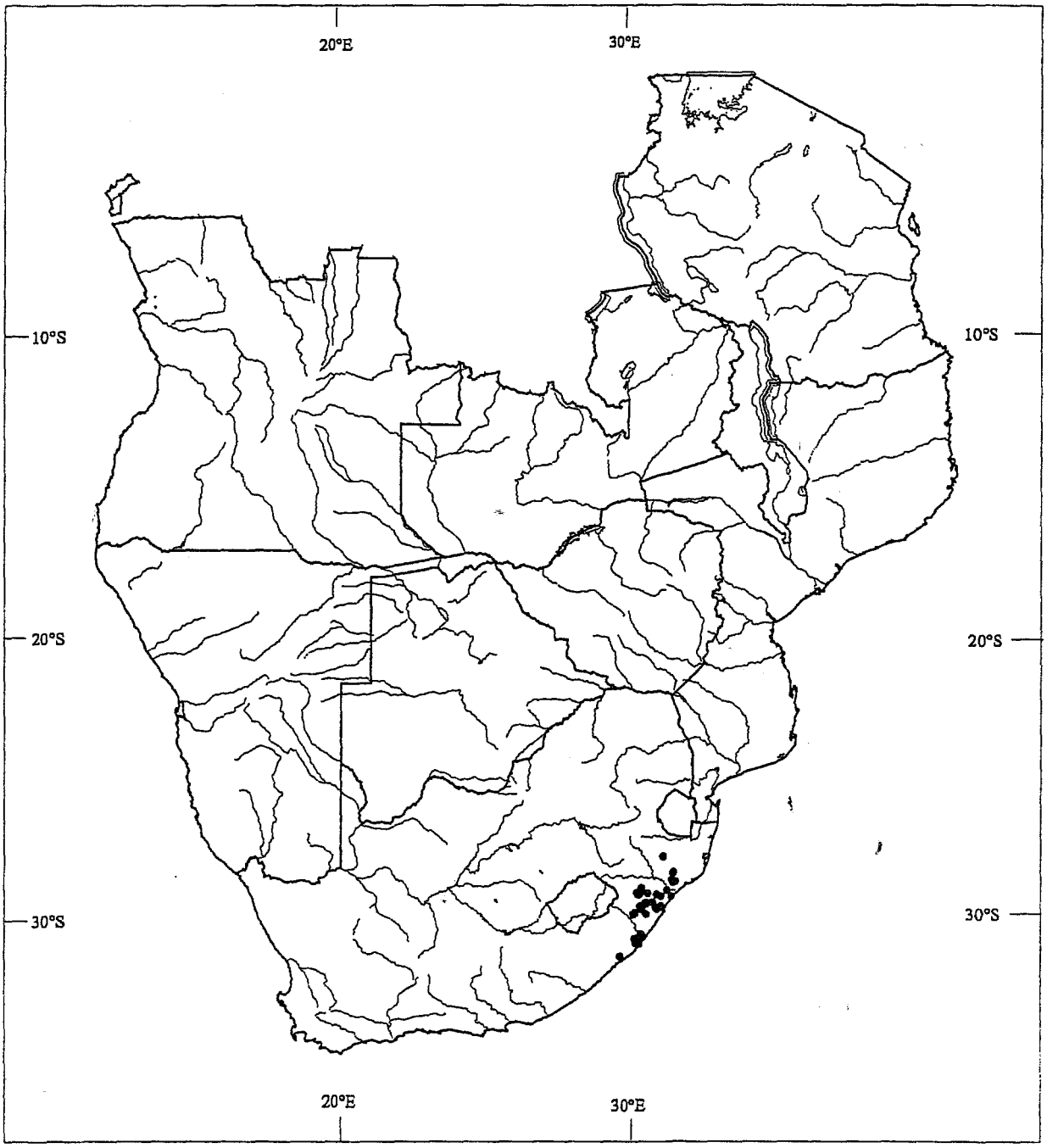


Figure F.92. Point distribution of *Barbus gurneyi*. Scale approximately 1:25 000 000

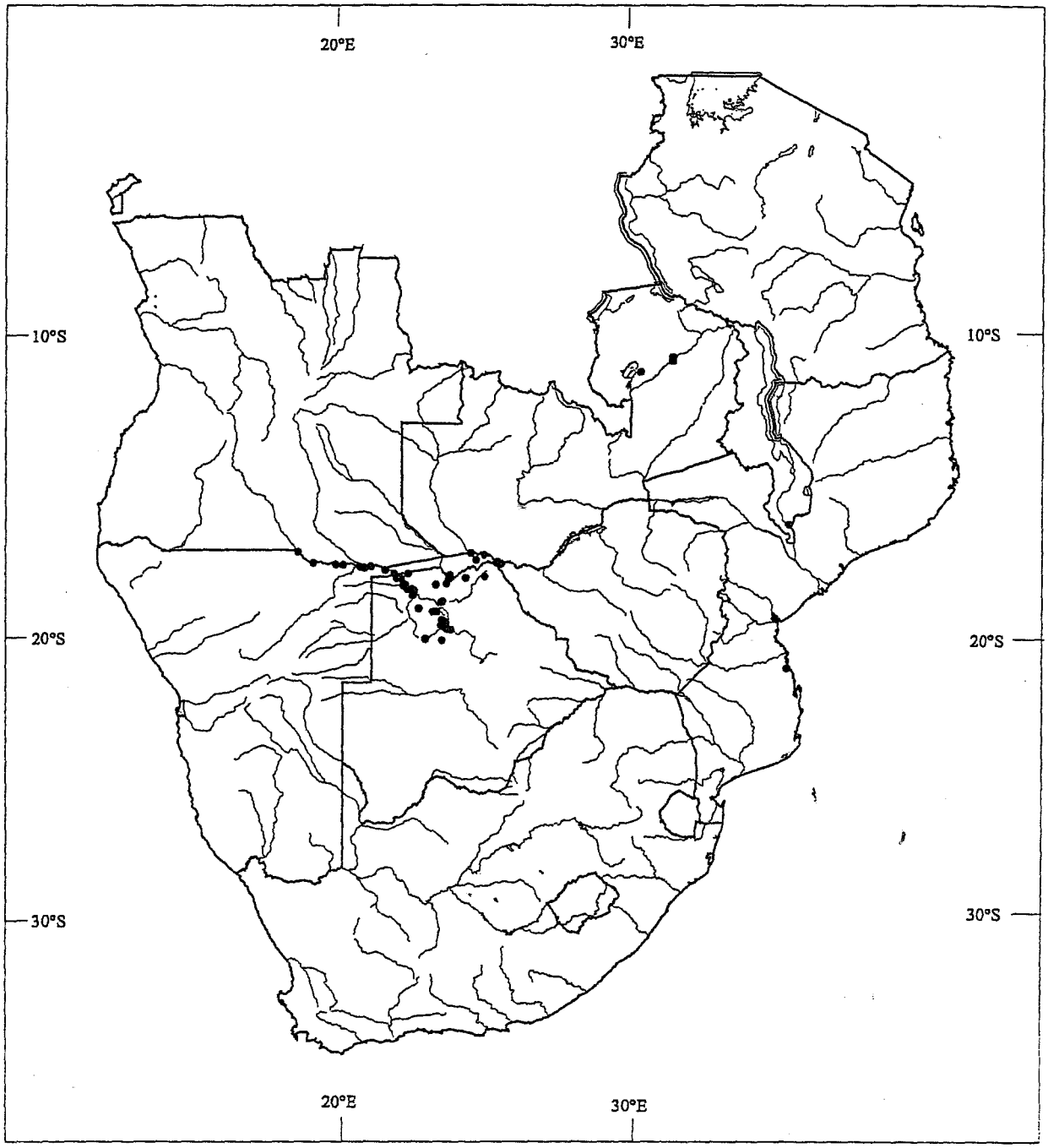


Figure F.93. Point distribution of *Barbus haasianus*. Scale approximately 1:25 000 000

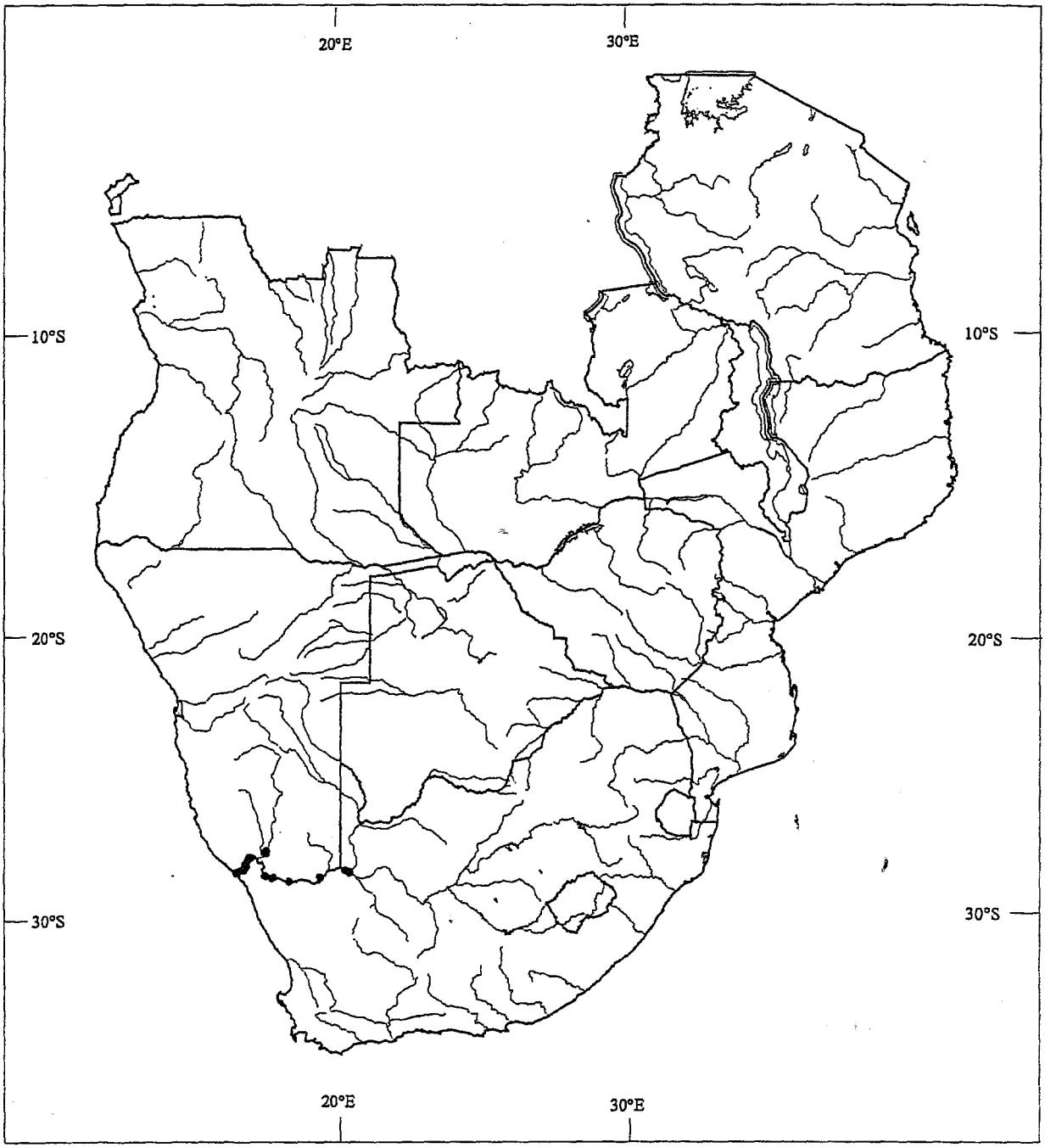


Figure F.94. Point distribution of *Barbus hospes*. Scale approximately 1:25 000 000

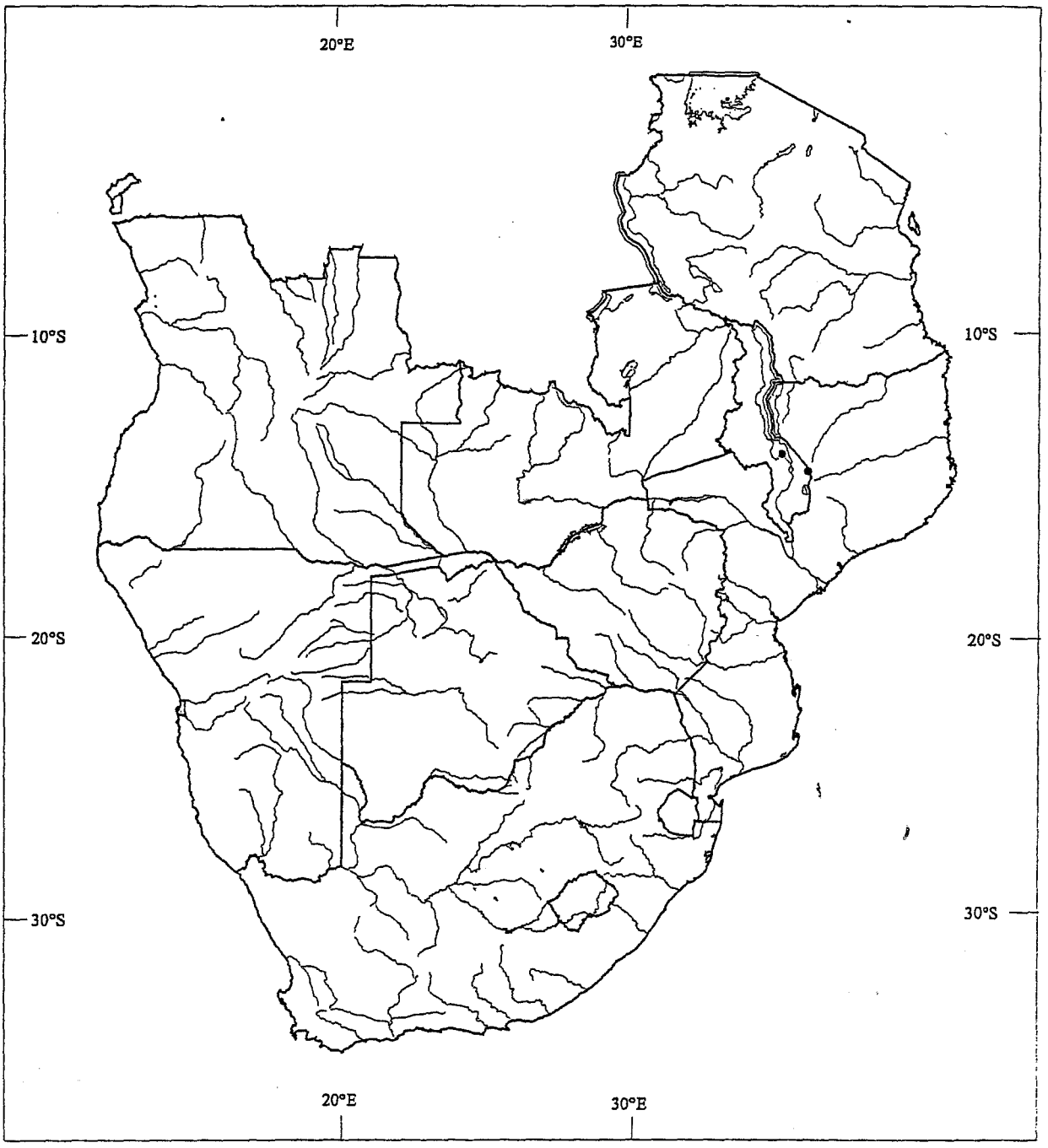


Figure F.95. Point distribution of *Barbus innocens*. Scale approximately 1:25 000 000

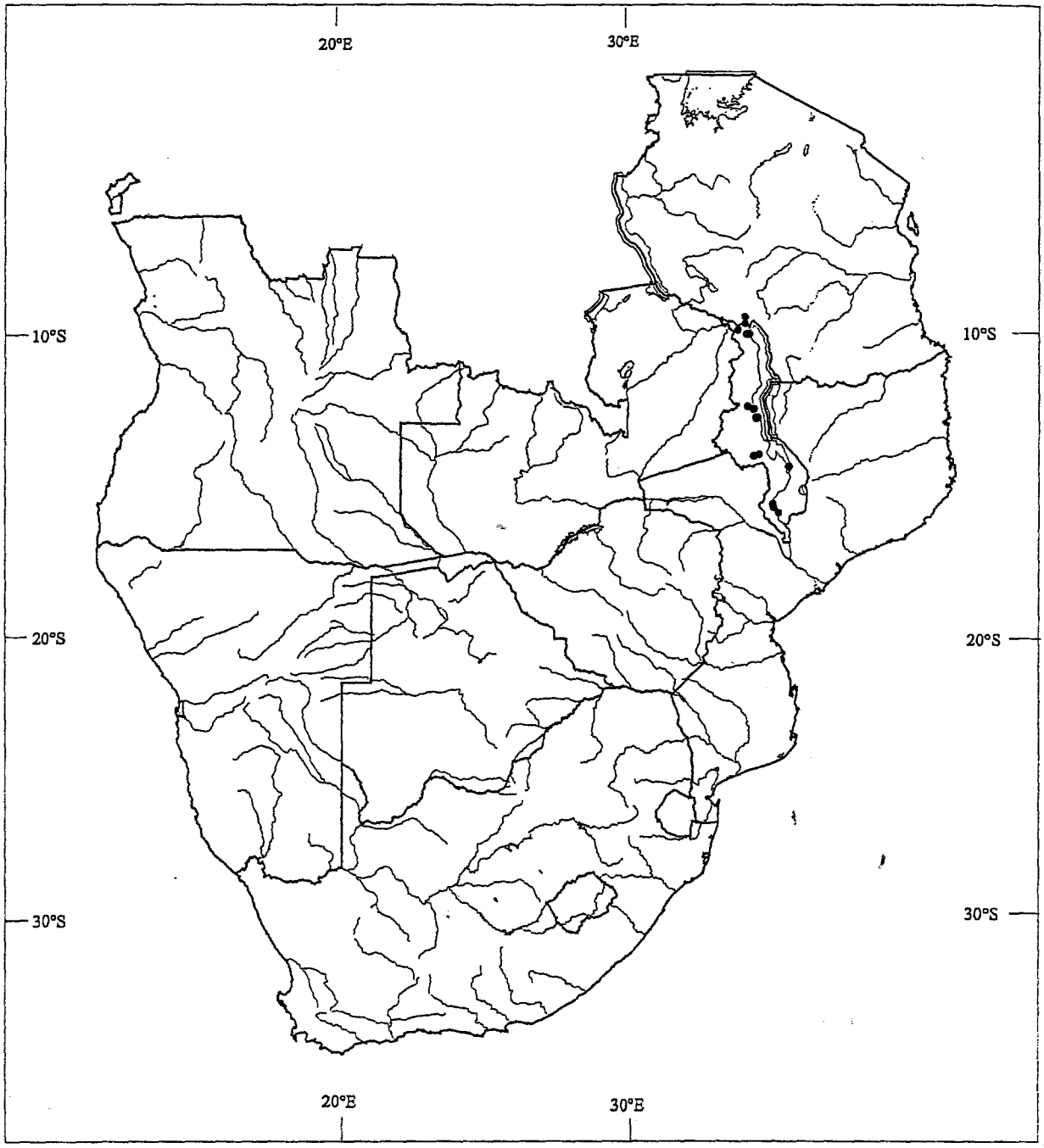


Figure F.96. Point distribution of *Barbus johnstonii*. Scale approximately 1:25 000 000

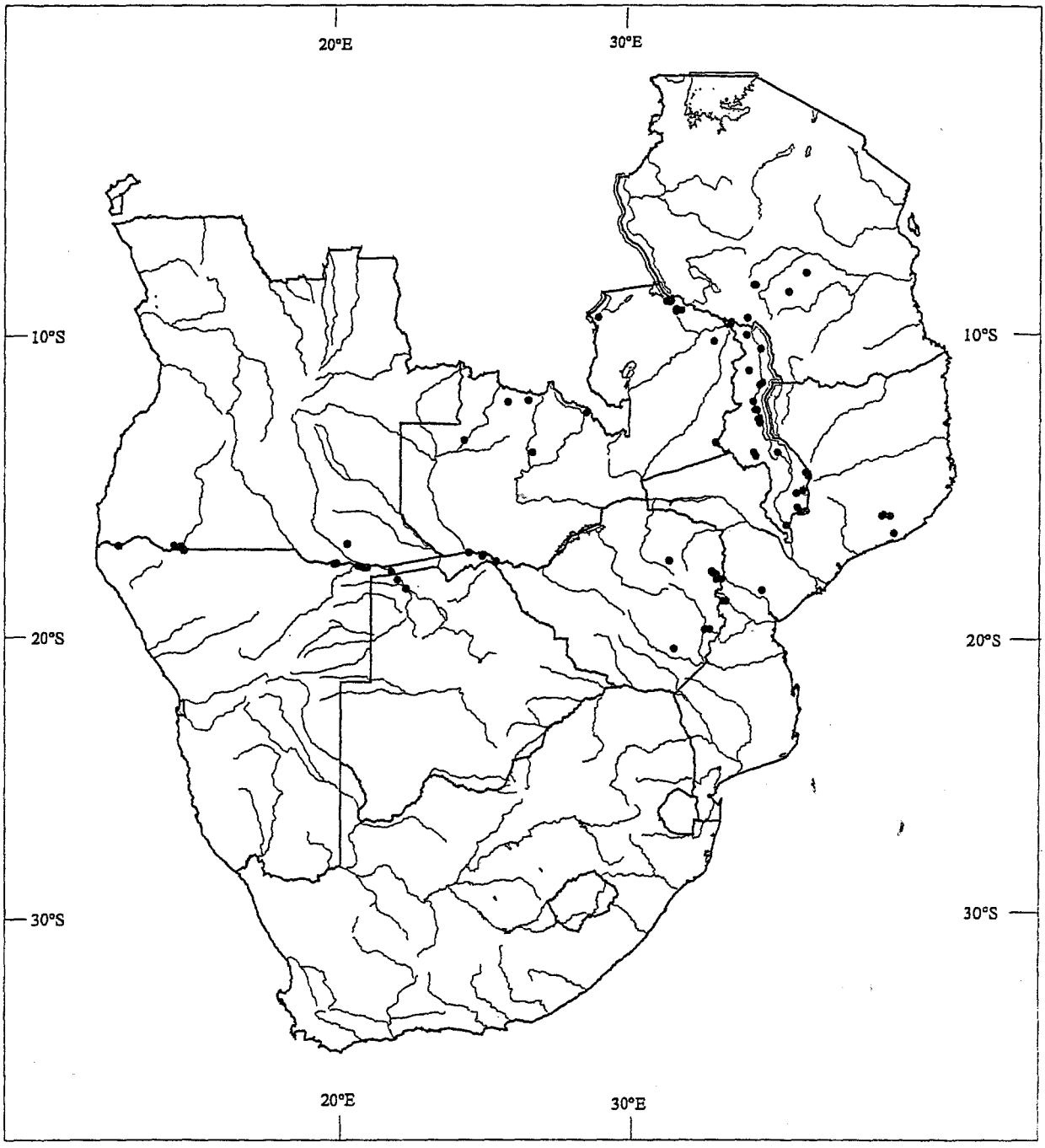


Figure F.97. Point distribution of *Barbus kerstenii*. Scale approximately 1:25 000 000

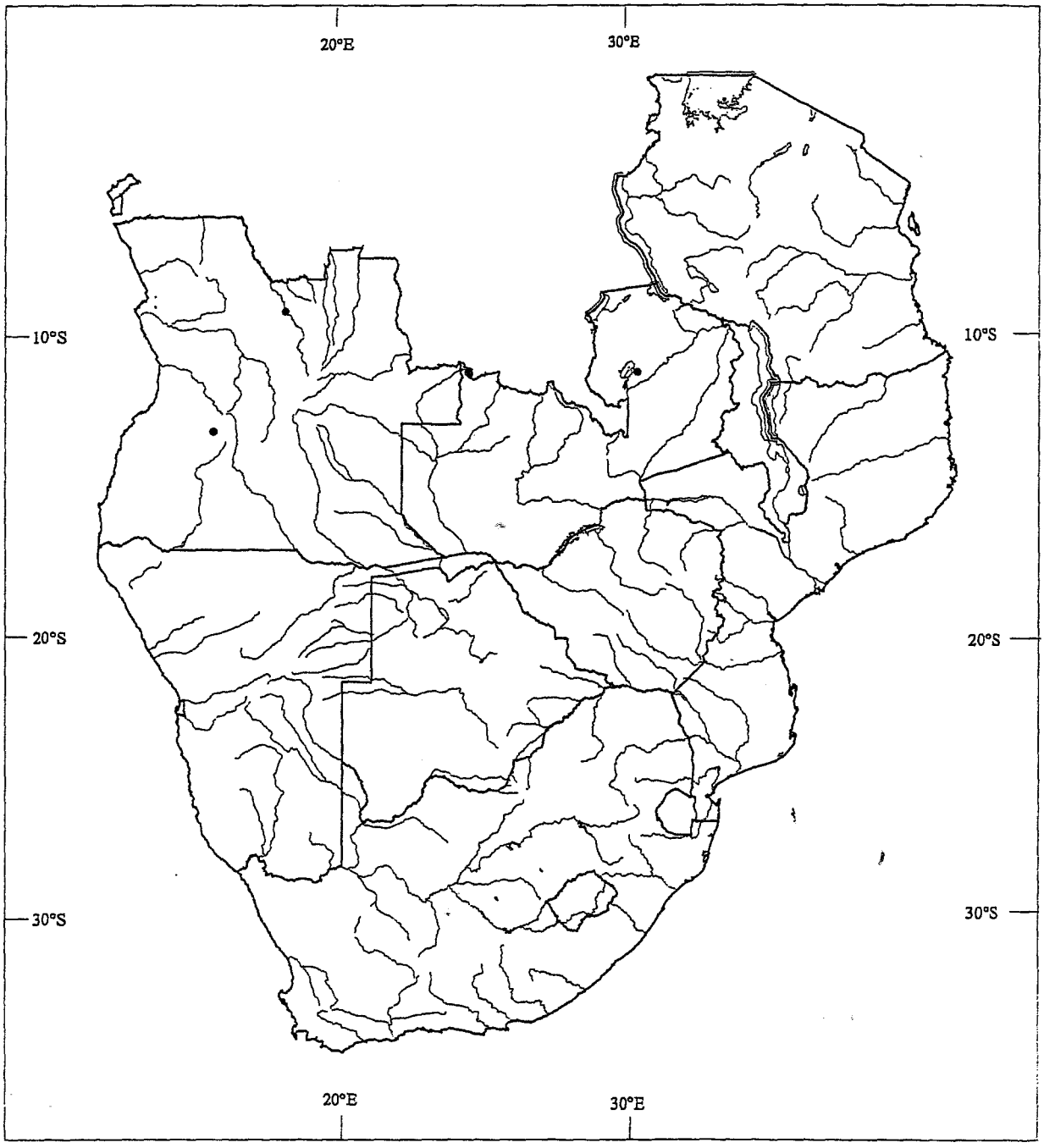


Figure F.98. Point distribution of *Barbus kessleri*. Scale approximately 1:25 000 000

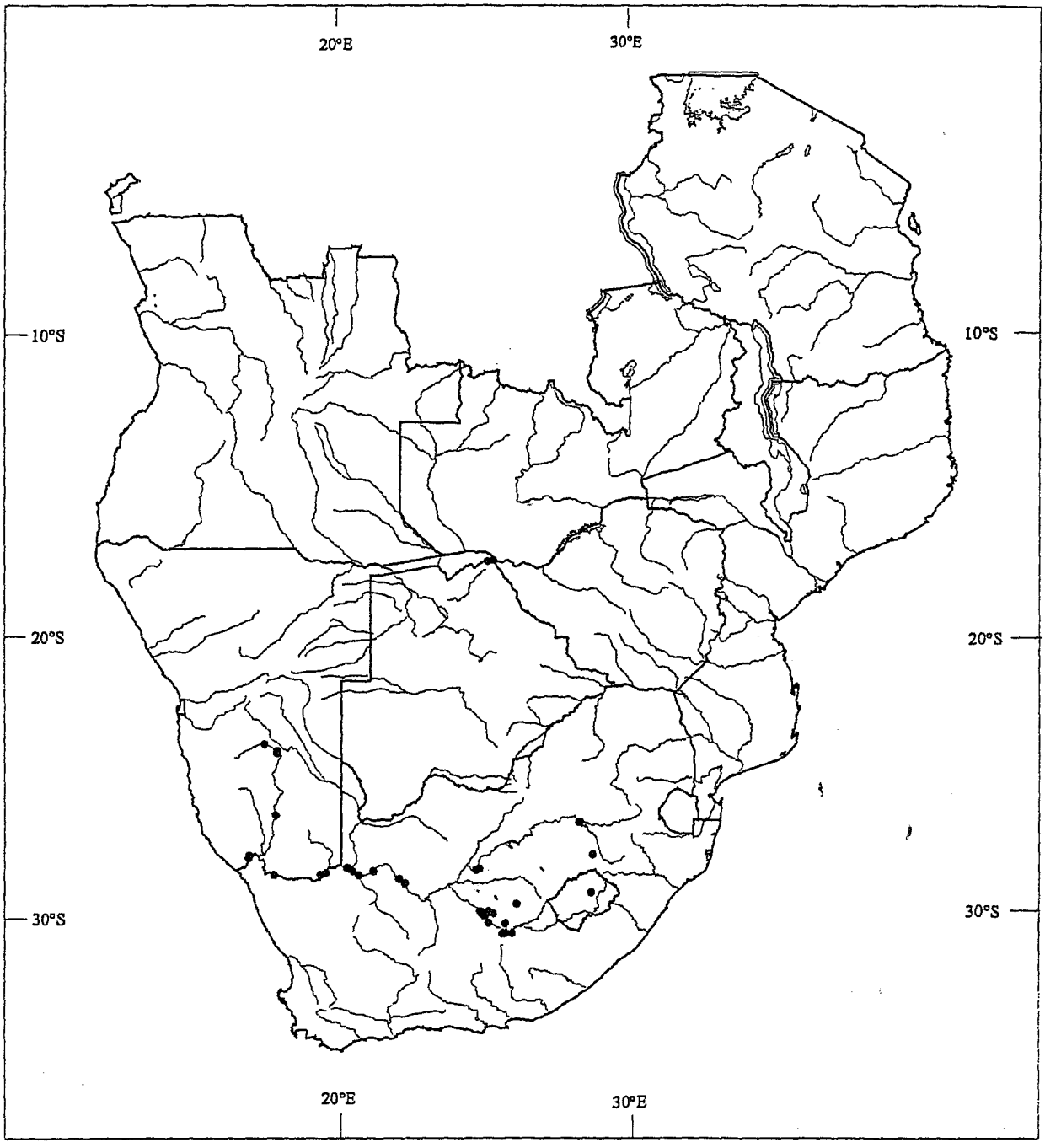


Figure F.99. Point distribution of *Barbus kimberleyensis*. Scale approximately 1:25 000 000

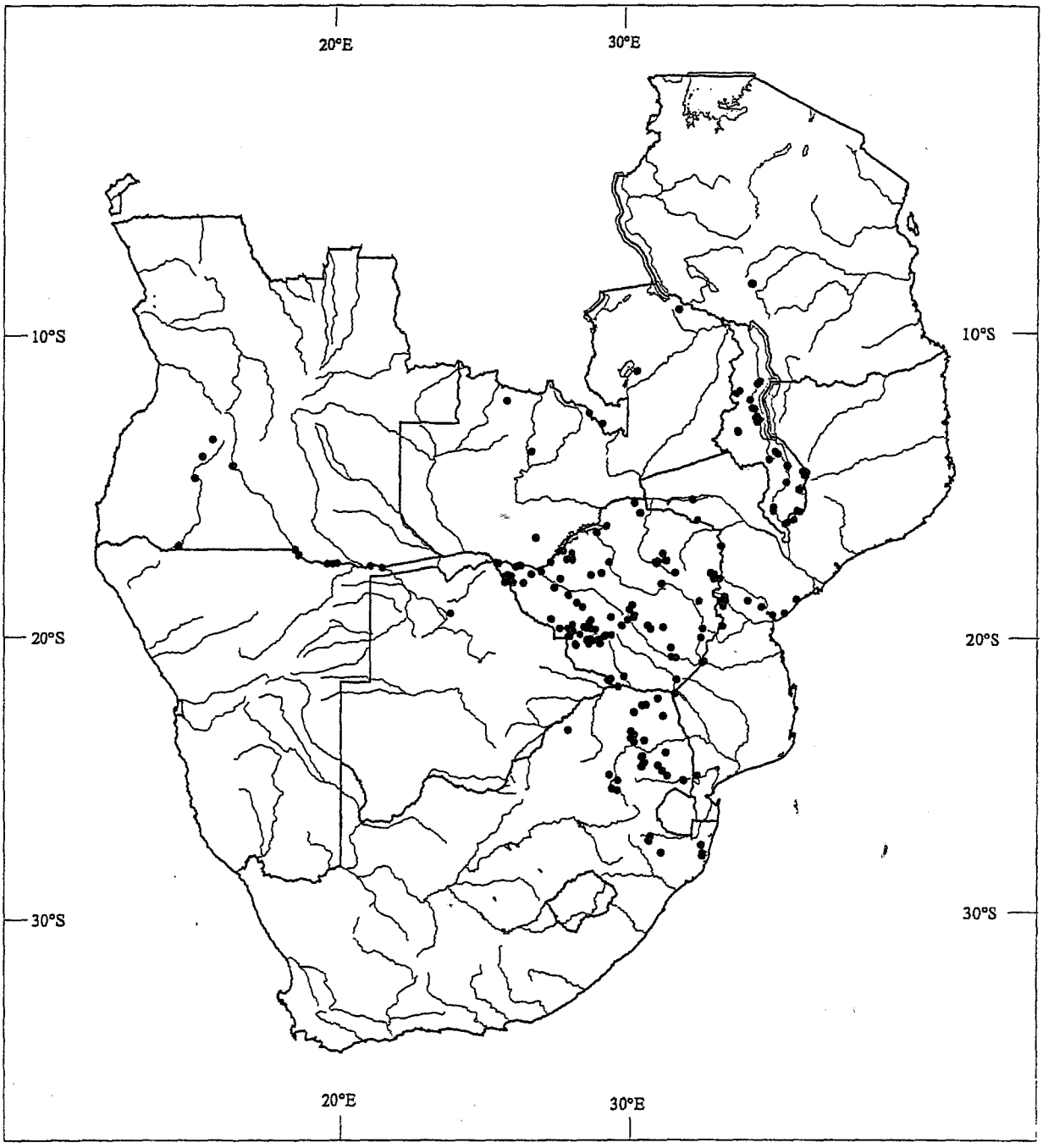


Figure F.100. Point distribution of *Barbus lineomaculatus*. Scale approximately 1:25 000 000

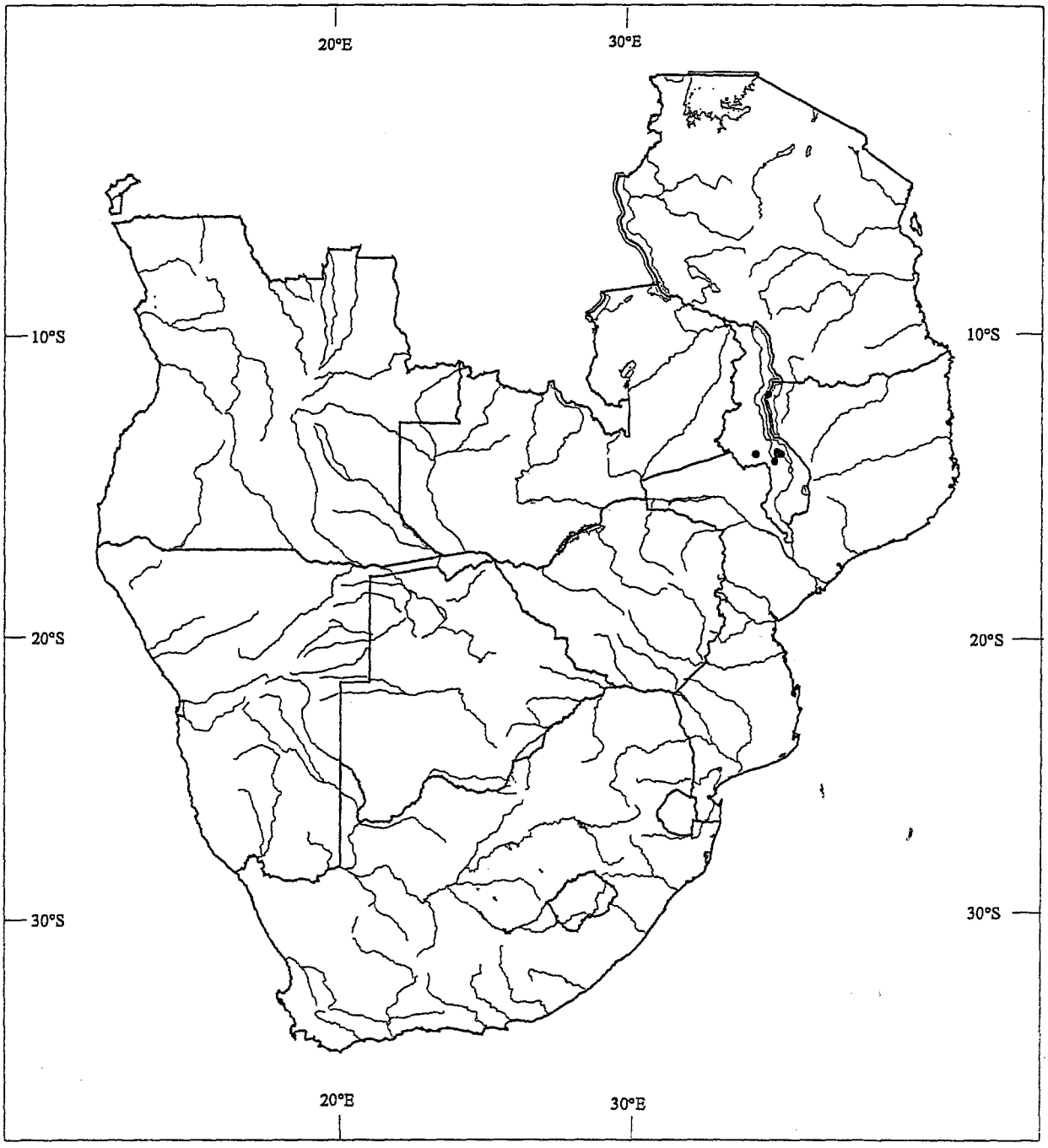


Figure F.101. Point distribution of *Barbus litamba*. Scale approximately 1:25 000 000

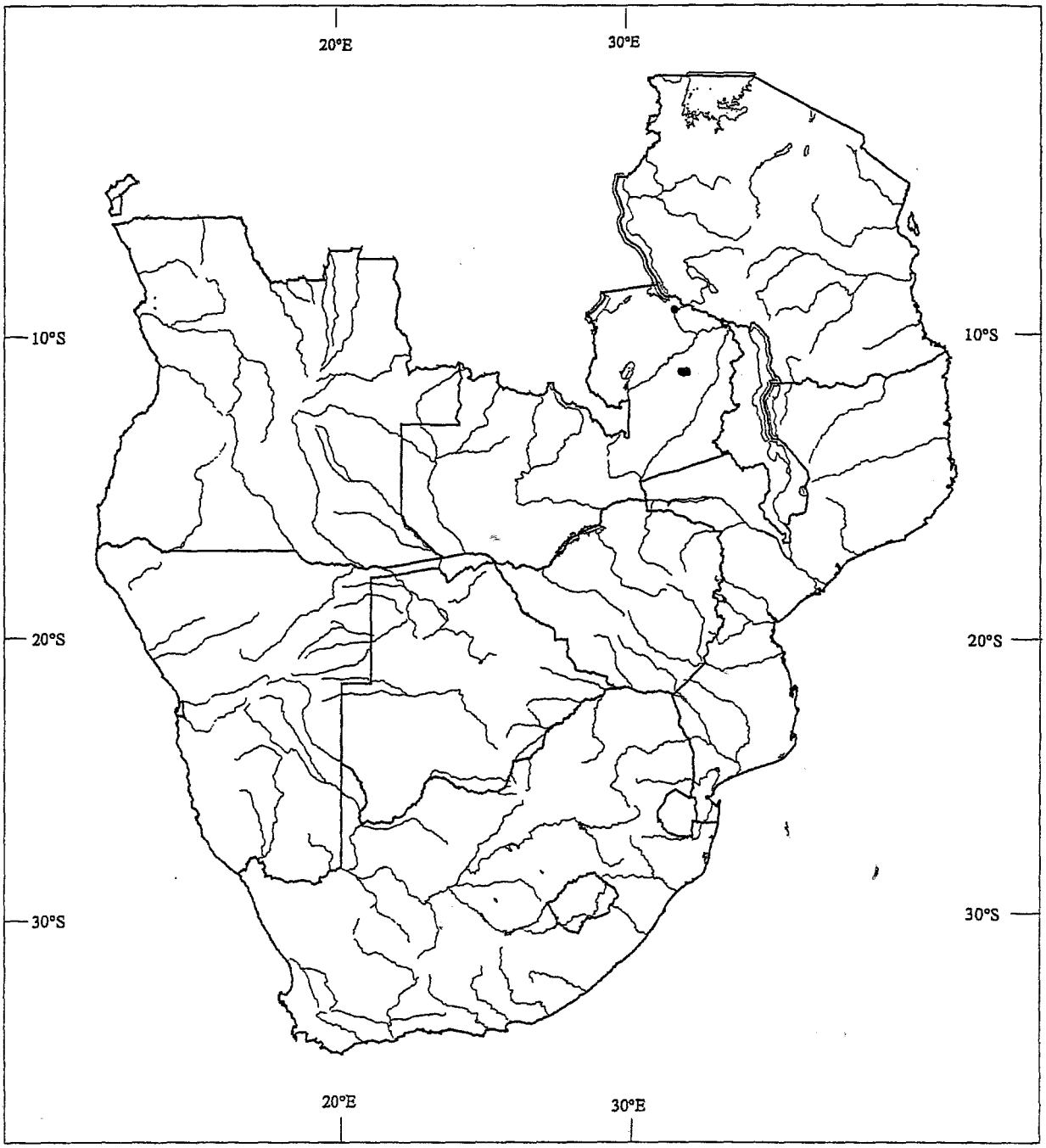


Figure F.102. Point distribution of *Barbus lornae*. Scale approximately 1:25 000 000

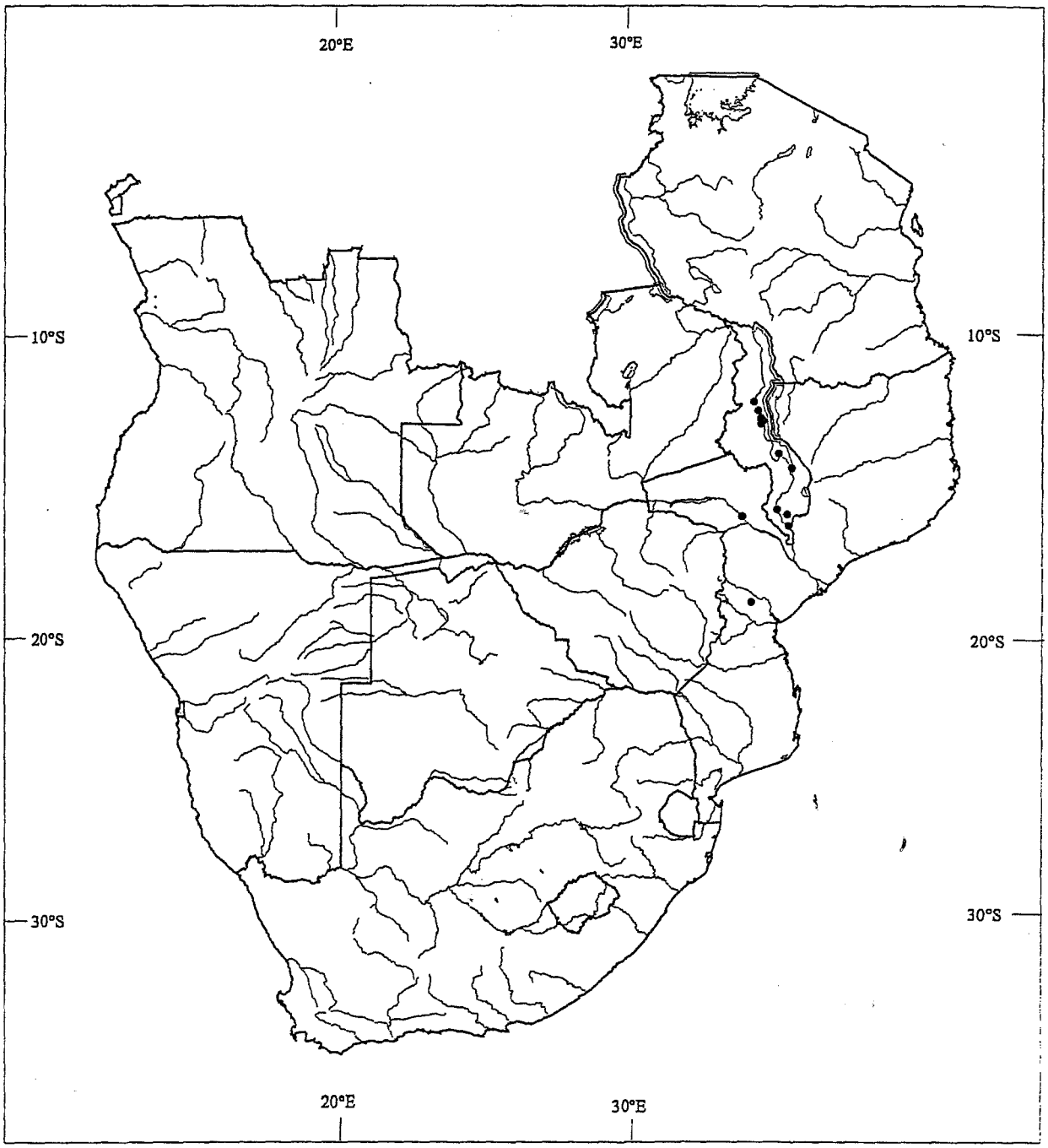


Figure F.103. Point distribution of *Barbus macrotaenia*. Scale approximately 1:25 000 000

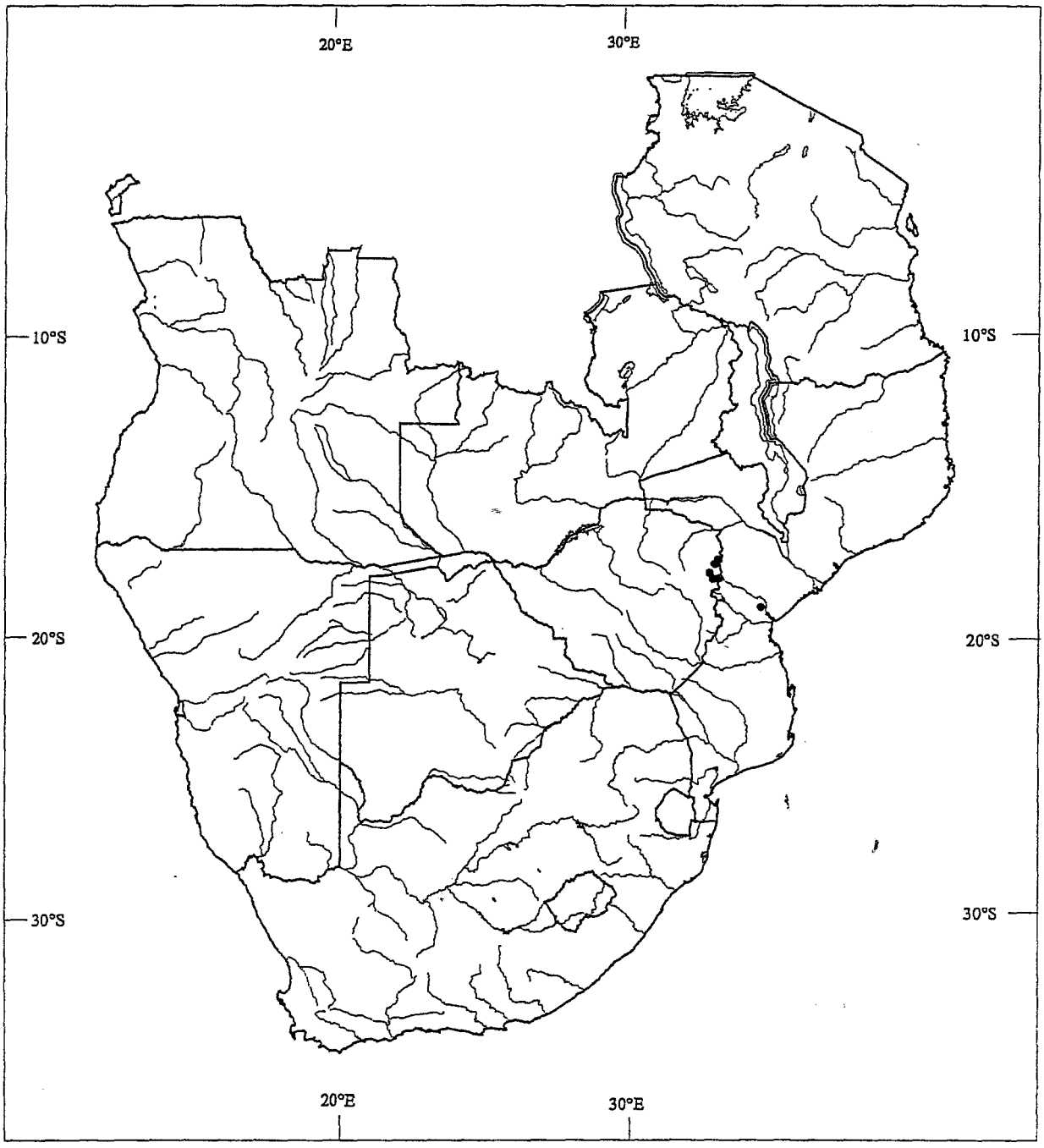


Figure F.104. Point distribution of *Barbus manicensis*. Scale approximately 1:25 000 000

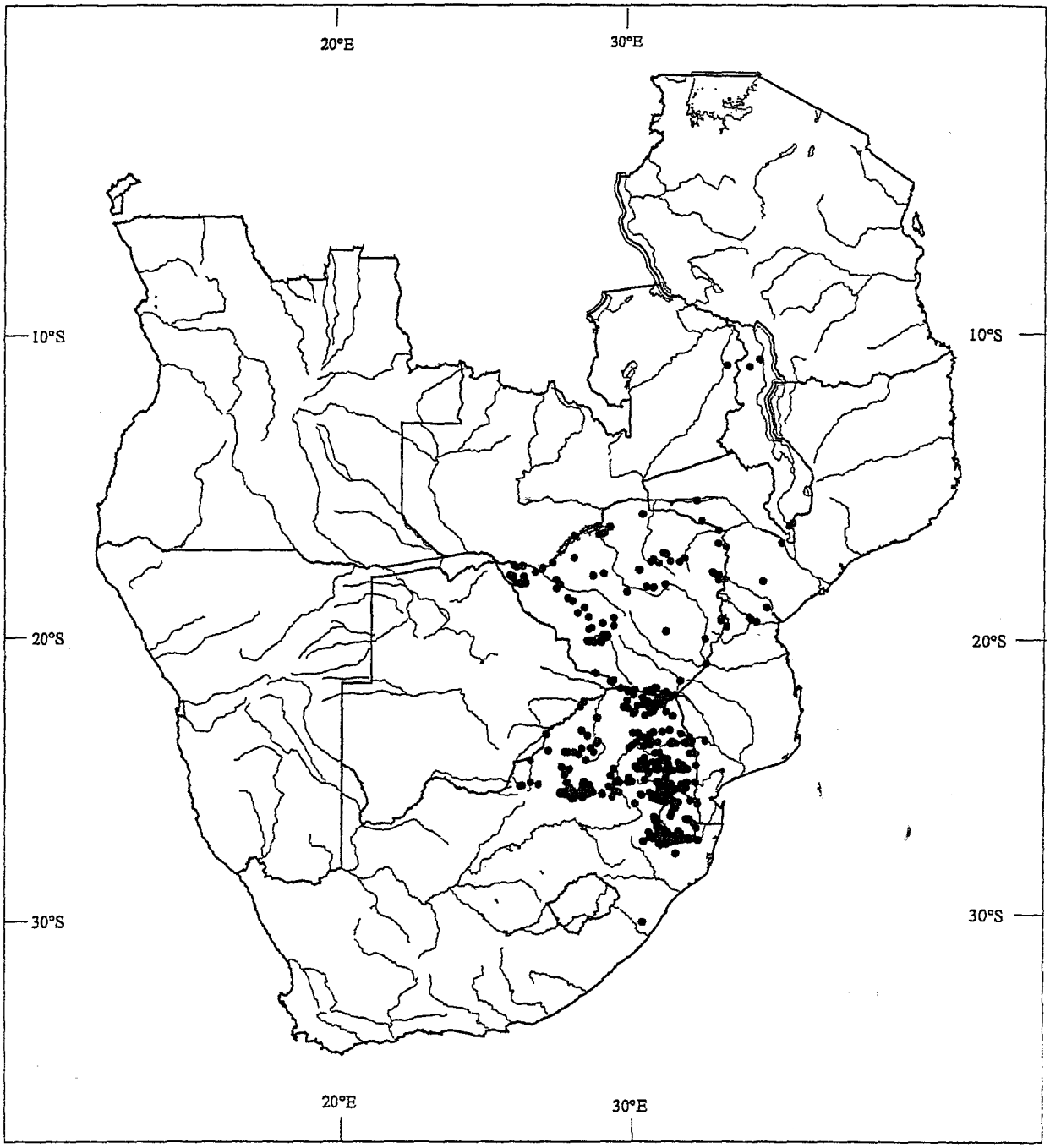


Figure F.105. Point distribution of *Barbus marequensis*. Scale approximately 1:25 000 000

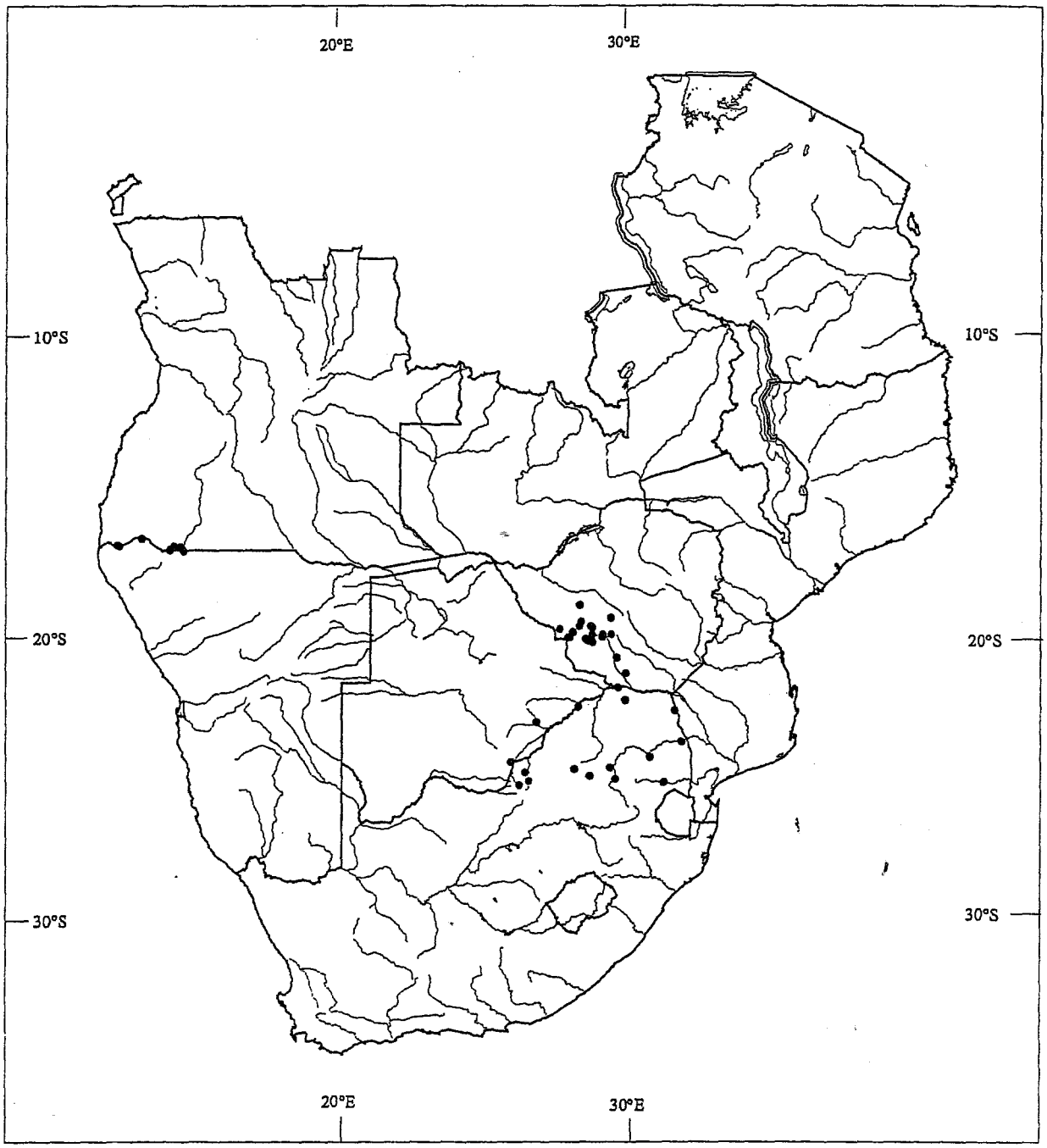


Figure F.106. Point distribution of *Barbus mattozi*. Scale approximately 1:25 000 000

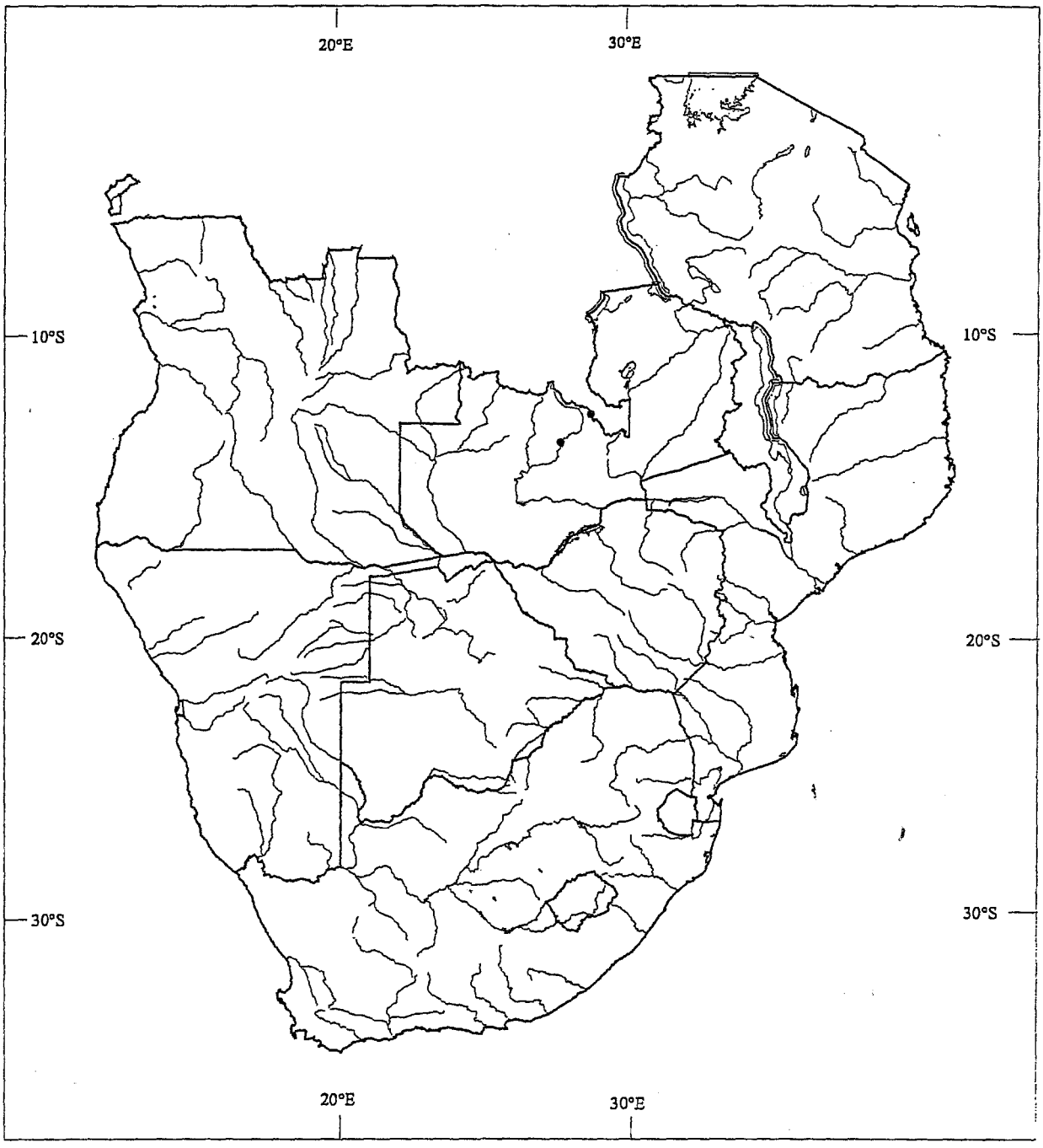


Figure F.107. Point distribution of *Barbus miolepis*. Scale approximately 1:25 000 000

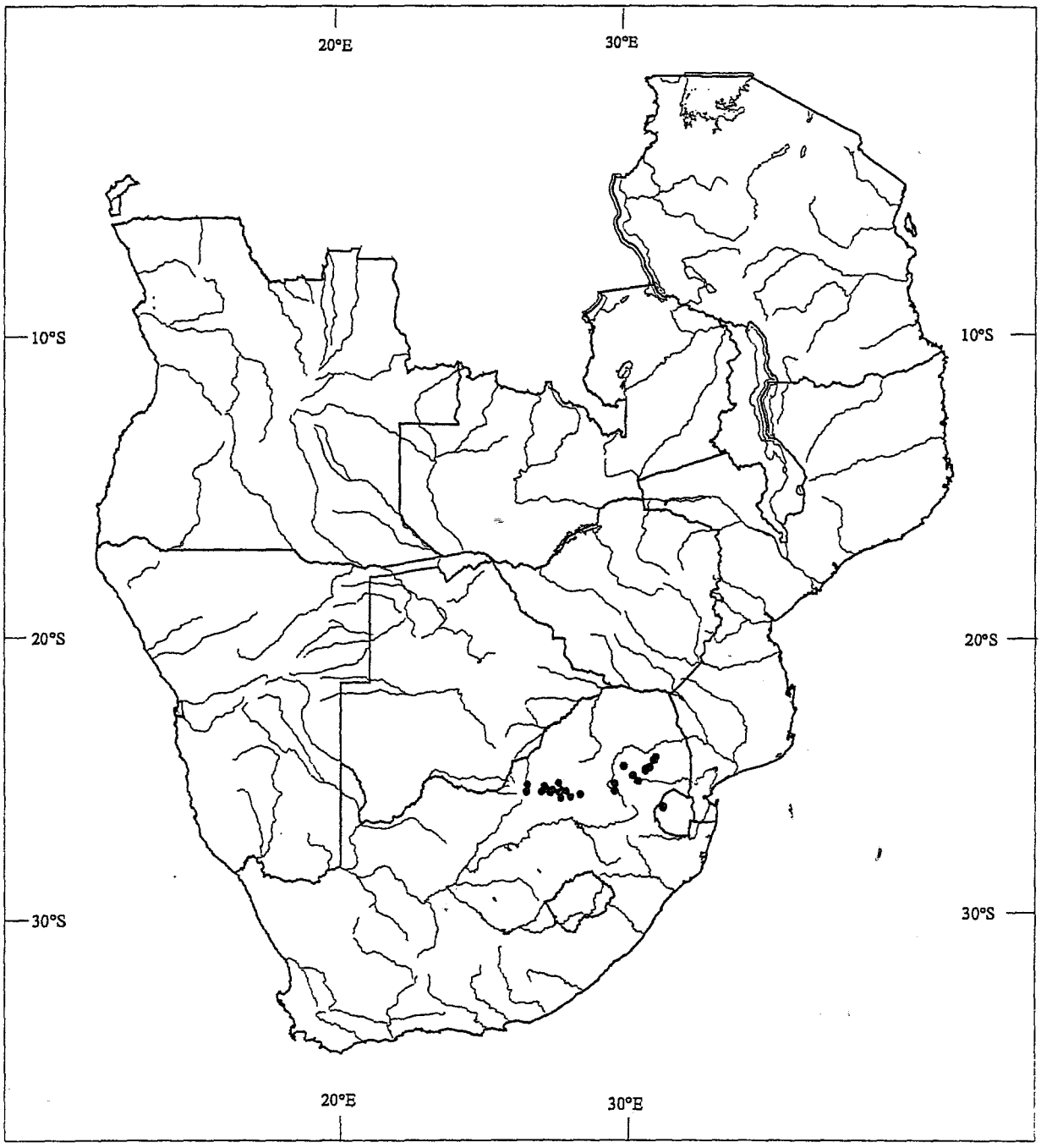


Figure F.108. Point distribution of *Barbus motebensis*. Scale approximately 1:25 000 000

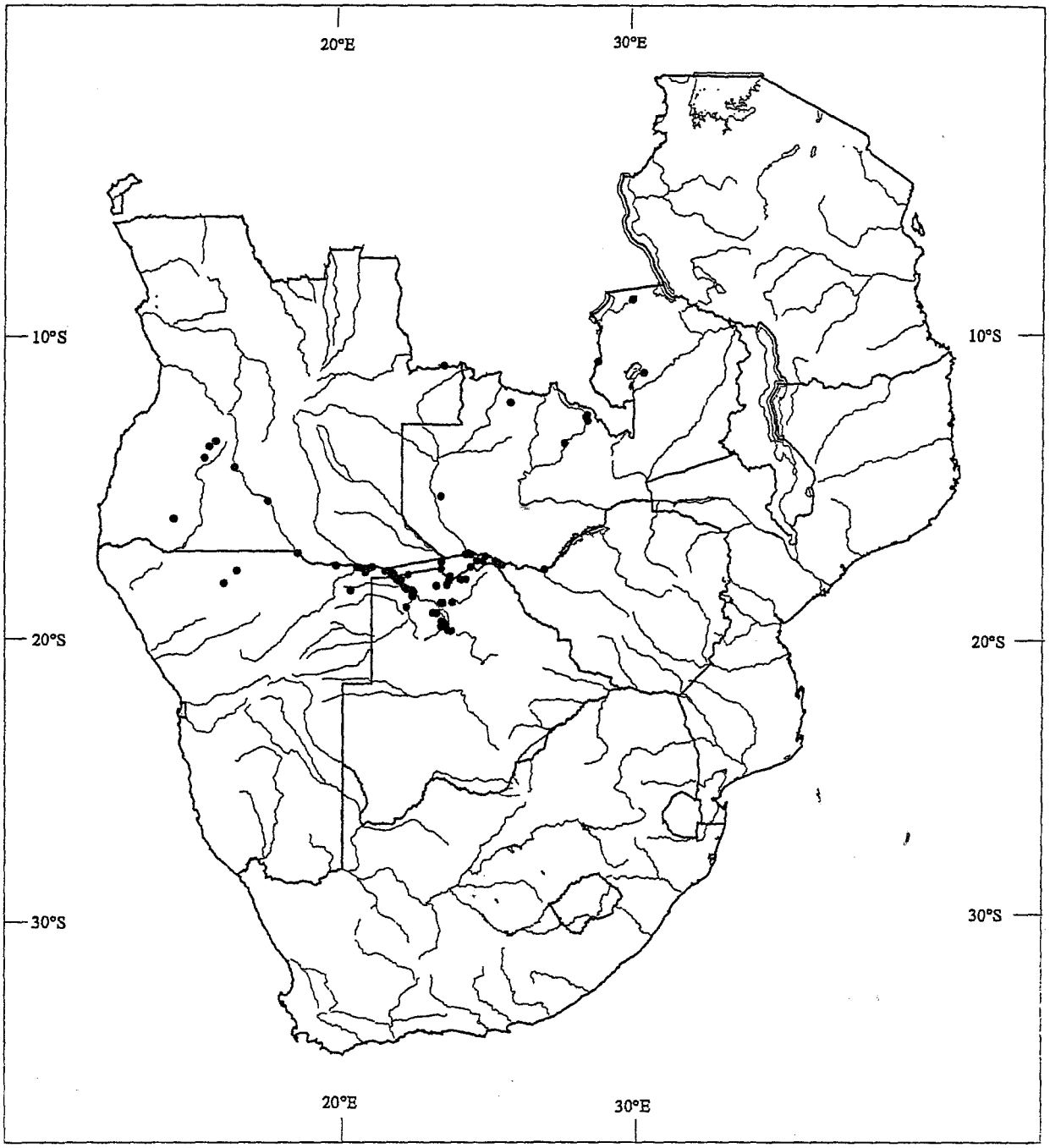


Figure F.109. Point distribution of *Barbus multilineatus*. Scale approximately 1:25 000 000

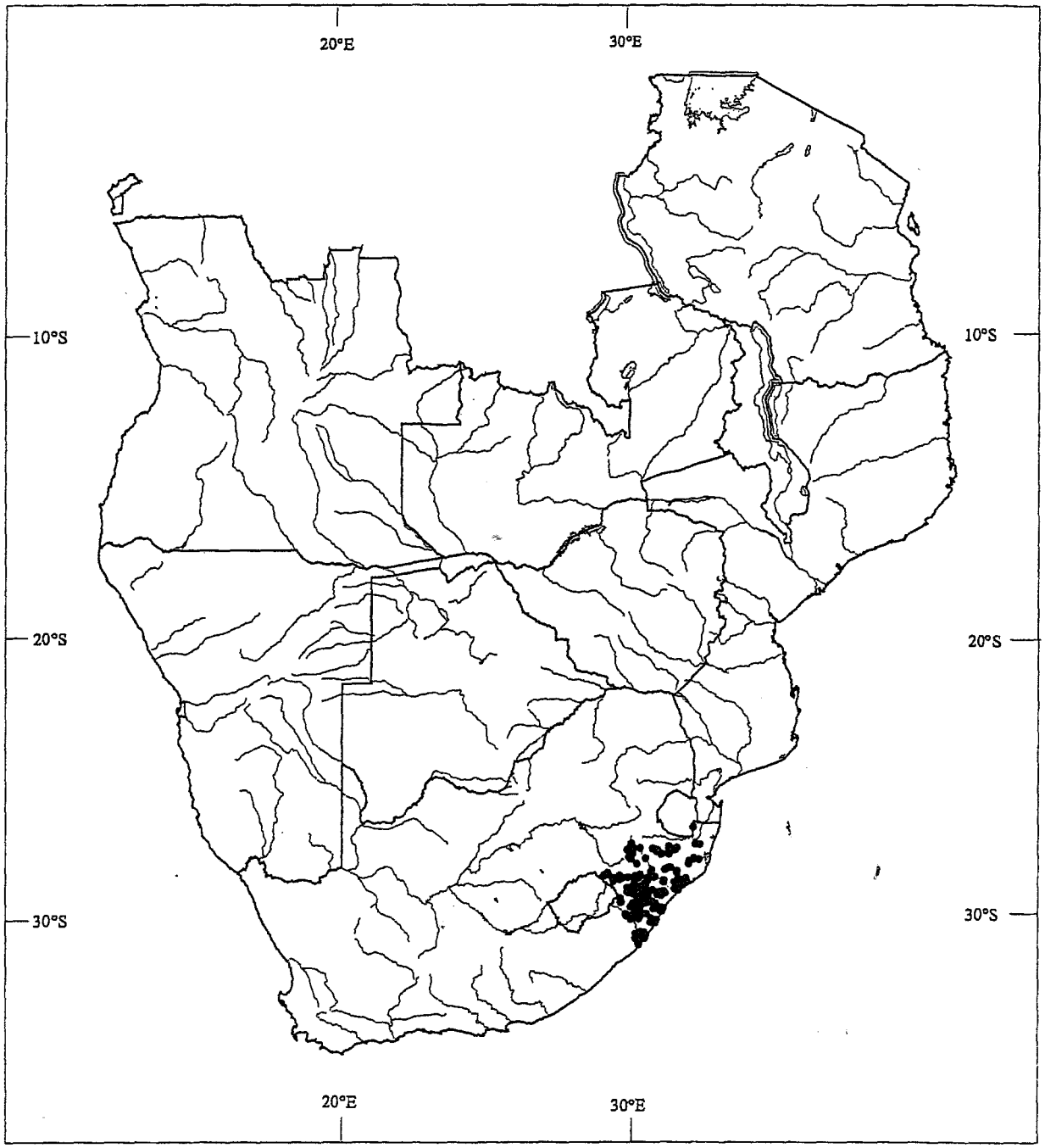


Figure F.110. Point distribution of *Barbus natalensis*. Scale approximately 1:25 000 000

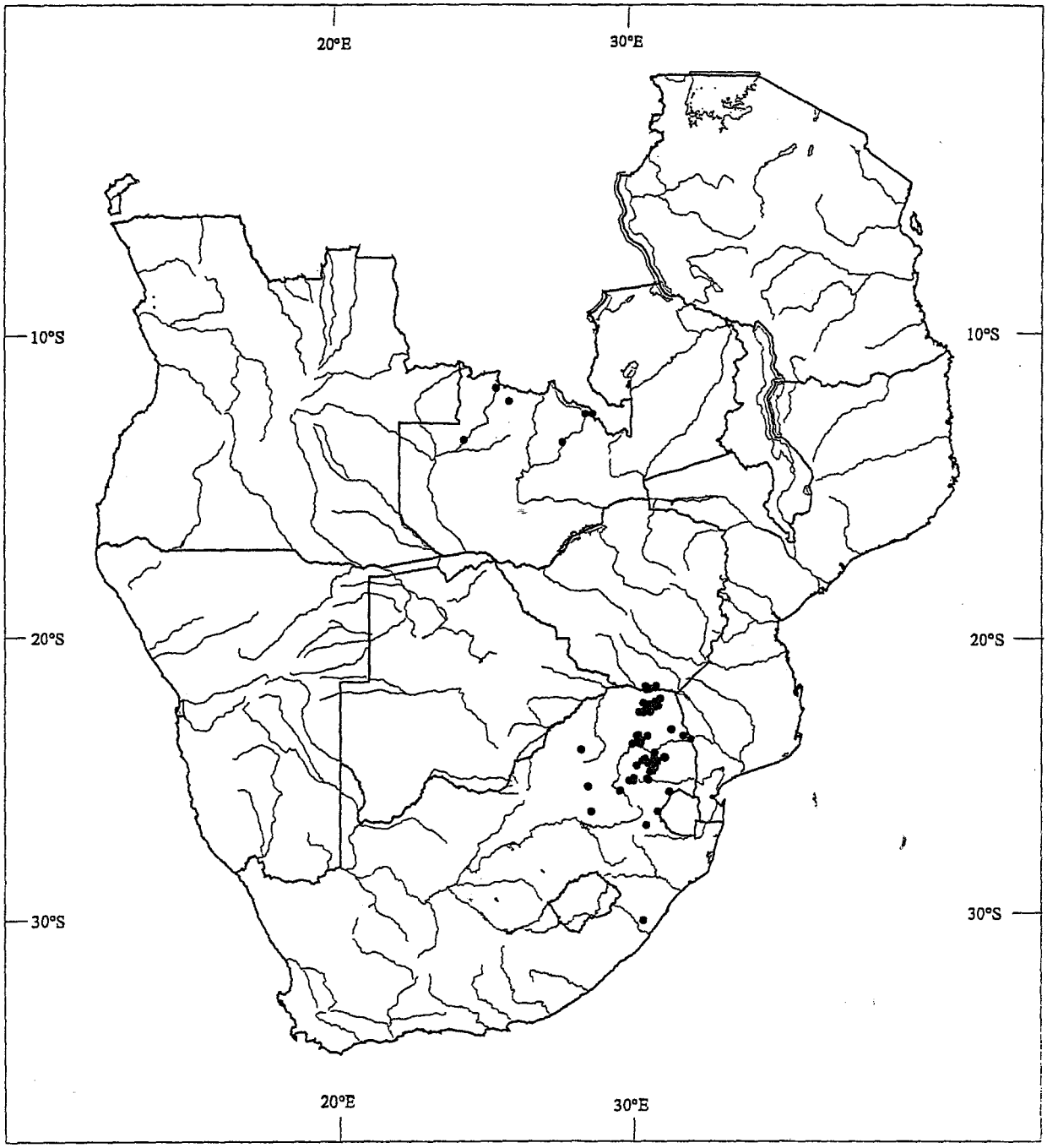


Figure F.111. Point distribution of *Barbus neefi*. Scale approximately 1:25 000 000

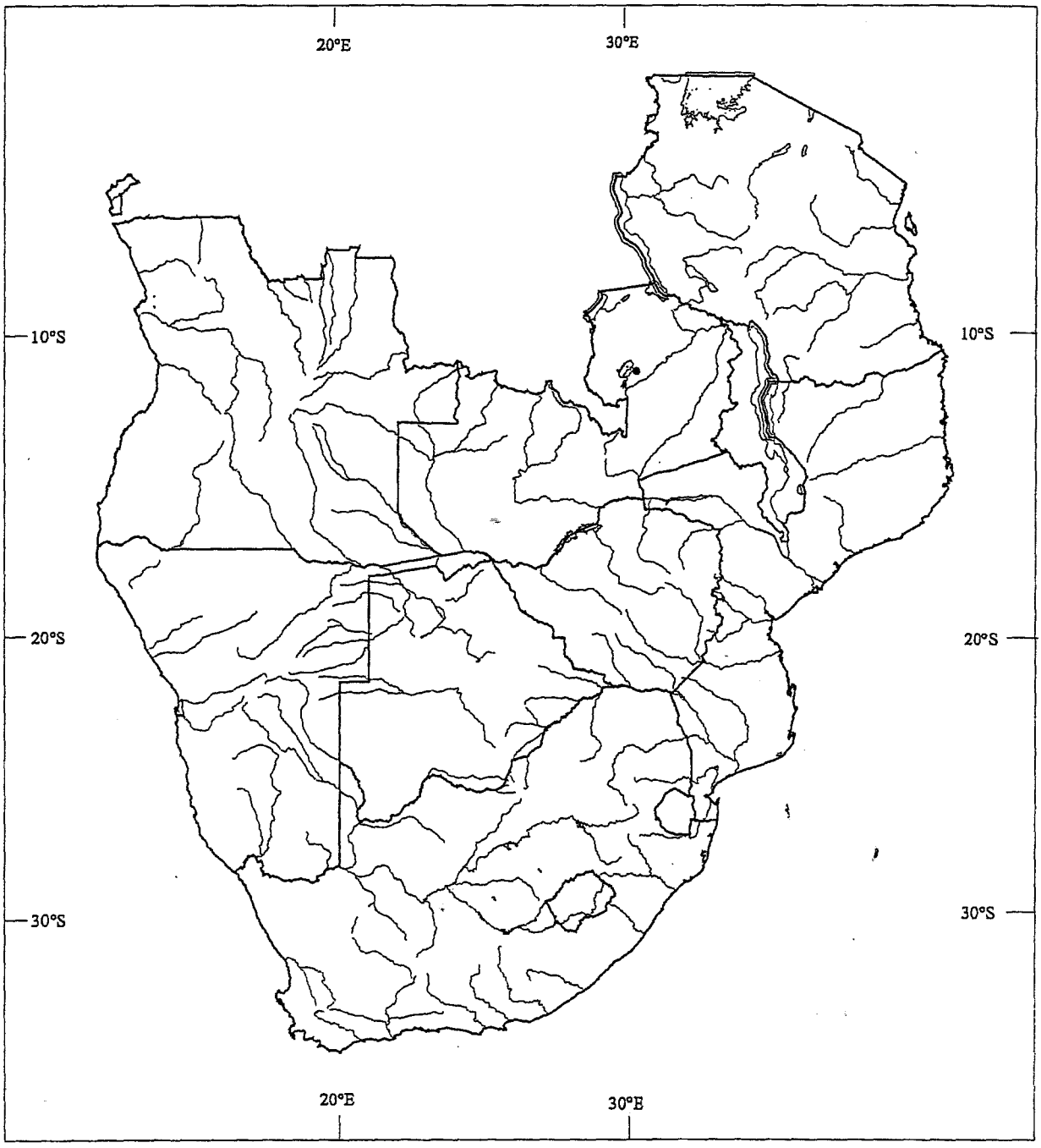


Figure F.112. Point distribution of *Barbus owenae*. Scale approximately 1:25 000 000

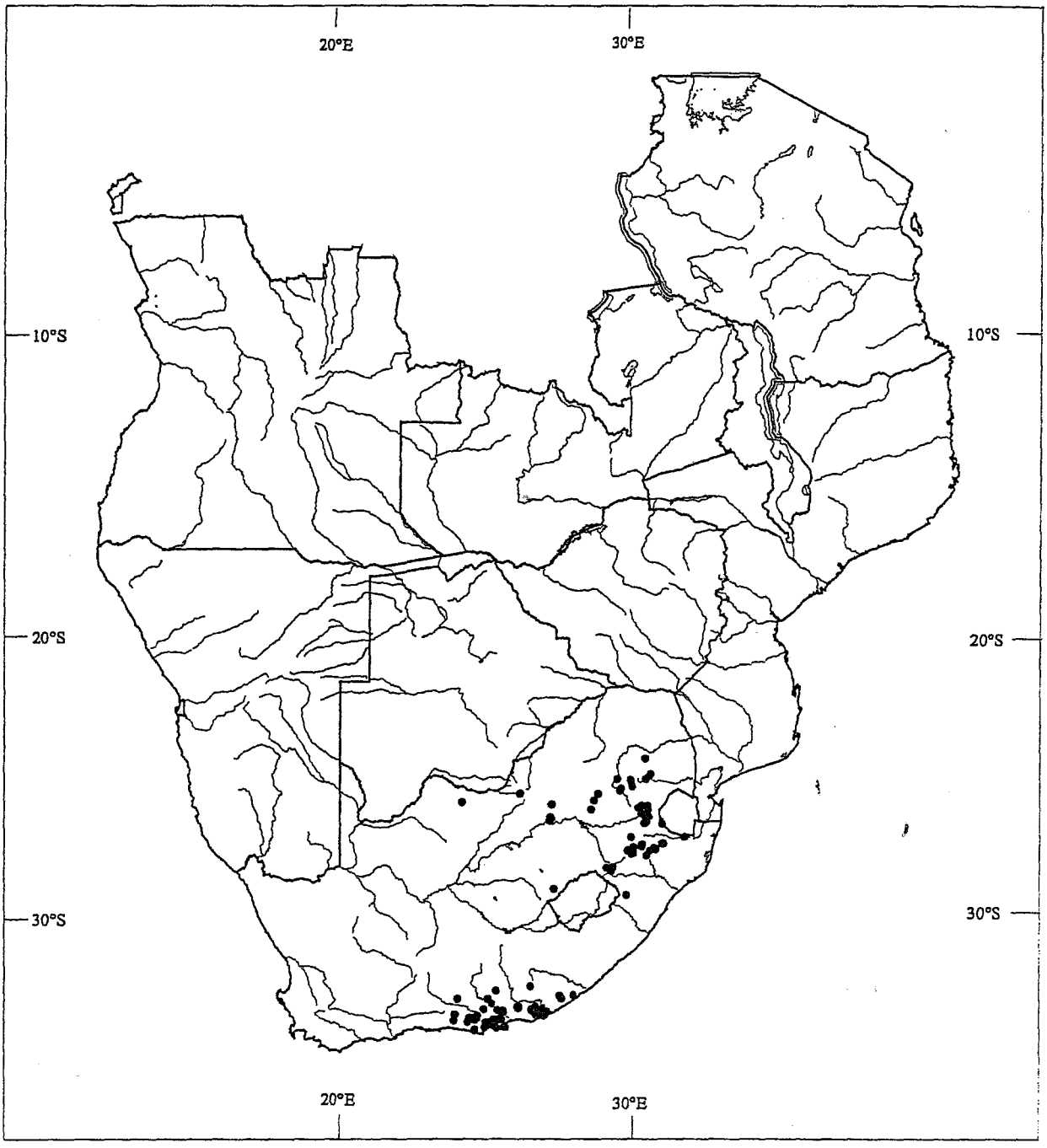


Figure F.113. Point distribution of *Barbus pallidus*. Scale approximately 1:25 000 000

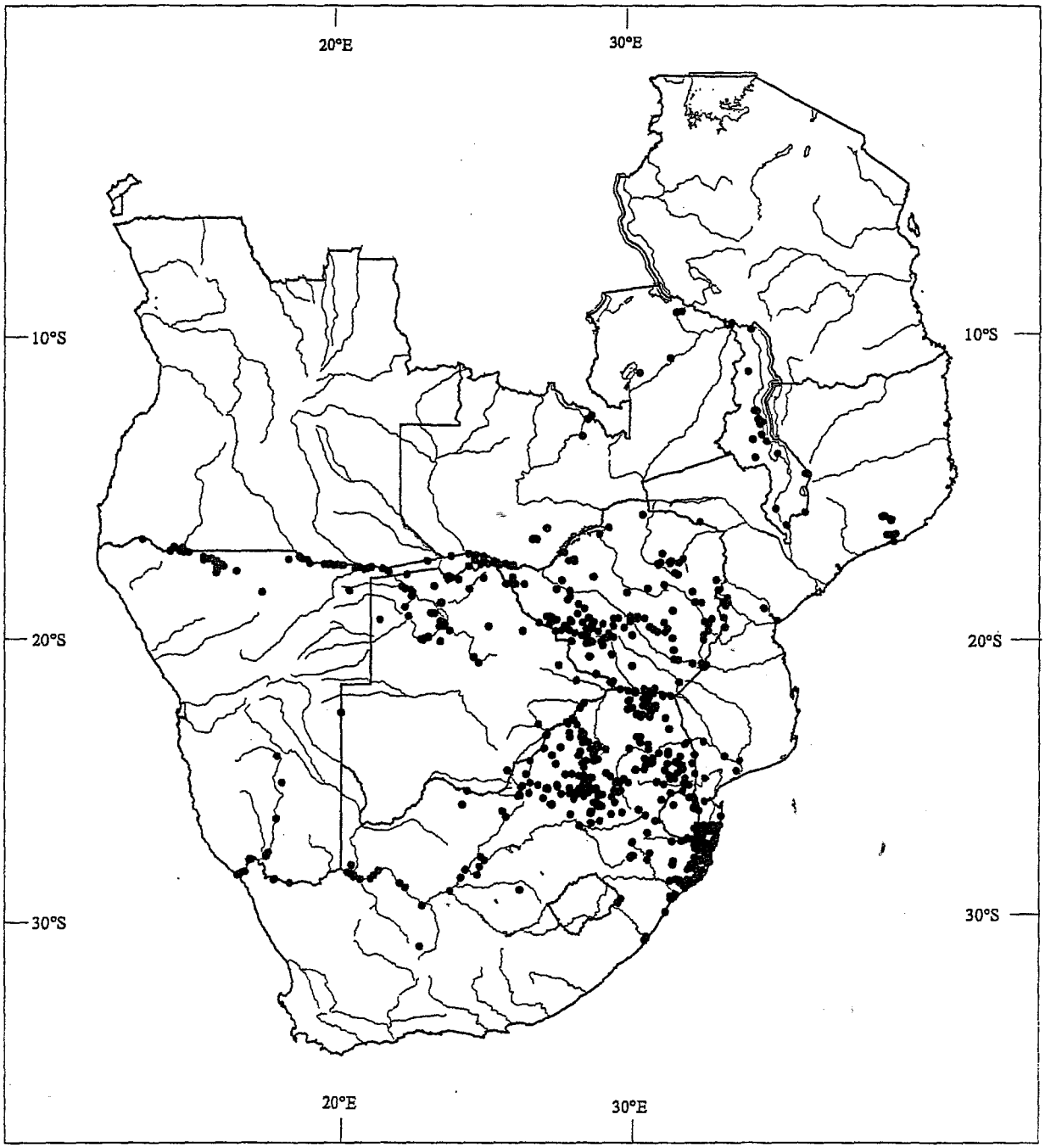


Figure F.114. Point distribution of *Barbus paludinosus*. Scale approximately 1:25 000 000

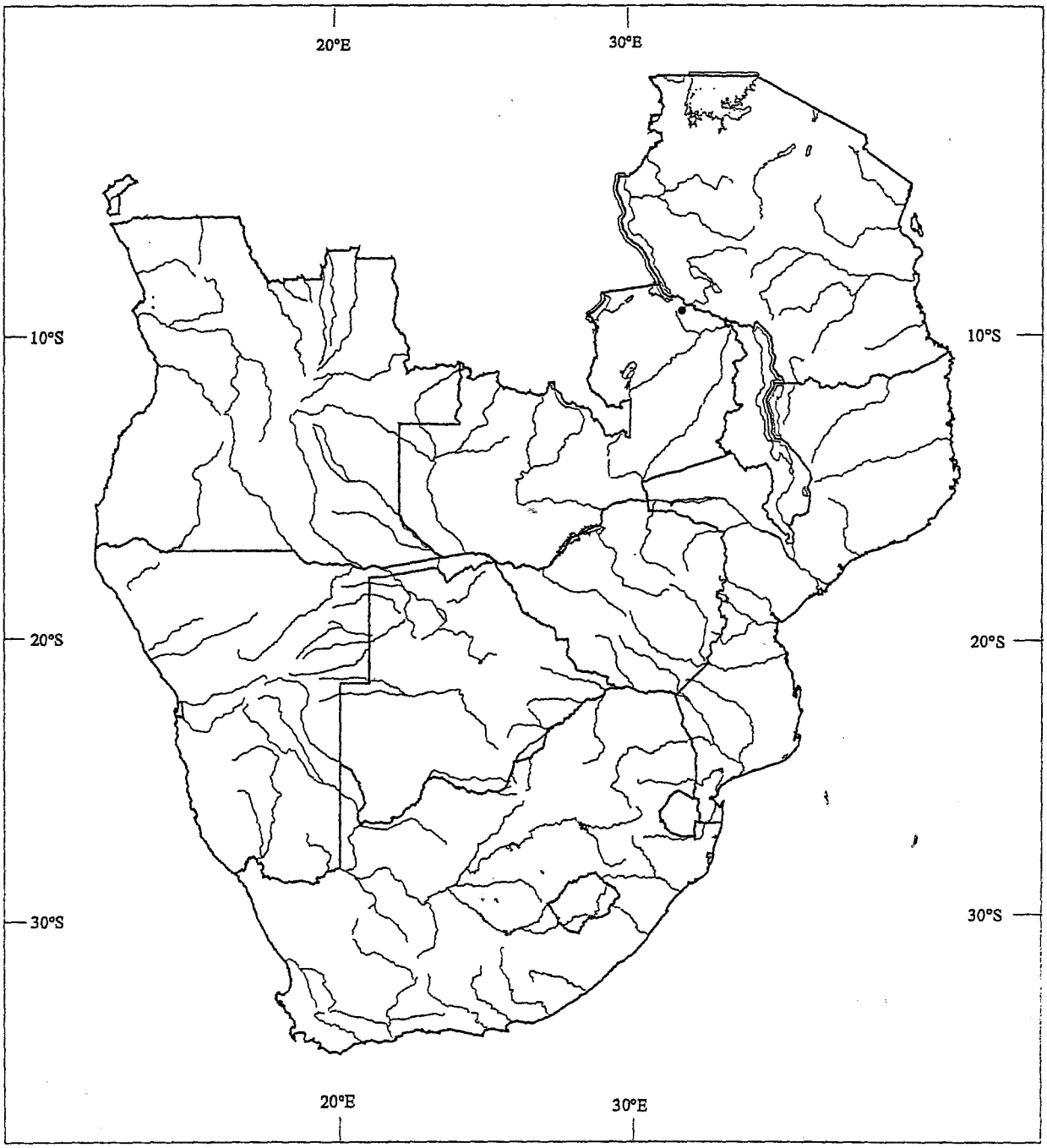


Figure F.115. Point distribution of *Barbus pellegrini*. Scale approximately 1:25 000 000

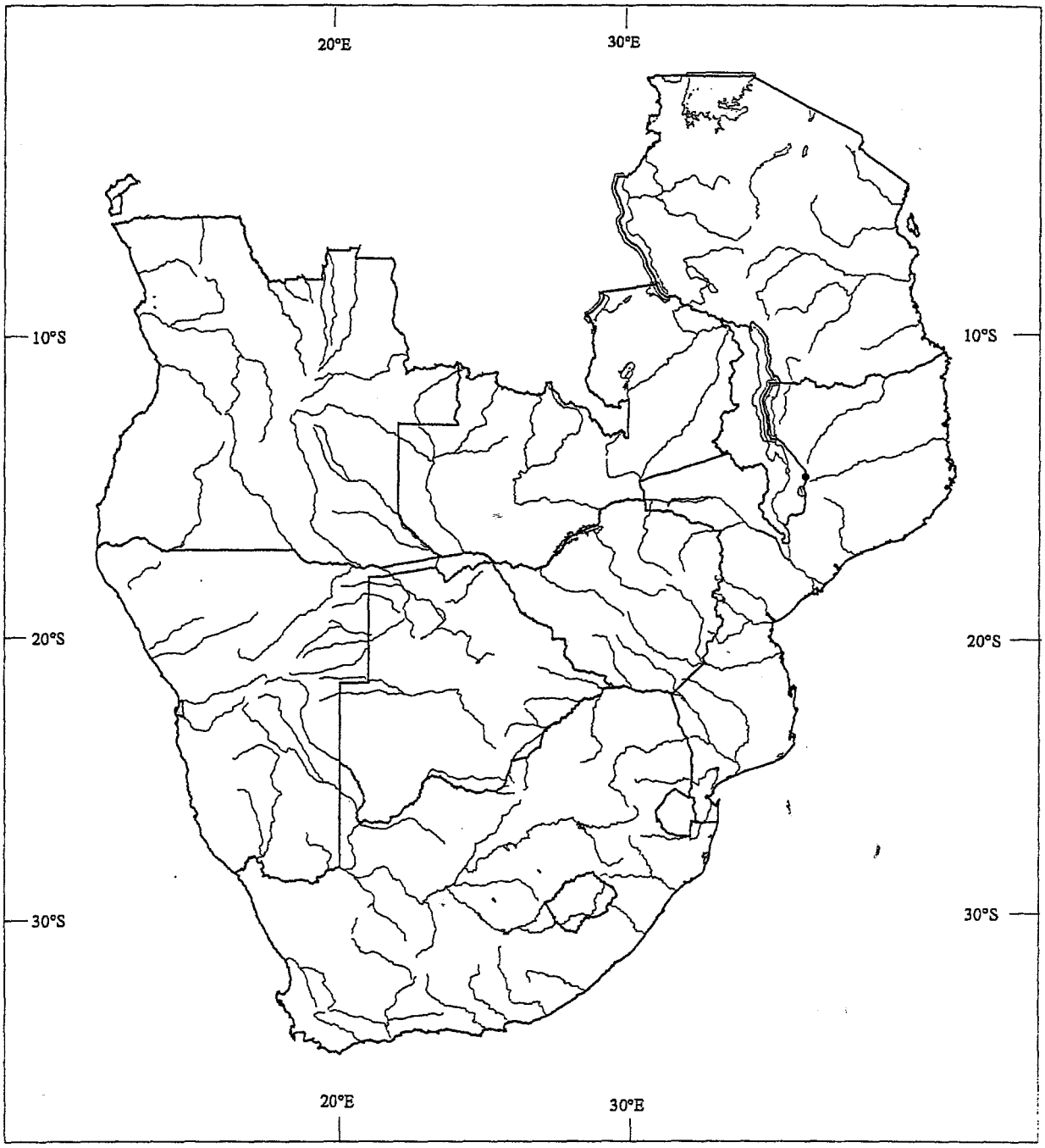


Figure F.116. Point distribution of *Barbus permistus*. Scale approximately 1:25 000 000

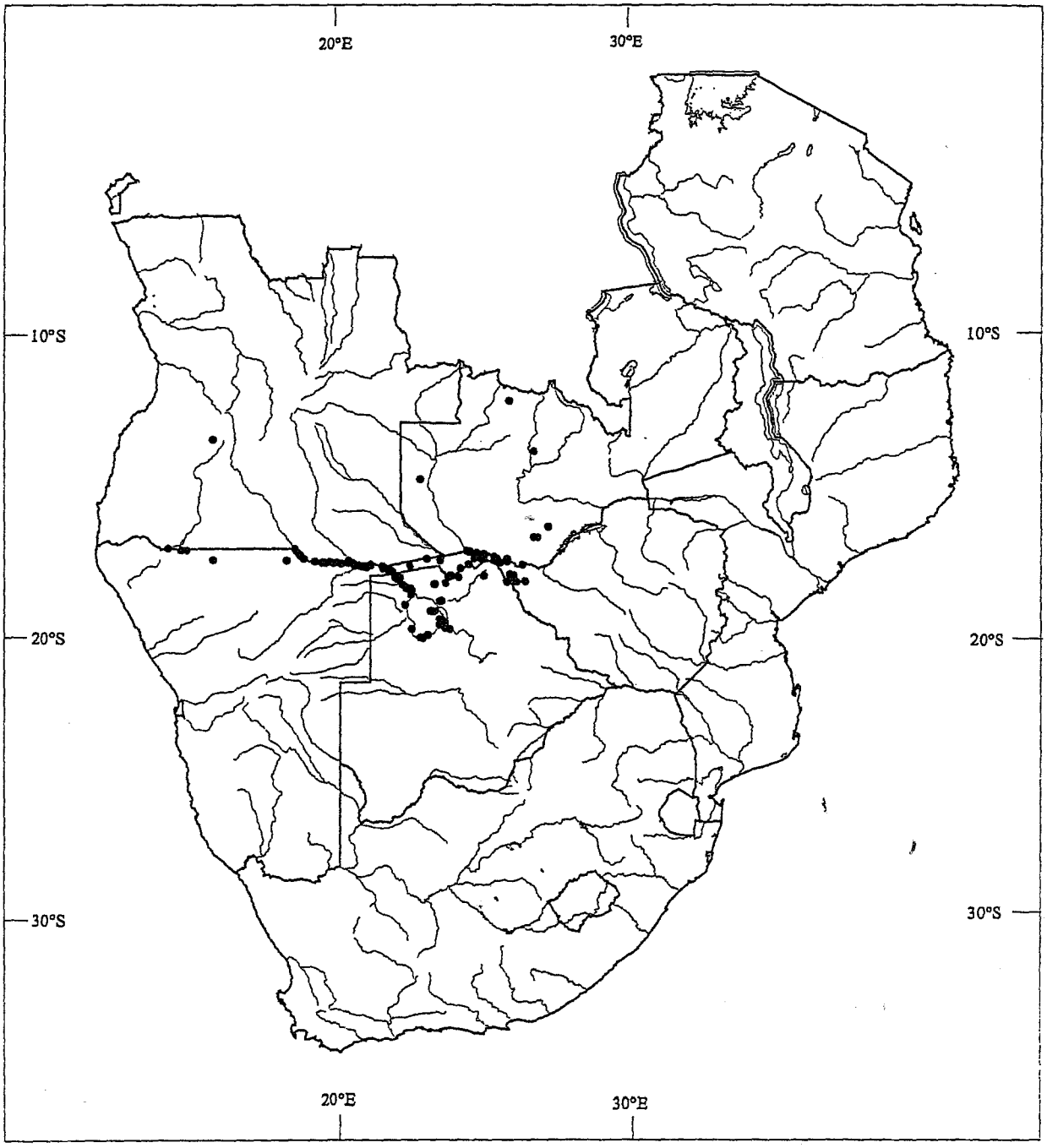


Figure F.117. Point distribution of *Barbus poechii*. Scale approximately 1:25 000 000

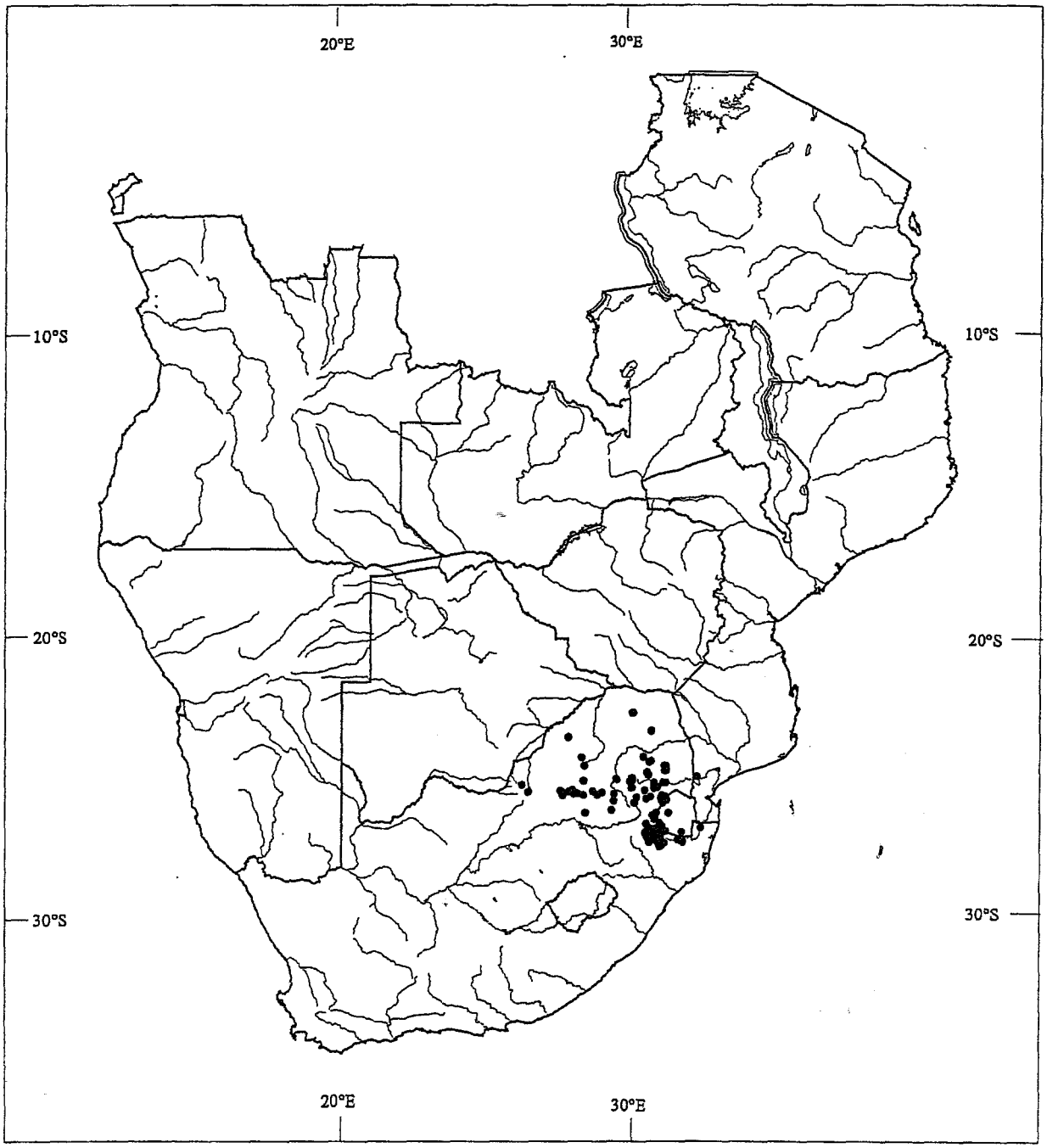


Figure F.118. Point distribution of *Barbus polylepis*. Scale approximately 1:25 000 000

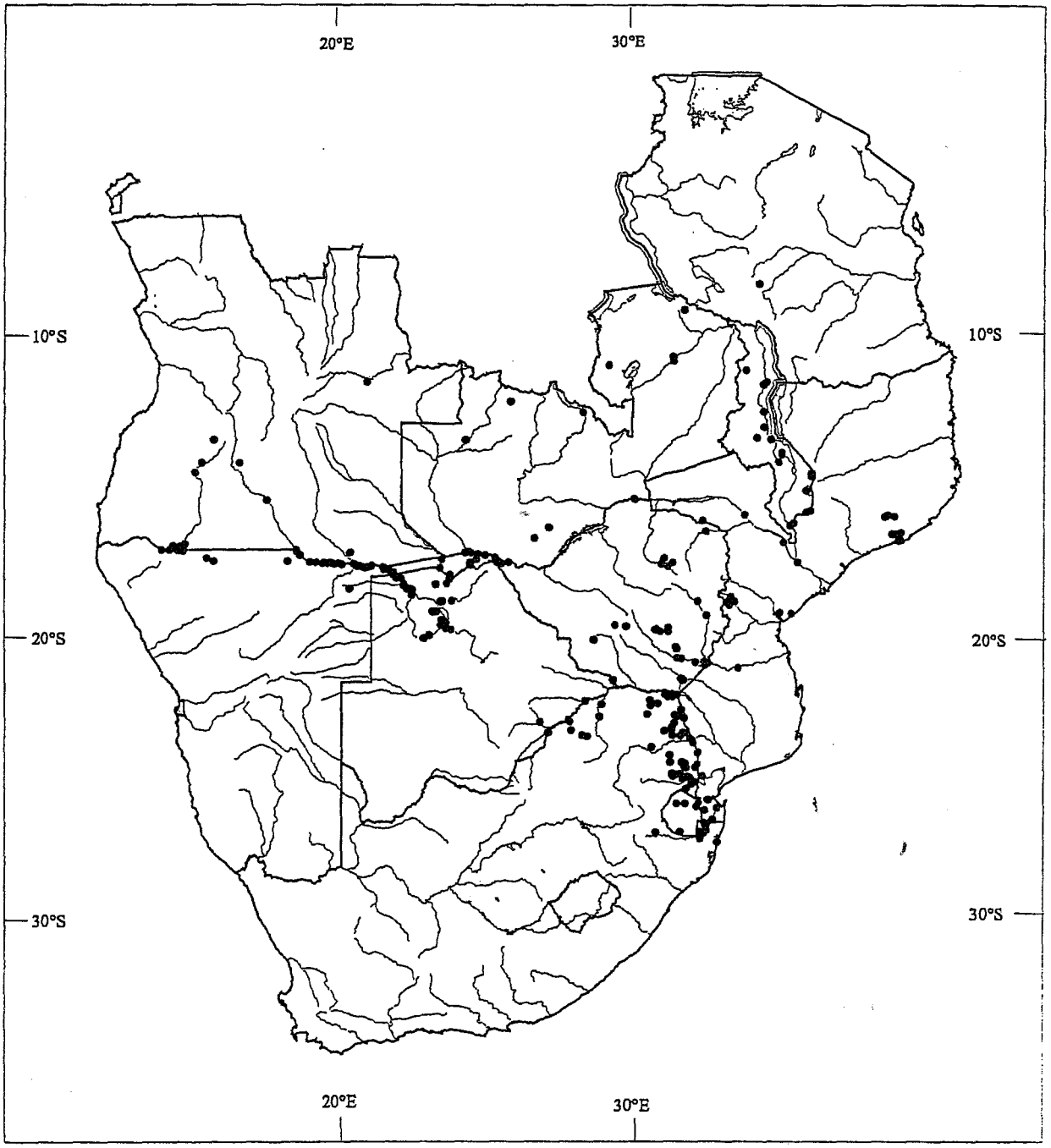


Figure F.119. Point distribution of *Barbus radiatus*. Scale approximately 1:25 000 000

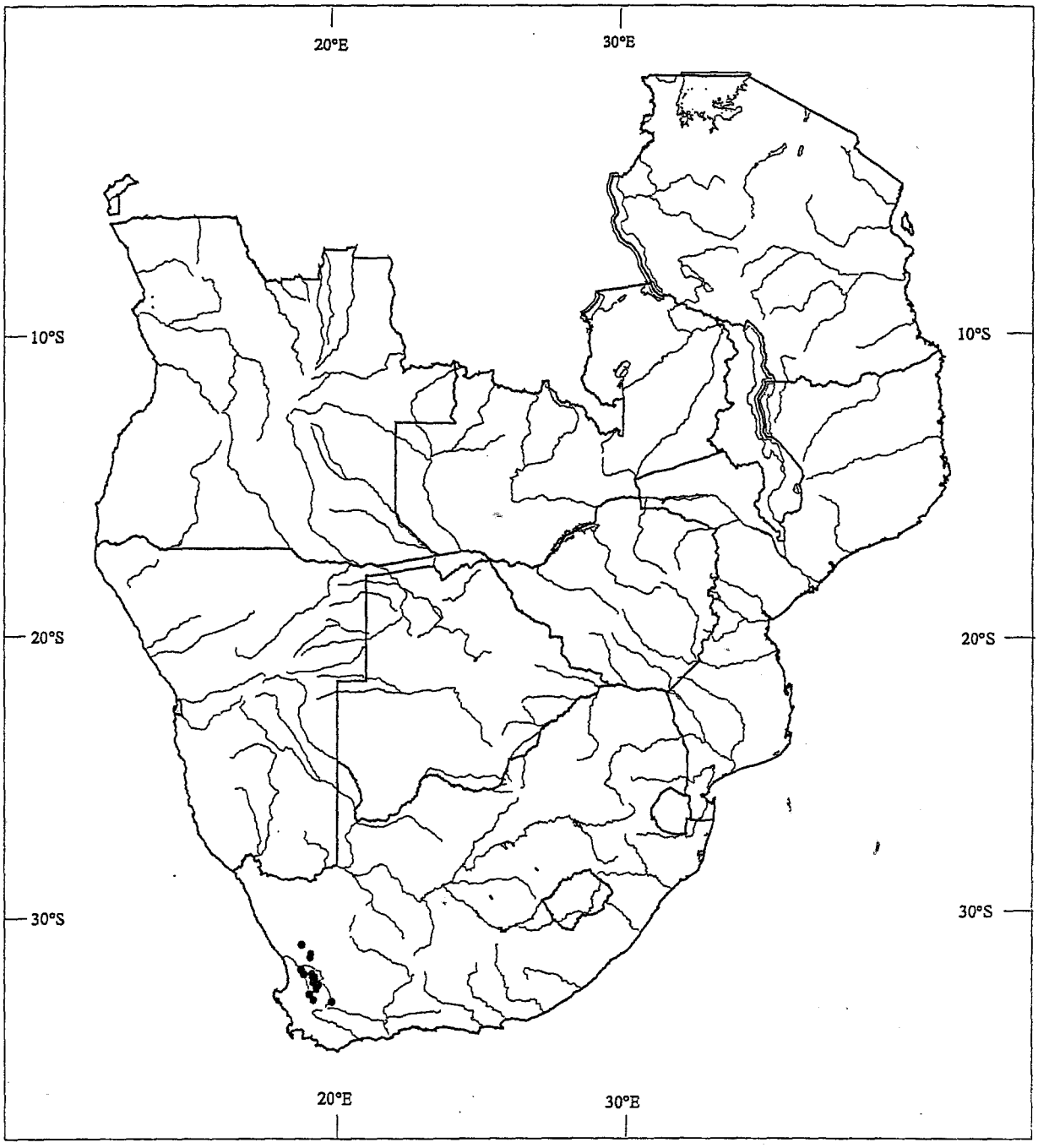


Figure F.120. Point distribution of *Barbus serra*. Scale approximately 1:25 000 000

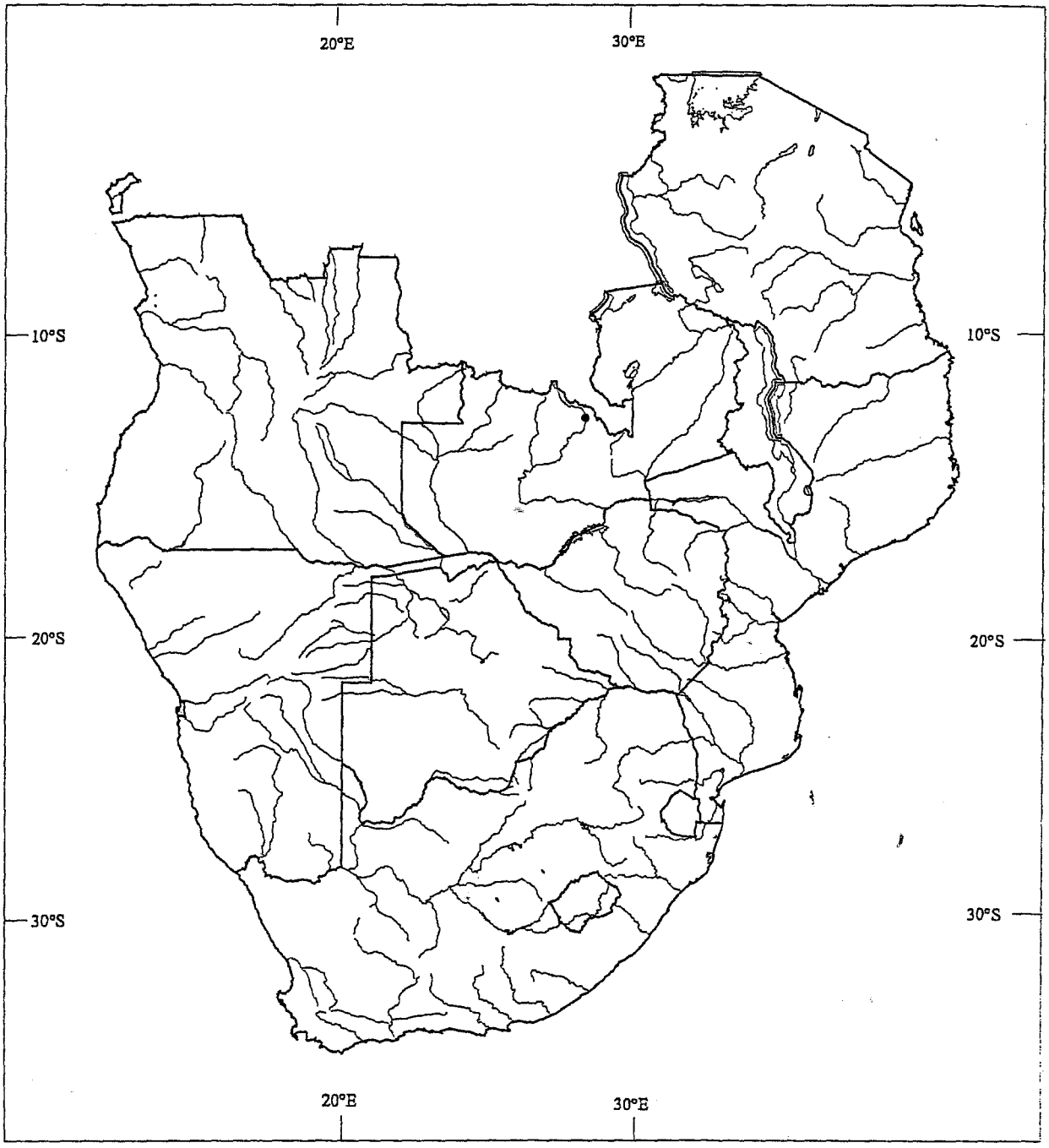


Figure F.121. Point distribution of *Barbus tetrastigma*. Scale approximately 1:25 000 000

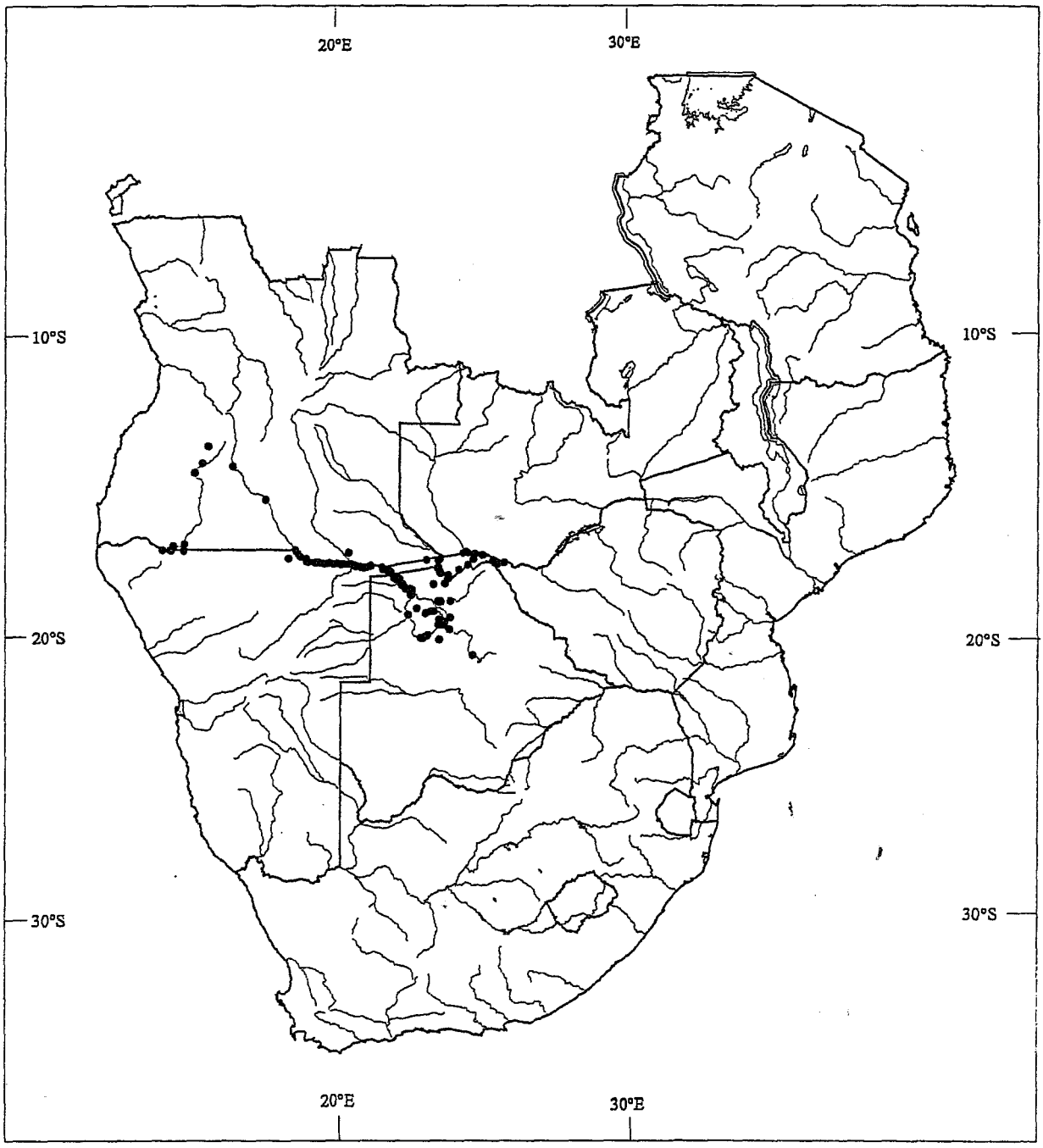


Figure F.122. Point distribution of *Barbus thamalakanensis*. Scale approximately 1:25 000 000

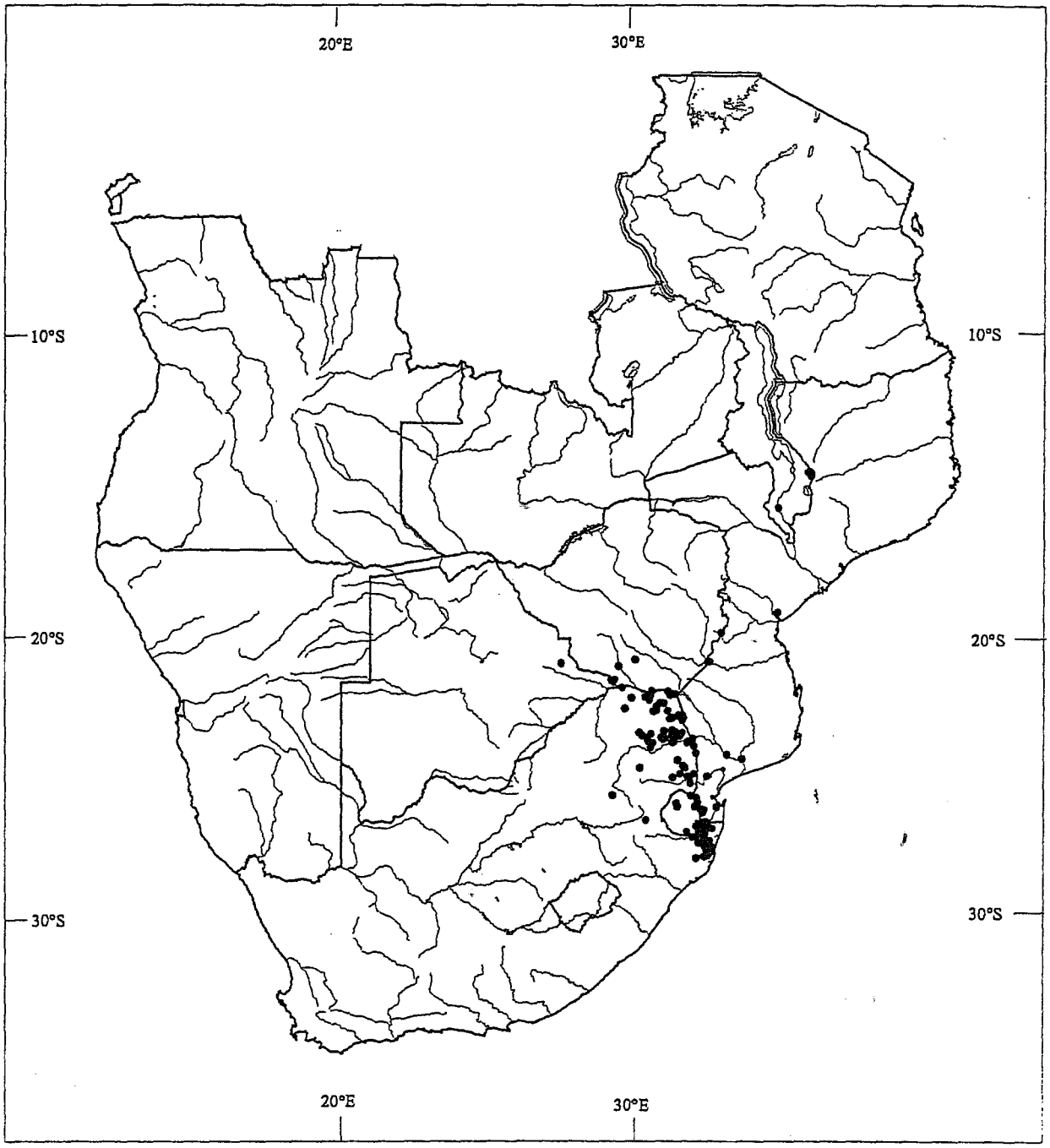


Figure F.123. Point distribution of *Barbus toppini*. Scale approximately 1:25 000 000

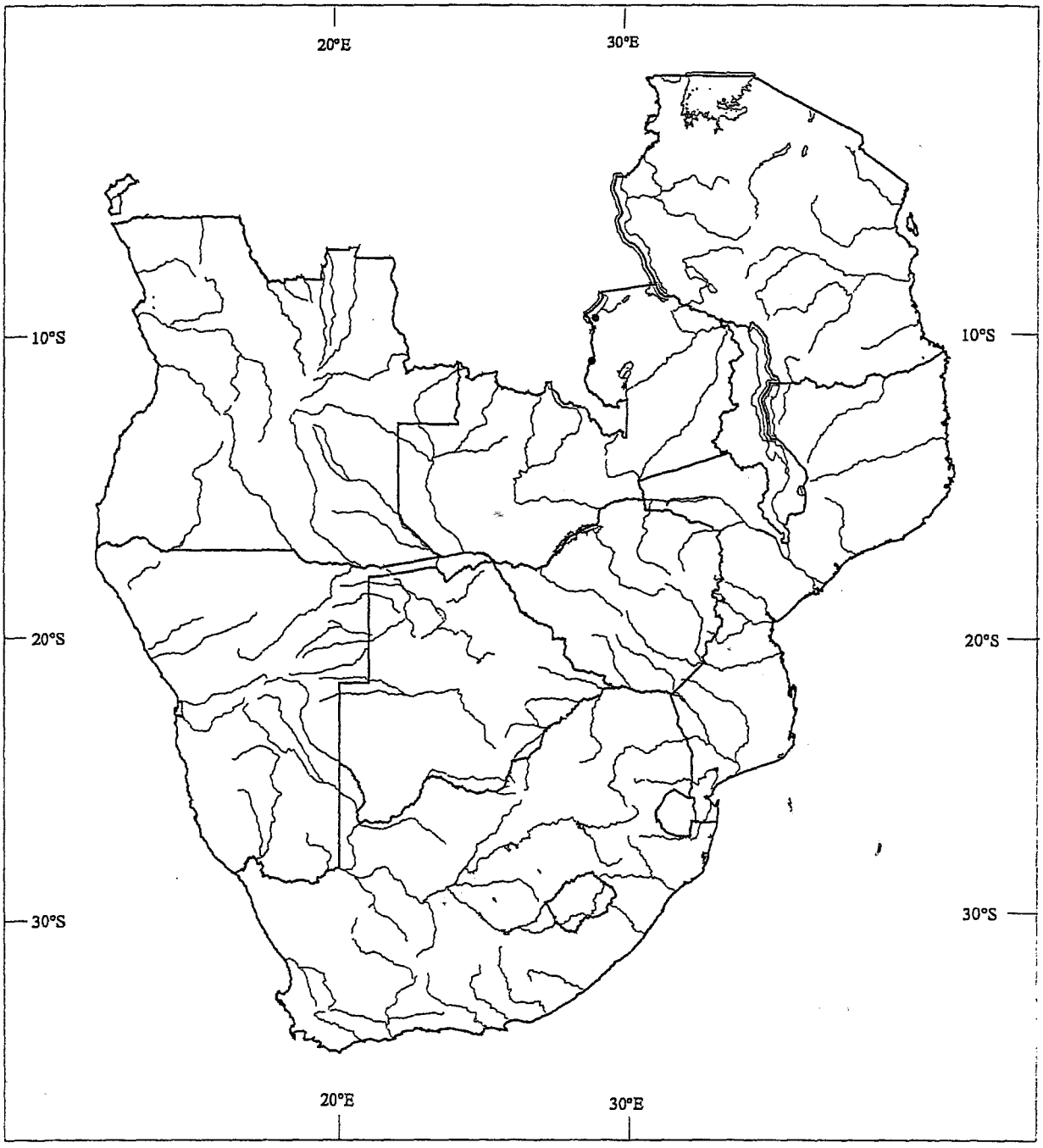


Figure F.124. Point distribution of *Barbus trachypterus*. Scale approximately 1:25 000 000

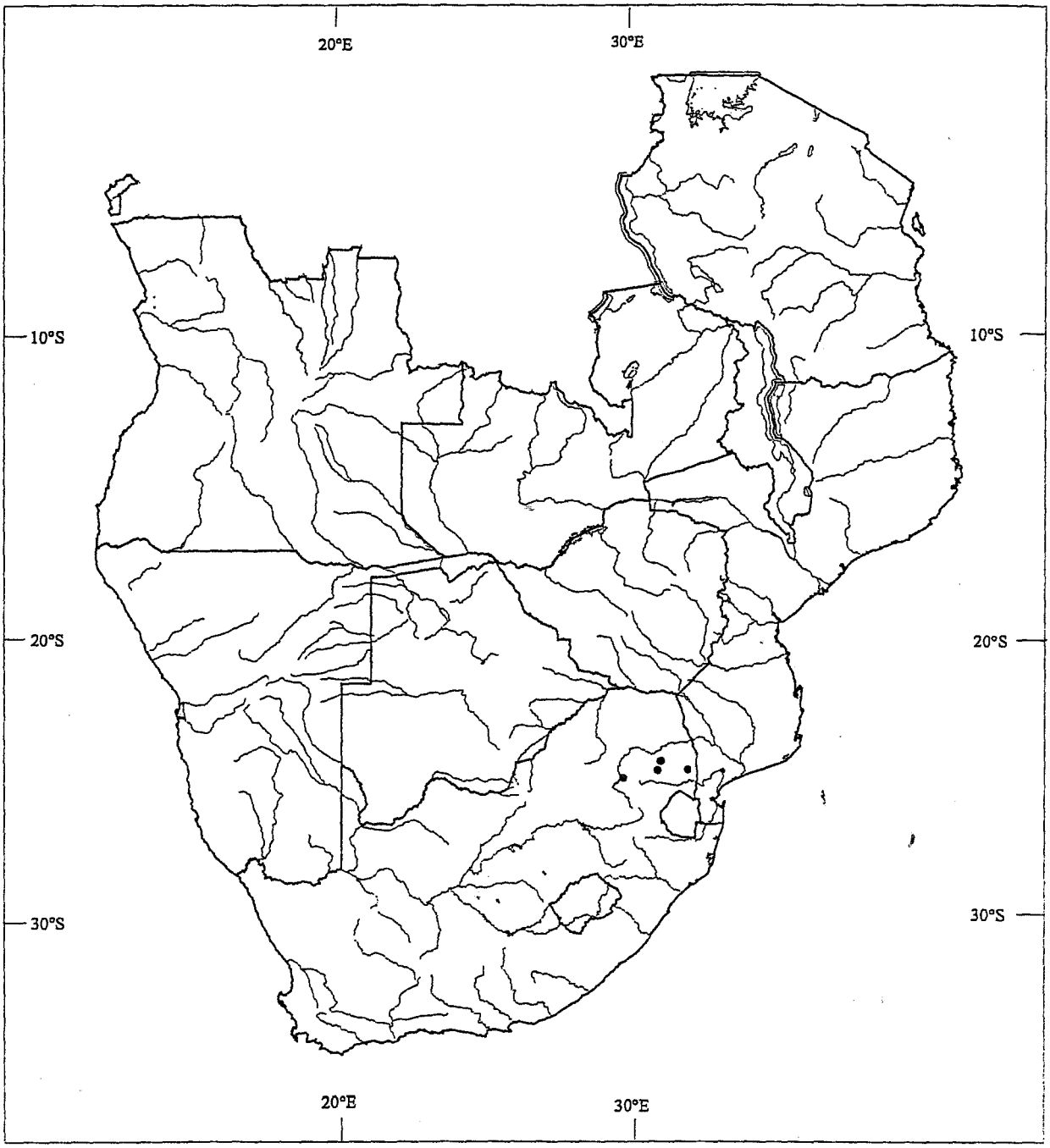


Figure F.125. Point distribution of *Barbus treurensis*. Scale approximately 1:25 000 000

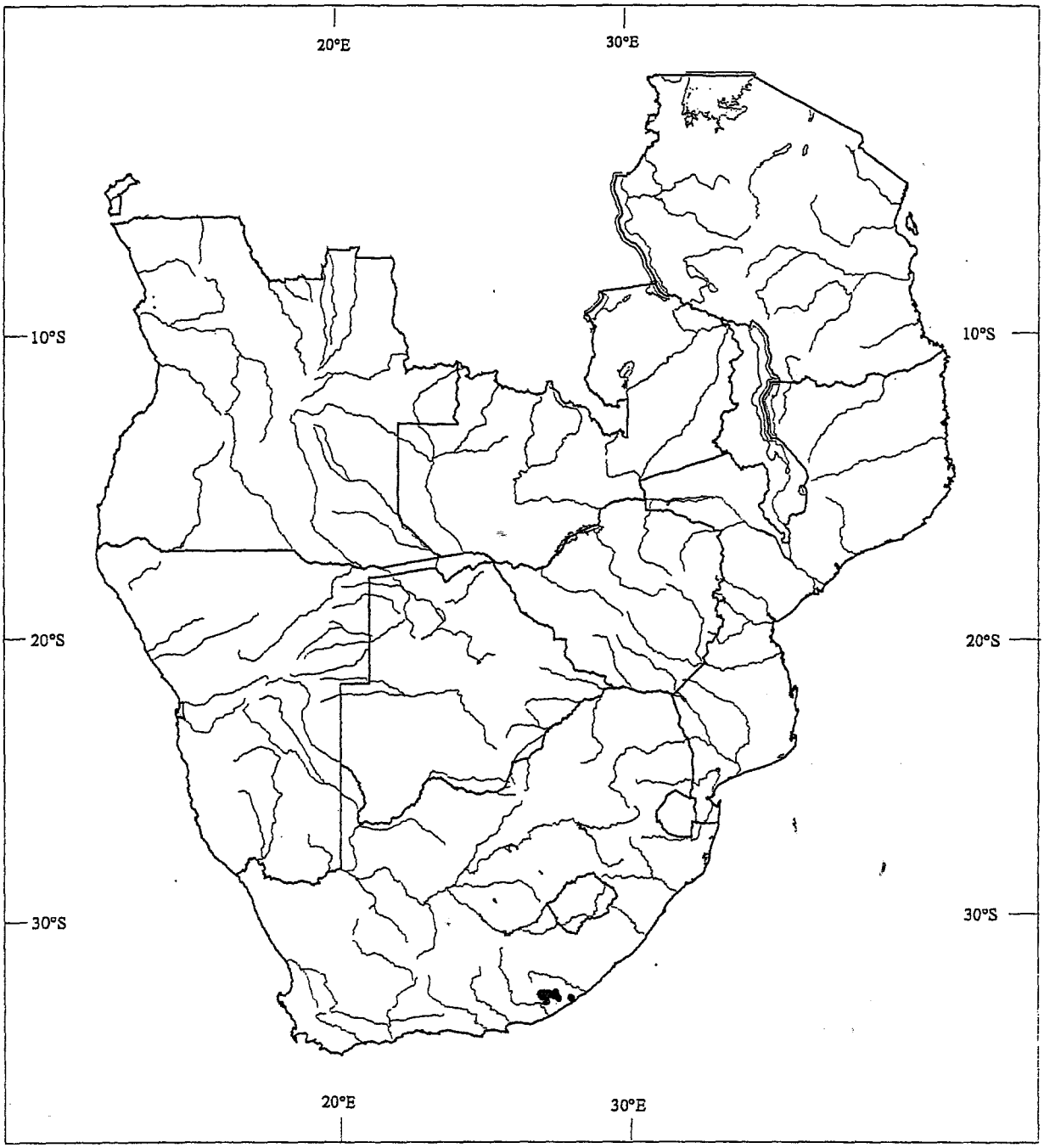


Figure F.126. Point distribution of *Barbus trevelyani*. Scale approximately 1:25 000 000

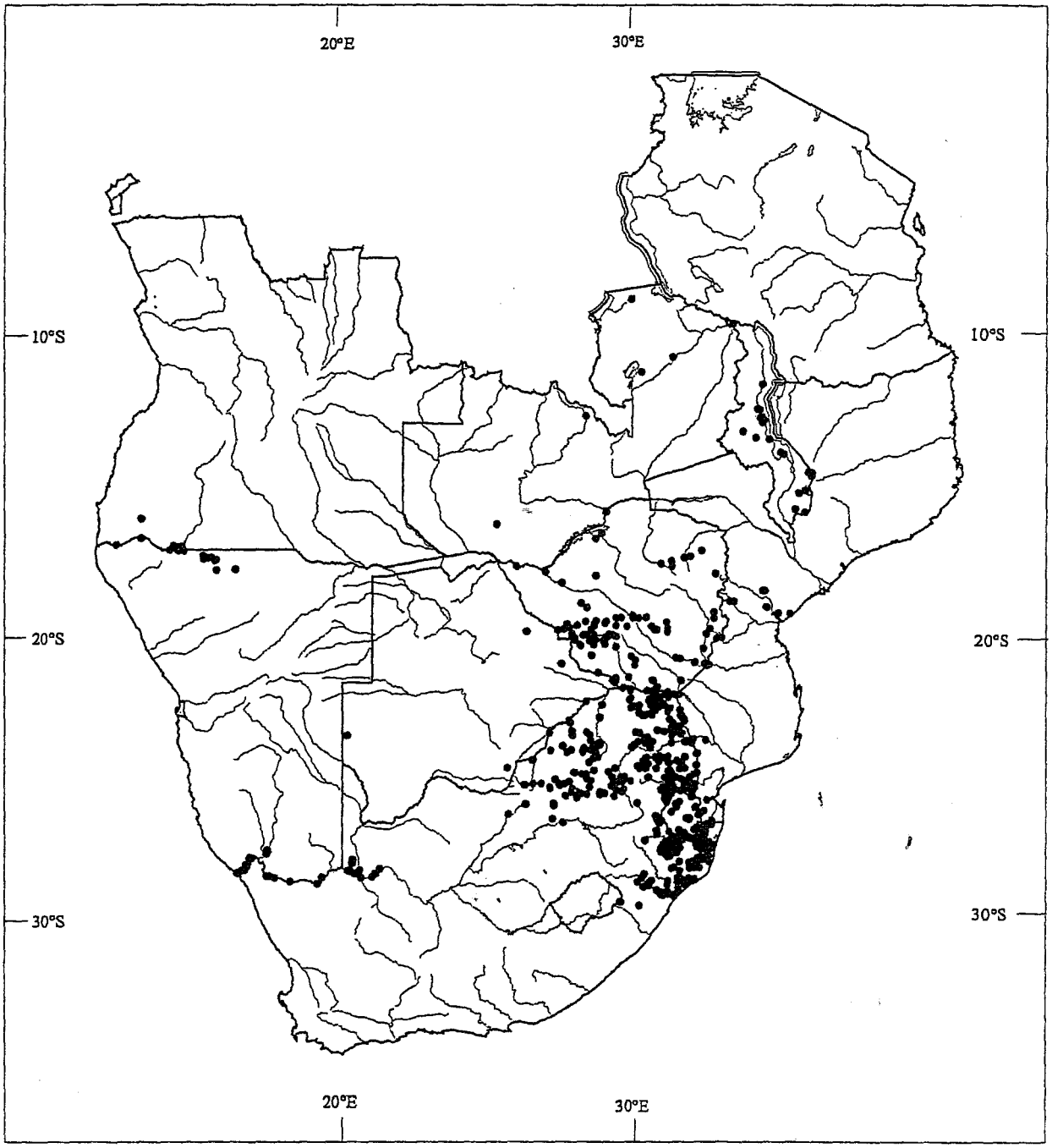


Figure F.127. Point distribution of *Barbus trimaculatus*. Scale approximately 1:25 000 000

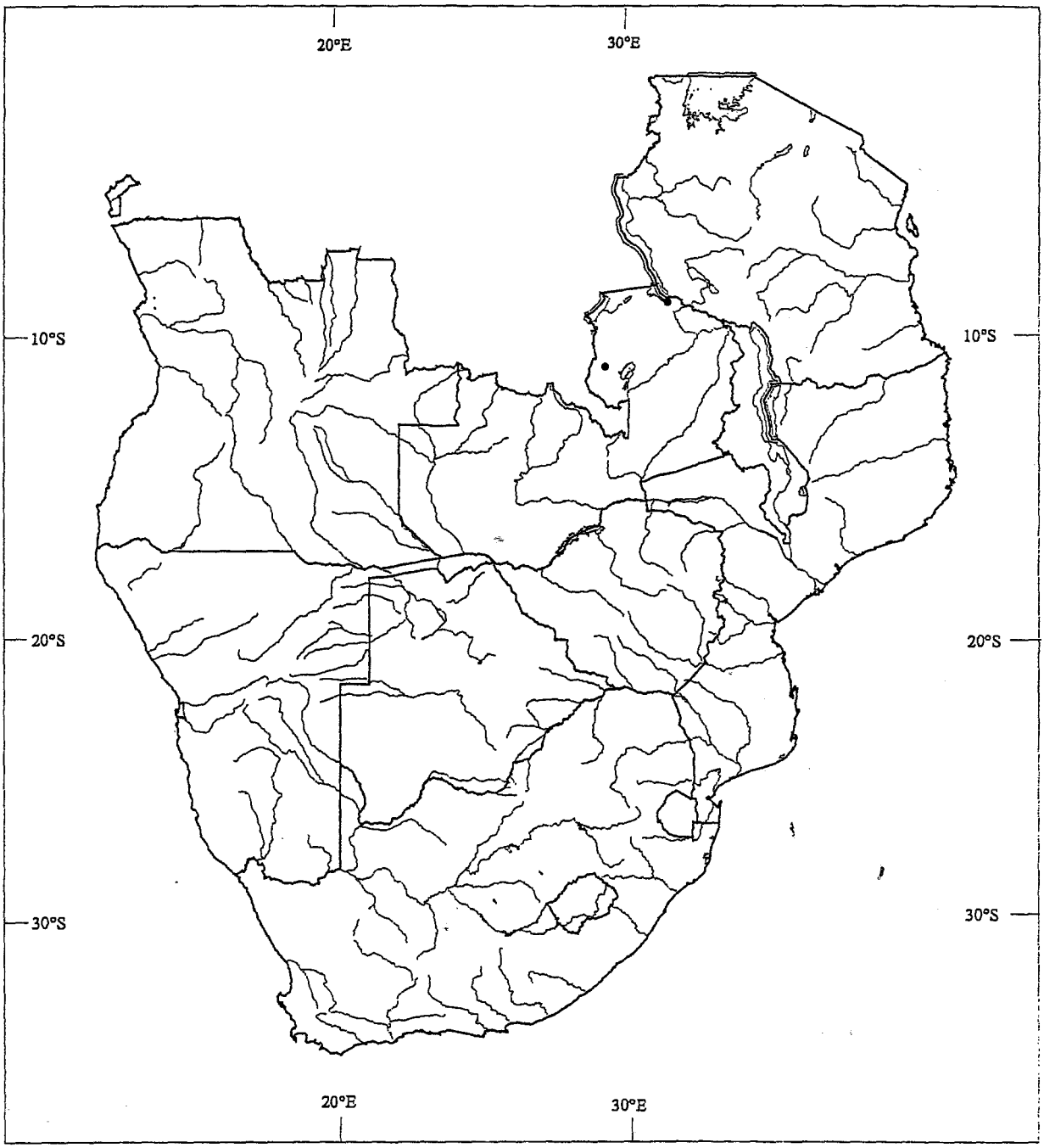


Figure F.128. Point distribution of *Barbus tropidolepis*. Scale approximately 1:25 000 000

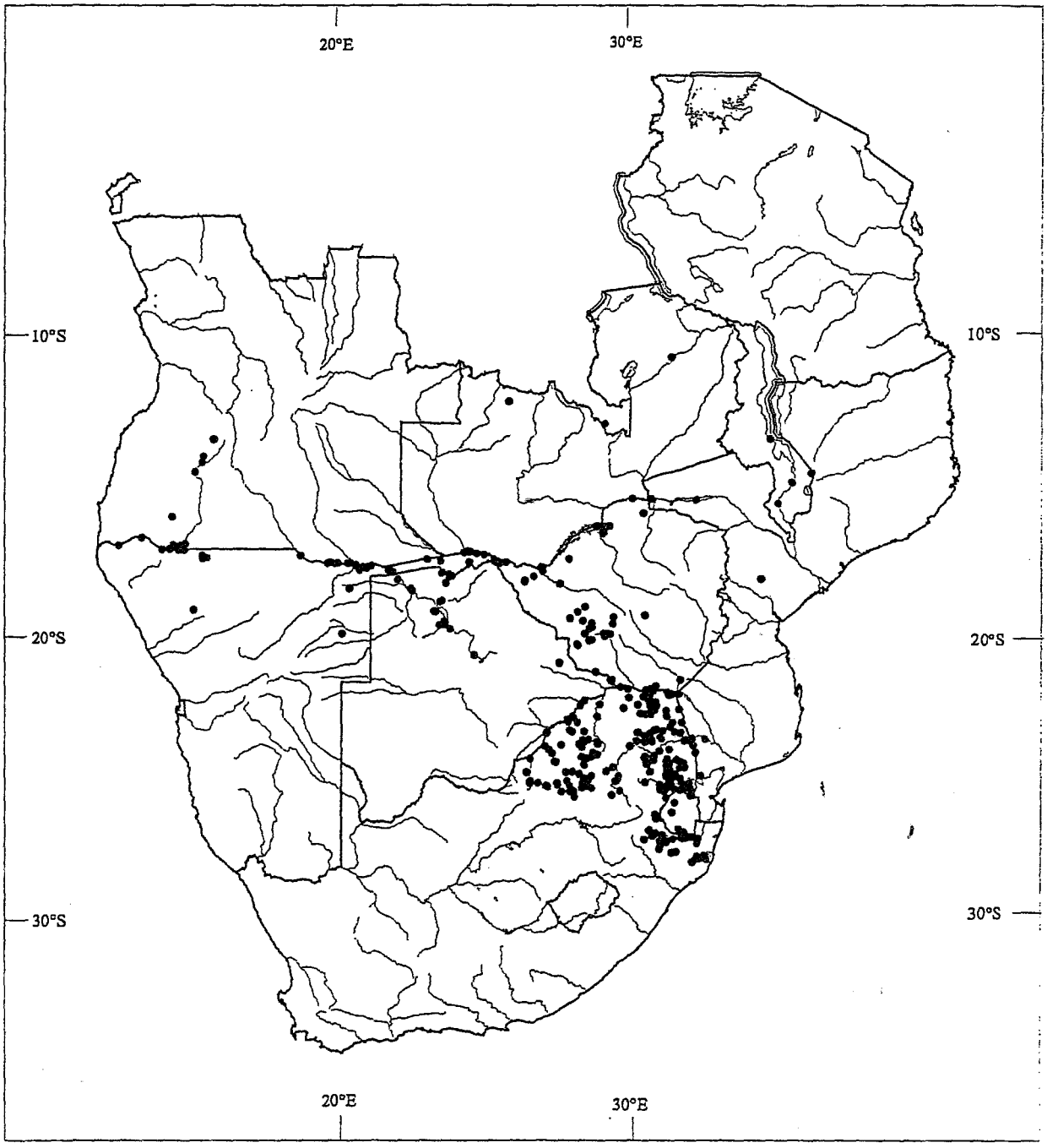


Figure F.129. Point distribution of *Barbus unitaeniatus*. Scale approximately 1:25 000 000

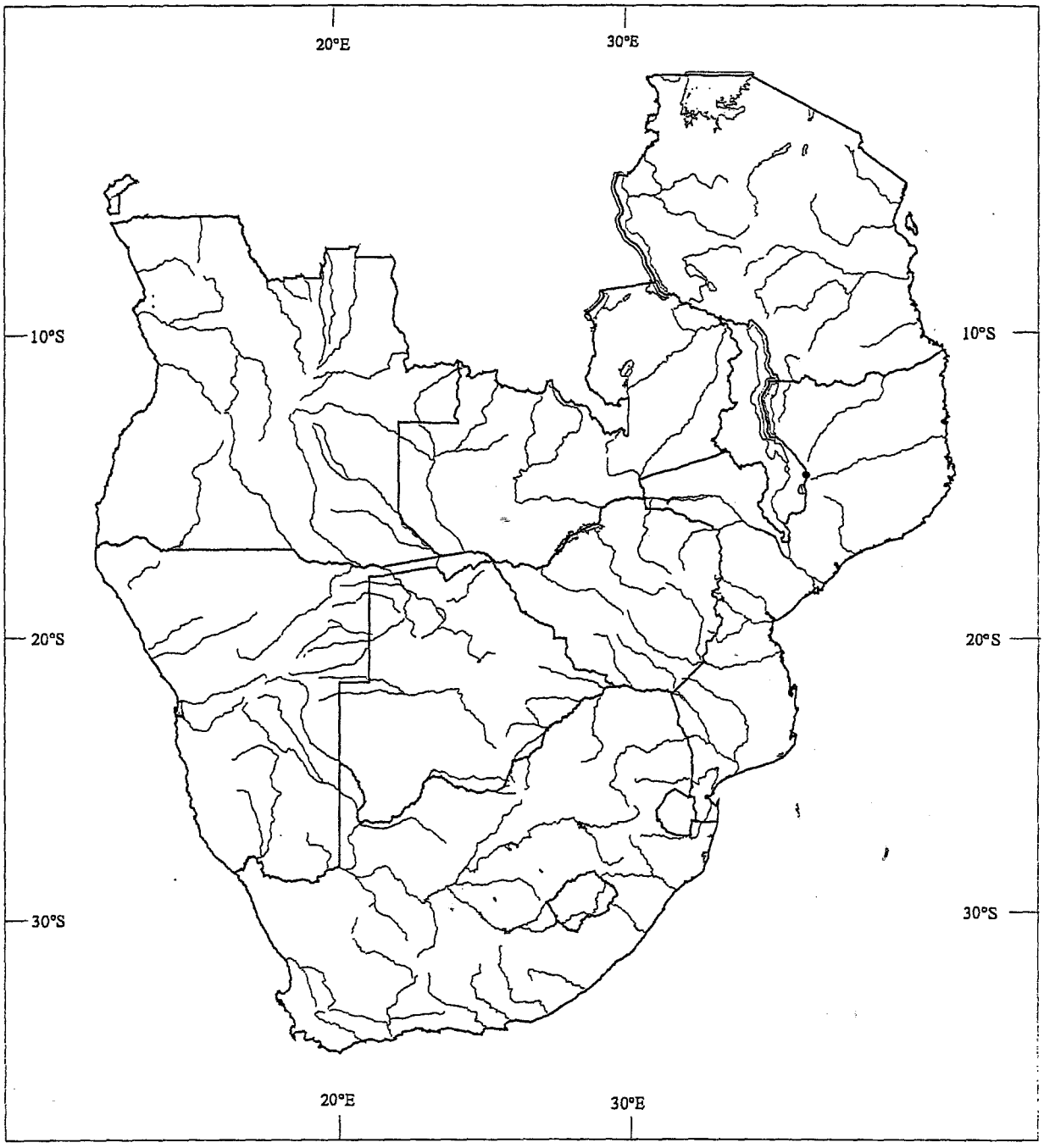


Figure F.130. Point distribution of *Barbus variabilis*. Scale approximately 1:25 000 000

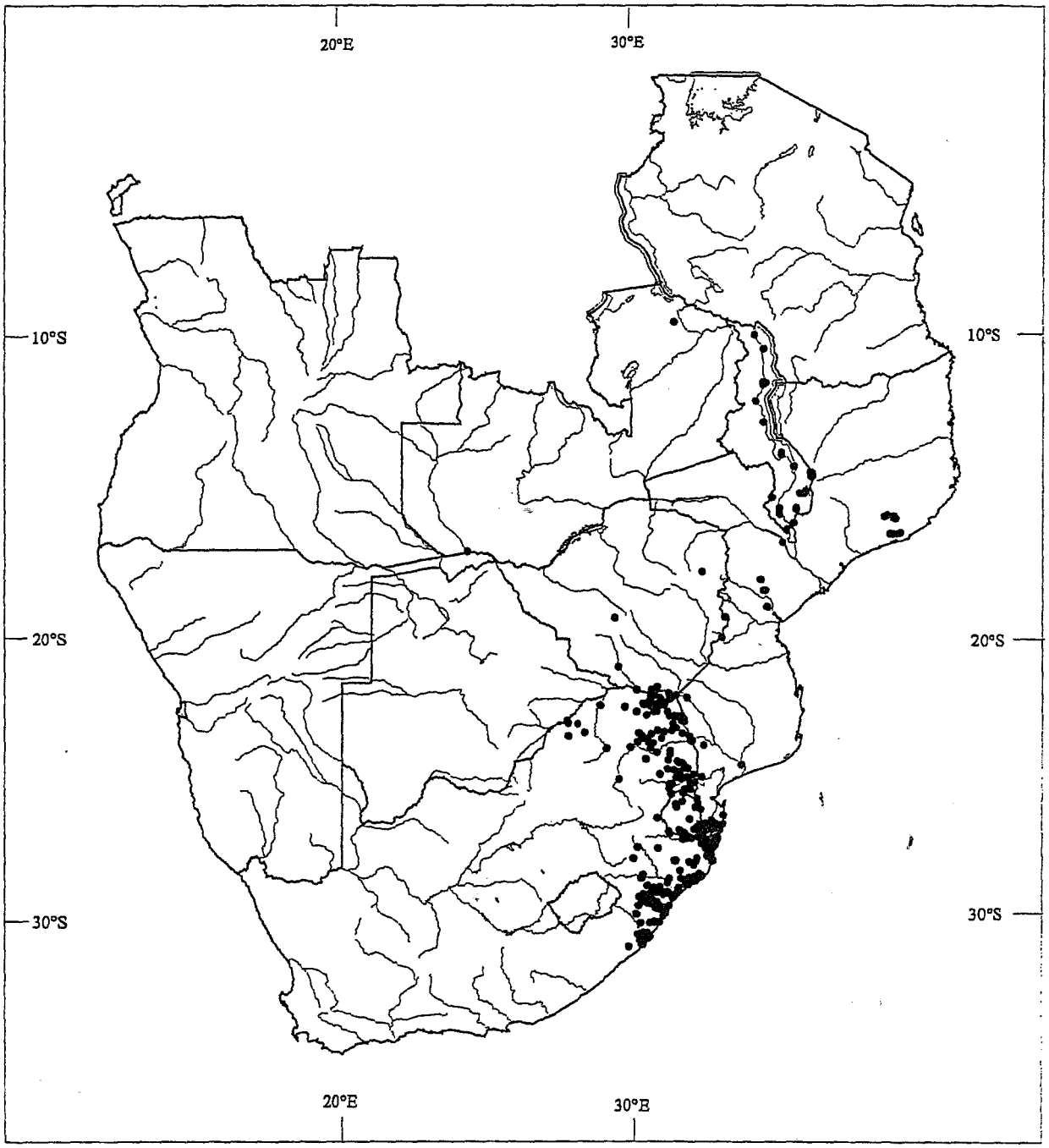


Figure F.131. Point distribution of *Barbus viviparus*. Scale approximately 1:25 000 000

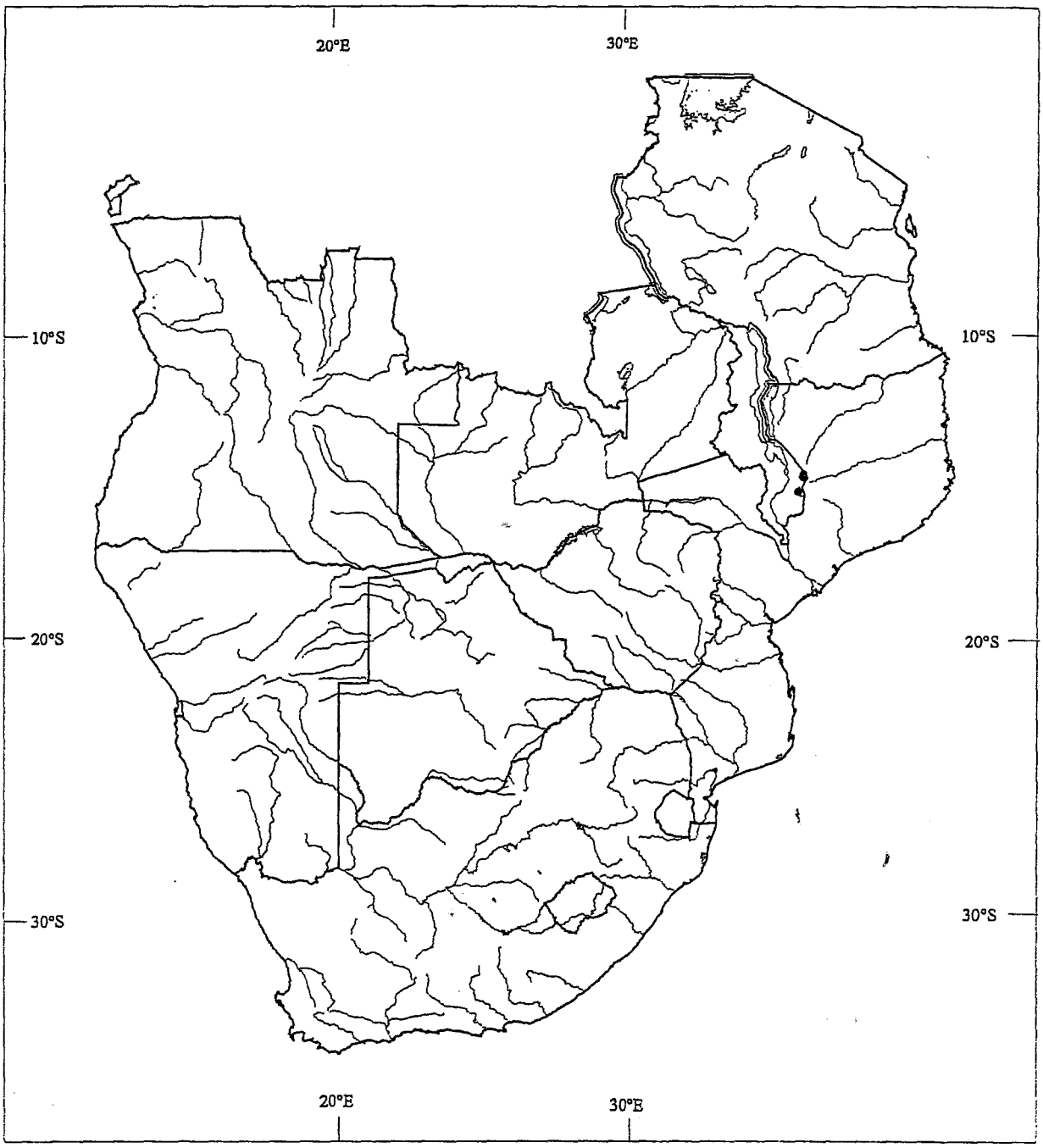


Figure F.132. Point distribution of *Barbus zanzibaricus*. Scale approximately 1:25 000 000

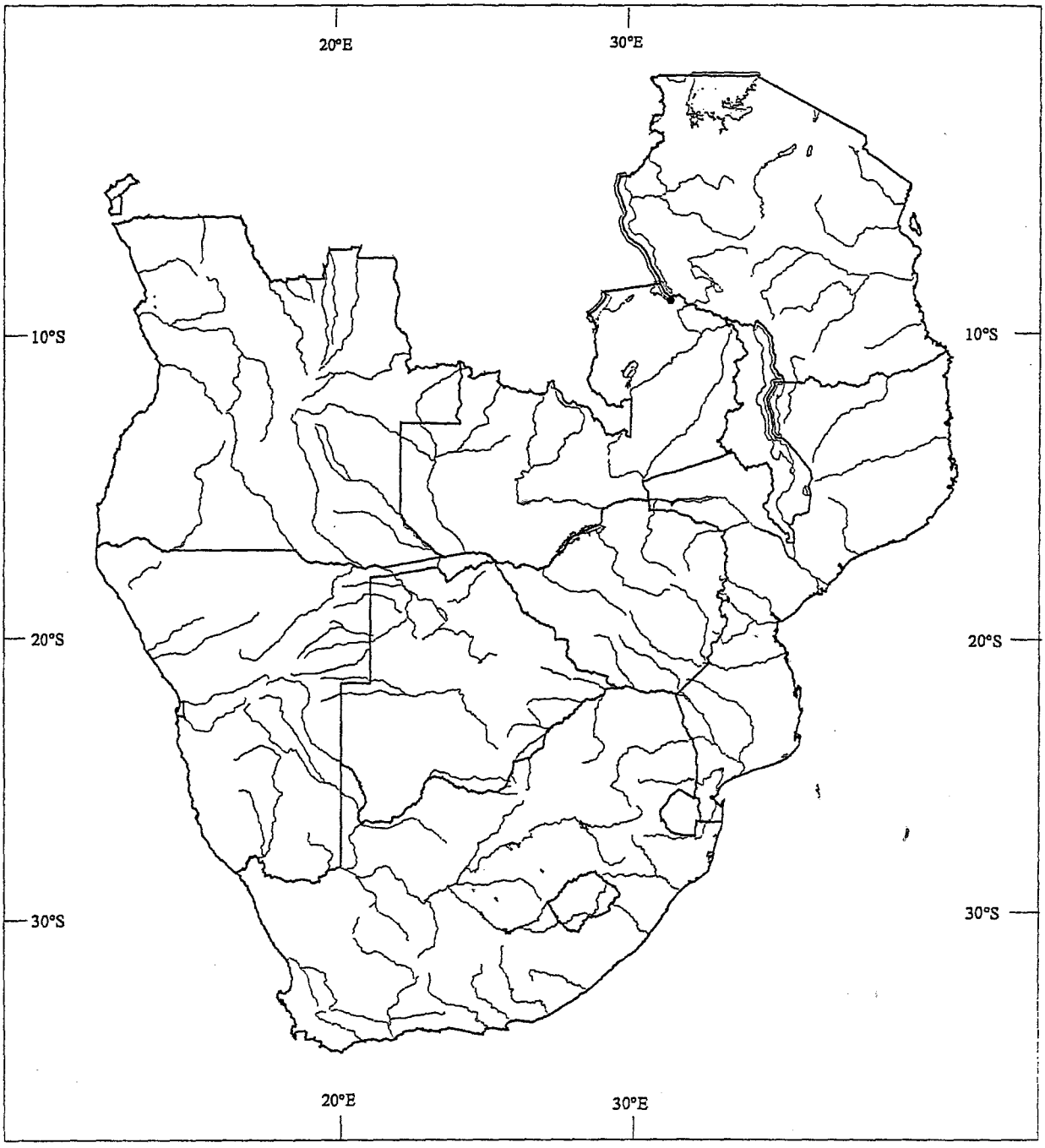


Figure F.133. Point distribution of *Bathybagrus teranema*. Scale approximately 1:25 000 000

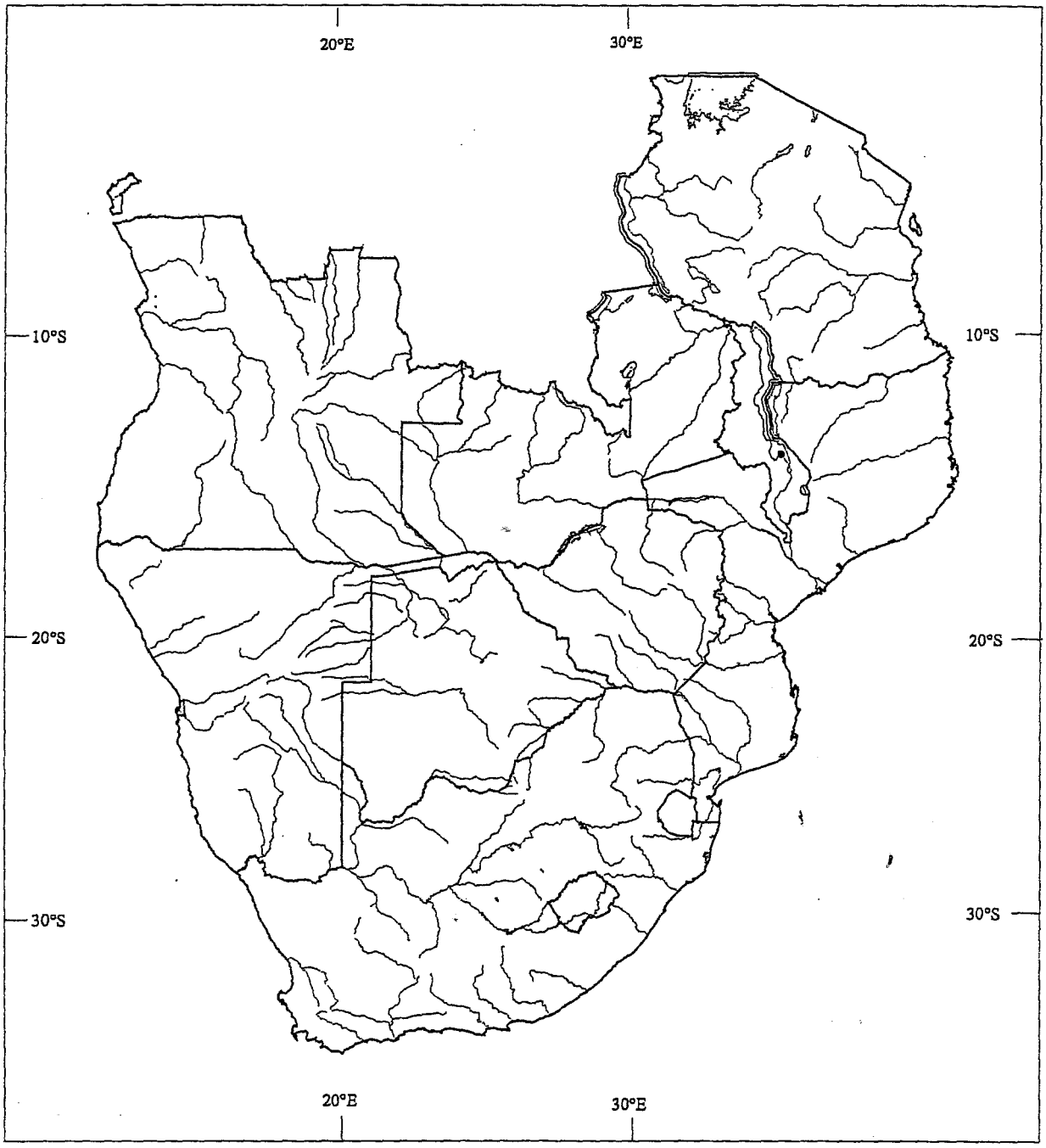


Figure F.134. Point distribution of *Bathyclarias filicibarbis*. Scale approximately 1:25 000 000

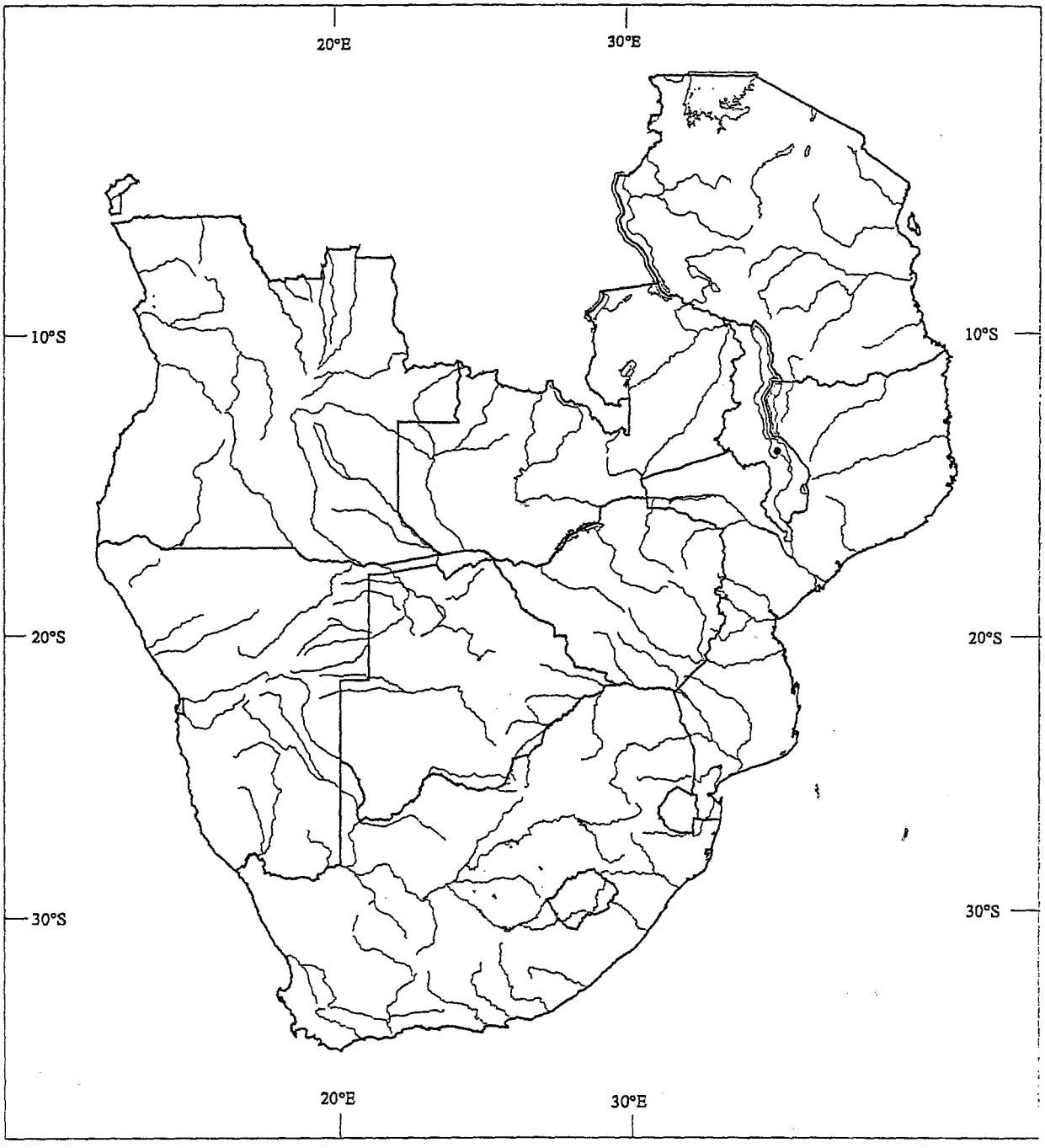


Figure F.135. Point distribution of *Bathyclarias foveolatus*. Scale approximately 1:25 000 000

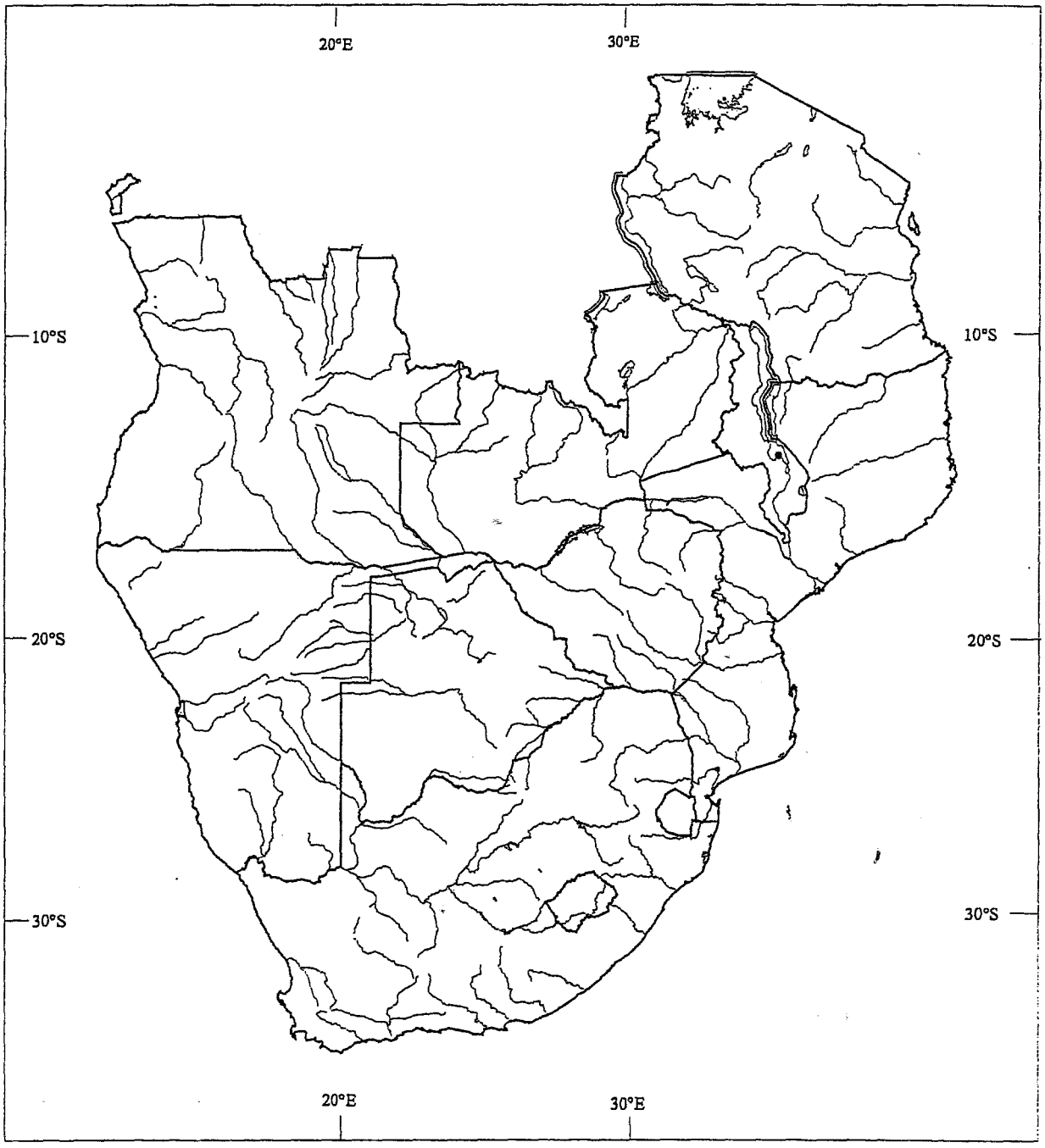


Figure F.136. Point distribution of *Bathyclarias gigas*. Scale approximately 1:25 000 000

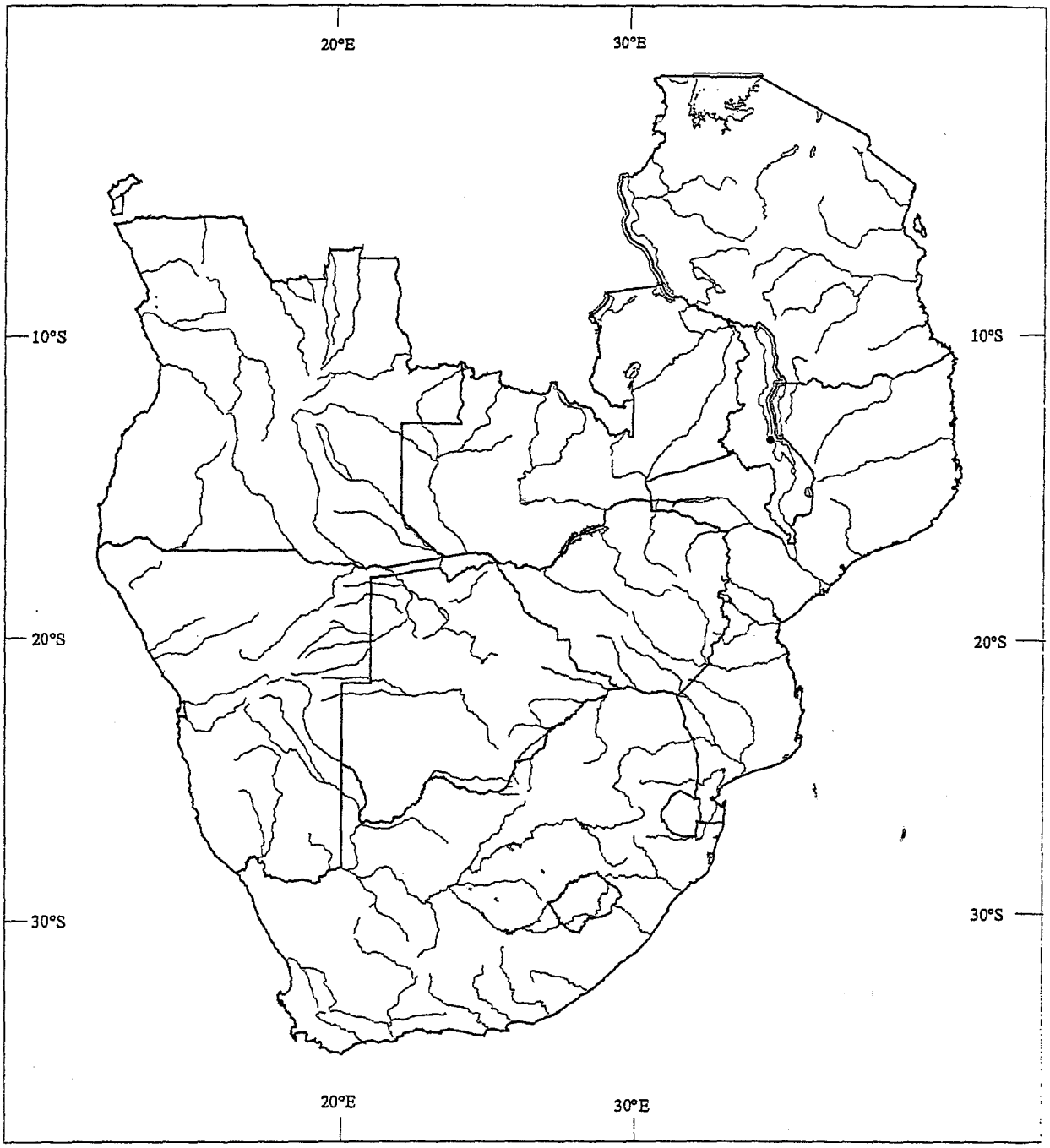


Figure F.137. Point distribution of *Bathyclarias longibarbis*. Scale approximately 1:25 000 000

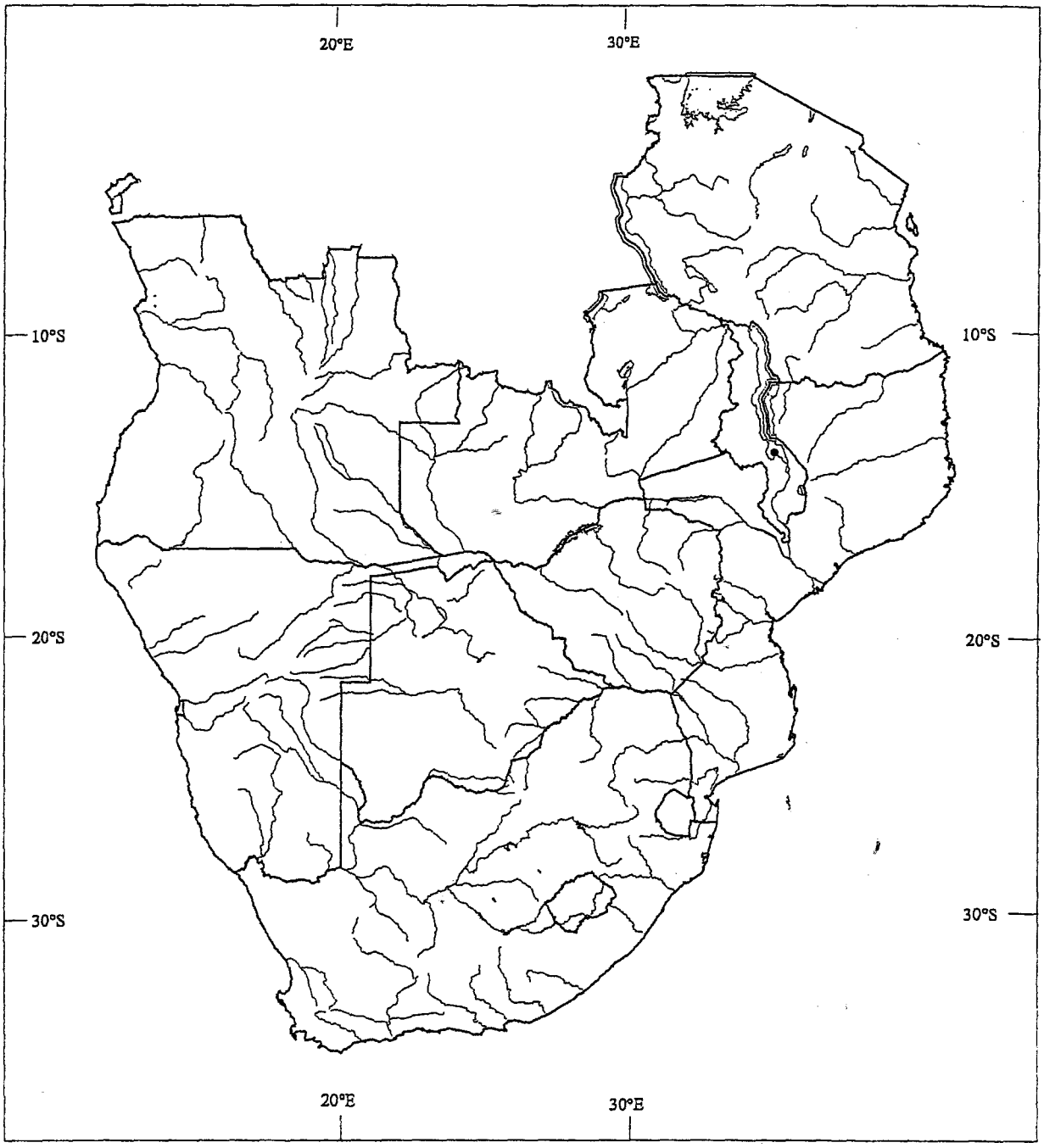


Figure F.138. Point distribution of *Bathyclarias loweae*. Scale approximately 1:25 000 000

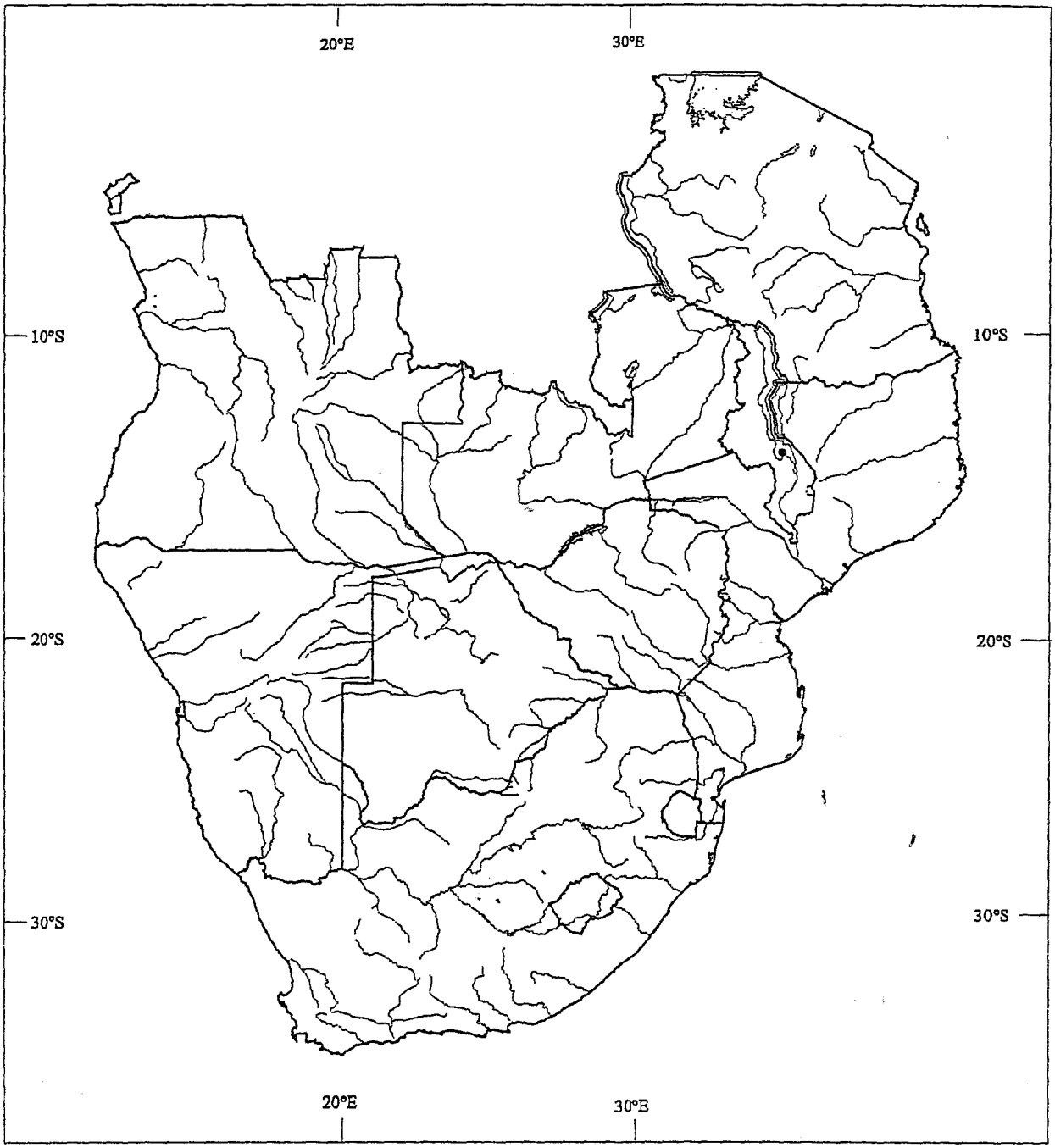


Figure F.139. Point distribution of *Bathyclarias meridionalis*. Scale approximately 1:25 000 000

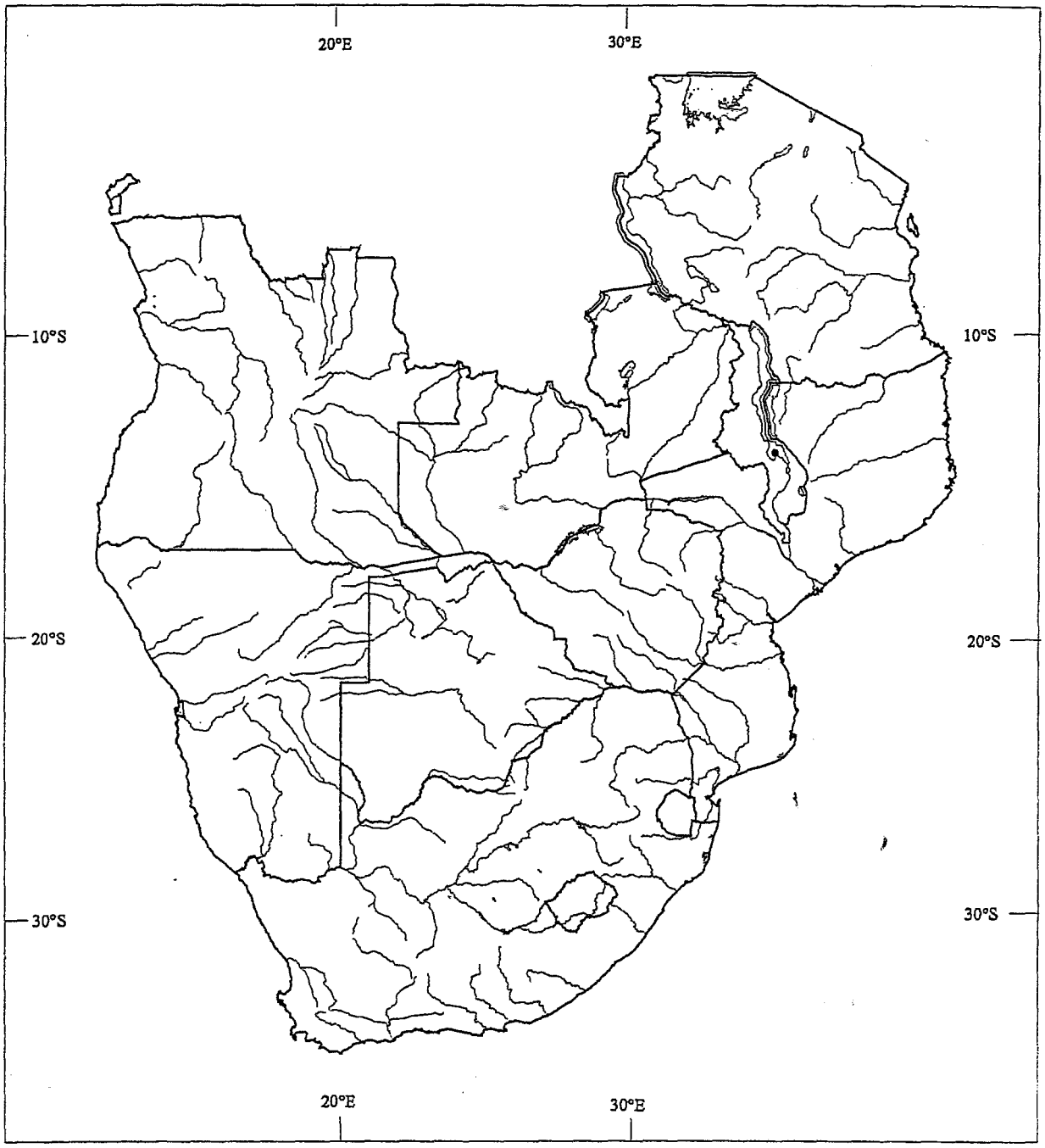


Figure F.140. Point distribution of *Bathyclarias nyasensis*. Scale approximately 1:25 000 000

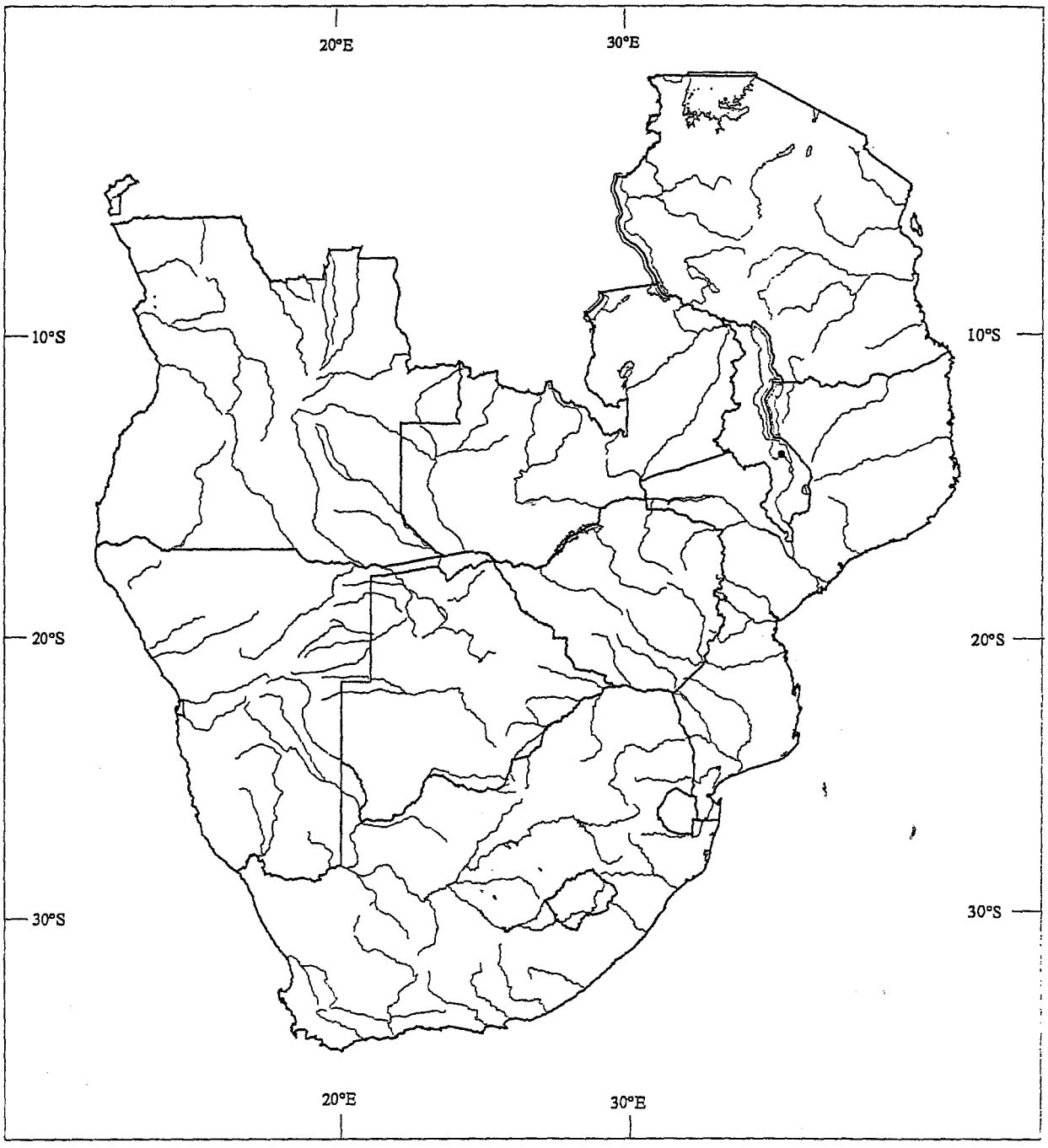


Figure F.141. Point distribution of *Bathyclarias rotundifrons*. Scale approximately 1:25 000 000

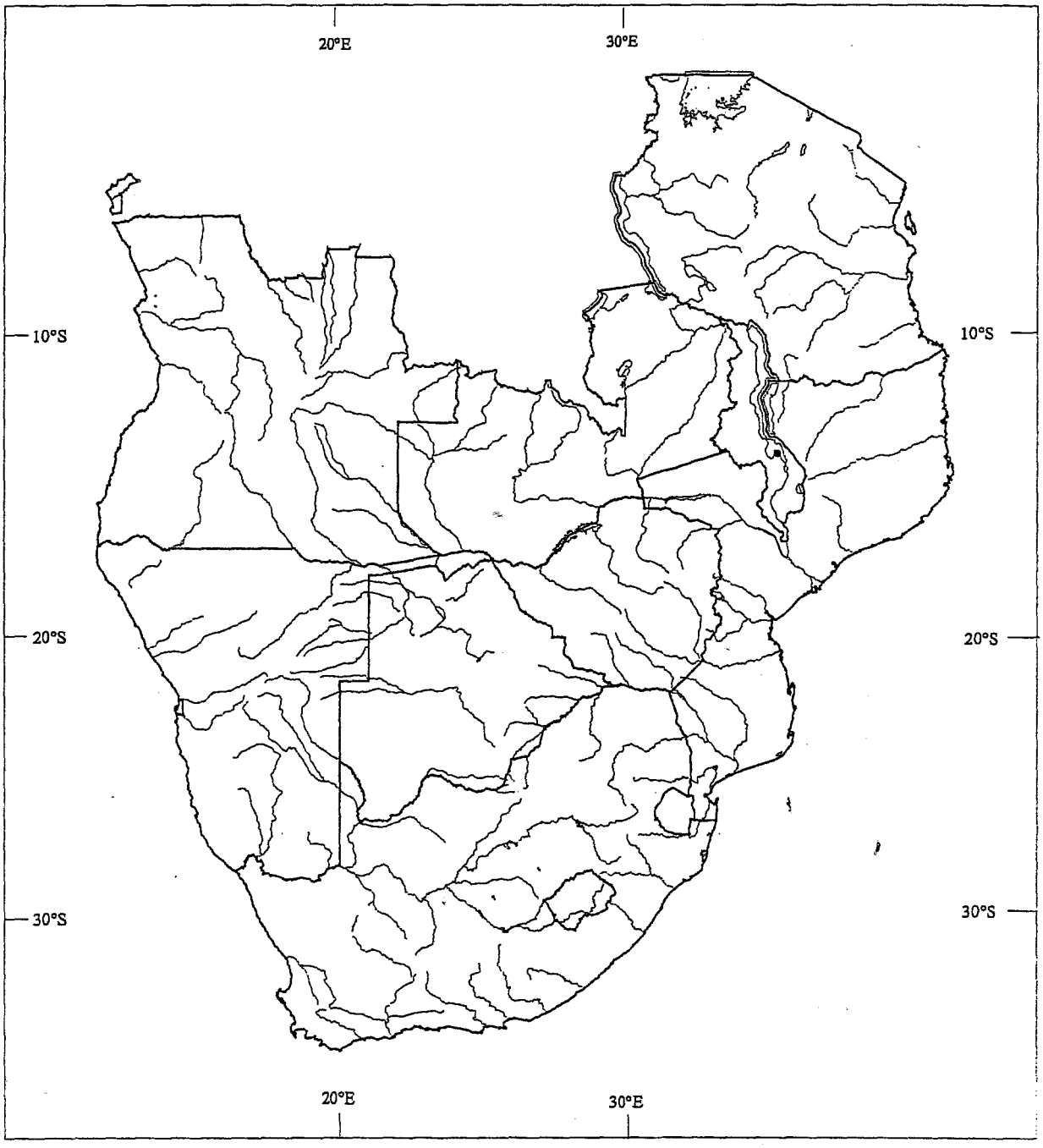


Figure F.142. Point distribution of *Bathyclarias worthingtoni*. Scale approximately 1:25 000 000

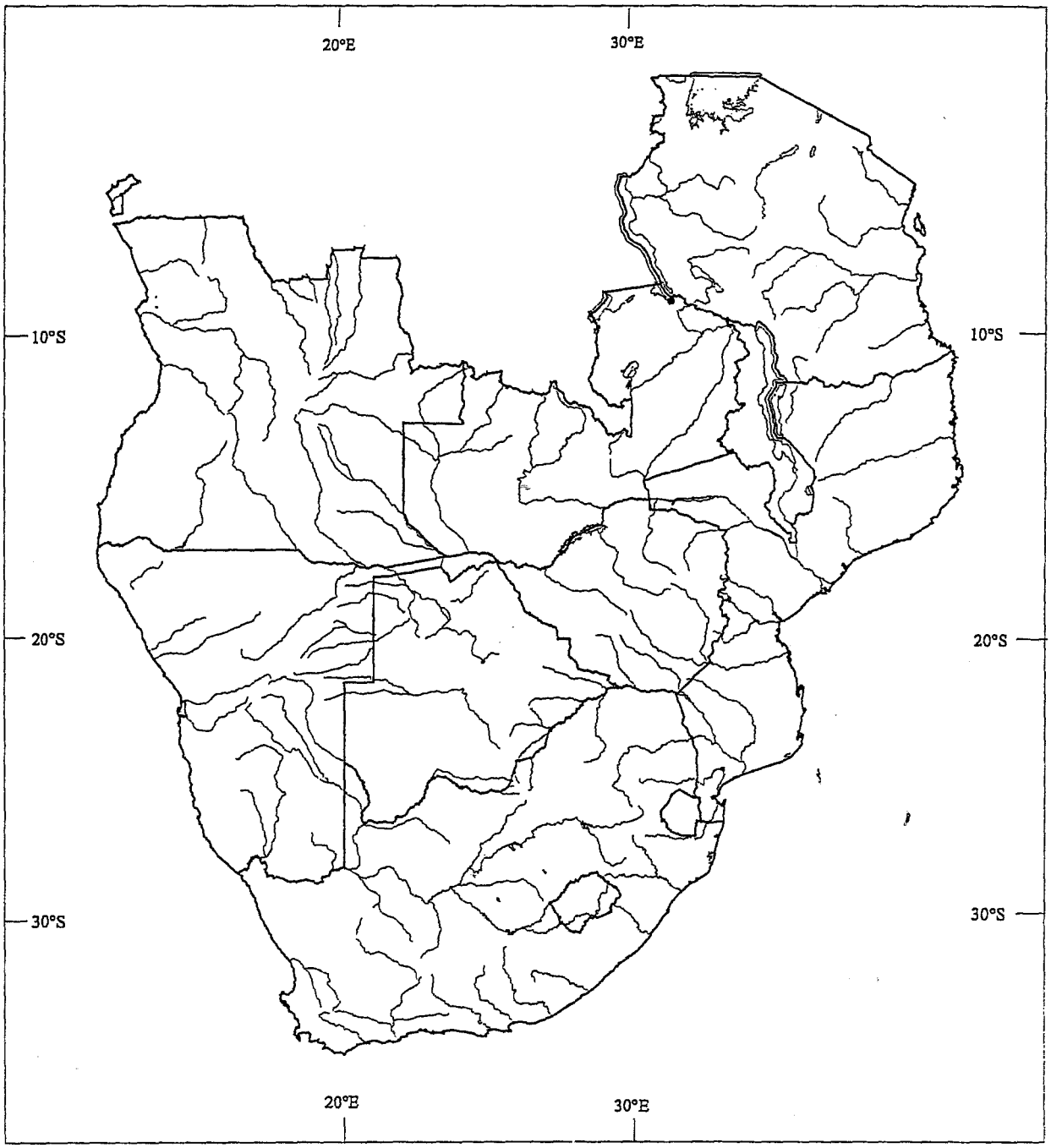


Figure F.143. Point distribution of *Benthochromis melanoides*. Scale approximately 1:25 000 000

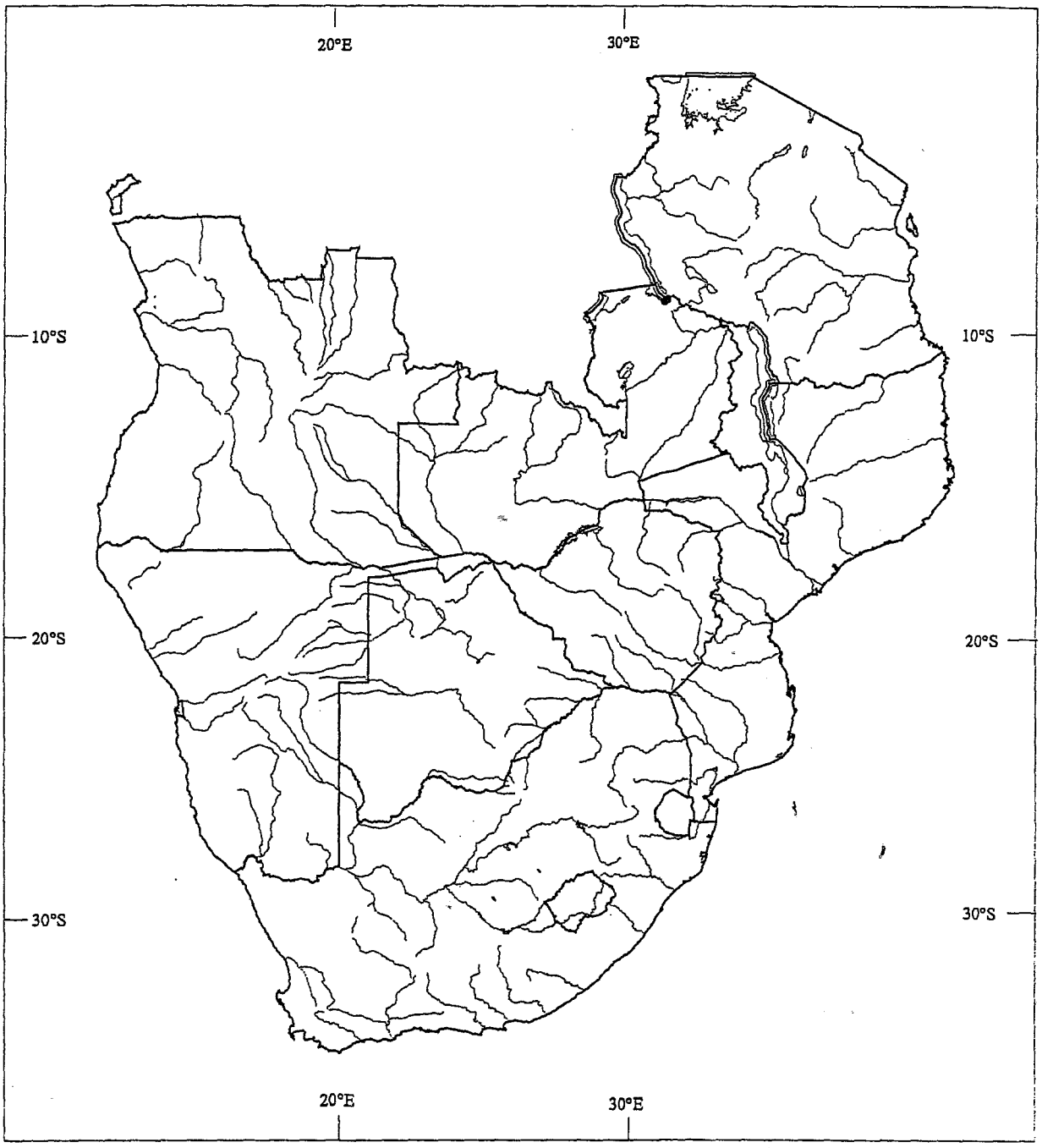


Figure F.144. Point distribution of *Benthochromis tricoti*. Scale approximately 1:25 000 000

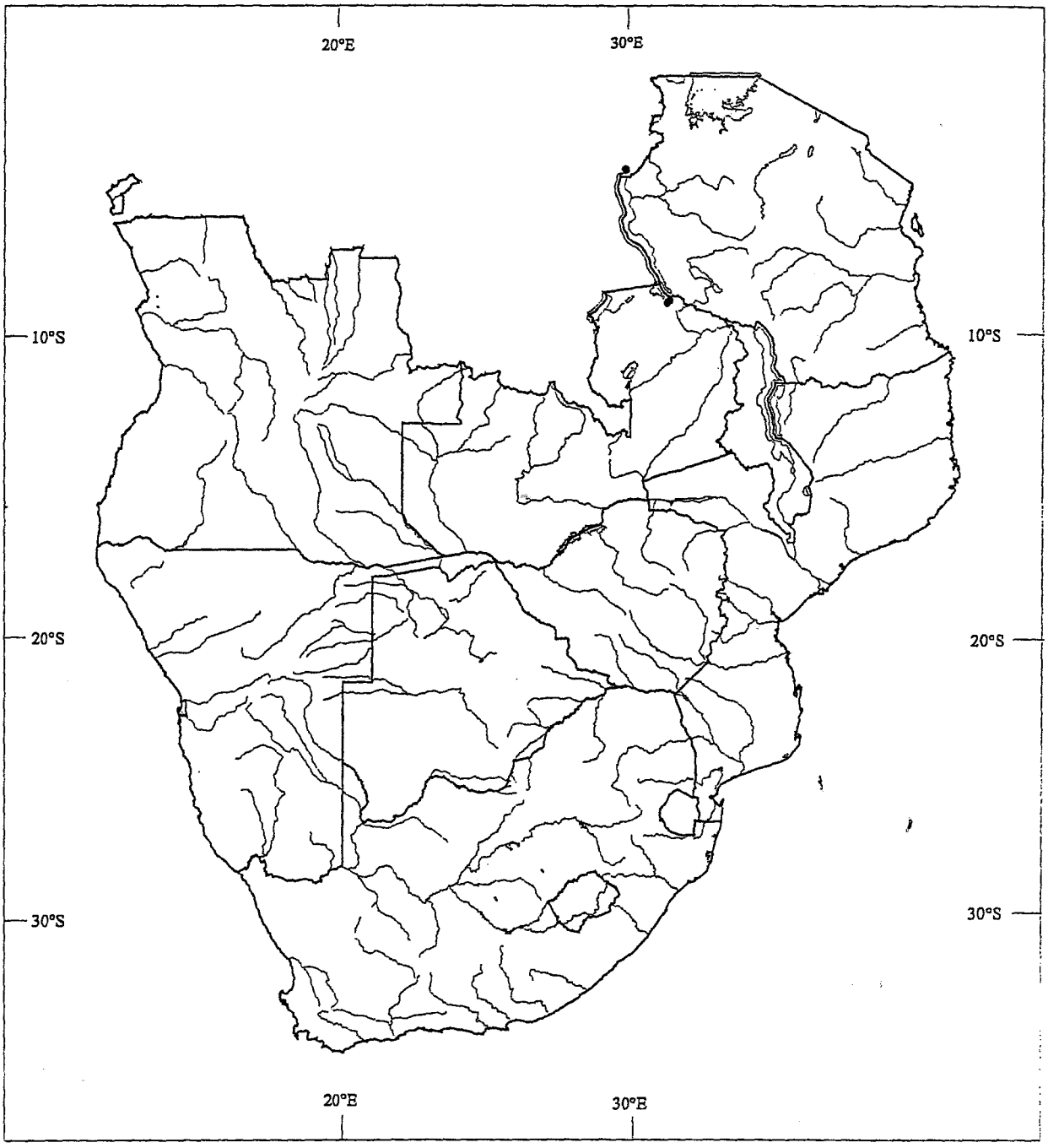


Figure F.145. Point distribution of *Boulengerochromis microlepis*. Scale approximately 1:25 000 000

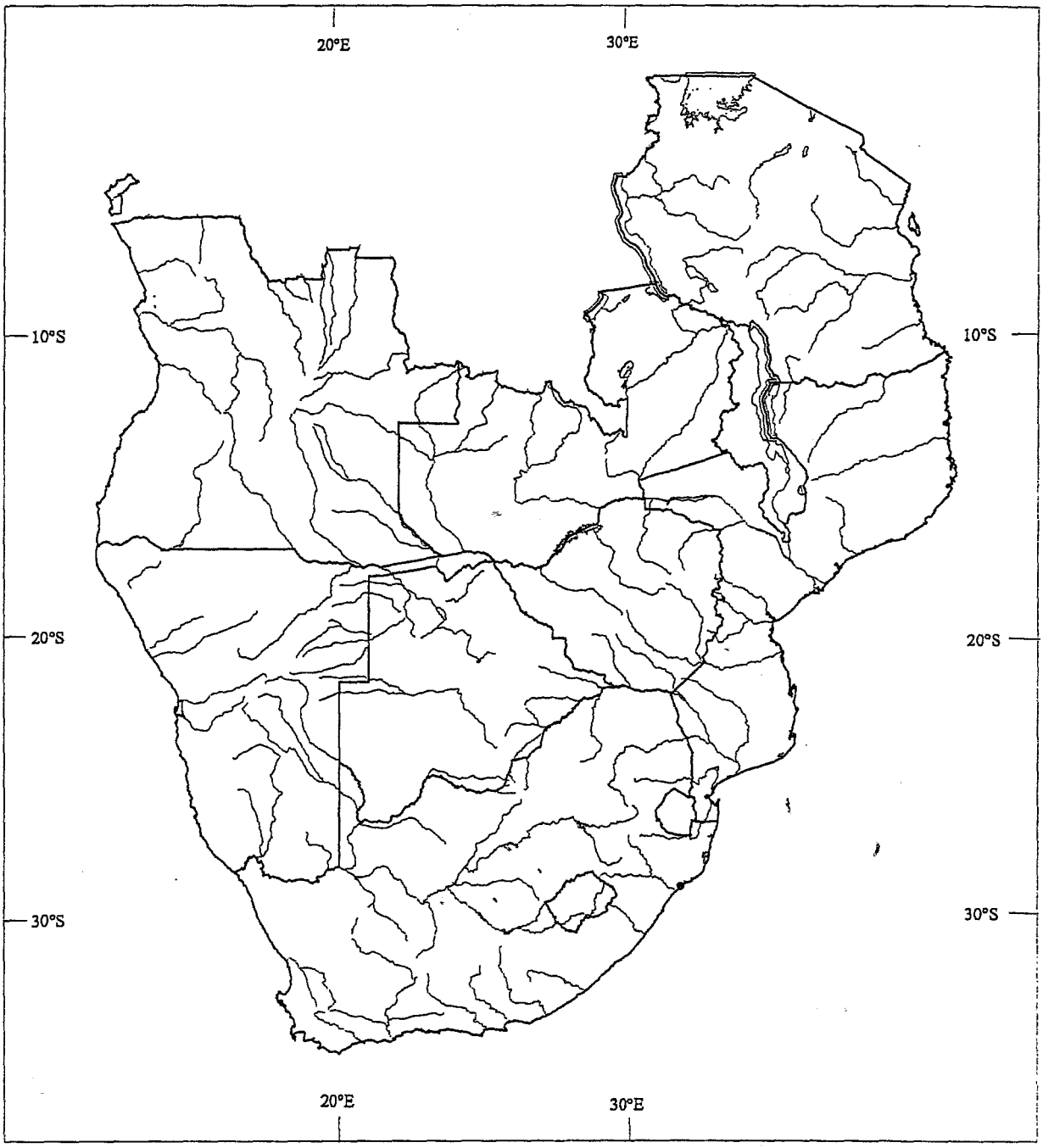


Figure F.146. Point distribution of *Brachydanio albolineatus*. Scale approximately 1:25 000 000

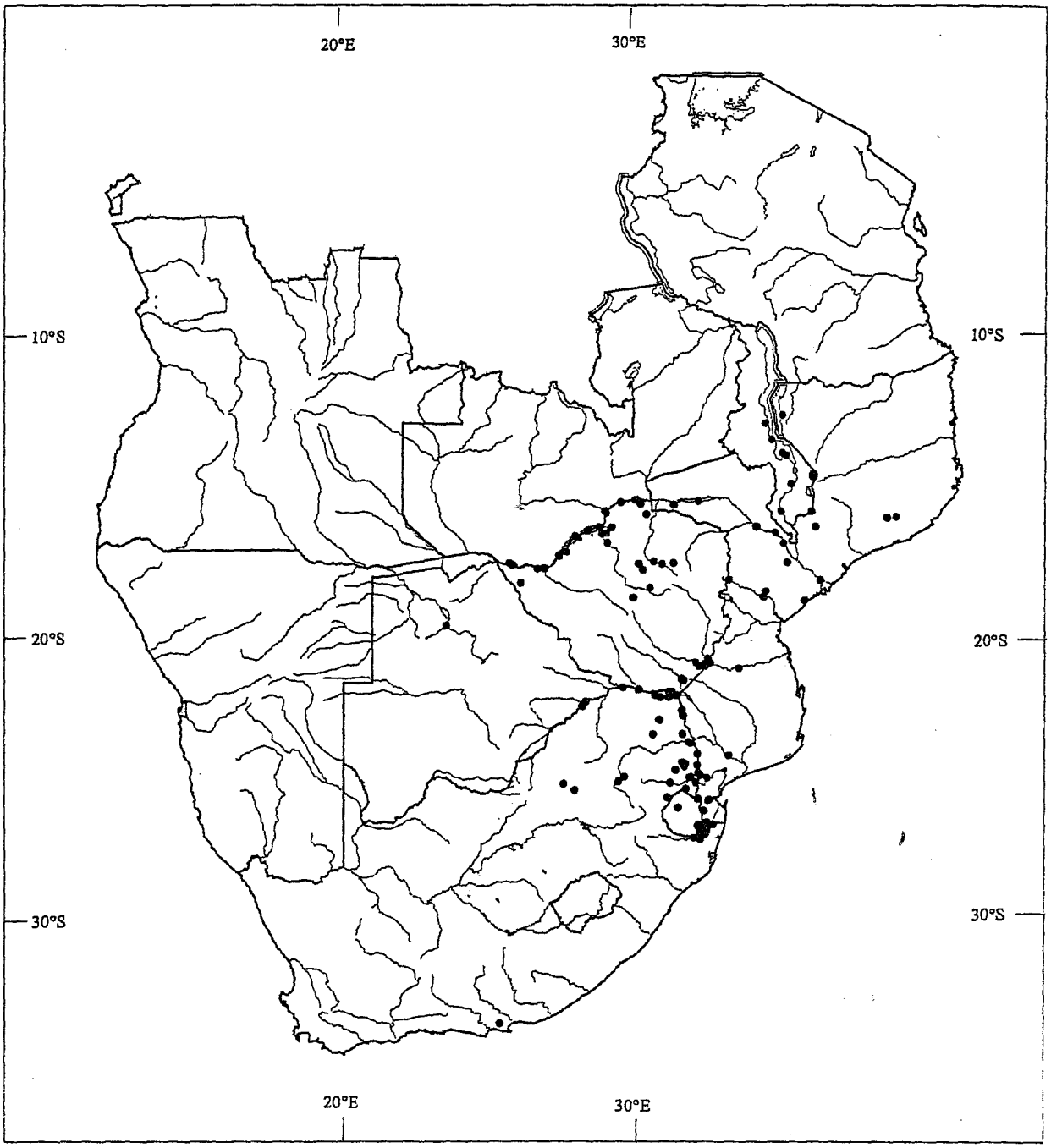


Figure F.147. Point distribution of *Brycinus imberi*. Scale approximately 1:25 000 000

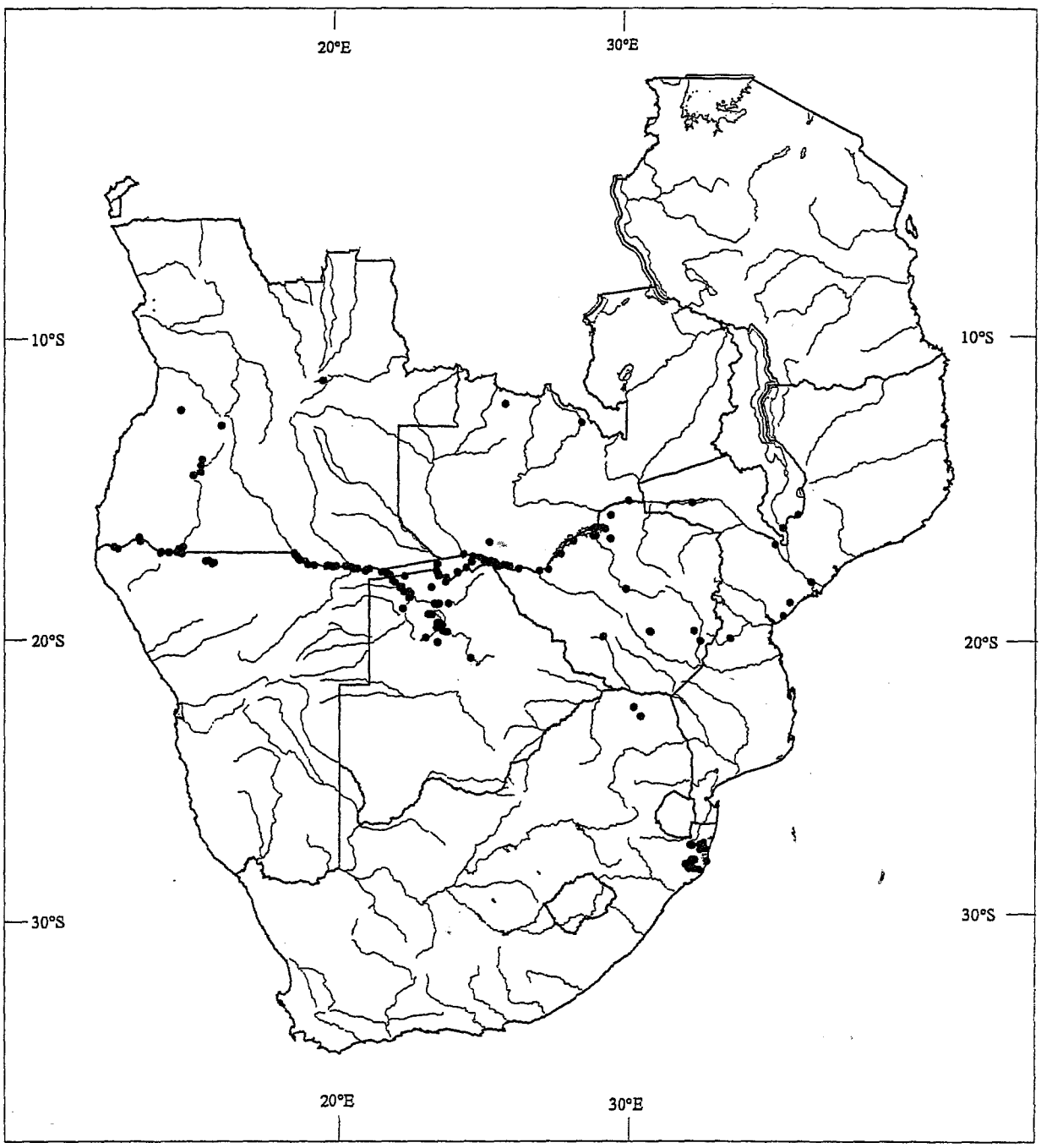


Figure F.148. Point distribution of *Brycinus lateralis*. Scale approximately 1:25 000 000

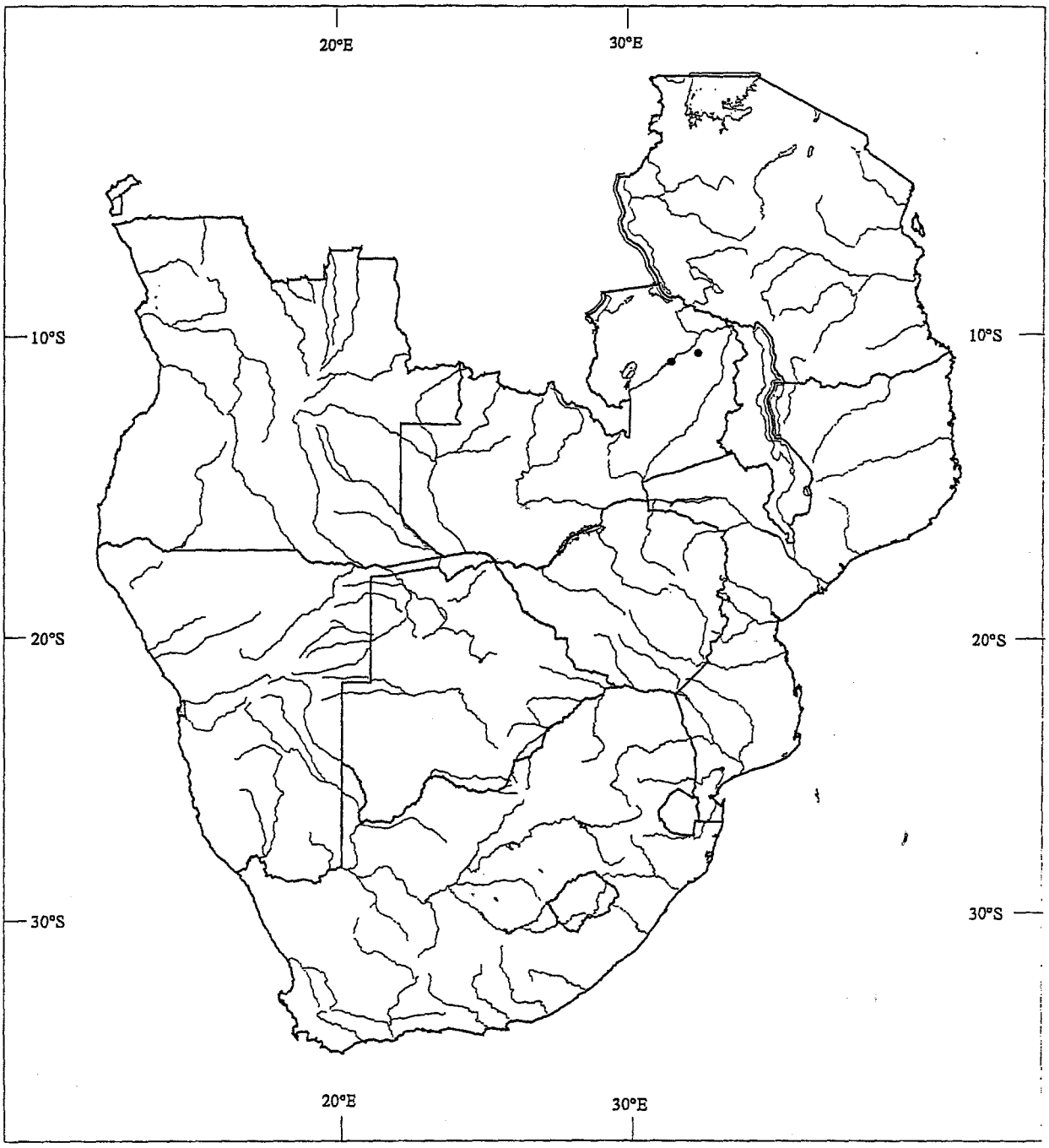


Figure F.149. Point distribution of *Bryconaethiops boulengeri*. Scale approximately 1:25 000 000

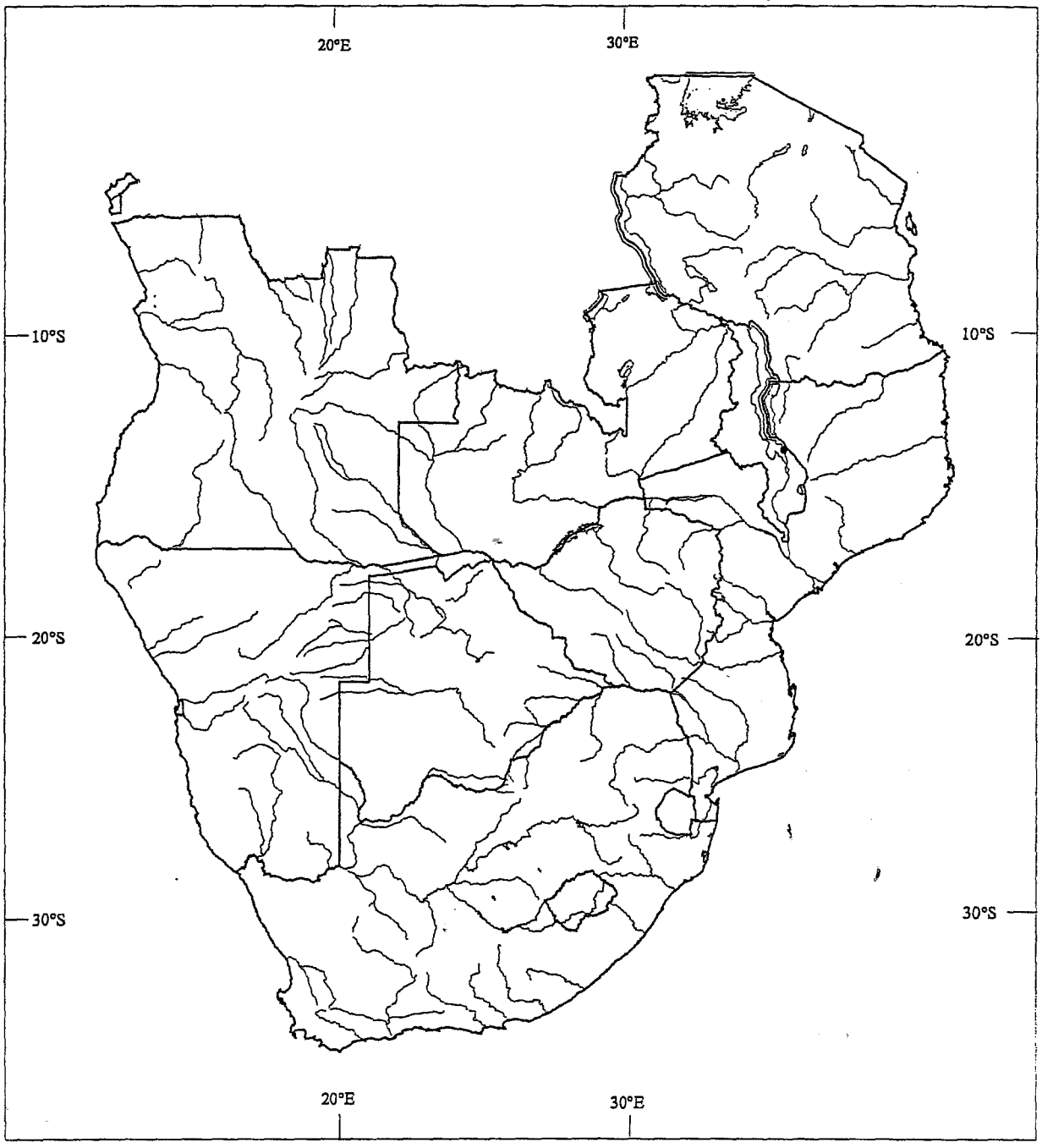


Figure F.150. Point distribution of *Buccochromis heterotaenia*. Scale approximately 1:25 000 000

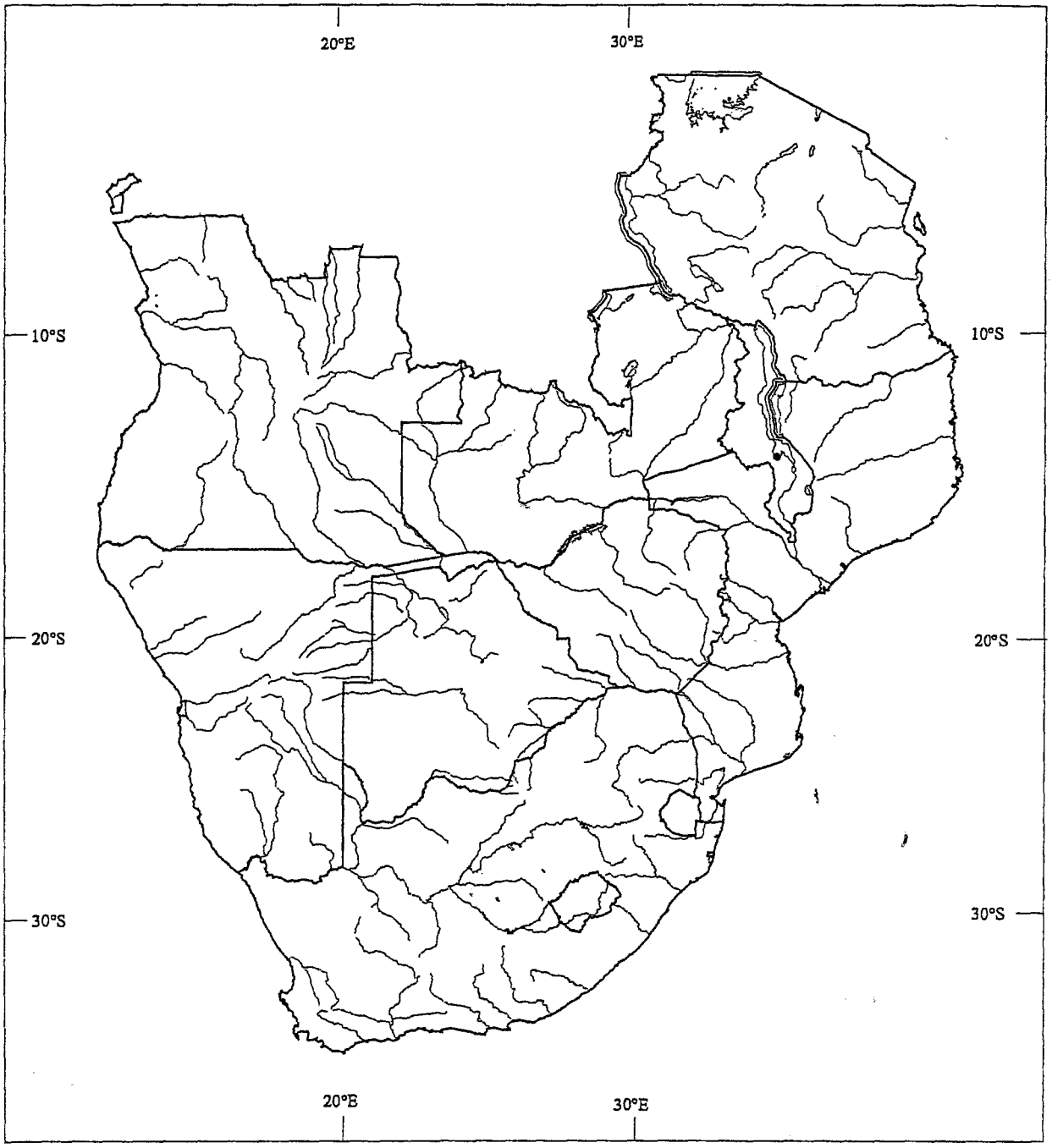


Figure F.151. Point distribution of *Buccochromis lepturus*. Scale approximately 1:25 000 000

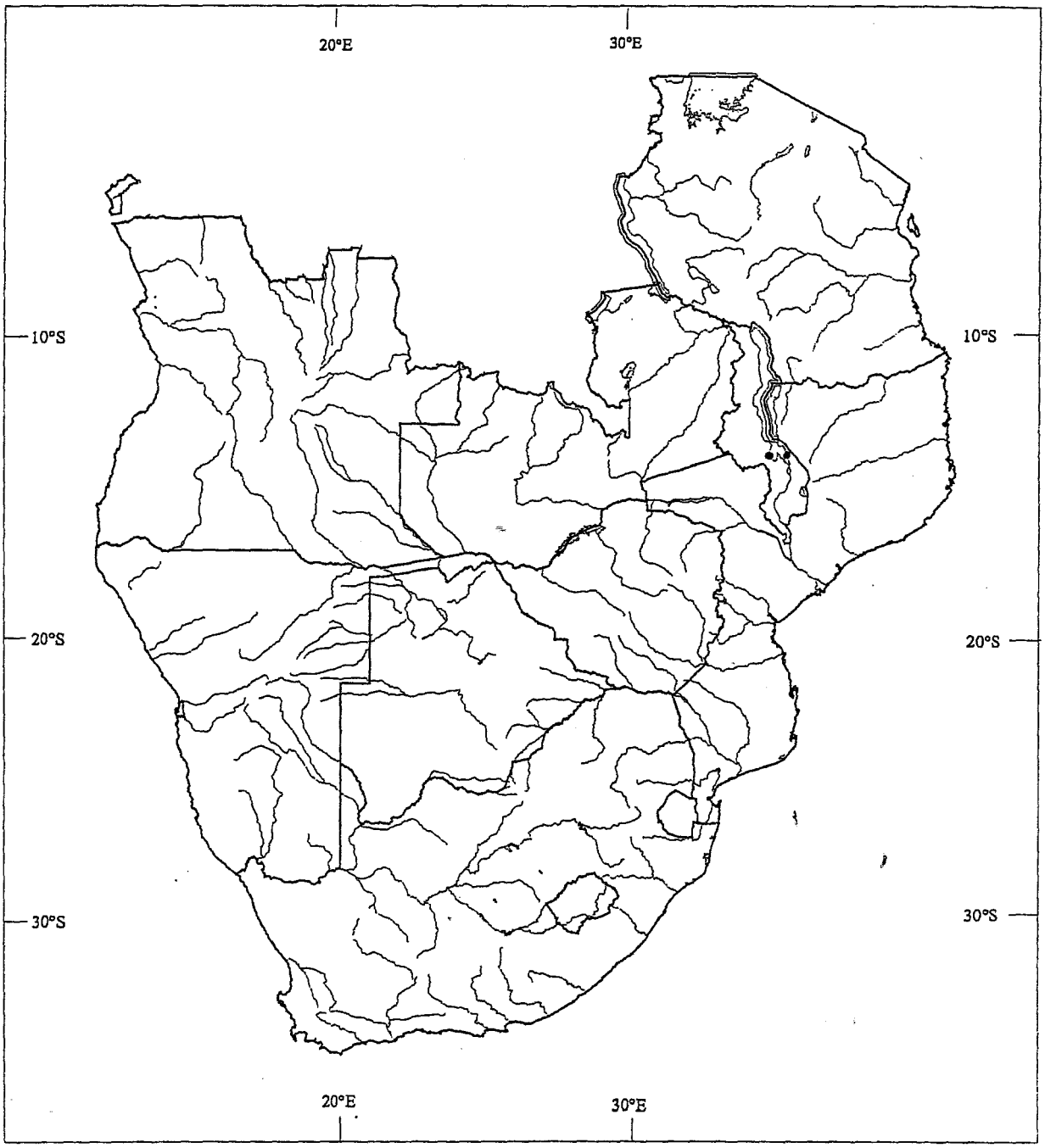


Figure F.152. Point distribution of *Buccochromis nototaenia*. Scale approximately 1:25 000 000

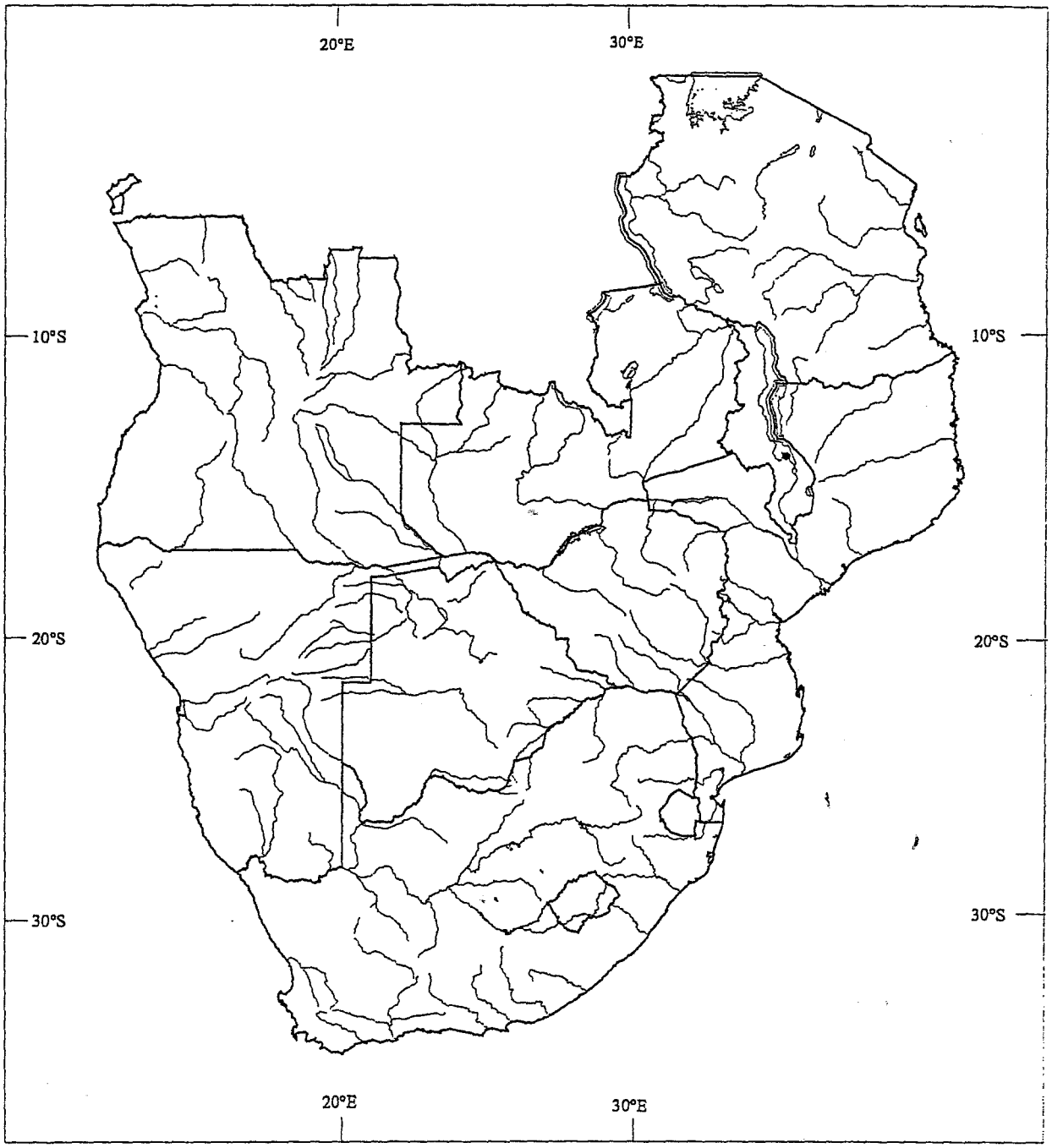


Figure F.153. Point distribution of *Buccochromis spectabilis*. Scale approximately 1:25 000 000

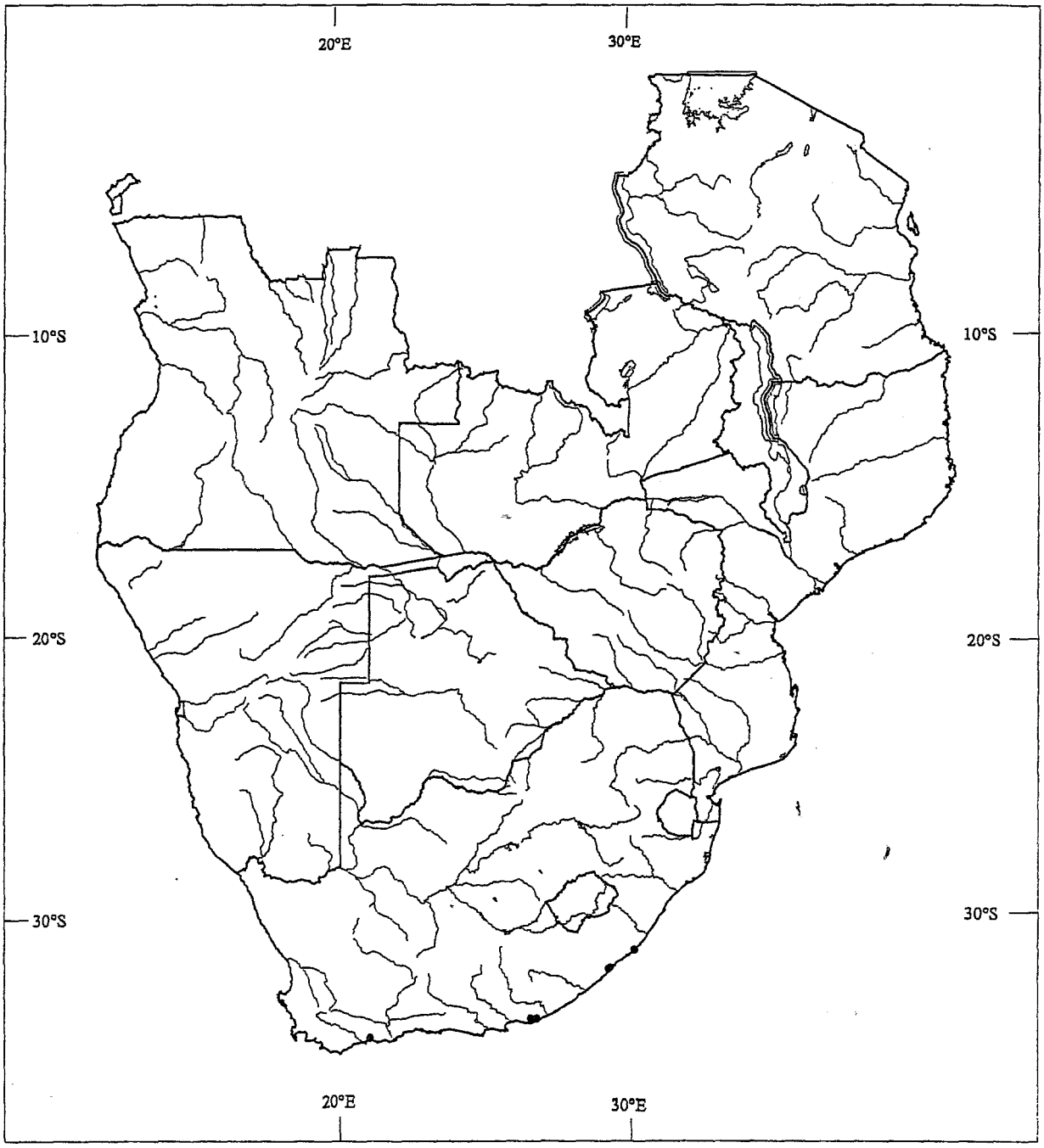


Figure F.154. Point distribution of *Caffrogobius multifasciatus*. Scale approximately 1:25 000 000

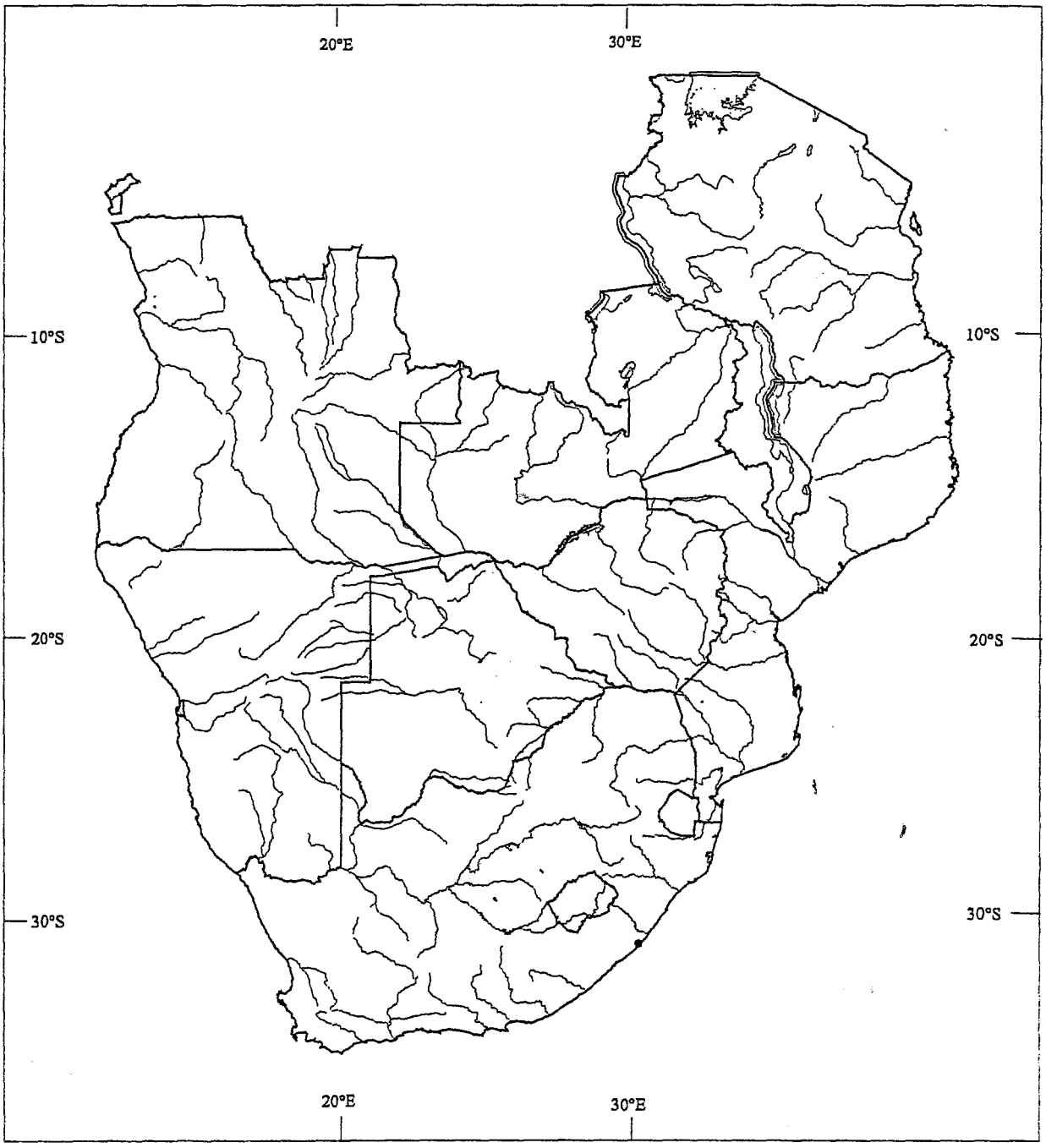


Figure F.155. Point distribution of *Cafrogobius caffer*. Scale approximately 1:25 000 000

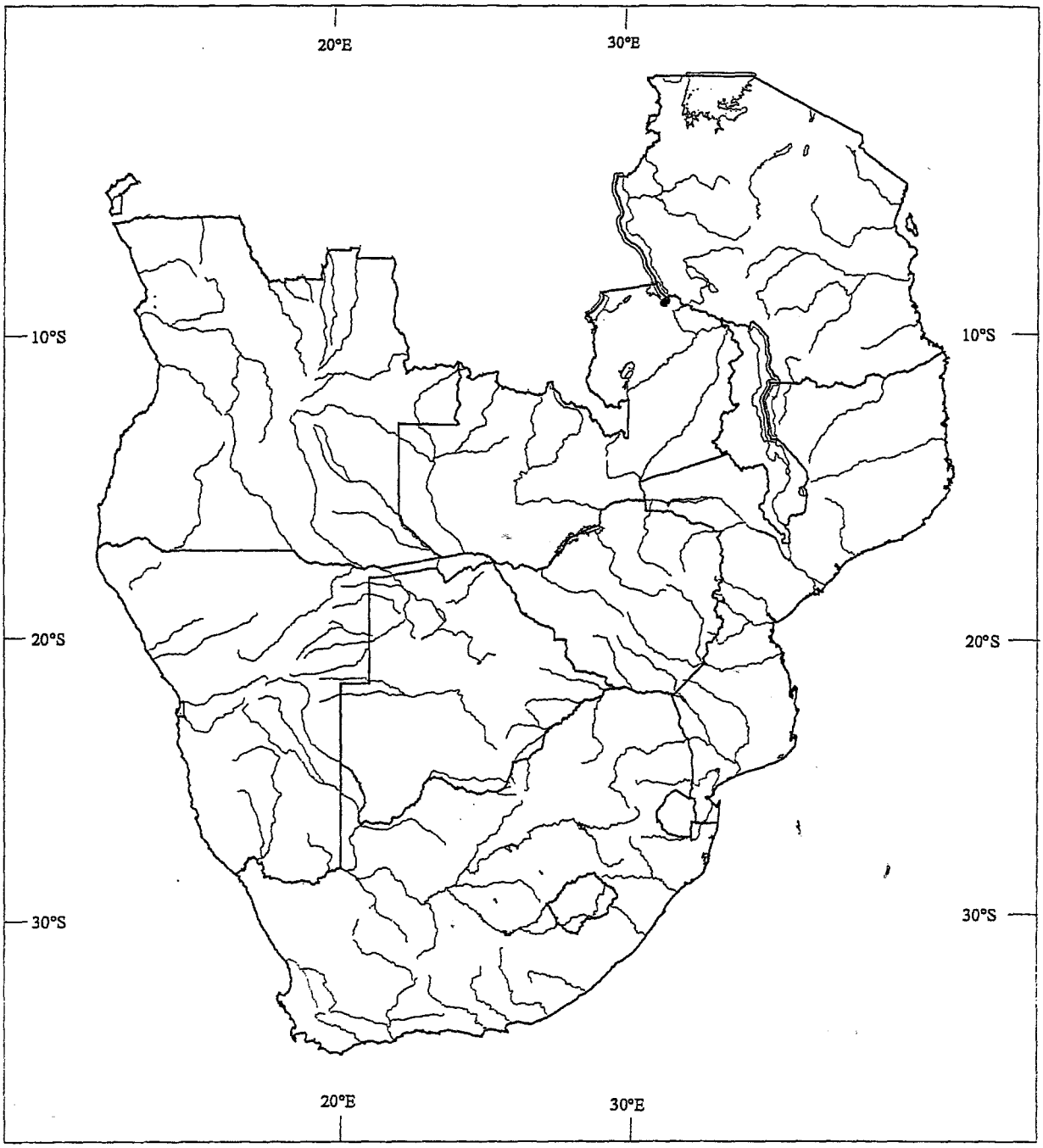


Figure F.156. Point distribution of *Callochromis macrops*. Scale approximately 1:25 000 000

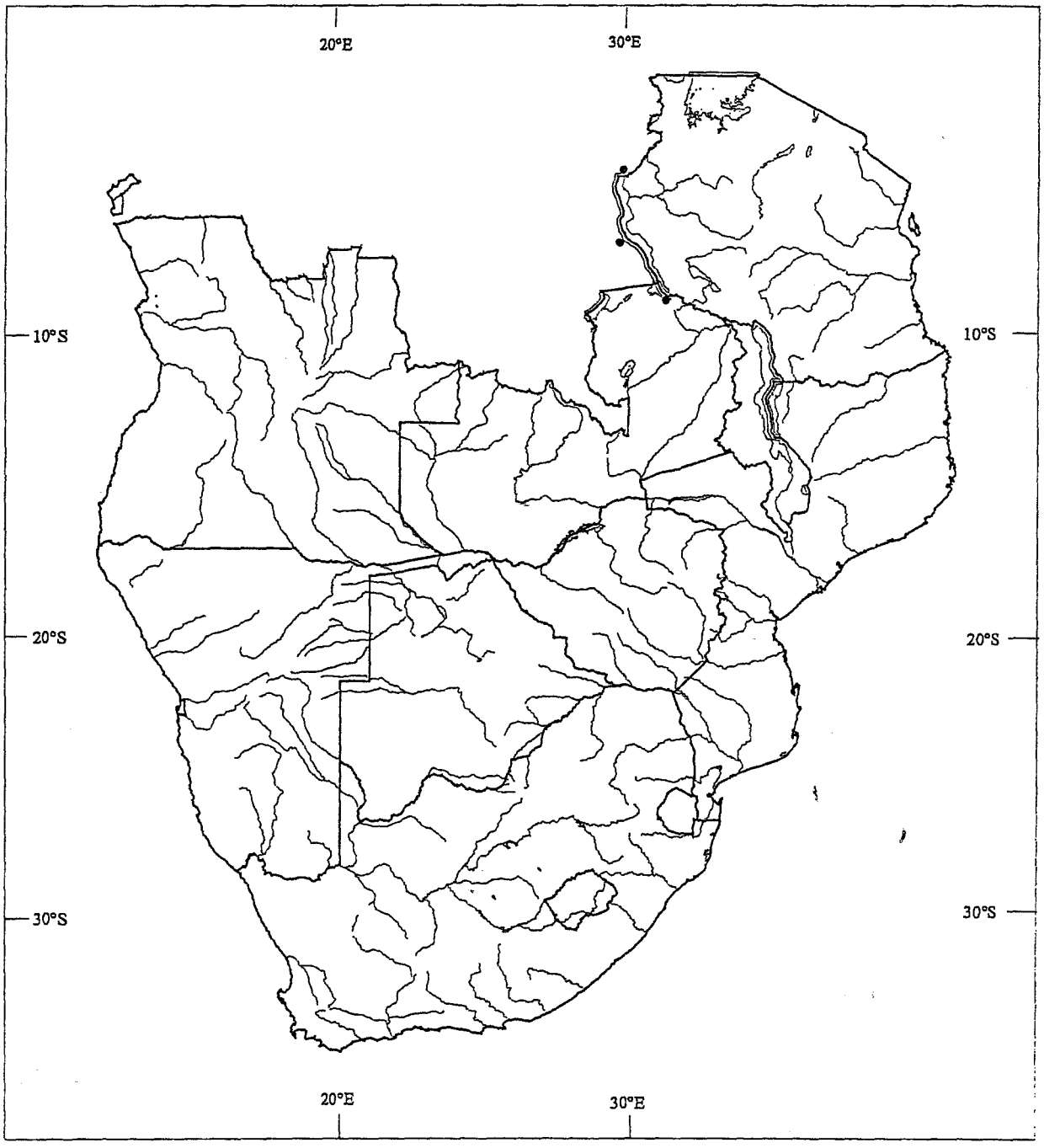


Figure F.157. Point distribution of *Callochromis pleurospilus*. Scale approximately 1:25 000 000

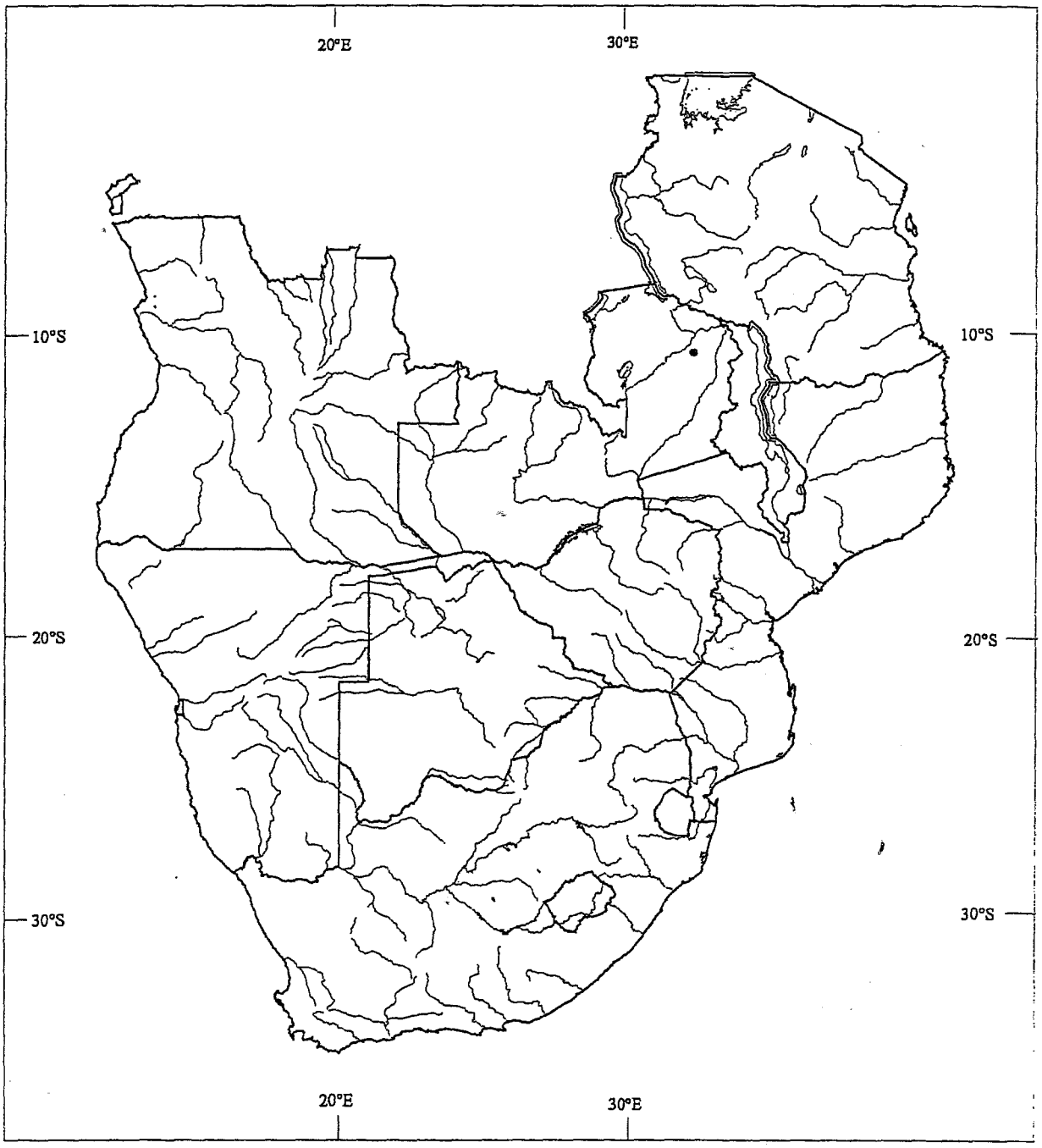


Figure F.158. Point distribution of *Campylomormyrus cassaicus*. Scale approximately 1:25 000 000

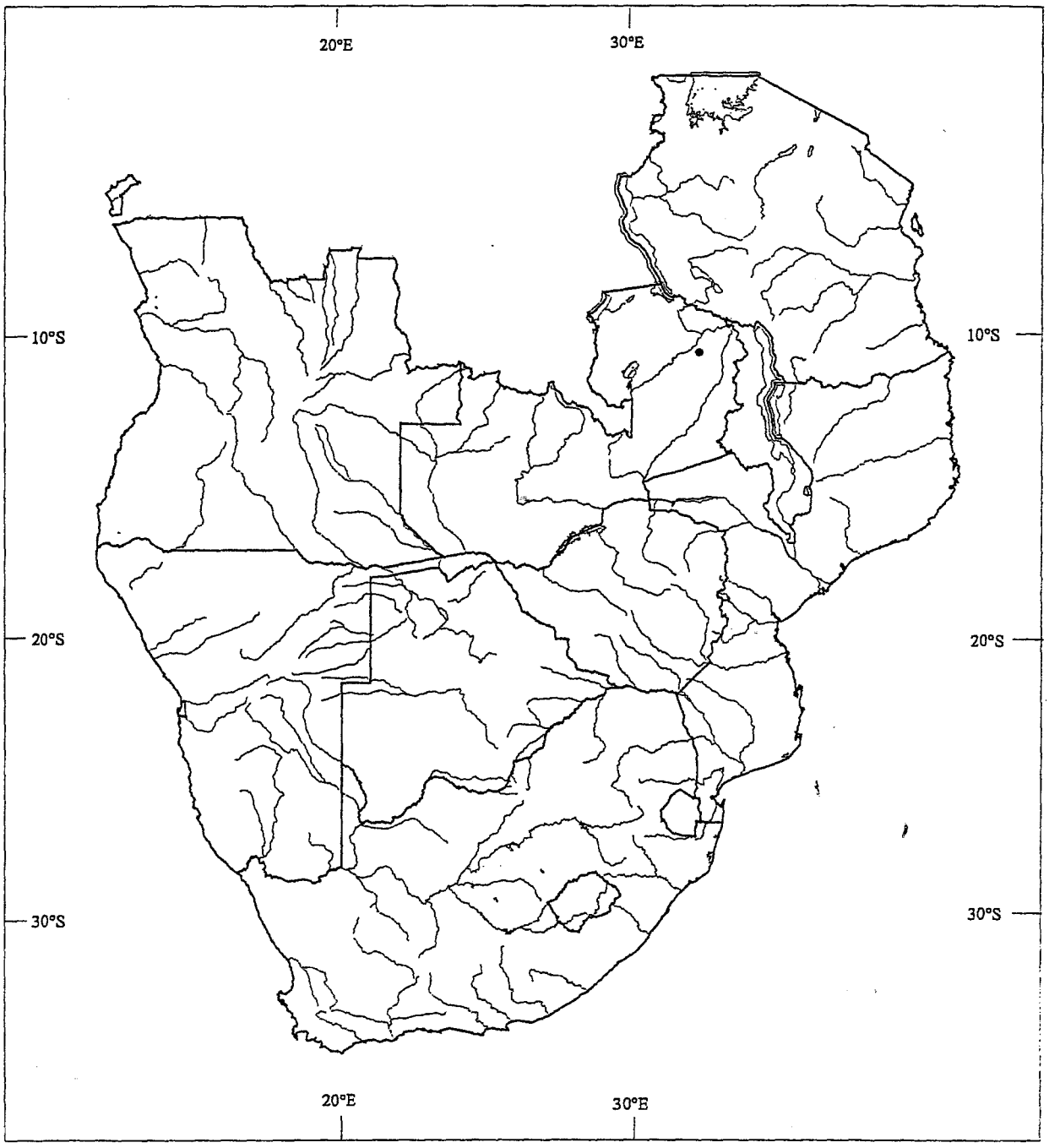


Figure F.159. Point distribution of *Campylomormyrus elephas*. Scale approximately 1:25 000 000

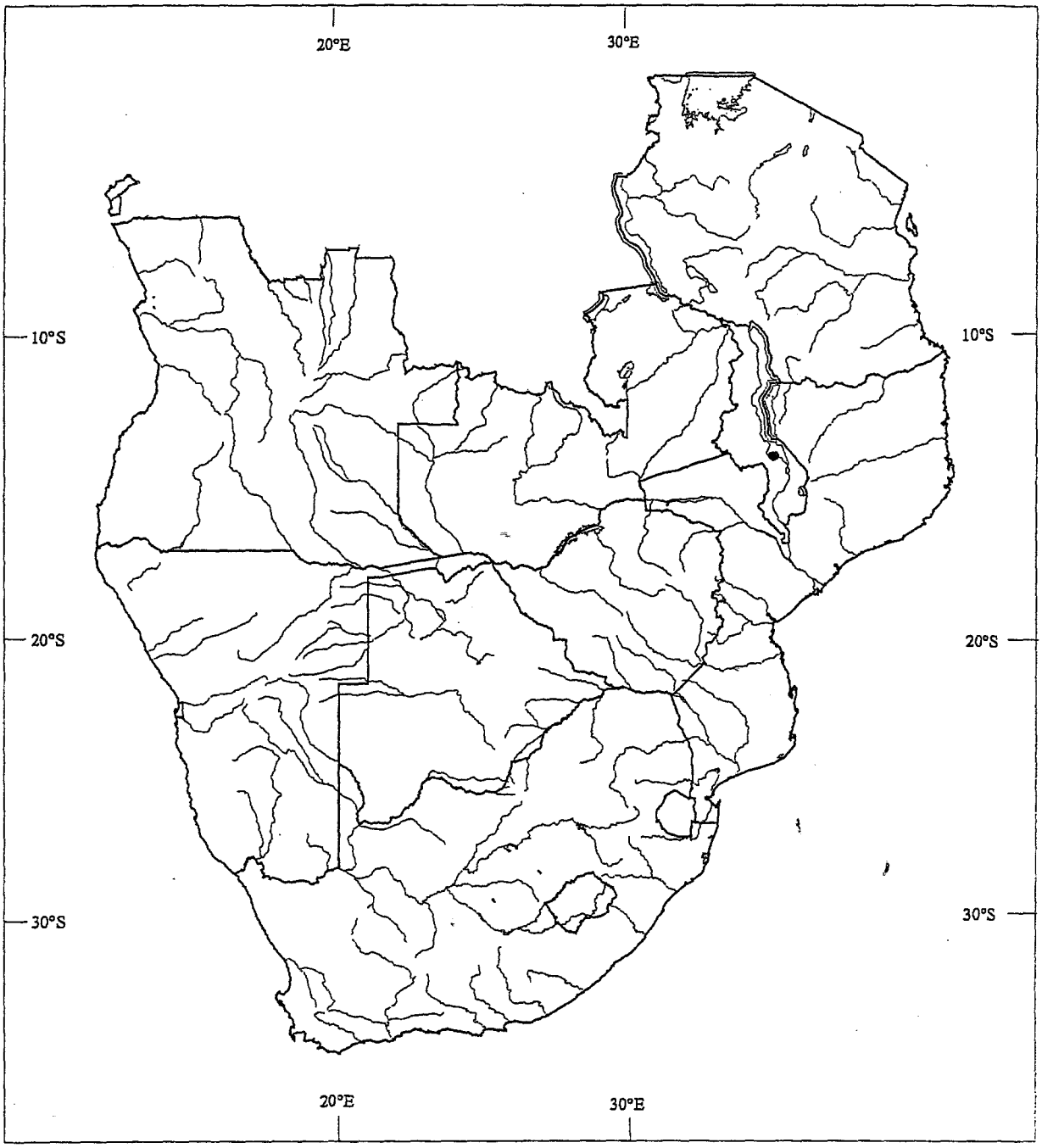


Figure F.160. Point distribution of *Caprichromis orthognathus*. Scale approximately 1:25 000 000

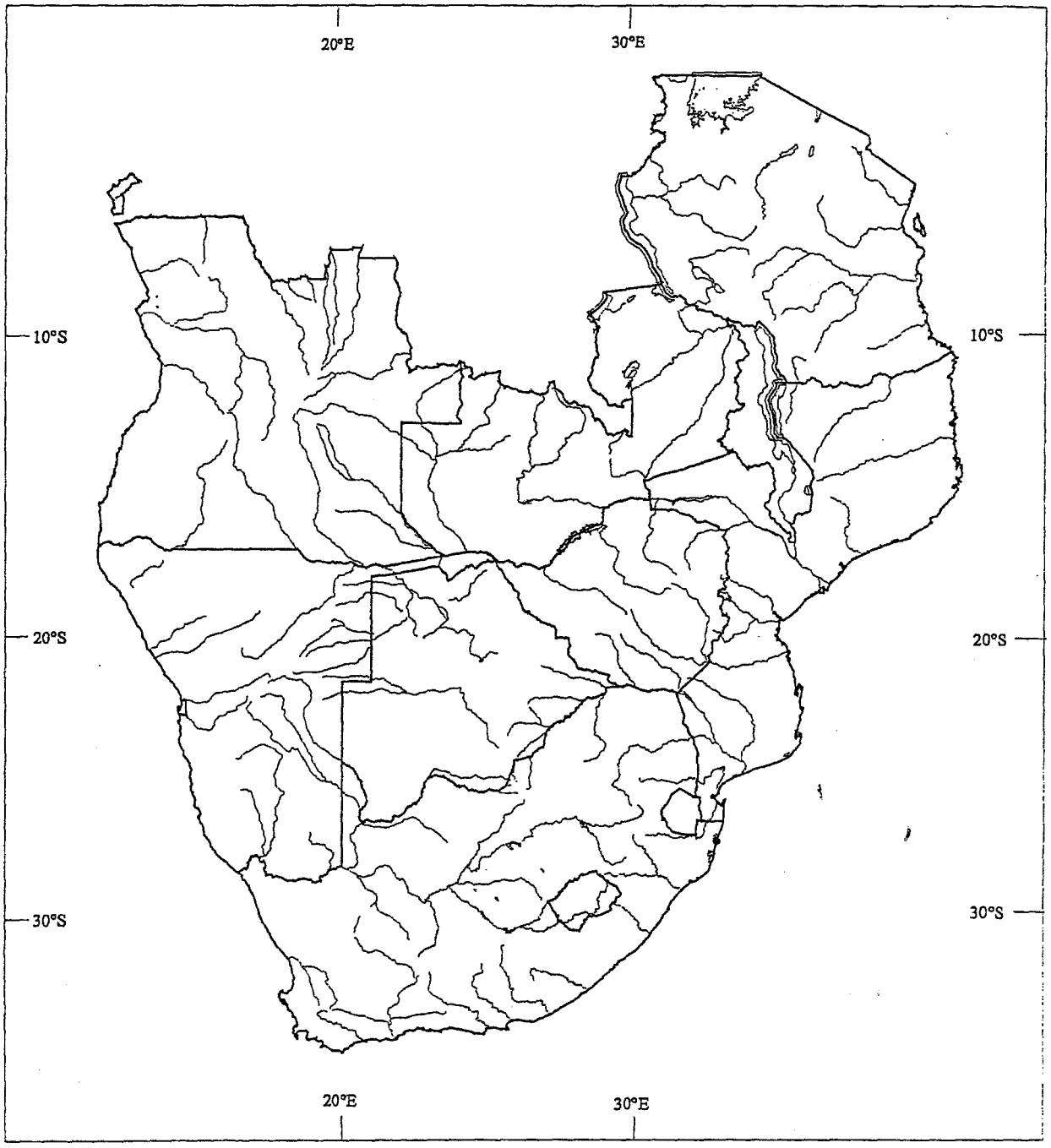


Figure F.161. Point distribution of *Caranx equula*. Scale approximately 1:25 000 000

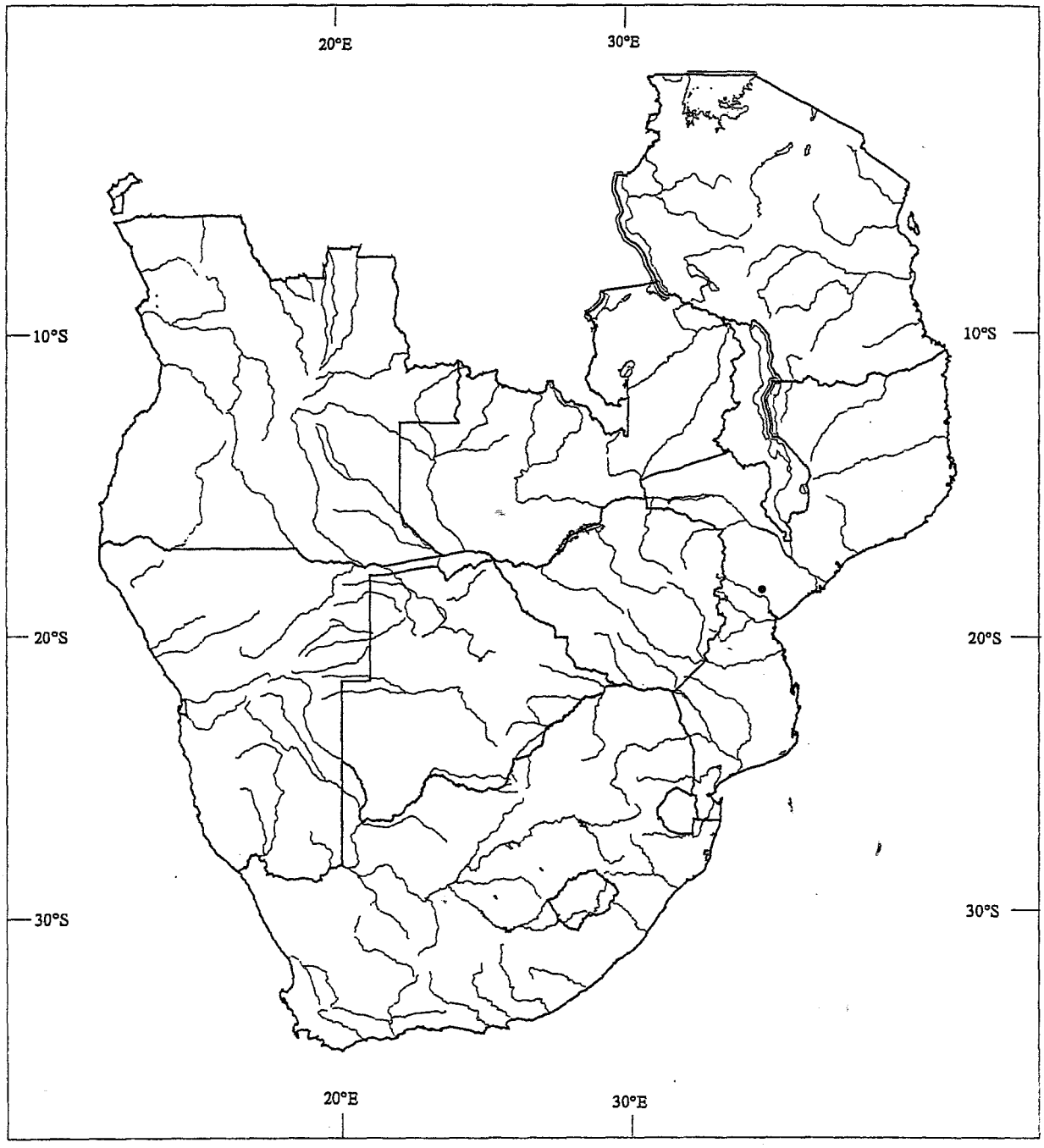


Figure F.162. Point distribution of *Caranx fasciatus*. Scale approximately 1:25 000 000

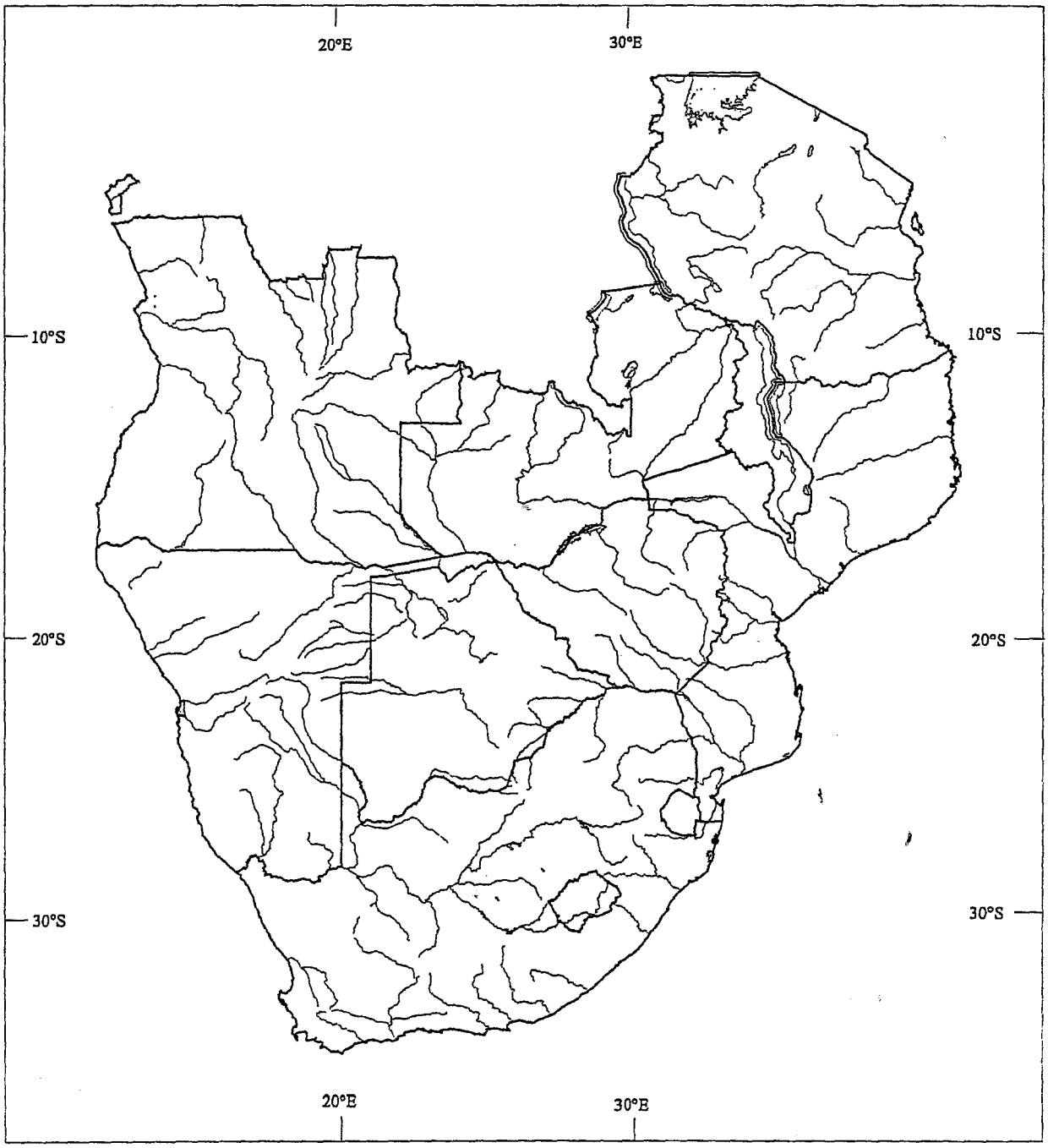


Figure F.163. Point distribution of *Caranx hippos*. Scale approximately 1:25 000 000

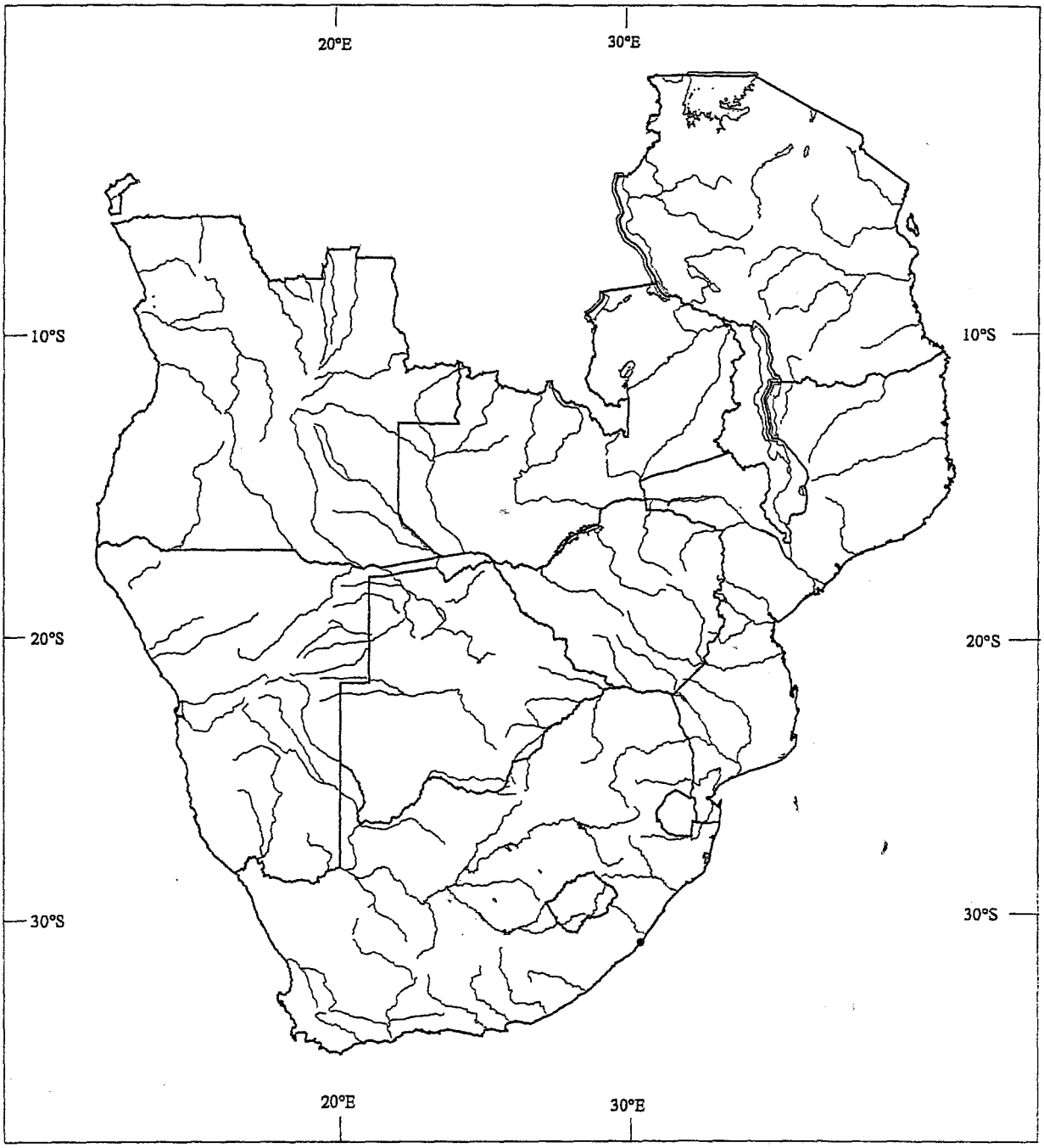


Figure F.164. Point distribution of *Caranx ignobilis*. Scale approximately 1:25 000 000

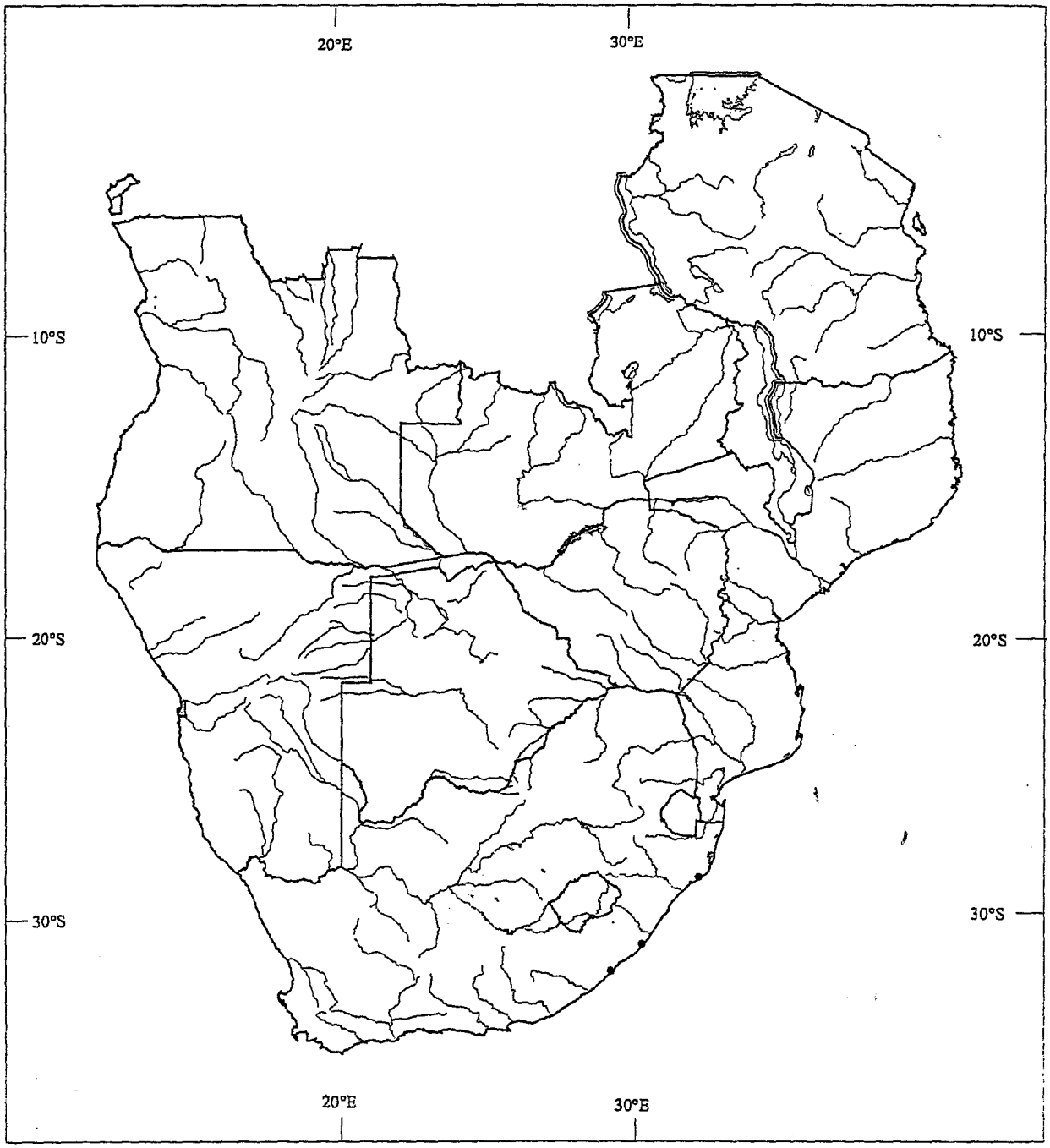


Figure F.165. Point distribution of *Caranx sexfasciatus*. Scale approximately 1:25 000 000

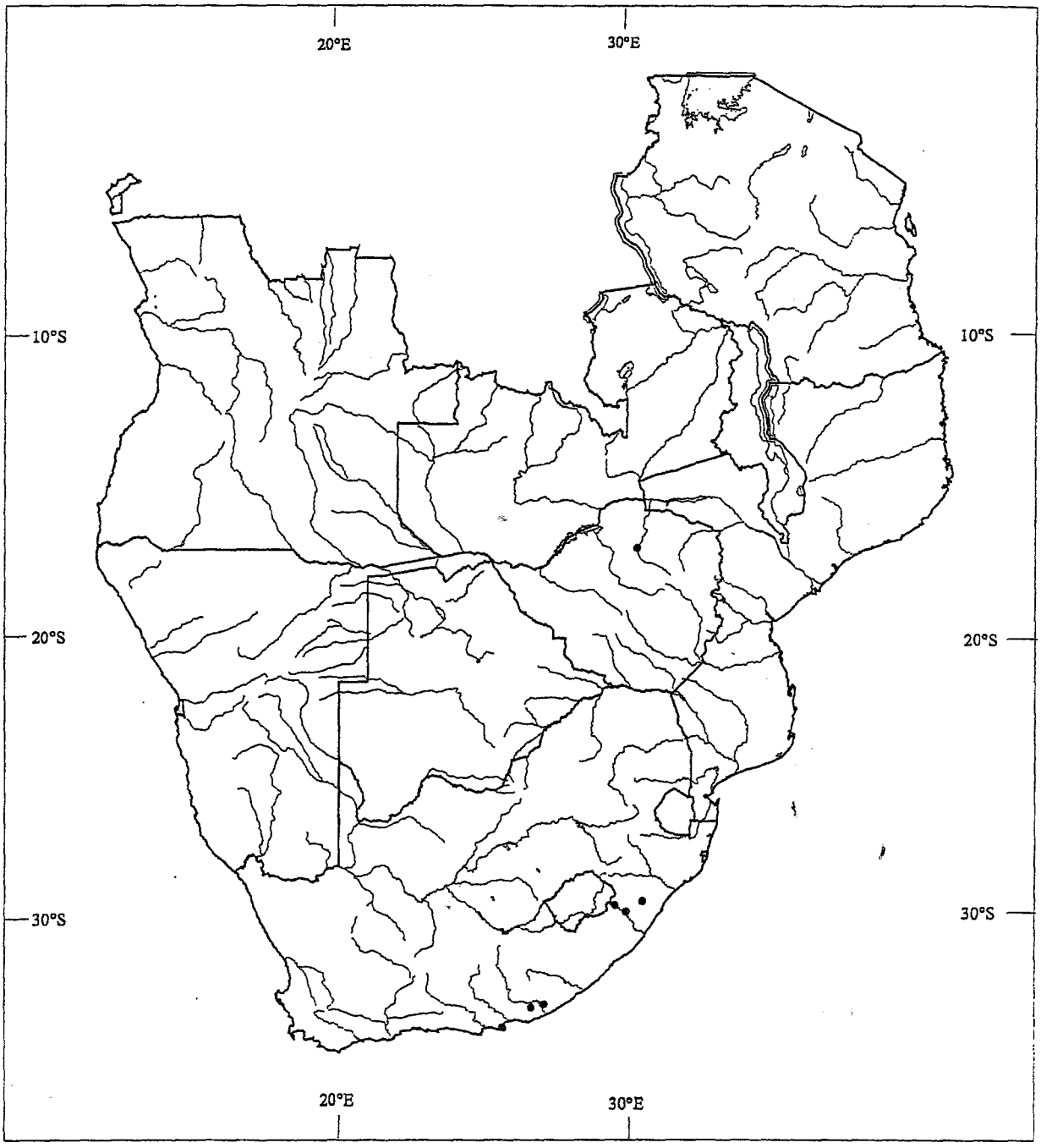


Figure F.166. Point distribution of *Carassius auratus*. Scale approximately 1:25 000 000

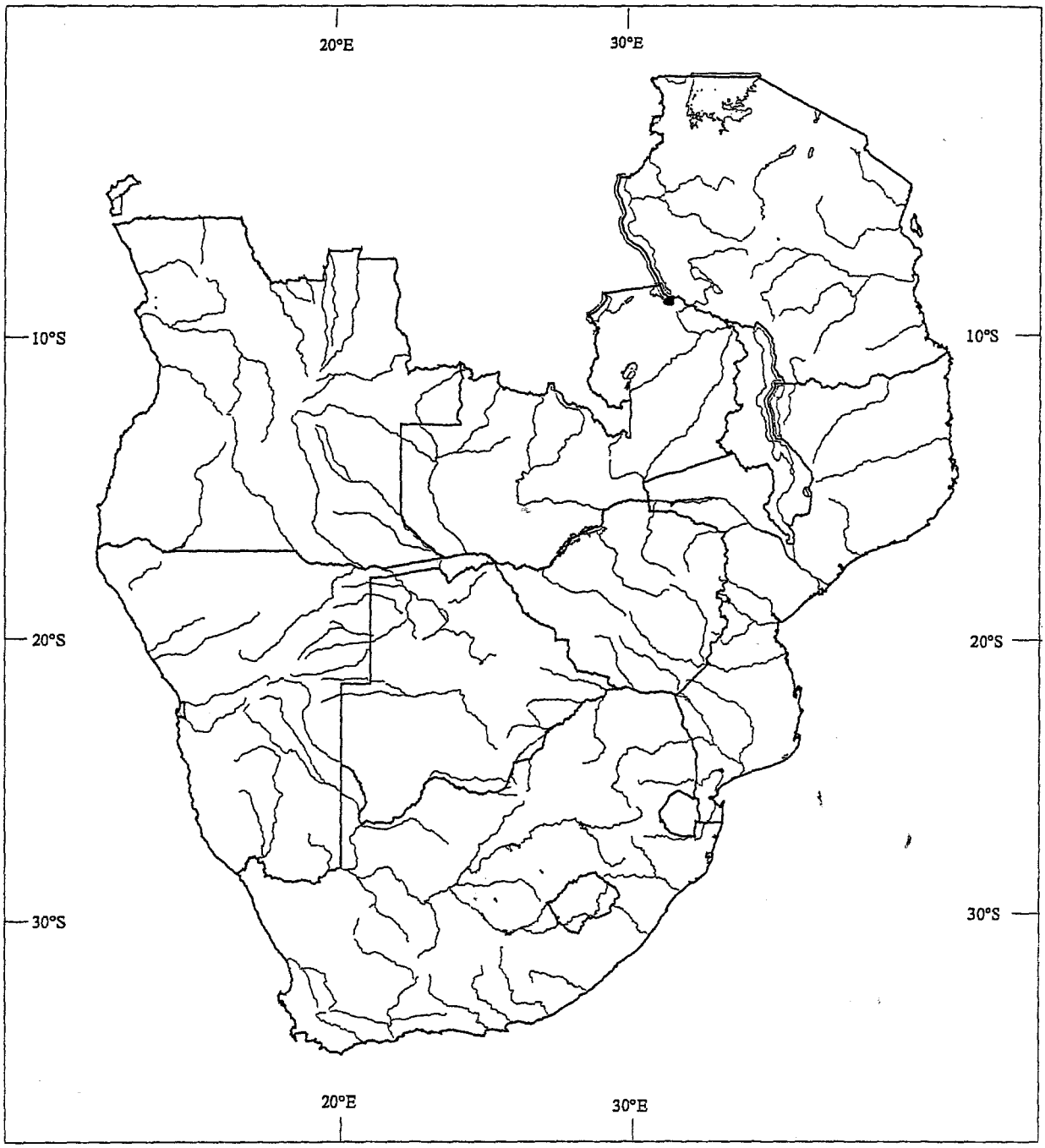


Figure F.167. Point distribution of *Chalinochromis brichardi*. Scale approximately 1:25 000 000

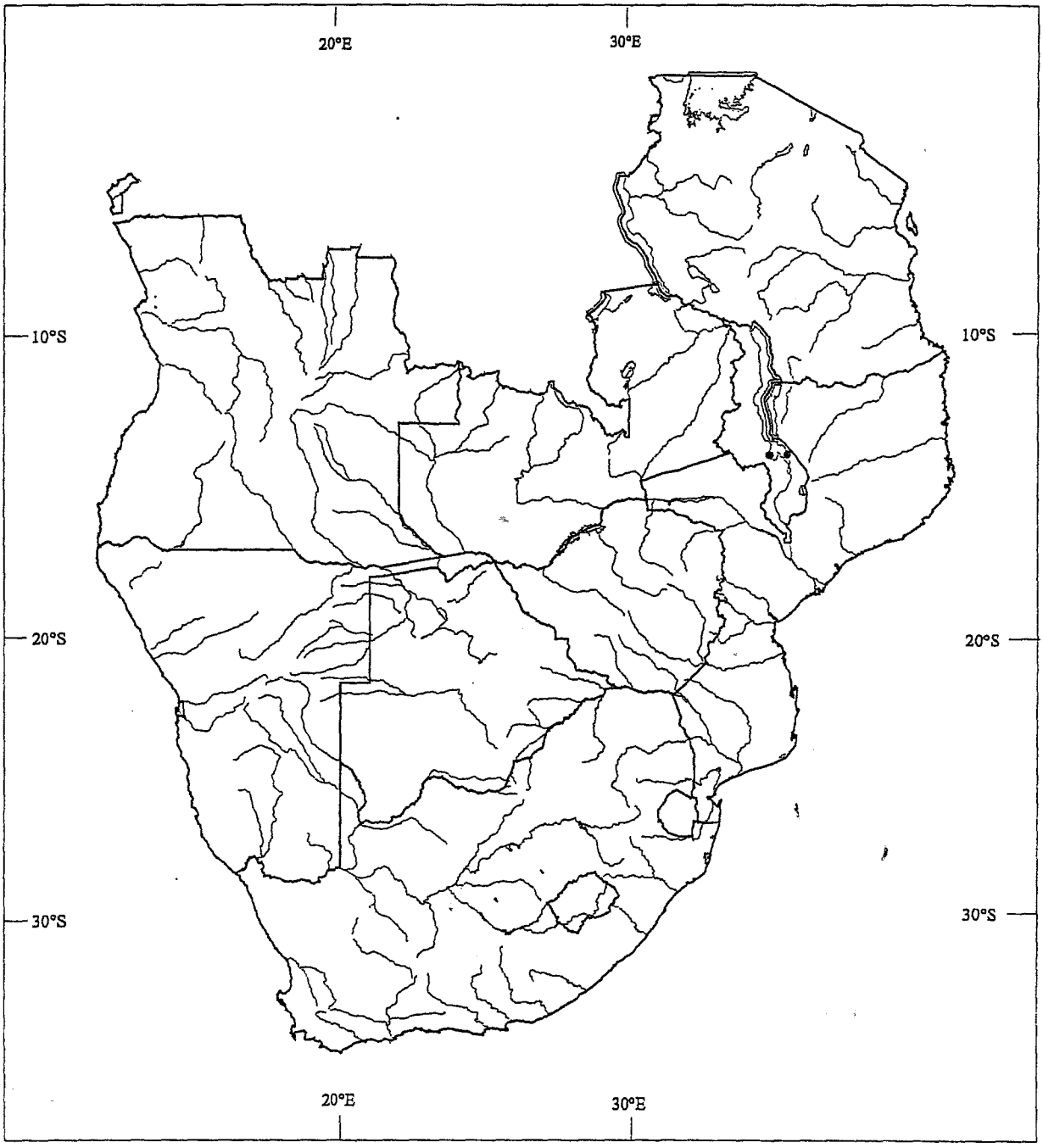


Figure F.168. Point distribution of *Champsochromis caerulea*. Scale approximately 1:25 000 000

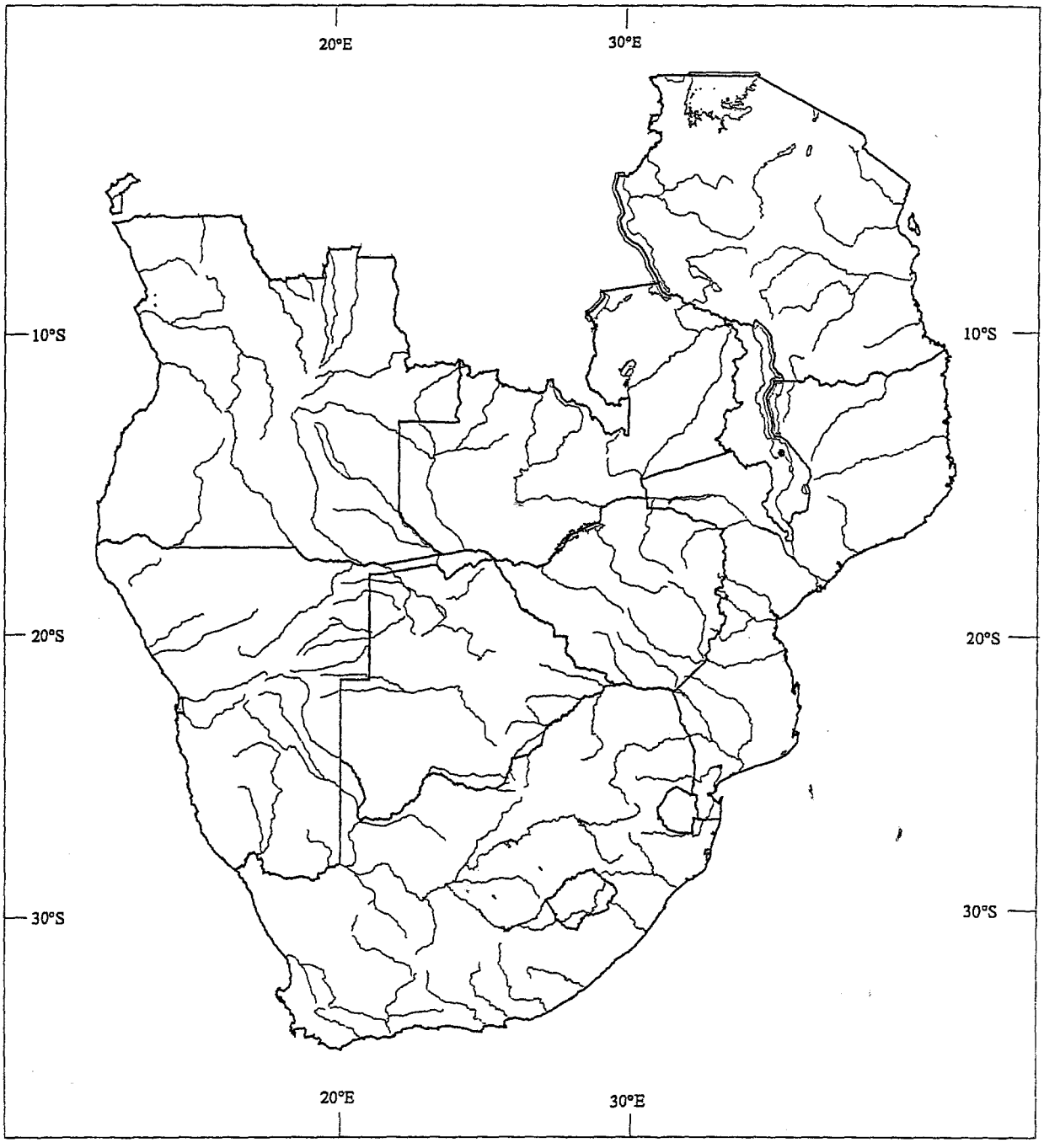


Figure F.169. Point distribution of *Champsochromis spilorhynchus*. Scale approximately 1:25 000 000

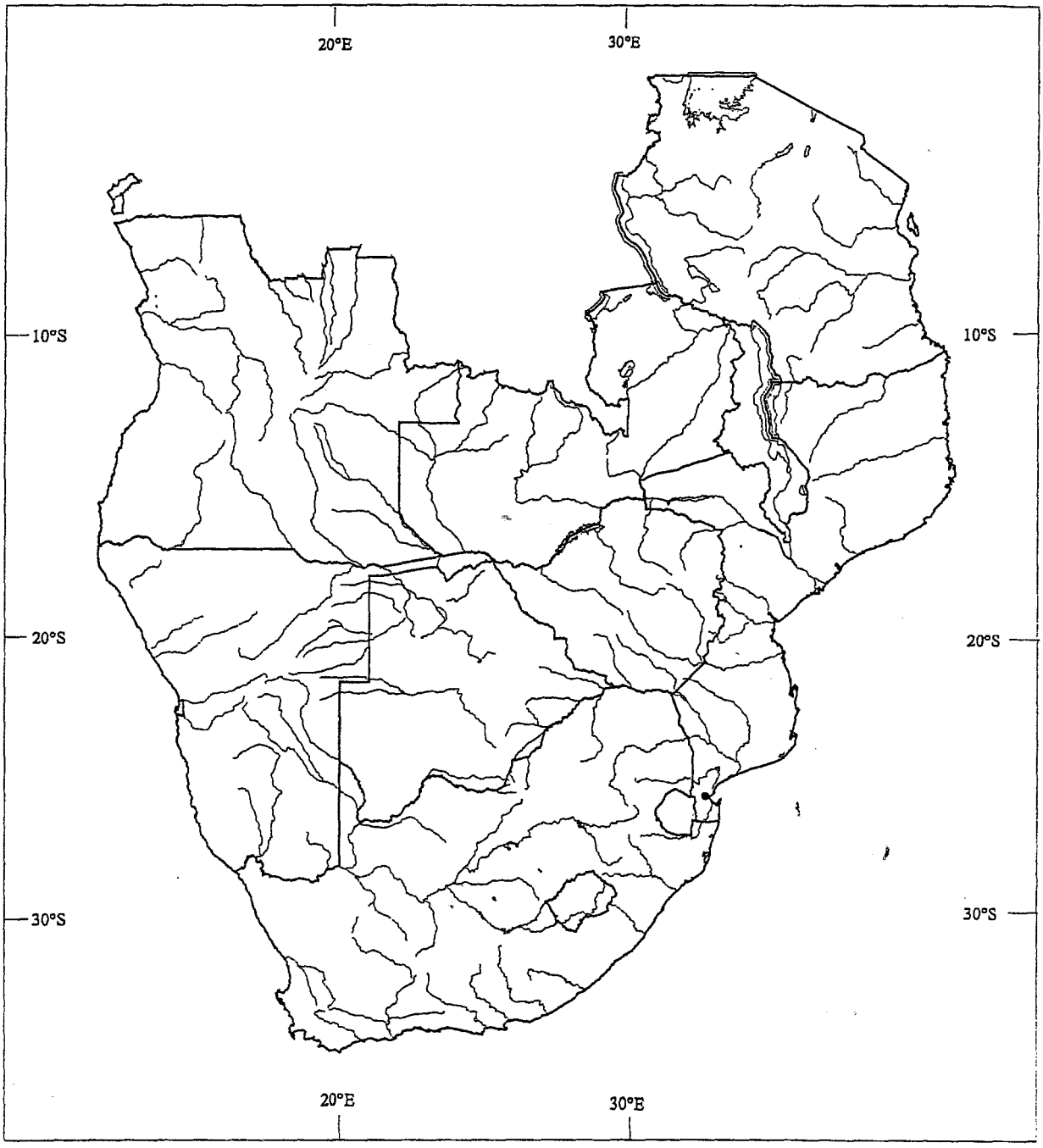


Figure F.170. Point distribution of *Channa punctata*. Scale approximately 1:25 000 000

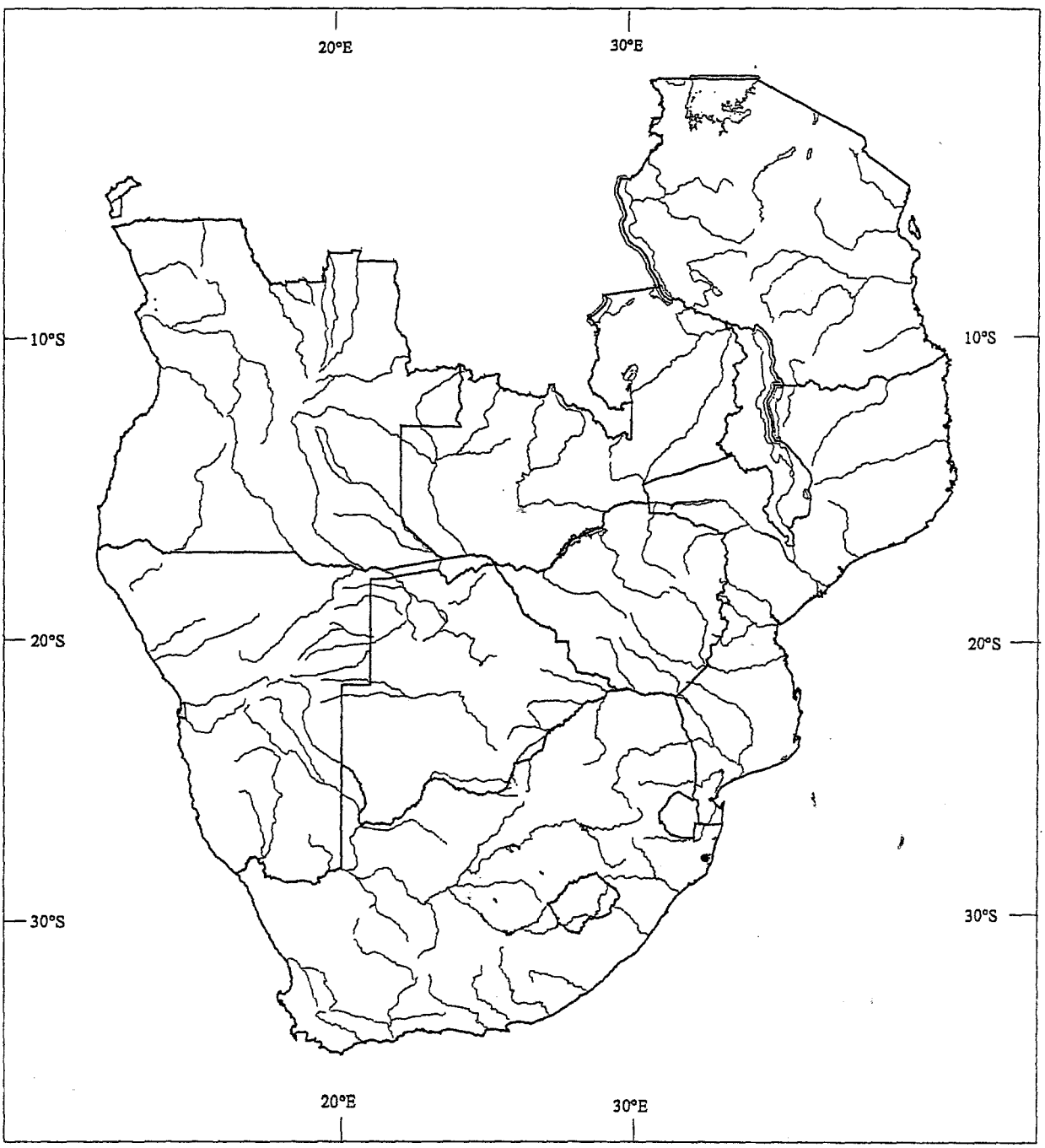


Figure F.171. Point distribution of *Chanos chanos*. Scale approximately 1:25 000 000

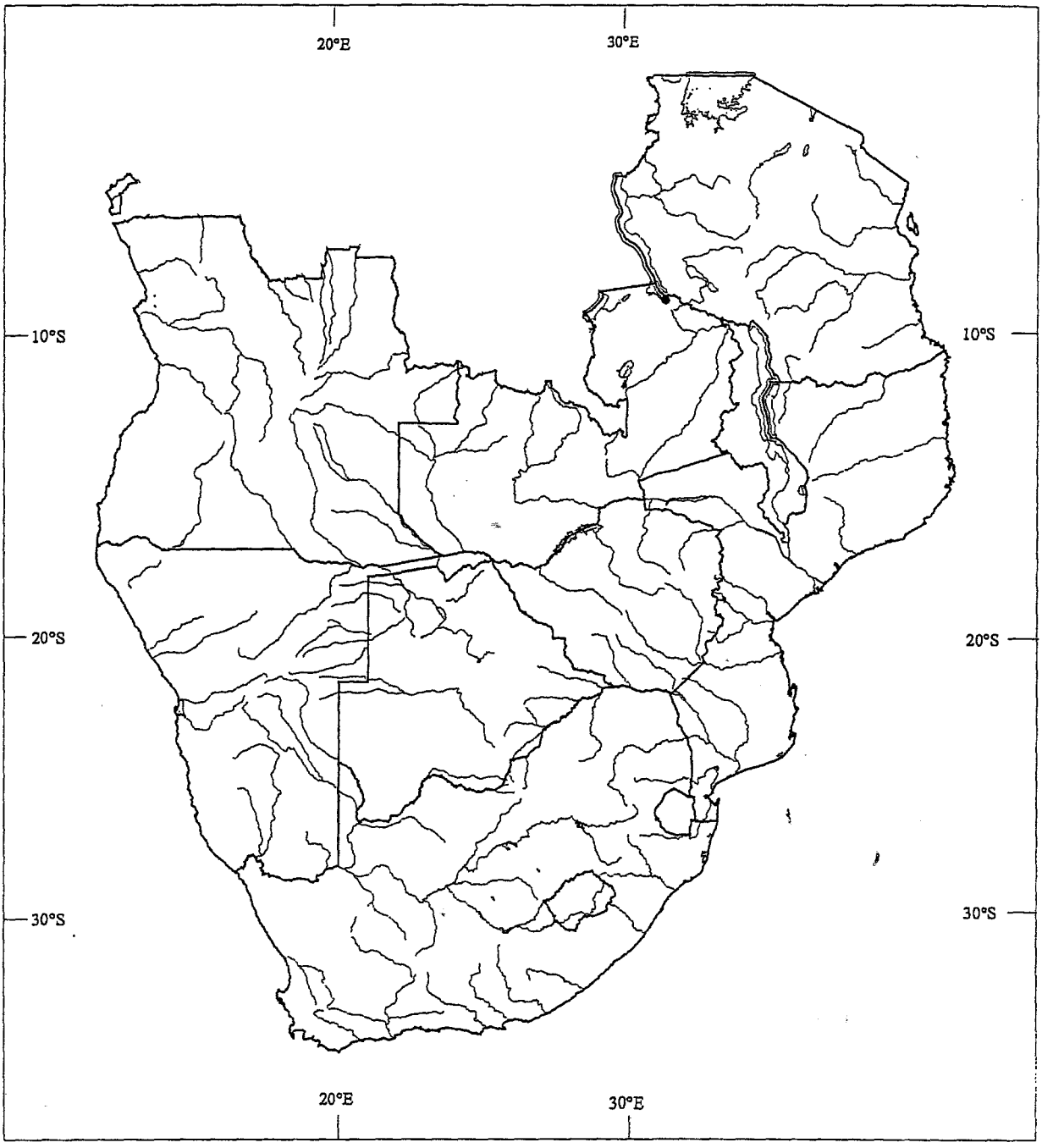


Figure F.172. Point distribution of *Chelaethiops minutus*. Scale approximately 1:25 000 000

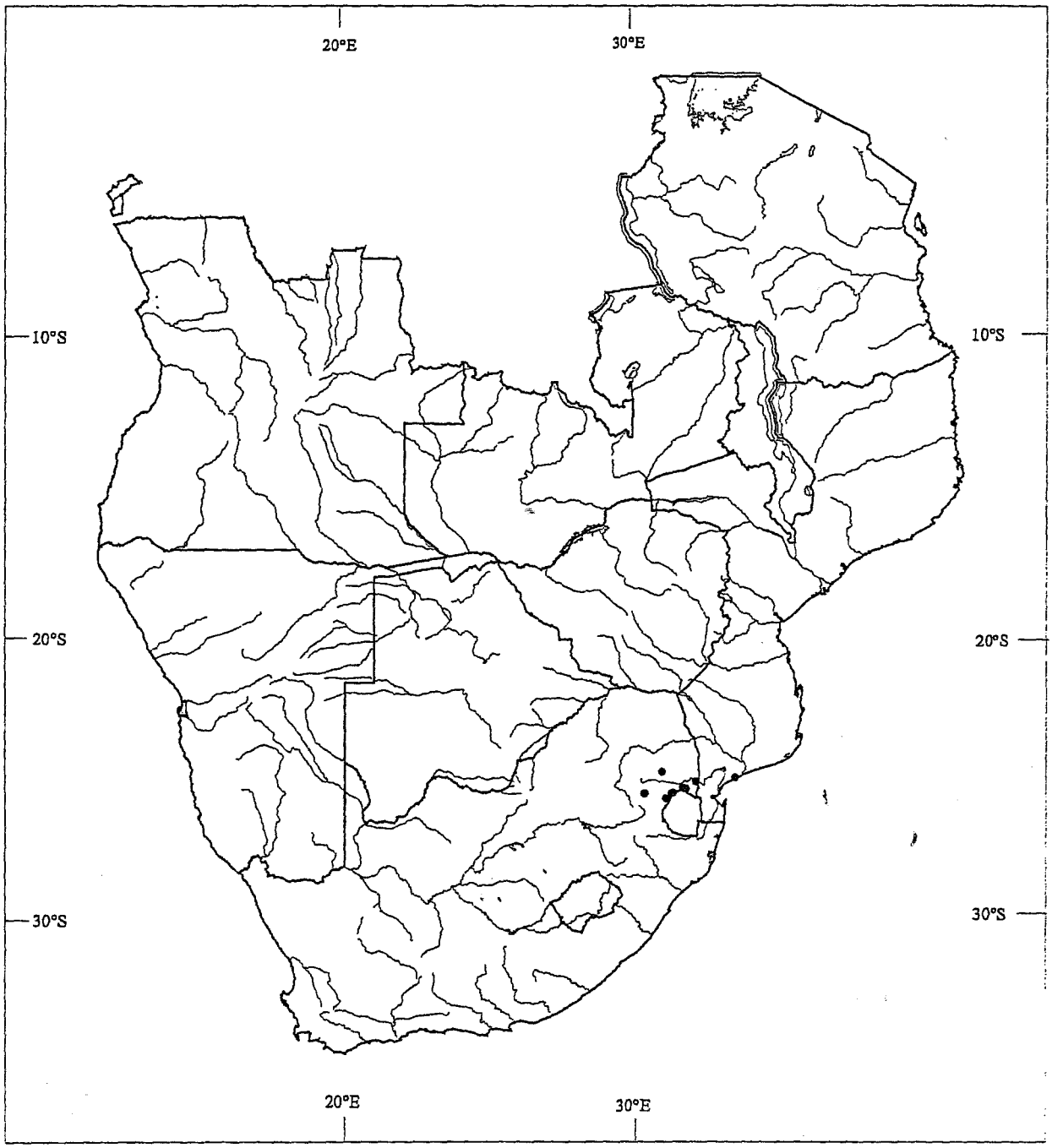


Figure F.173. Point distribution of *Chetia brevis*. Scale approximately 1:25 000 000

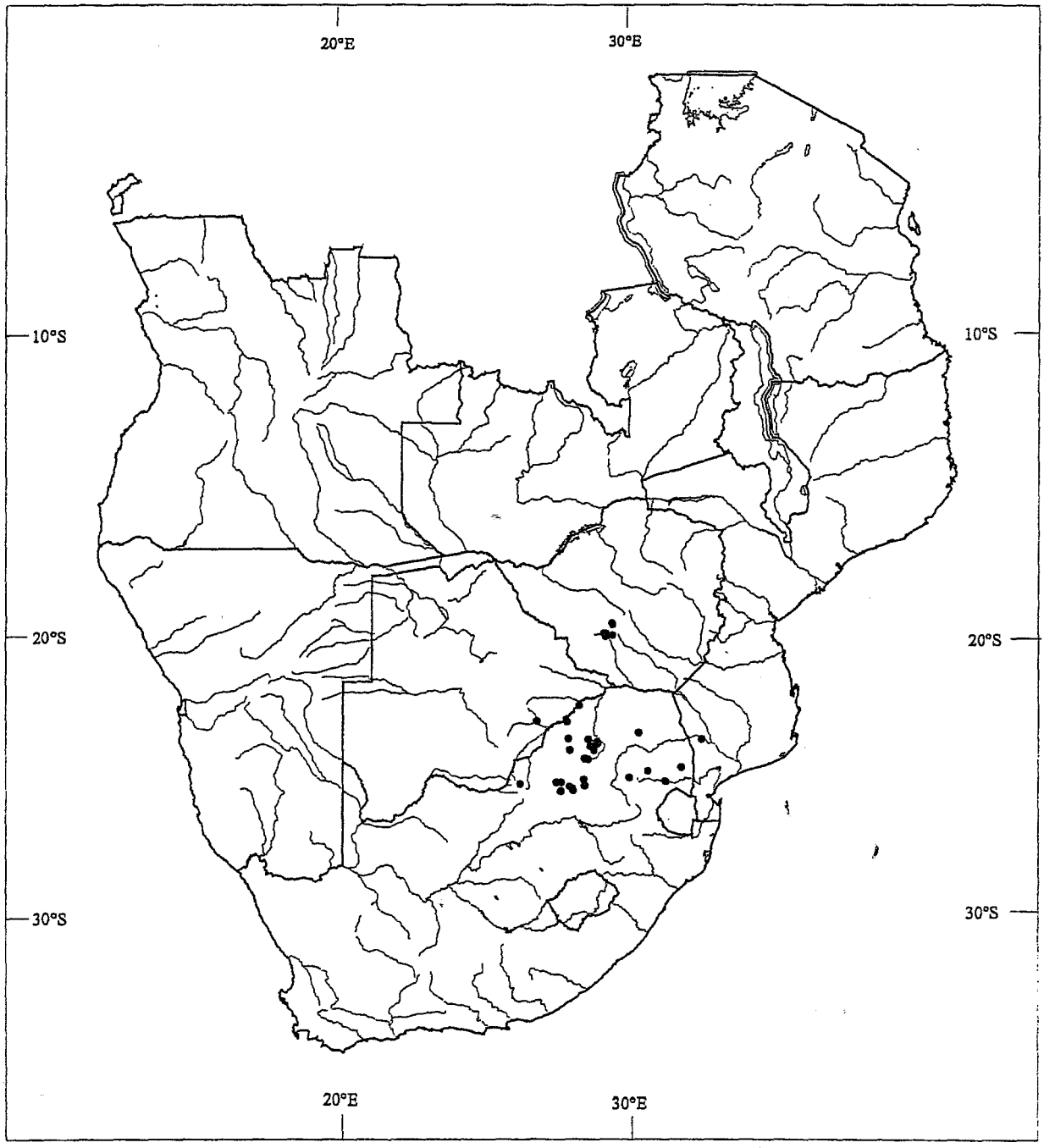


Figure F.174. Point distribution of *Chetia flaviventris*. Scale approximately 1:25 000 000

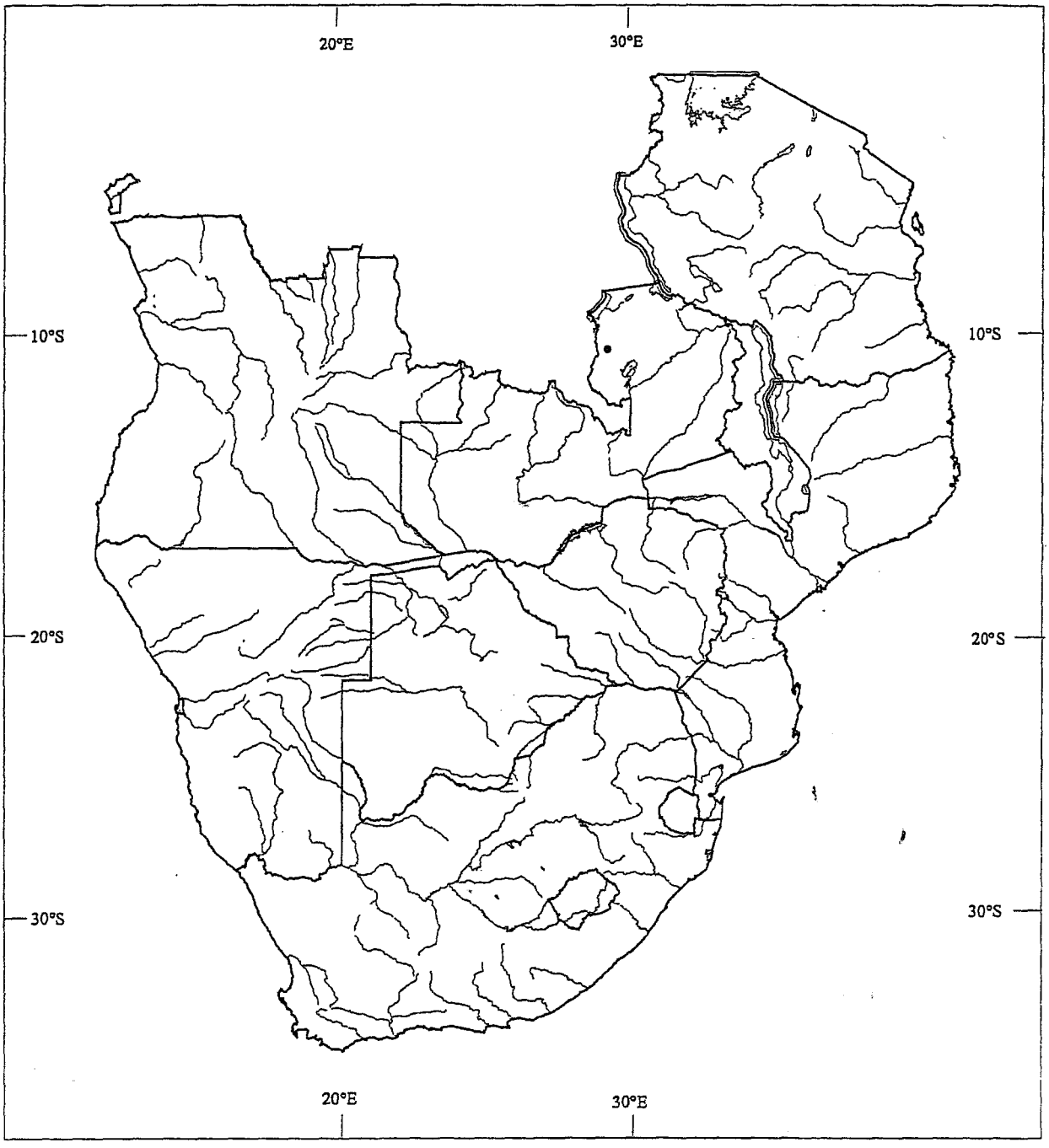


Figure F.175. Point distribution of *Chetia mola*. Scale approximately 1:25 000 000

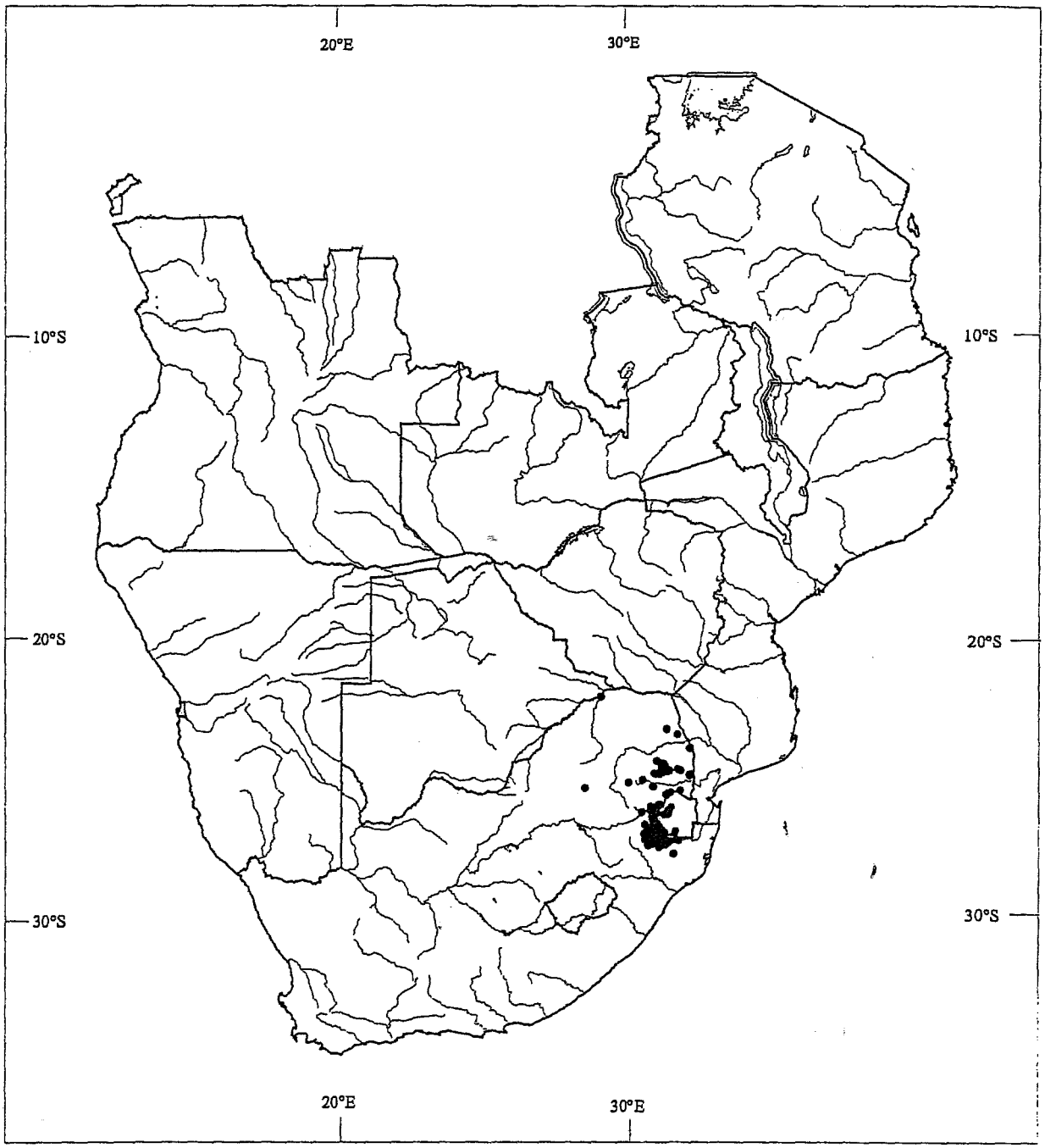


Figure F.176. Point distribution of *Chiloglanis anoterus*. Scale approximately 1:25 000 000

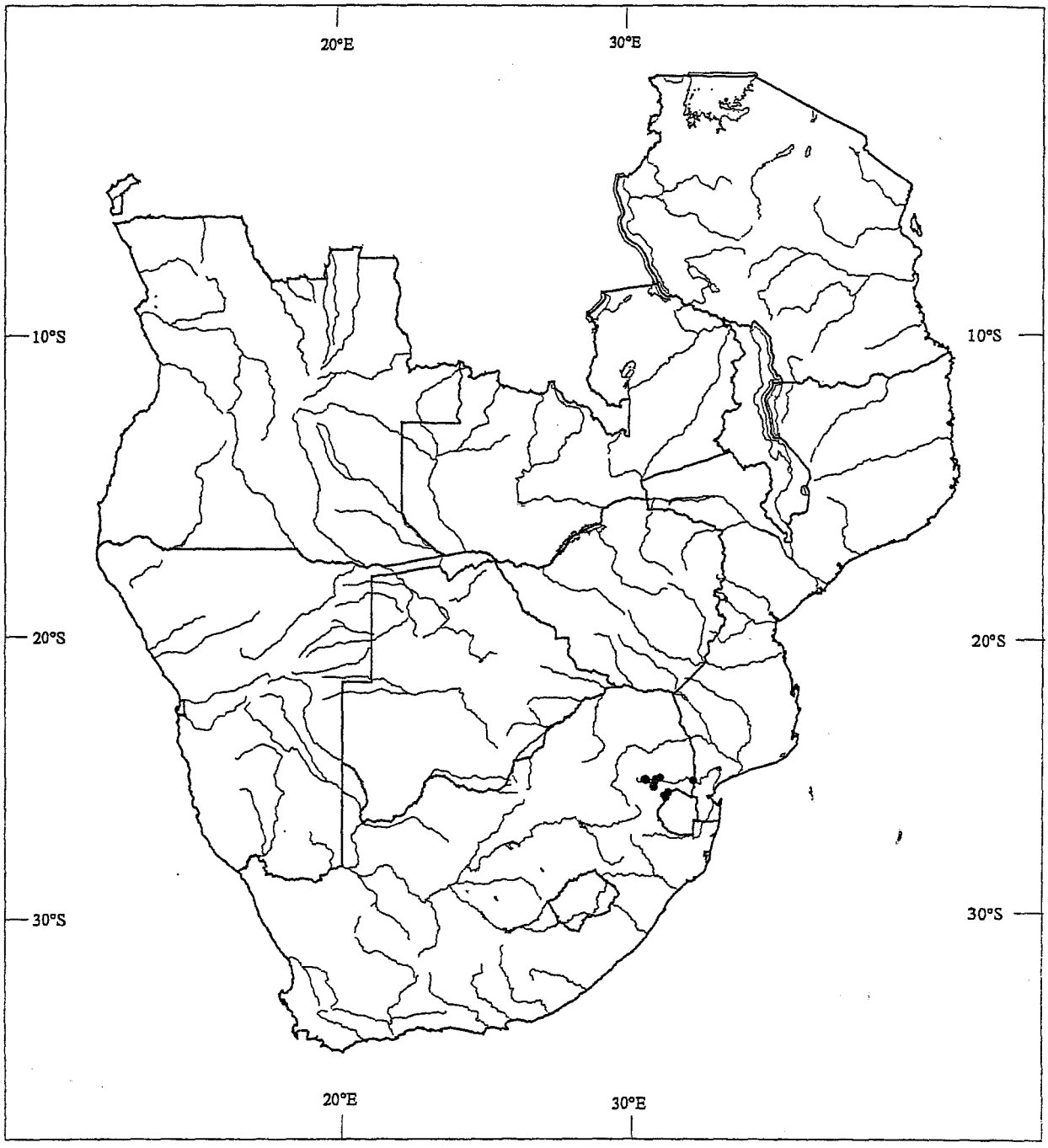


Figure F.177. Point distribution of *Chiloglanis bifurcus*. Scale approximately 1:25 000 000

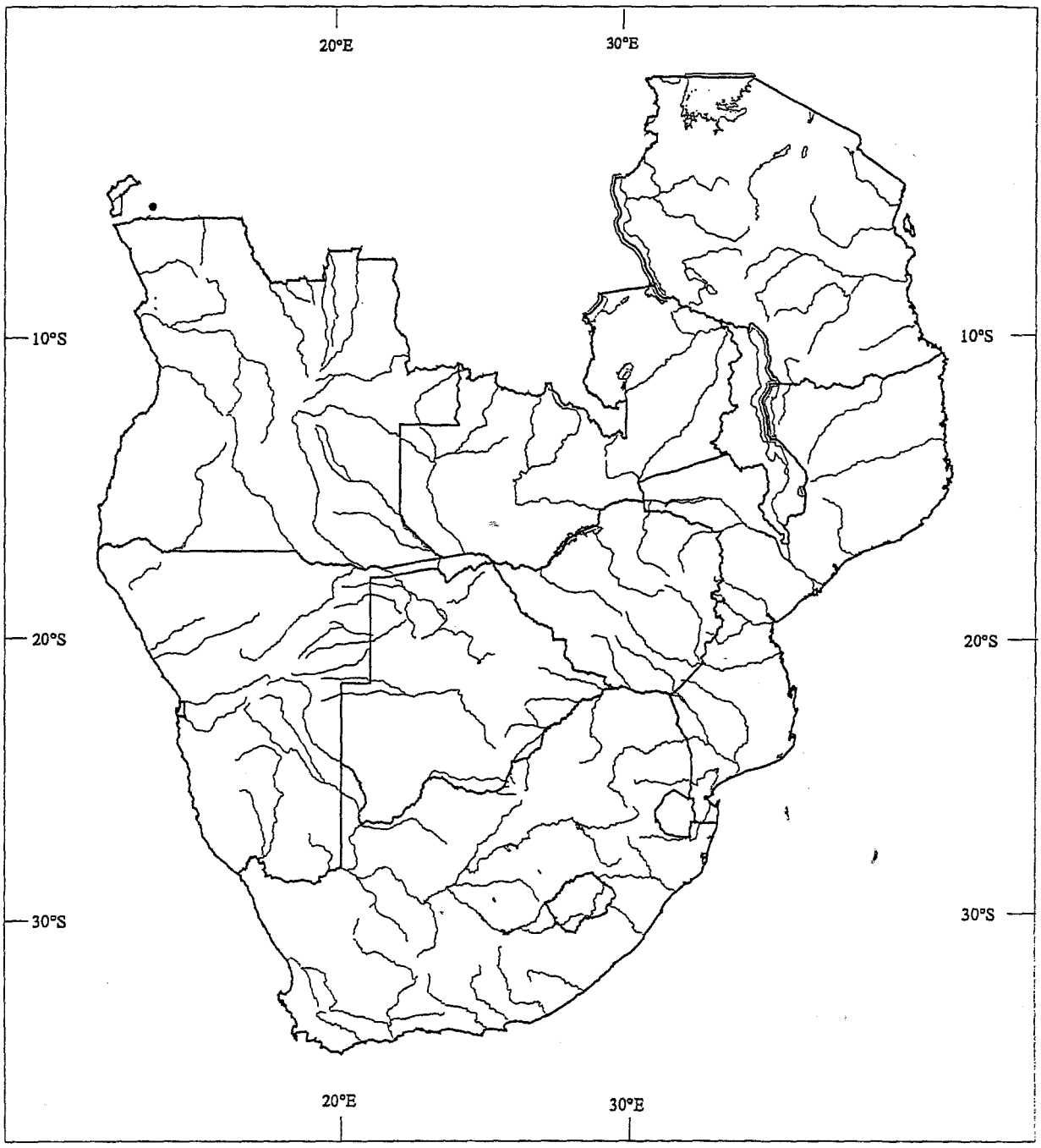


Figure F.178. Point distribution of *Chiloglanis carnosus*. Scale approximately 1:25 000 000

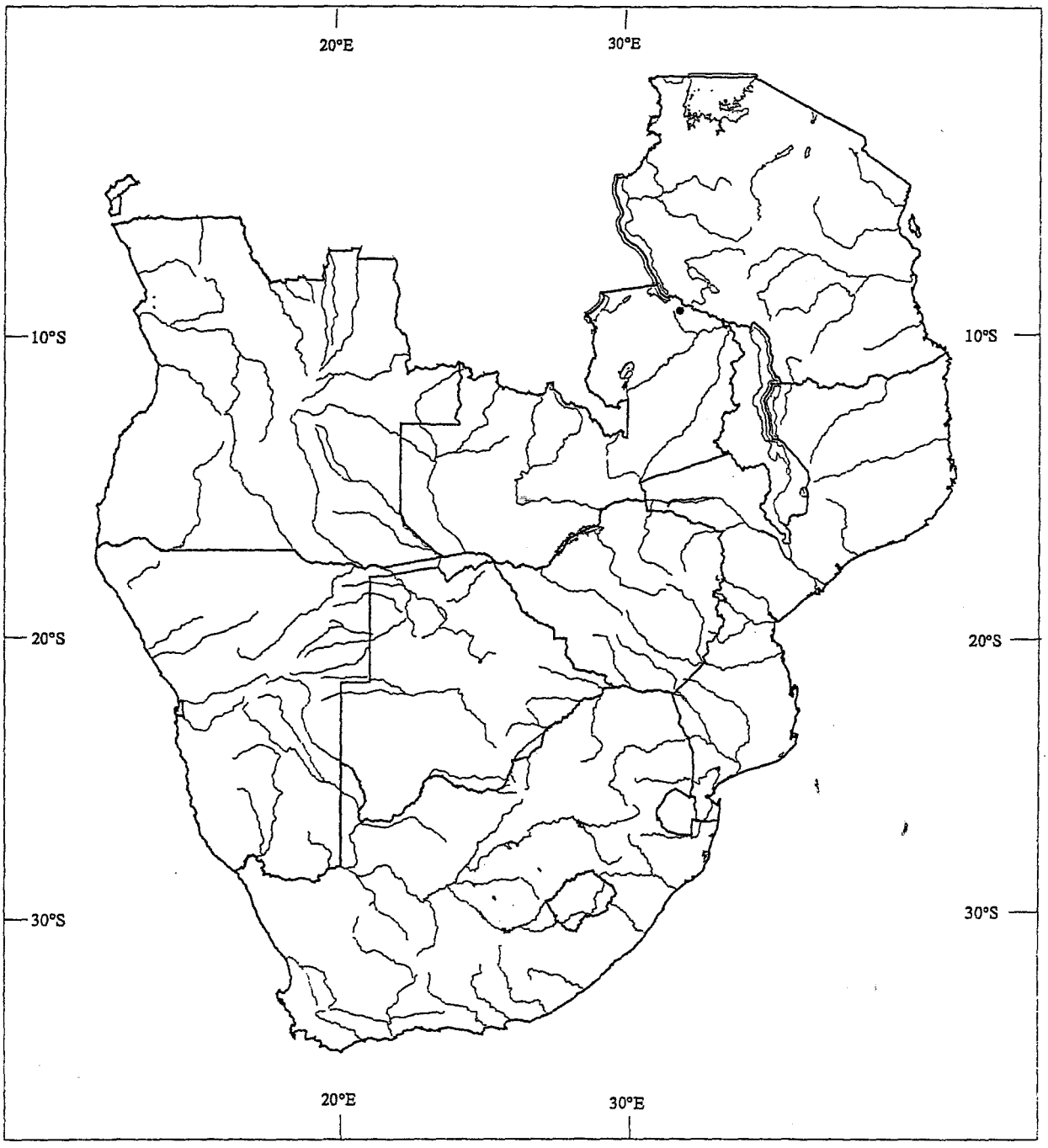


Figure F.179. Point distribution of *Chiloglanis deckenii*. Scale approximately 1:25 000 000

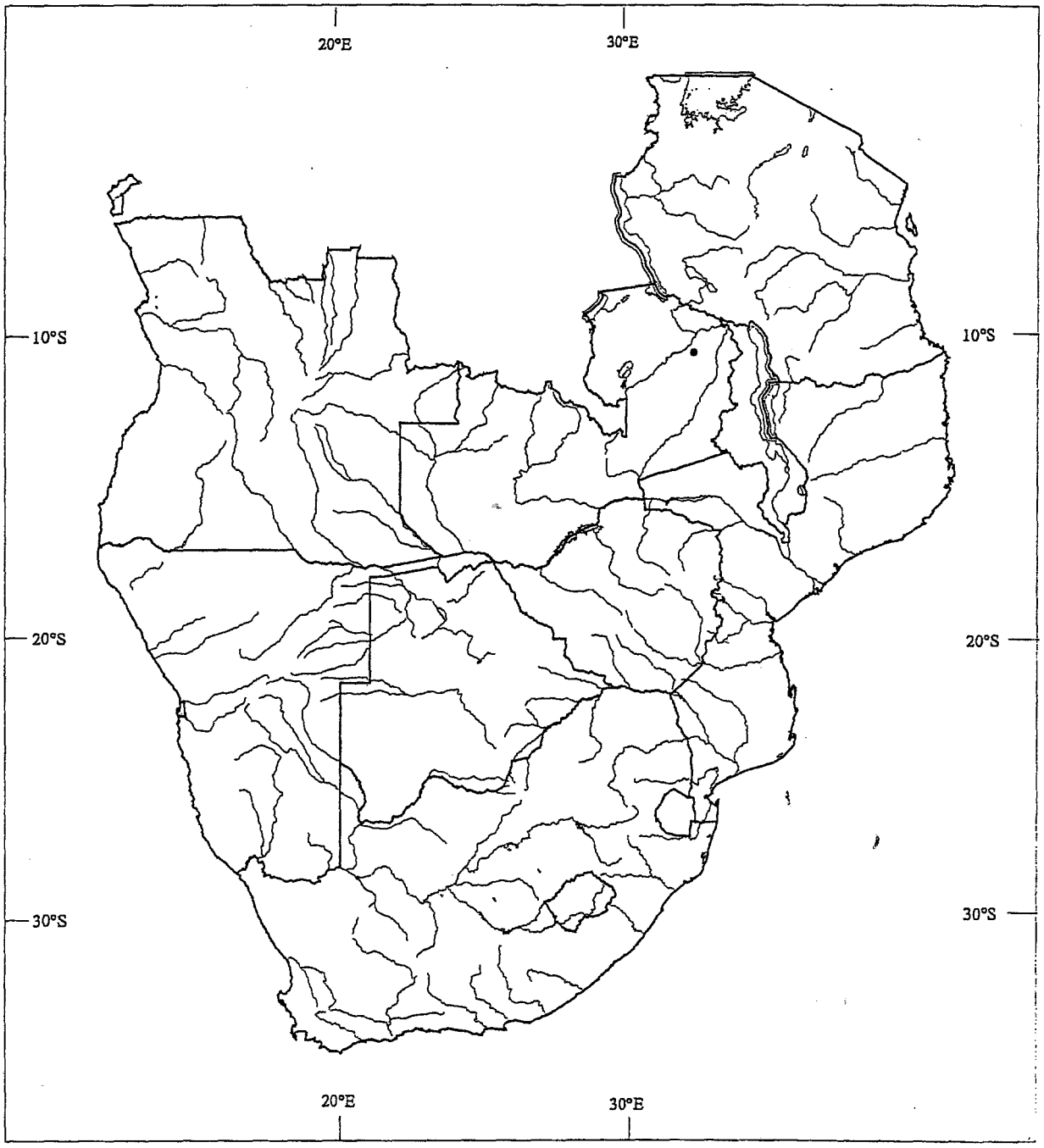


Figure F.180. Point distribution of *Chiloglanis elizabethianus*. Scale approximately 1:25 000 000

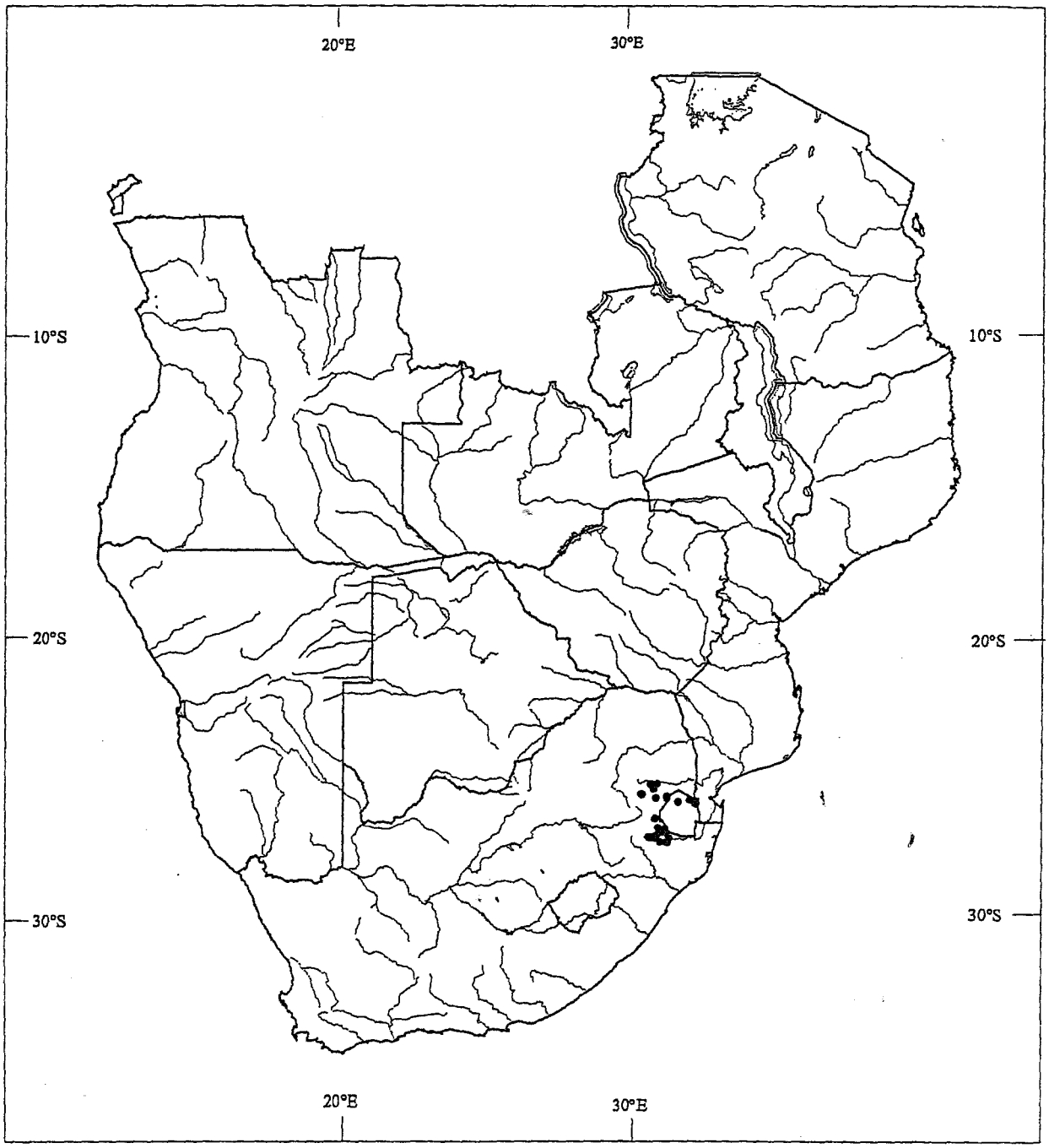


Figure F.181. Point distribution of *Chiloglanis emarginatus*. Scale approximately 1:25 000 000

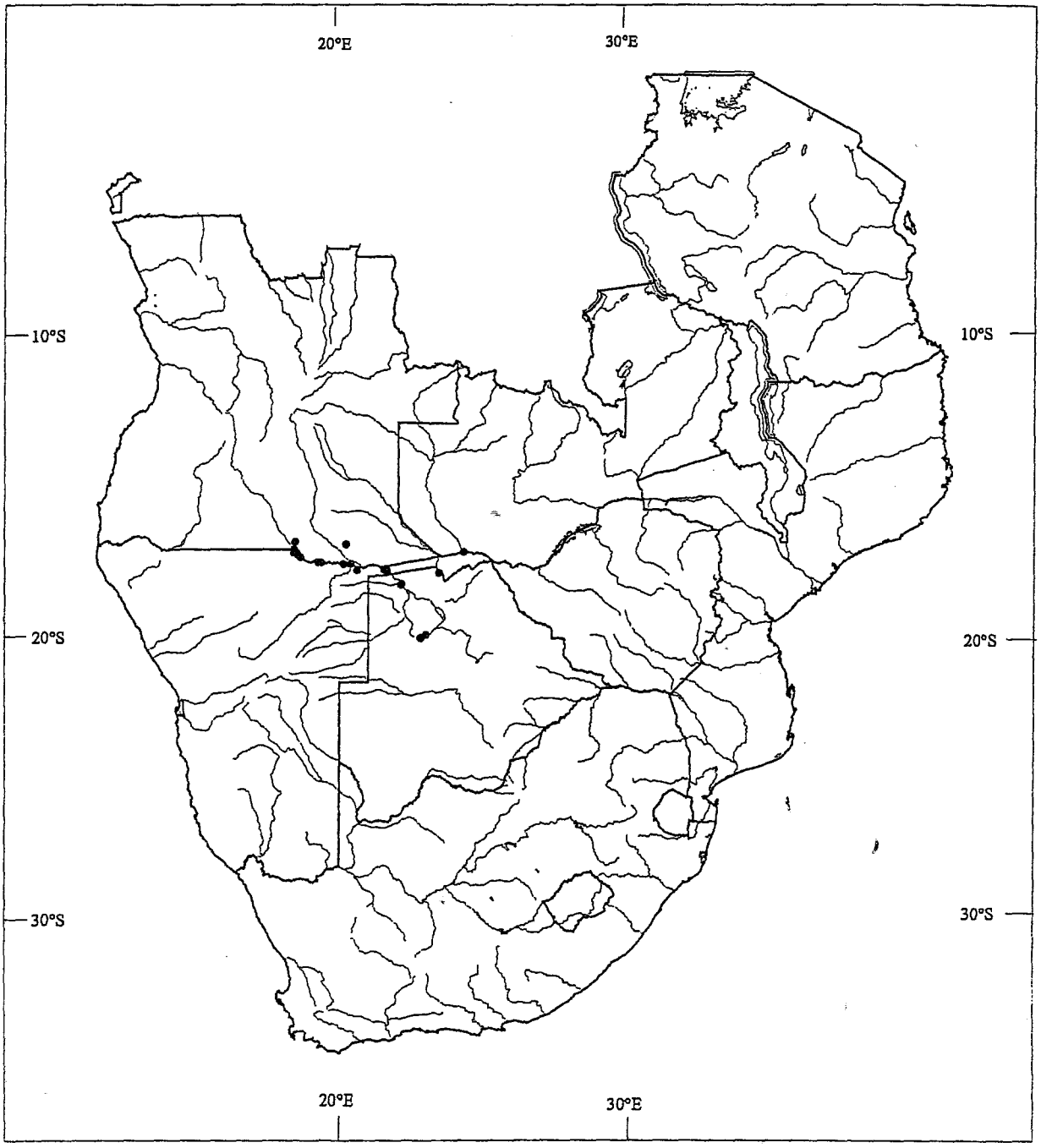


Figure F.182. Point distribution of *Chiloglanis fasciatus*. Scale approximately 1:25 000 000

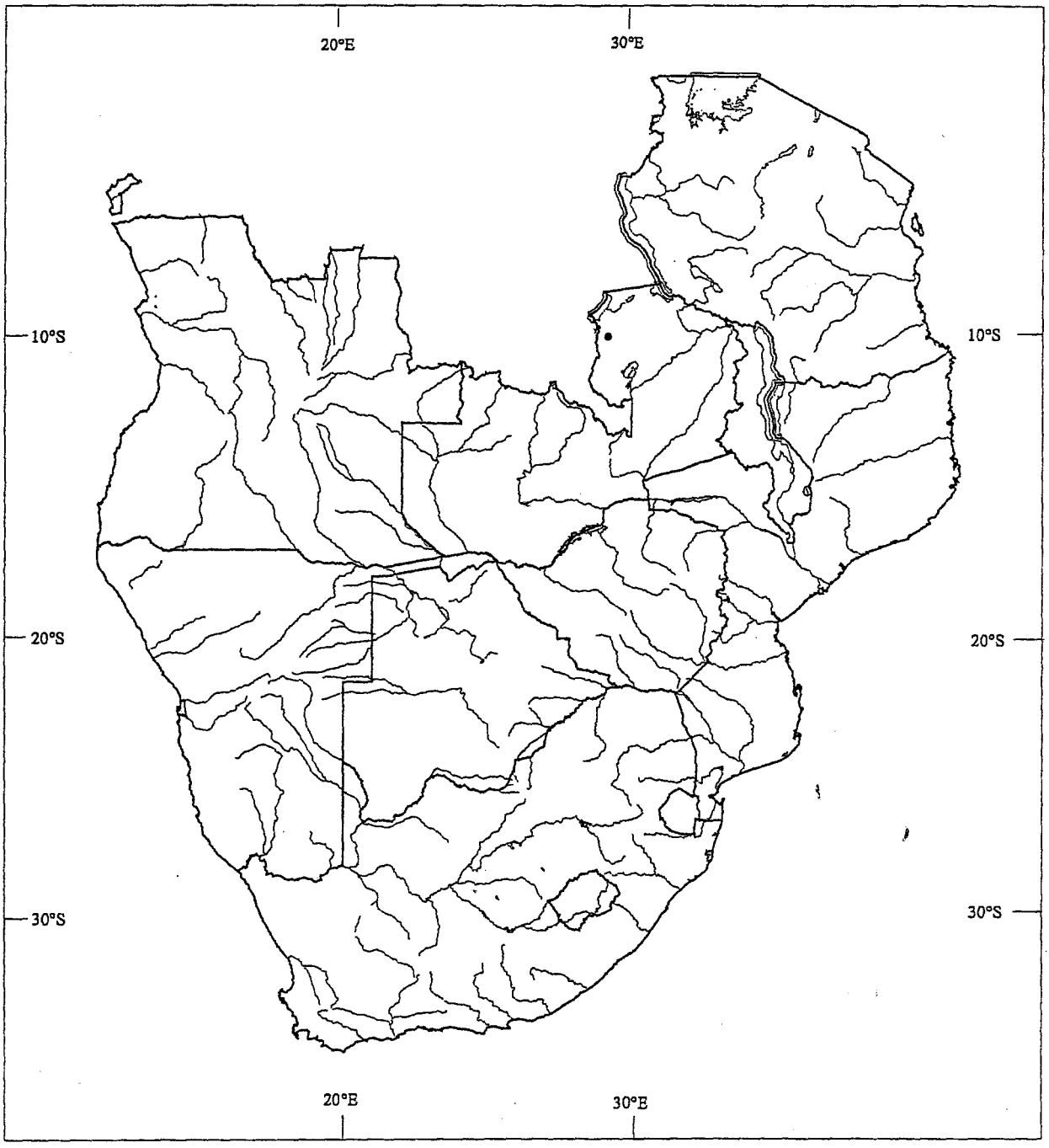


Figure F.183. Point distribution of *Chiloglanis macropterus*. Scale approximately 1:25 000 000

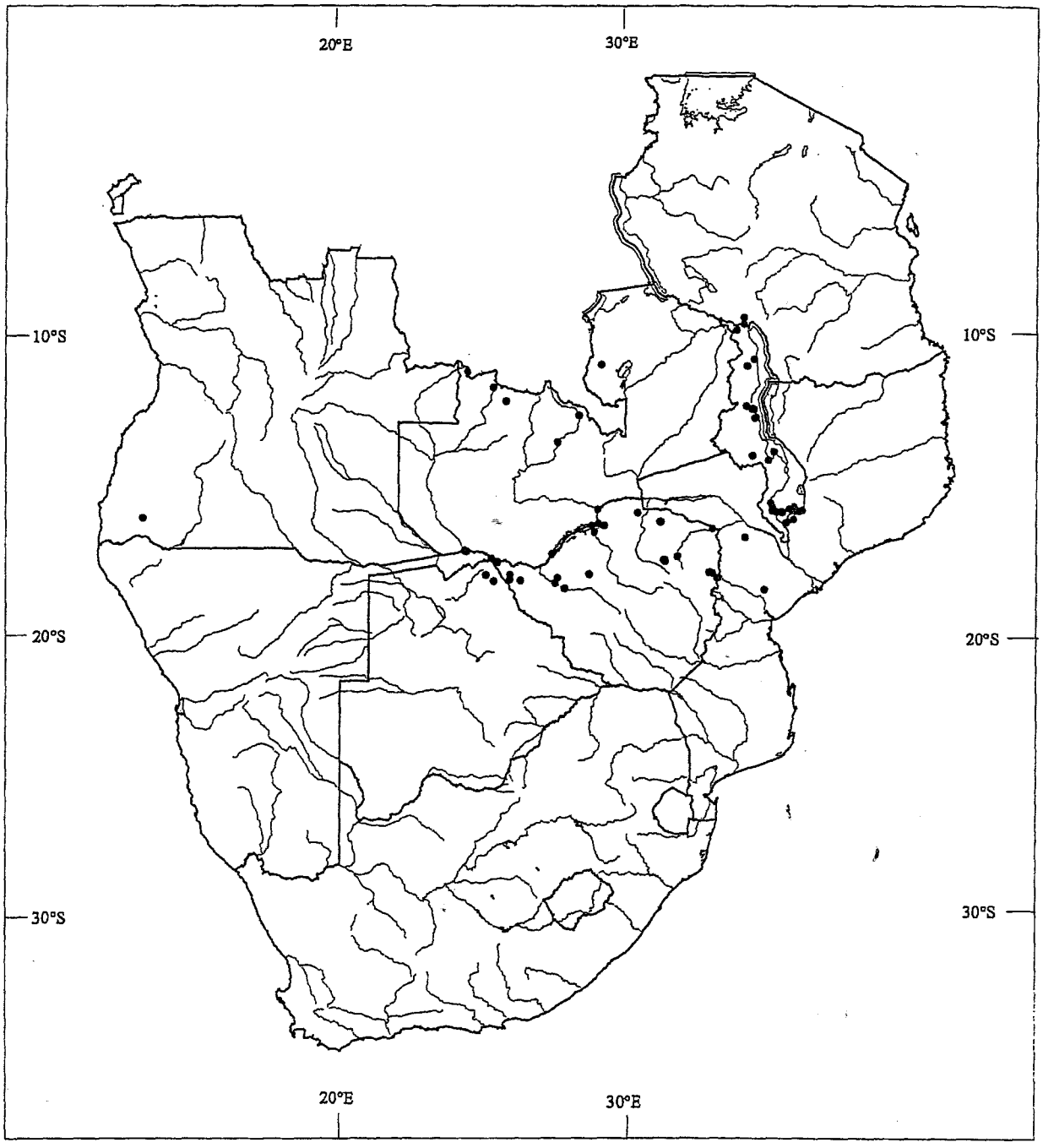


Figure F.184. Point distribution of *Chiloglanis neumanni*. Scale approximately 1:25 000 000

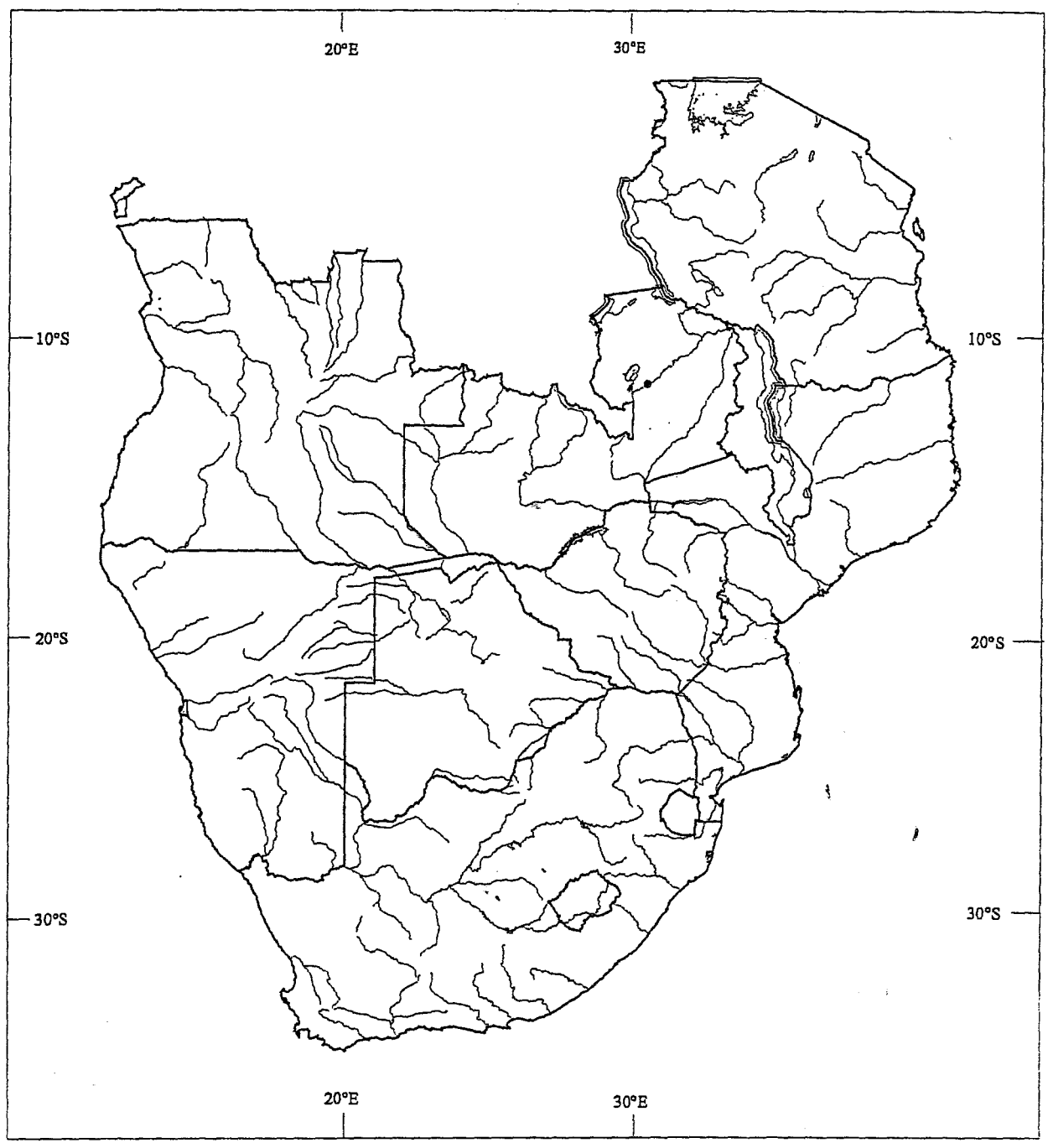


Figure F.185. Point distribution of *Chiloglanis nilotinus*. Scale approximately 1:25 000 000

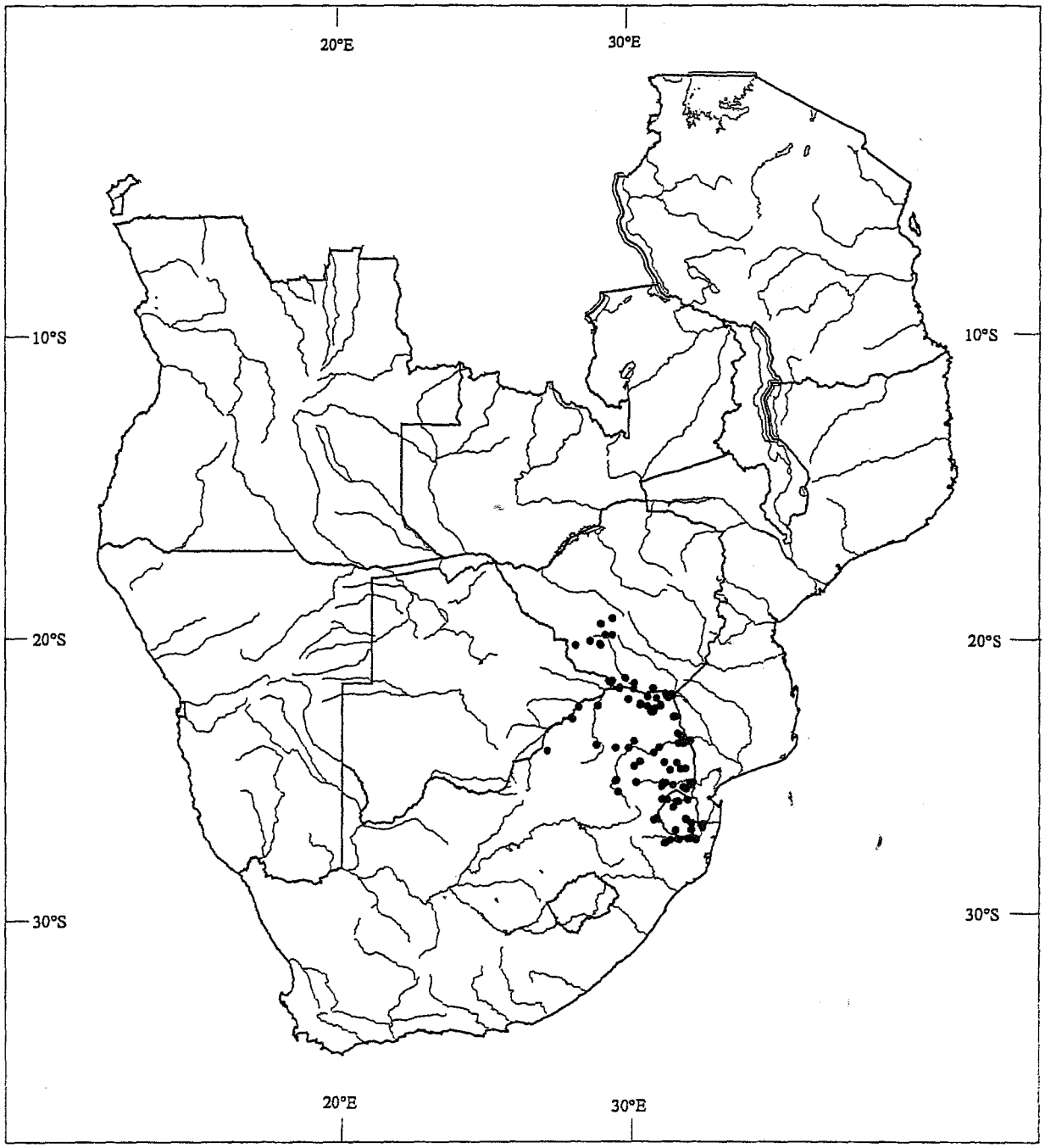


Figure F.186. Point distribution of *Chiloglanis paratus*. Scale approximately 1:25 000 000

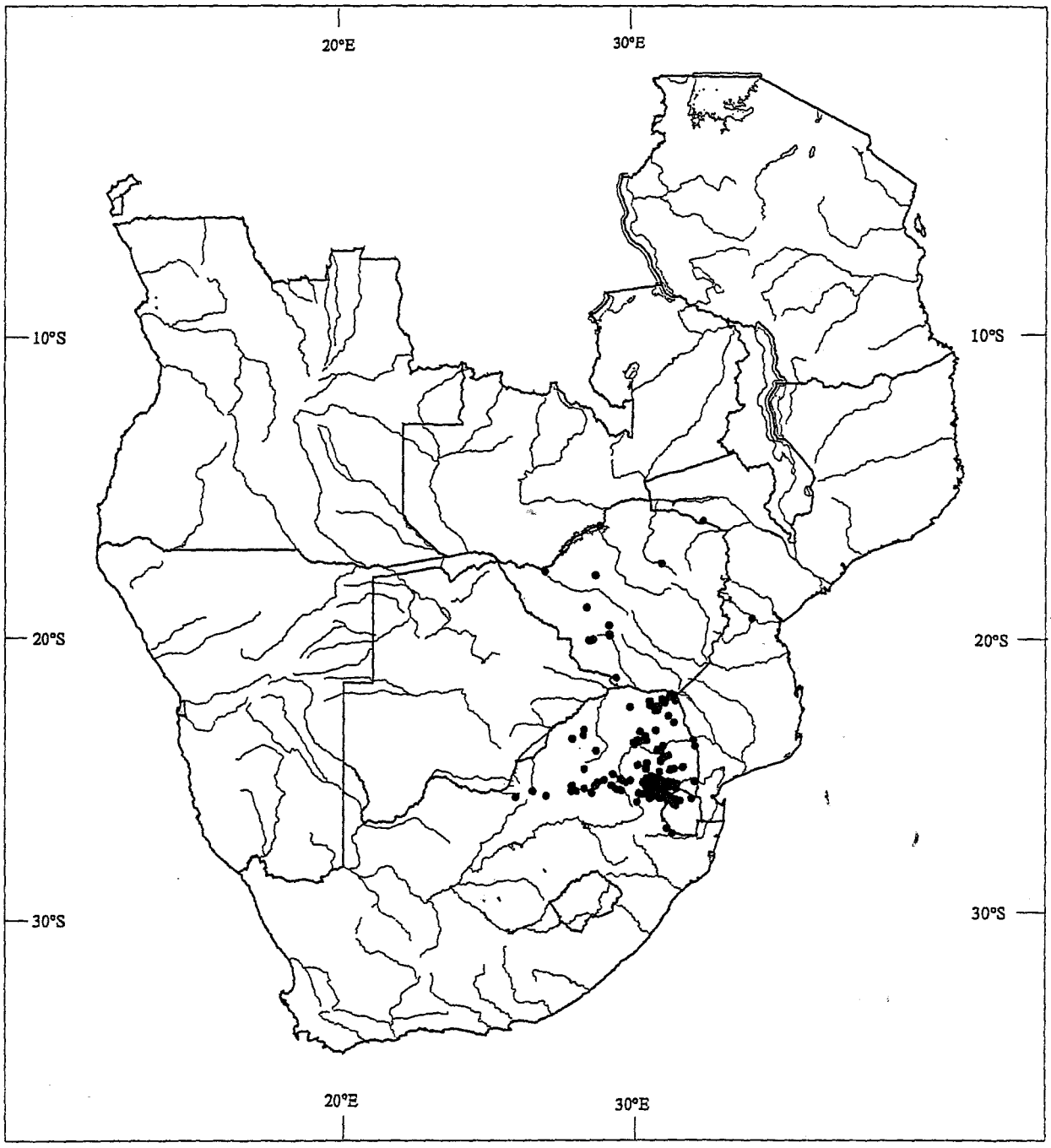


Figure F.187. Point distribution of *Chiloglanis pretoriae*. Scale approximately 1:25 000 000

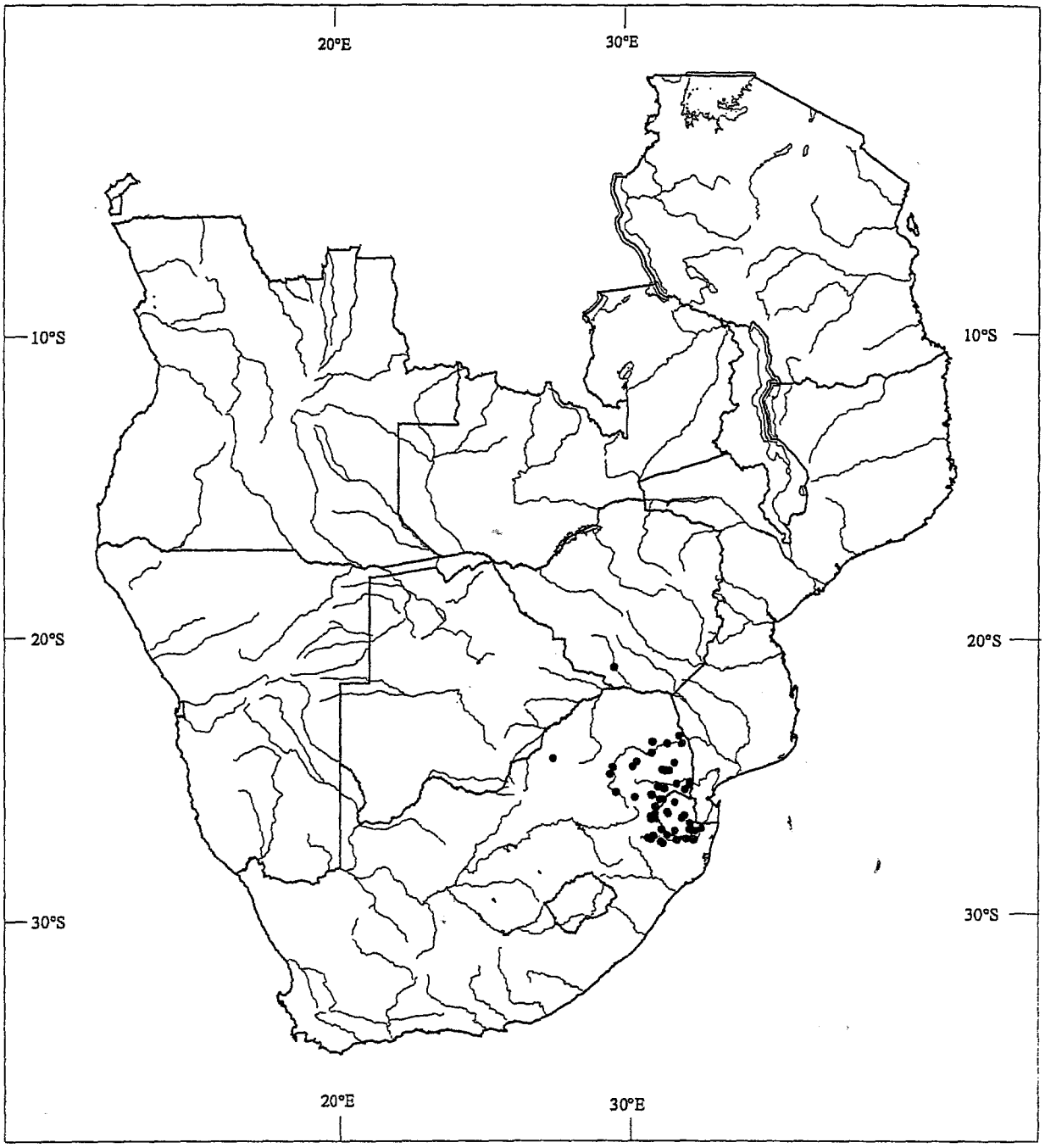


Figure F.188. Point distribution of *Chiloglanis swierstrai*. Scale approximately 1:25 000 000

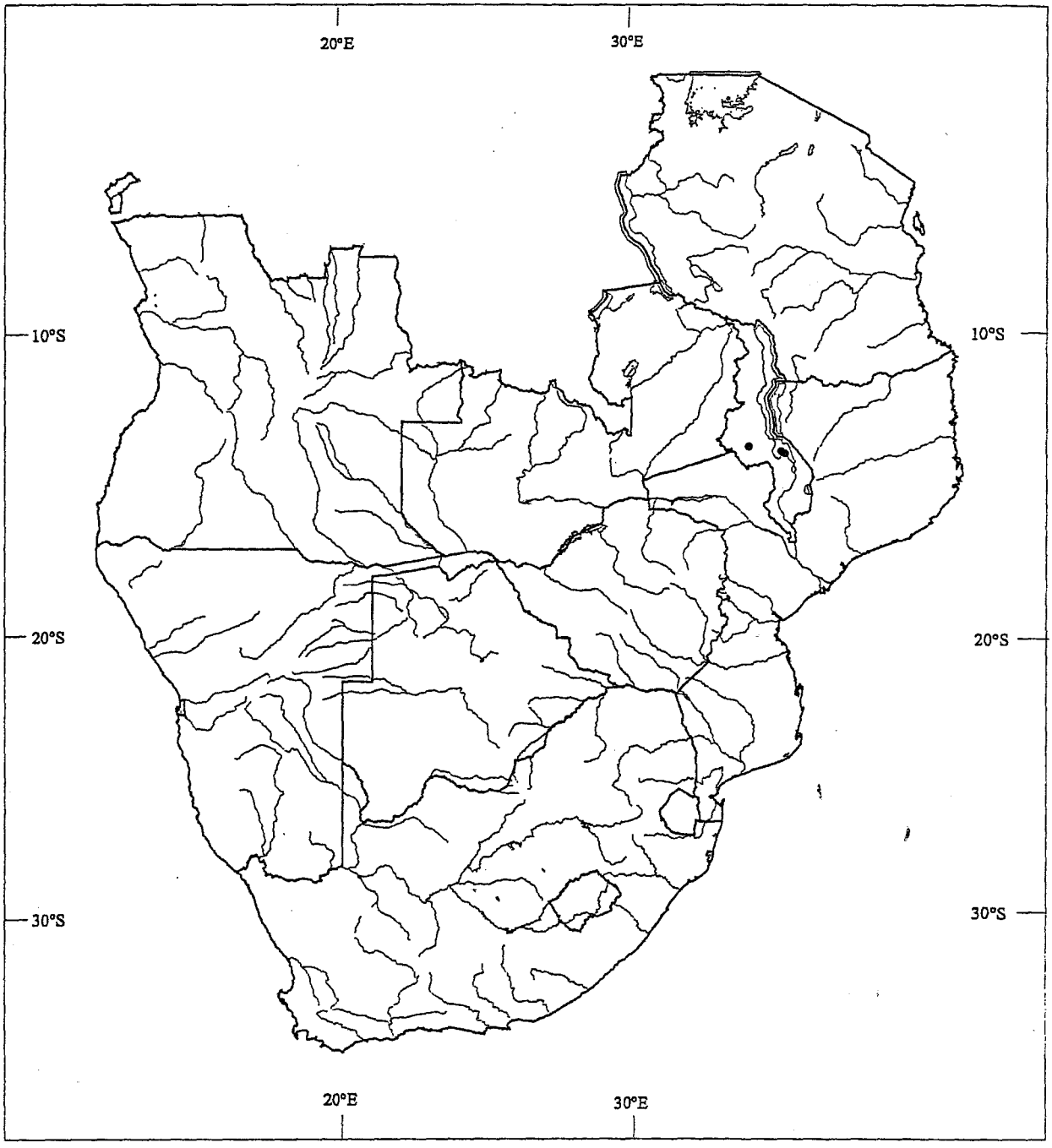


Figure F.189. Point distribution of *Chilotilapia rhoadesii*. Scale approximately 1:25 000 000

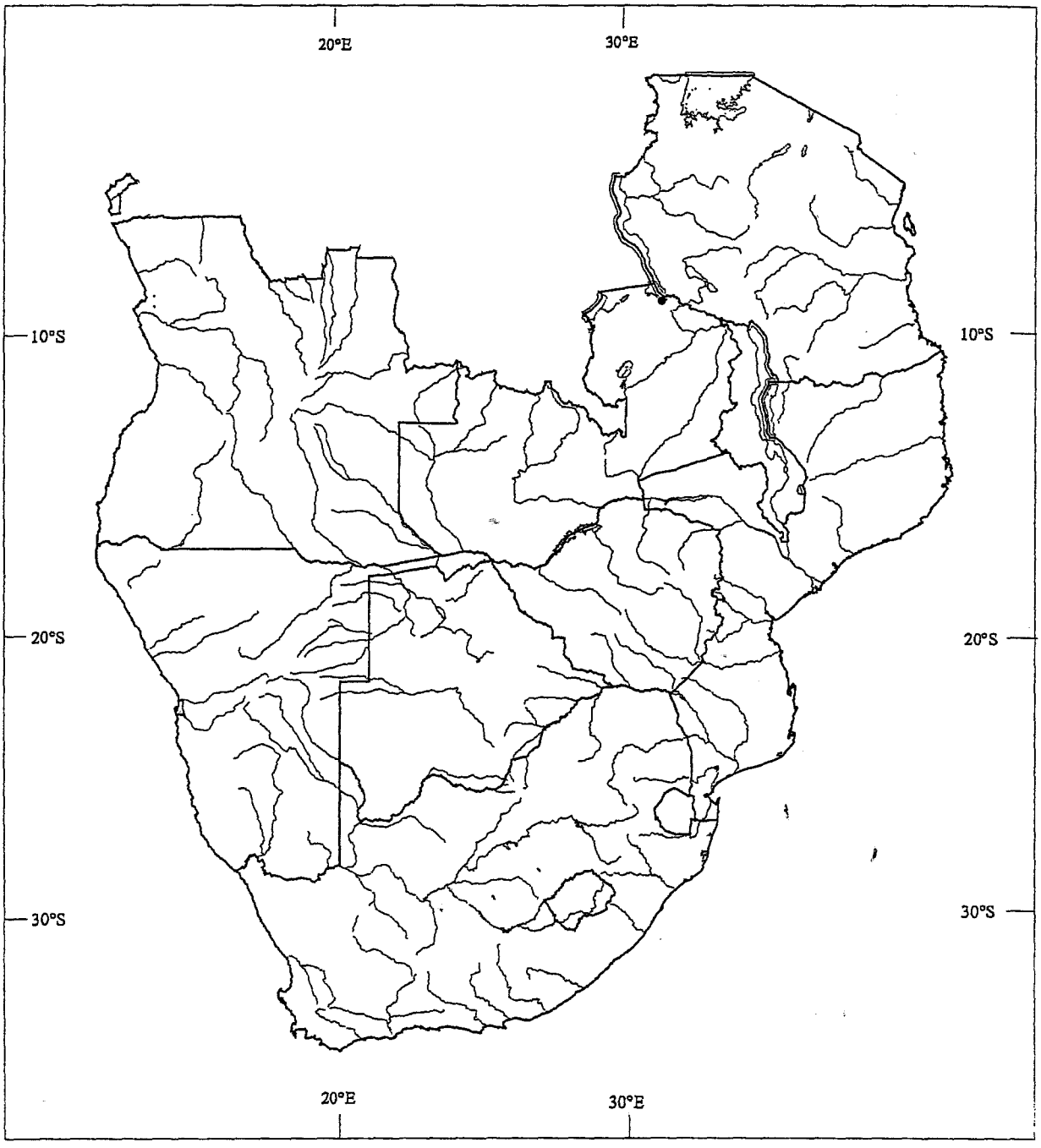


Figure F.190. Point distribution of *Chrysichthys brachynema*. Scale approximately 1:25 000 000

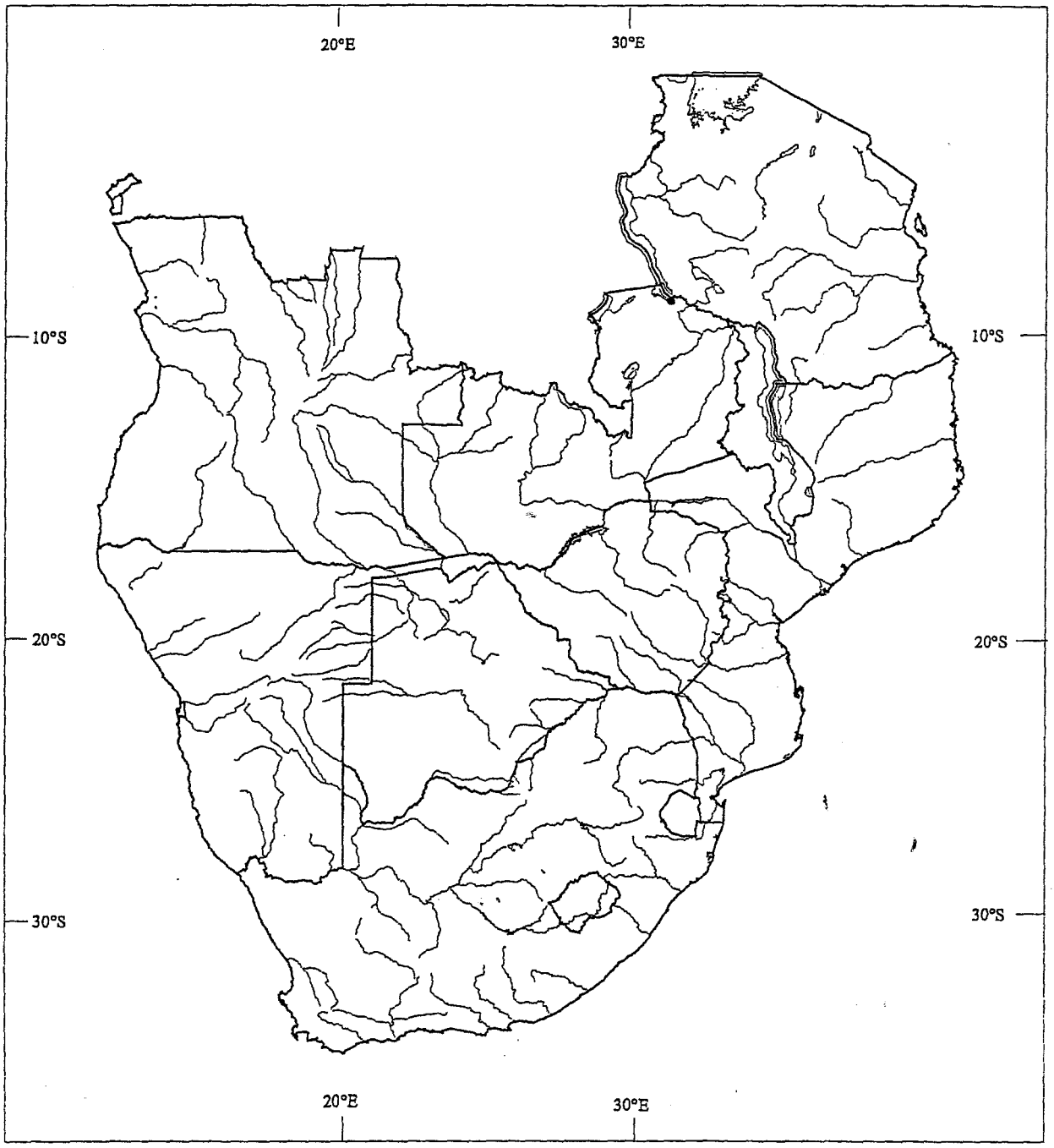


Figure F.191. Point distribution of *Chrysichthys grandis*. Scale approximately 1:25 000 000

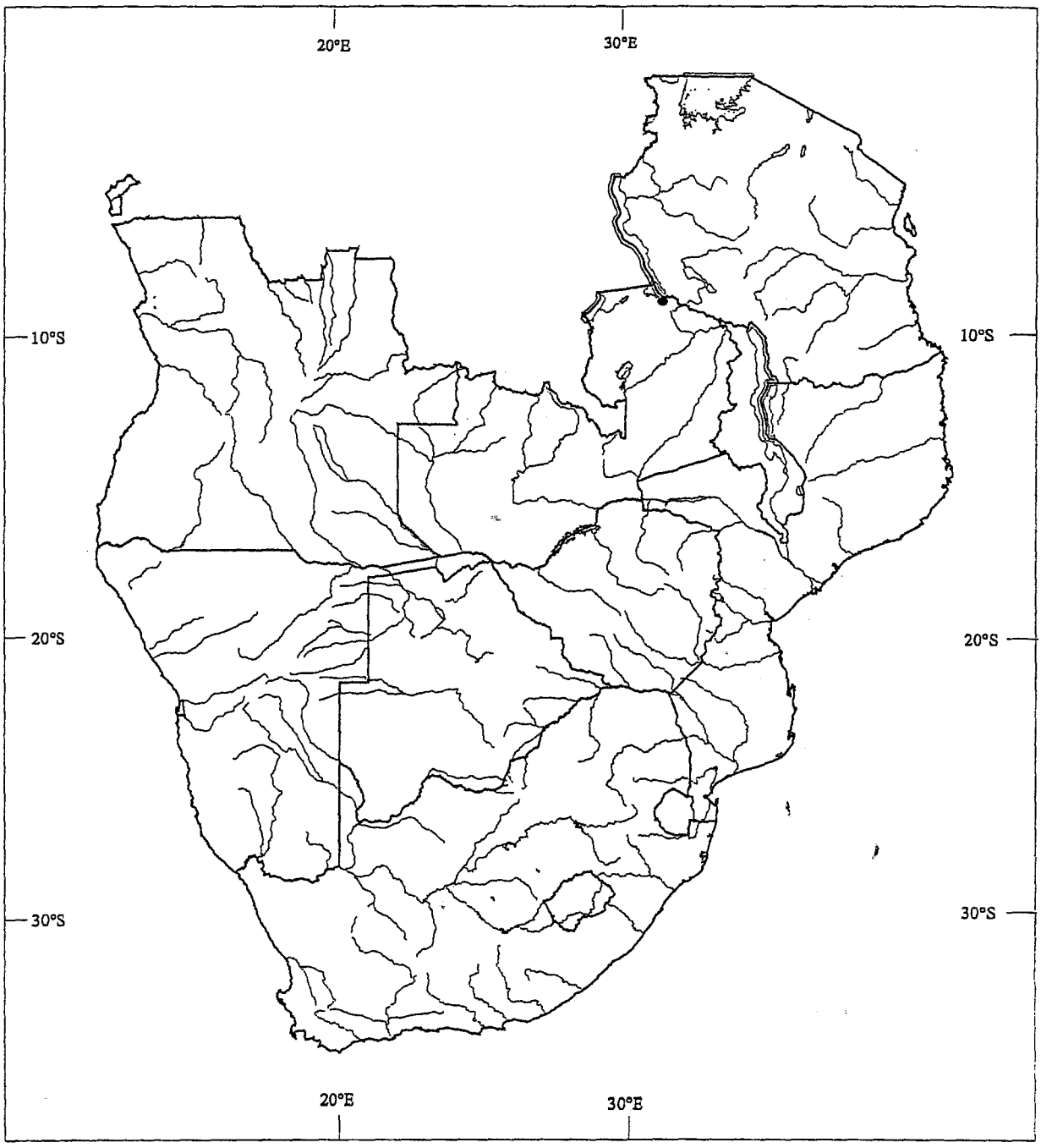


Figure F.192. Point distribution of *Chrysichthys platycephalus*. Scale approximately 1:25 000 000

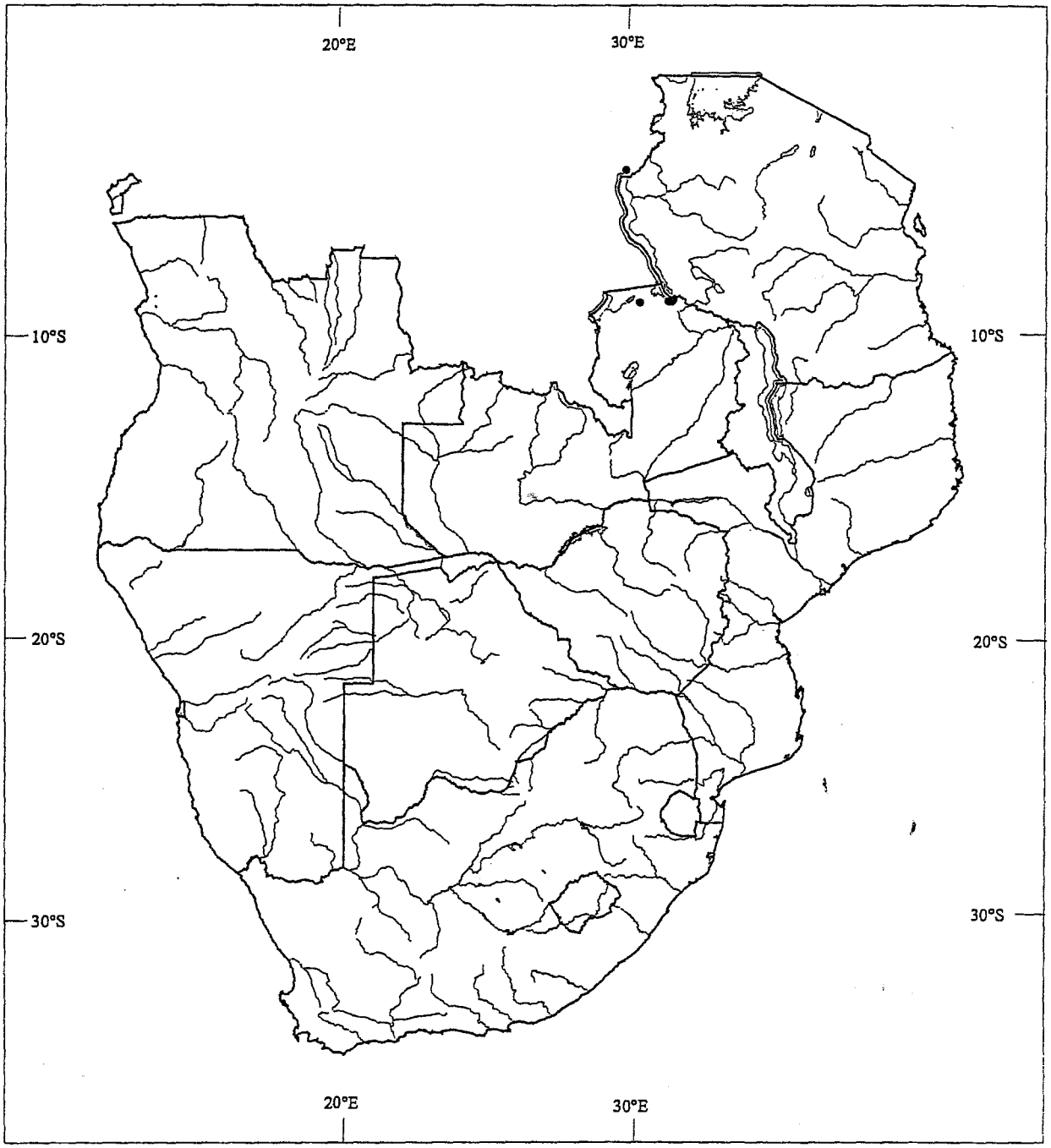


Figure F.193. Point distribution of *Chrysichthys sianenna*. Scale approximately 1:25 000 000

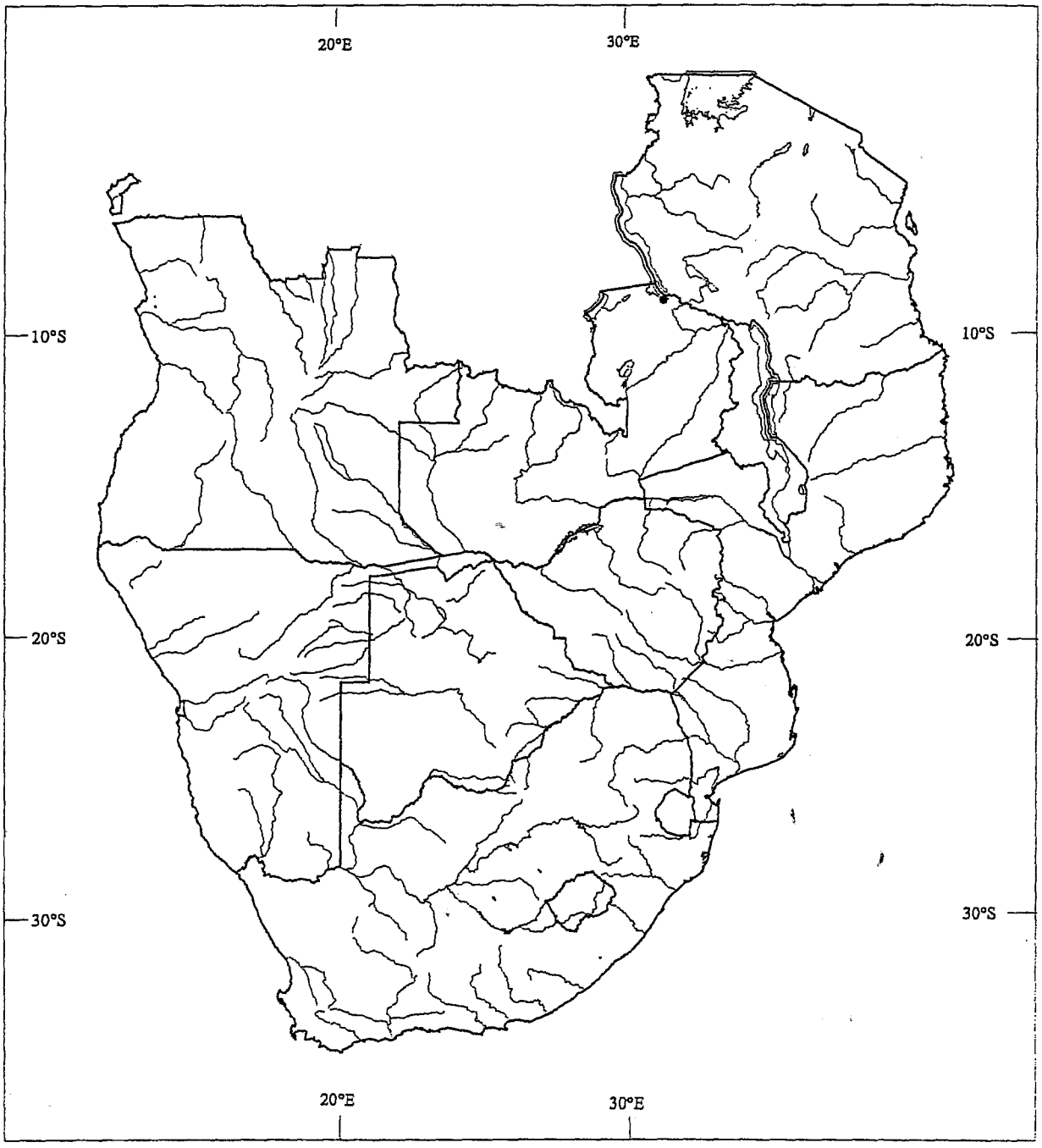


Figure F.194. Point distribution of *Chrysichthys stappersi*. Scale approximately 1:25 000 000

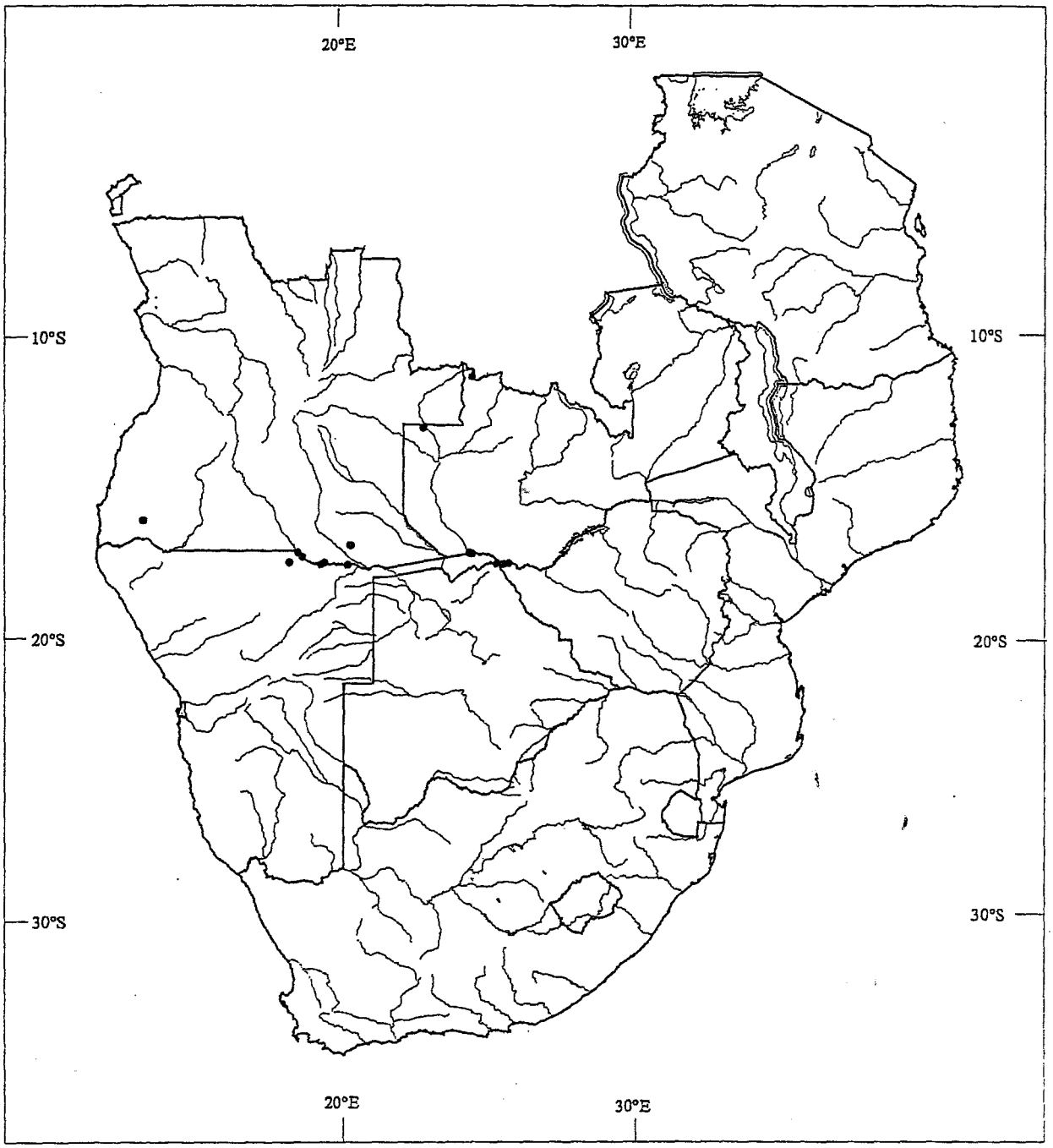


Figure F.195. Point distribution of *Clariallabes platyprosopos*. Scale approximately 1:25 000 000

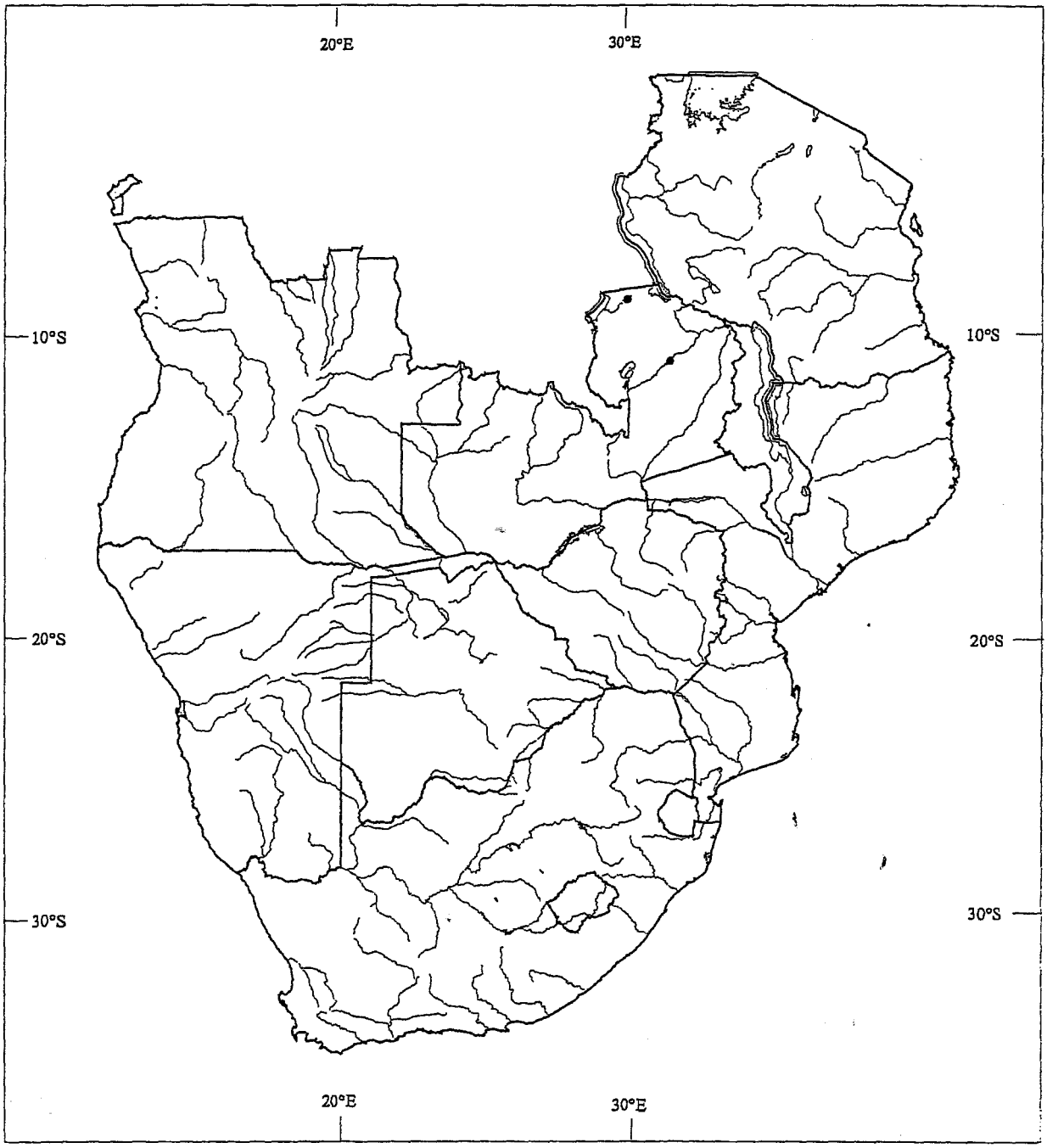


Figure F.196. Point distribution of *Clarias buthupogon*. Scale approximately 1:25 000 000

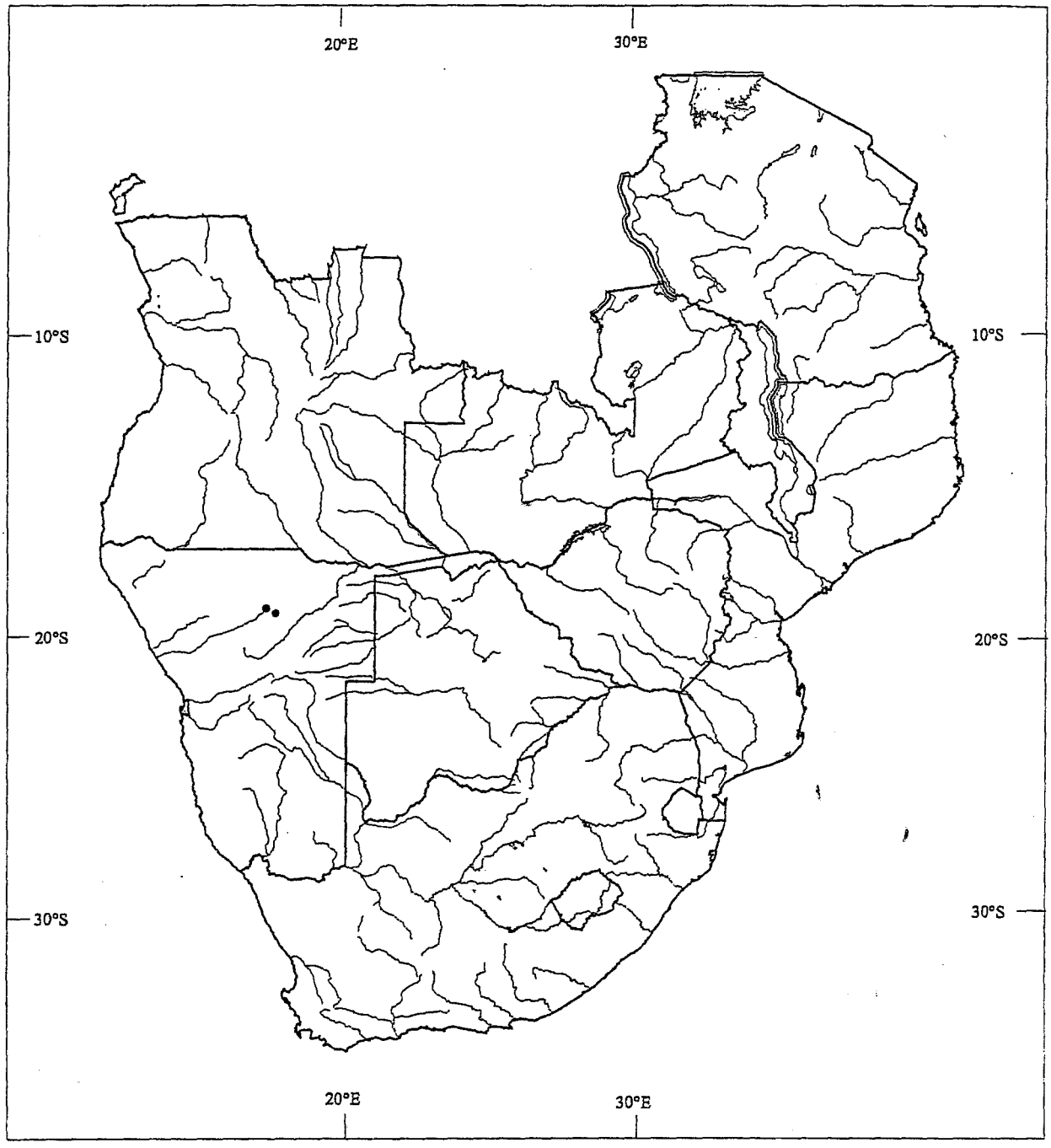


Figure F.197. Point distribution of *Clarias cavernicola*. Scale approximately 1:25 000 000

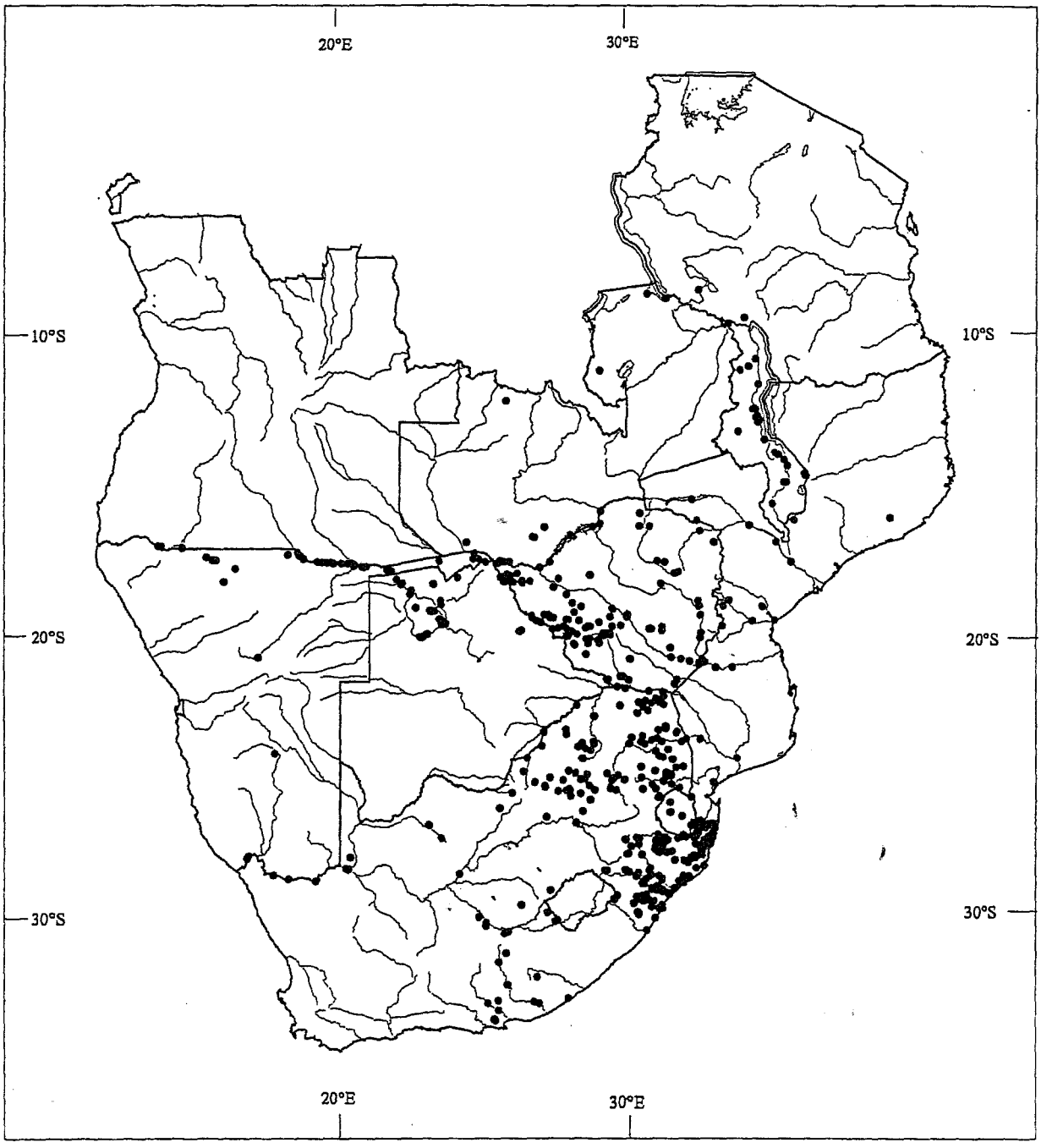


Figure F.198. Point distribution of *Clarias gariepinus*. Scale approximately 1:25 000 000

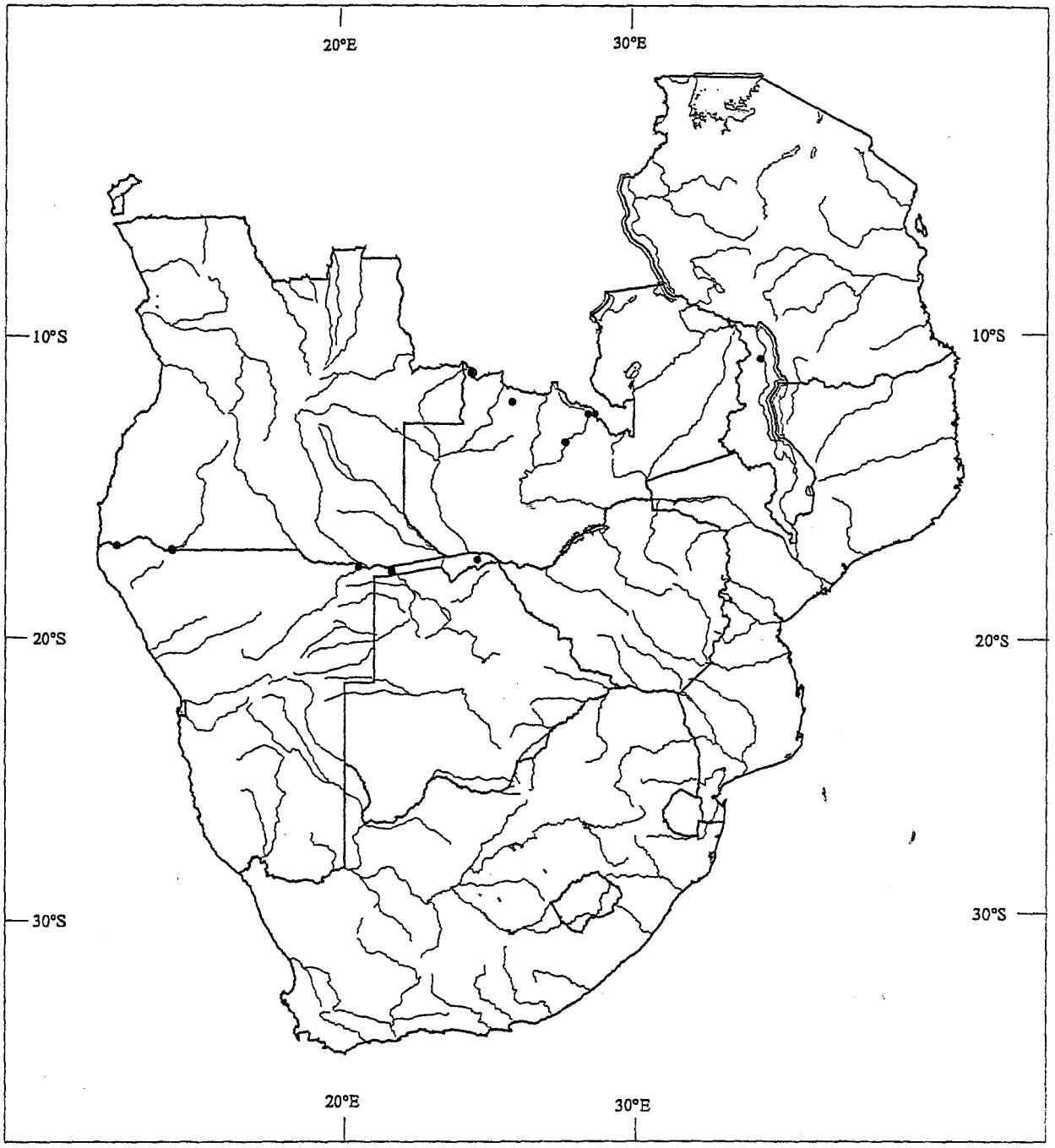


Figure F.199. Point distribution of *Clarias liocephalus*. Scale approximately 1:25 000 000

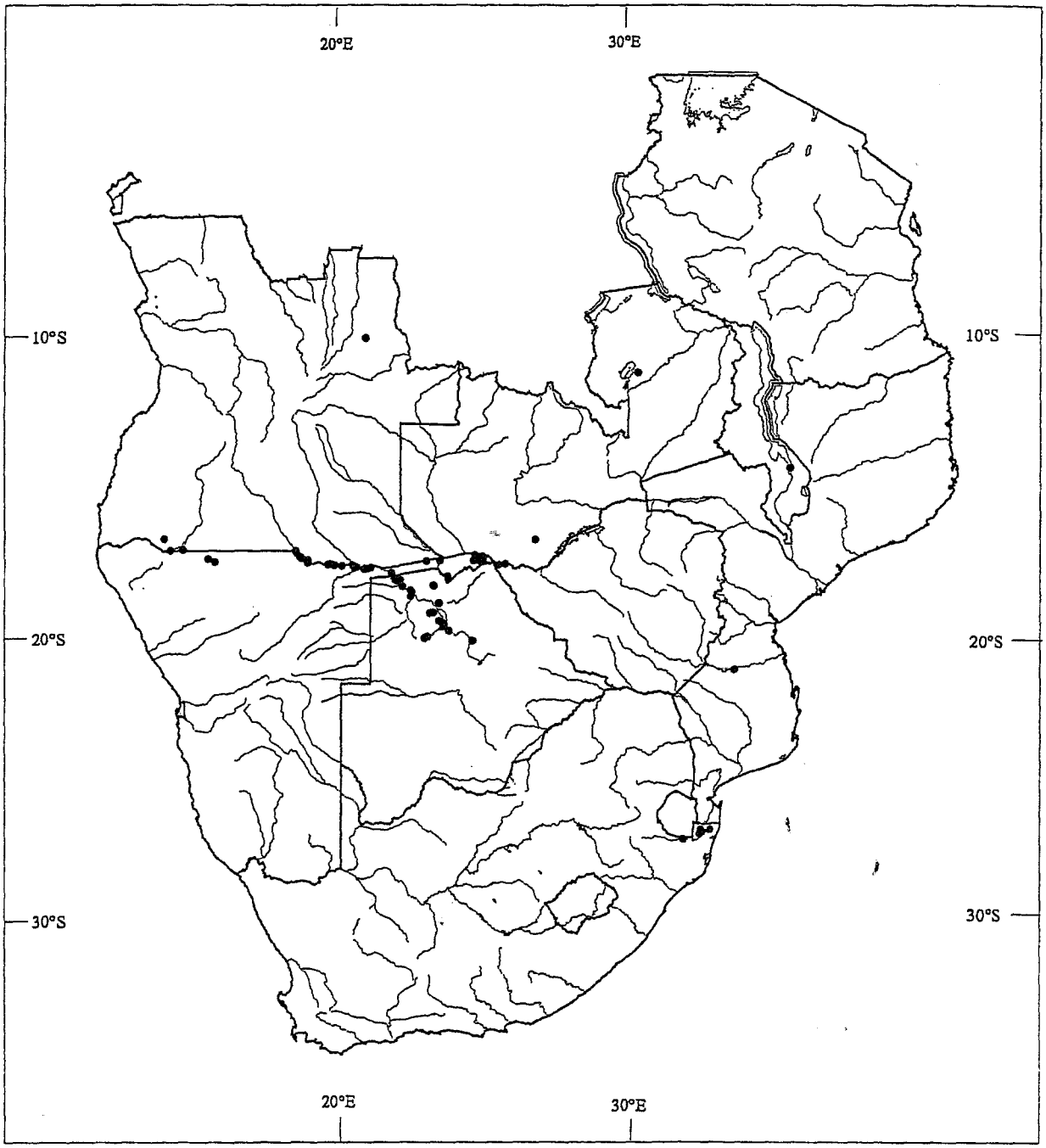


Figure F.200. Point distribution of *Clarias ngamensis*. Scale approximately 1:25 000 000

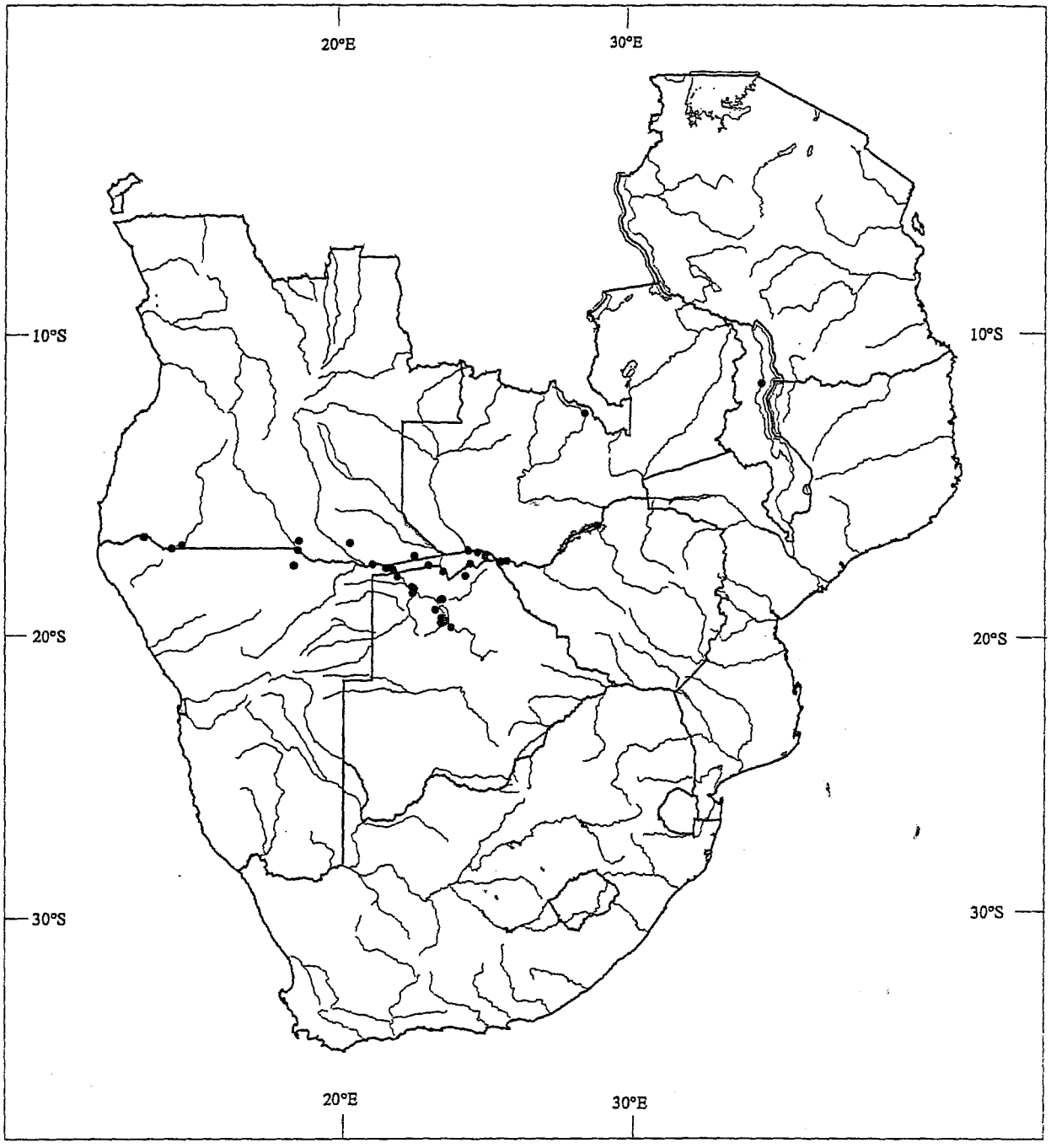


Figure F.201. Point distribution of *Clarias stappersii*. Scale approximately 1:25 000 000

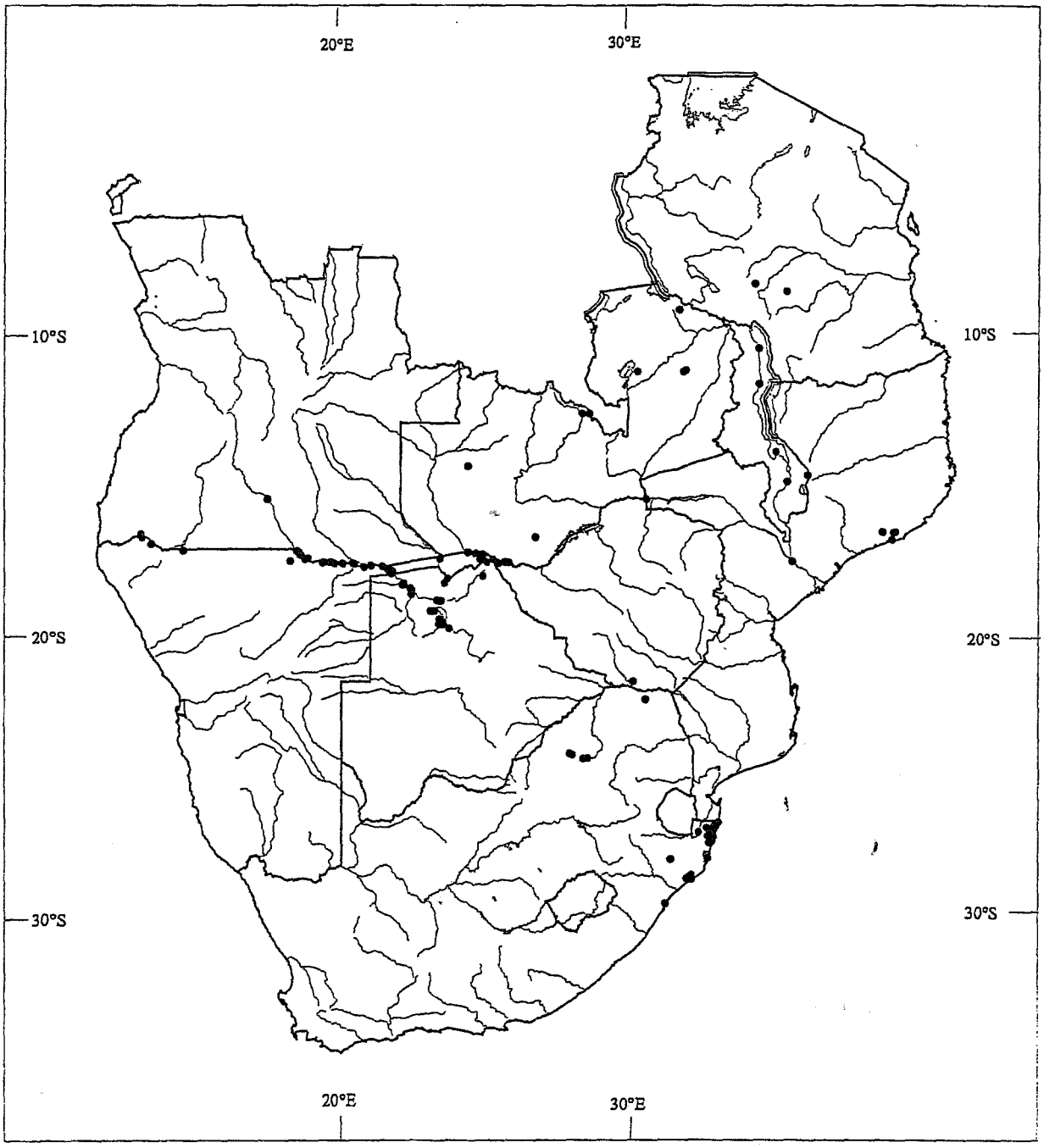


Figure F.202. Point distribution of *Clarias theodorae*. Scale approximately 1:25 000 000

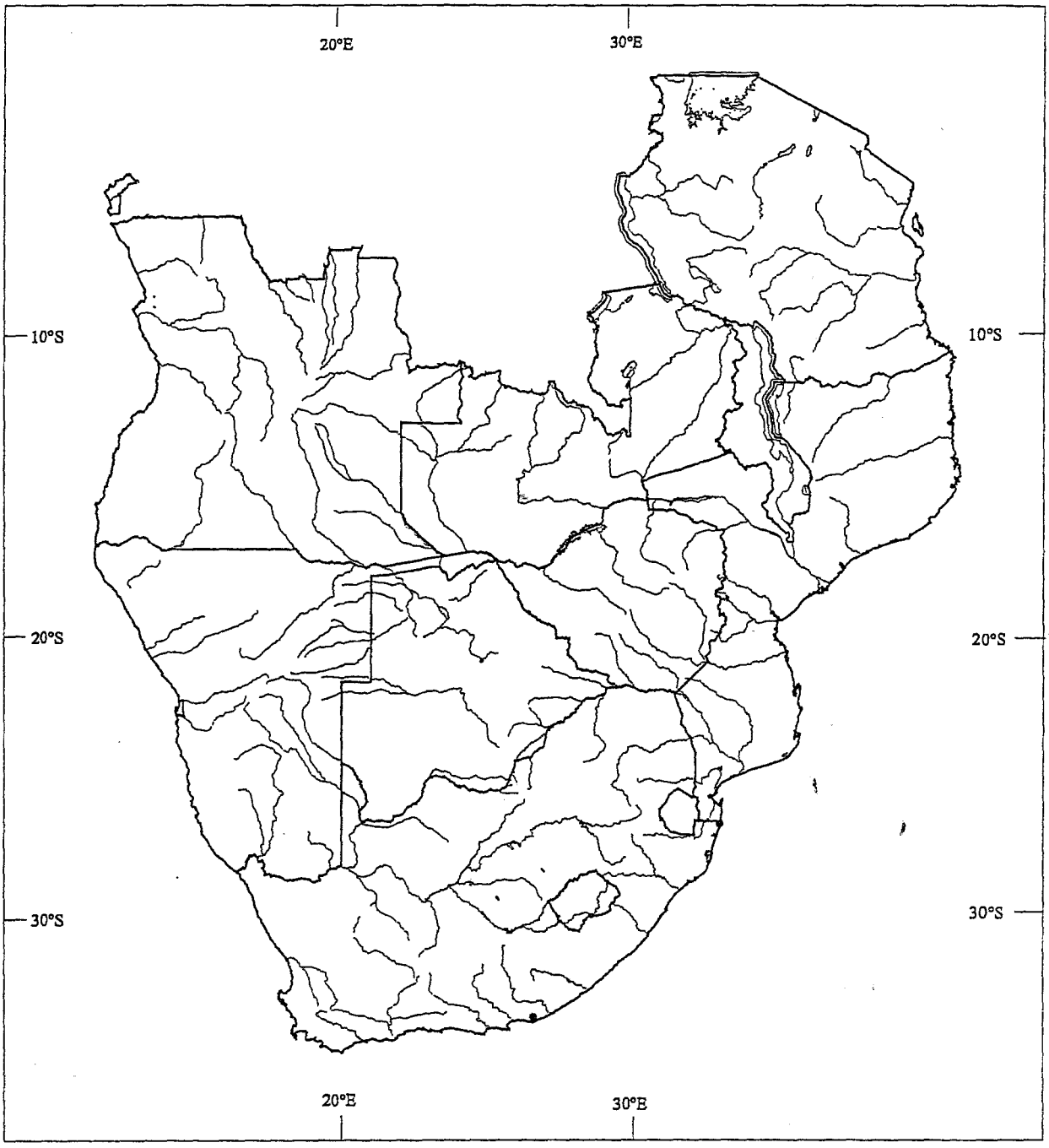


Figure F.203. Point distribution of *Clinid sp.*. Scale approximately 1:25 000 000

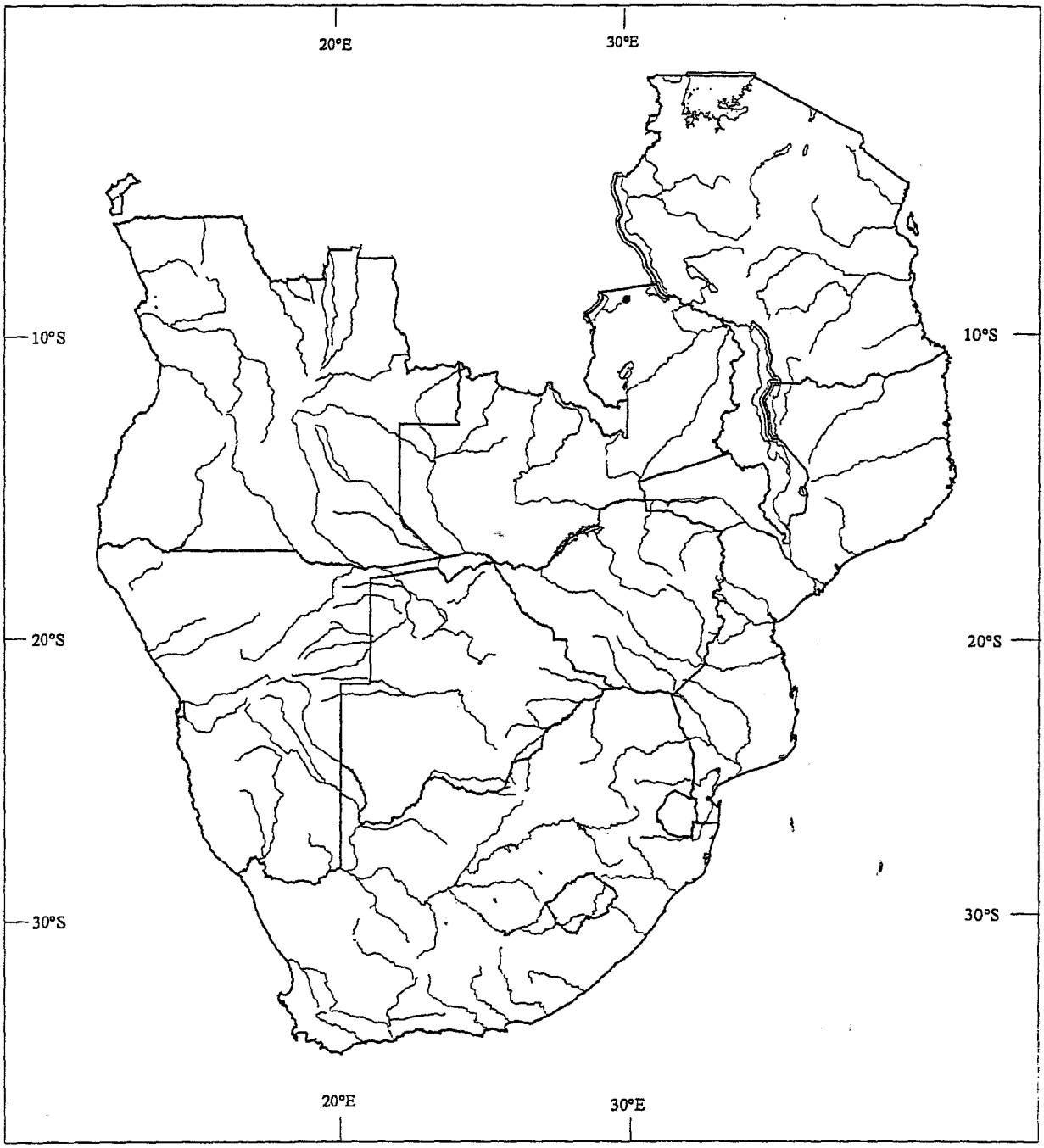


Figure F.204. Point distribution of *Clypeobarbus pseudognathon*. Scale approximately 1:25 000 000

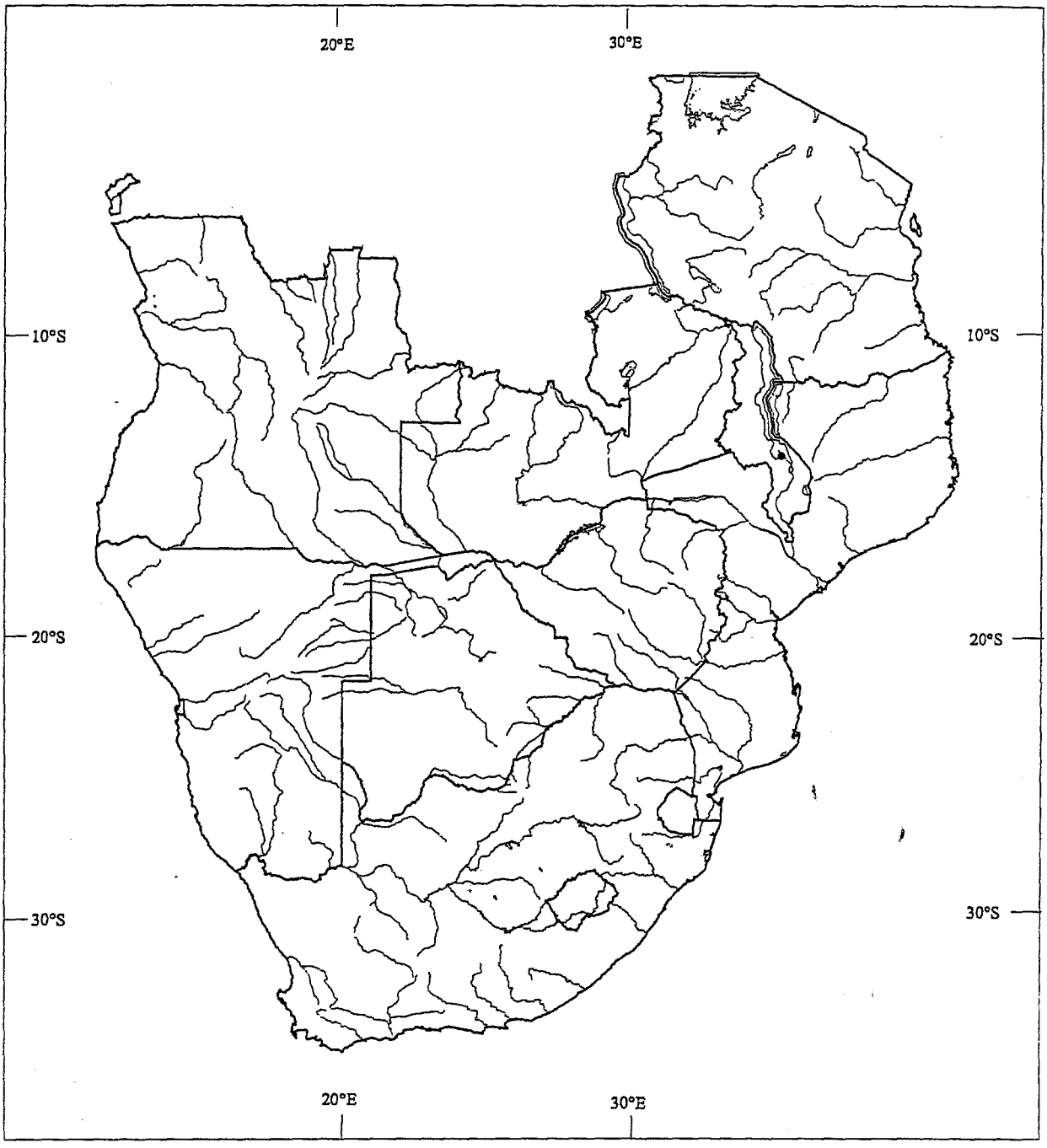


Figure F.205. Point distribution of *Copadichromis azureus*. Scale approximately 1:25 000 000

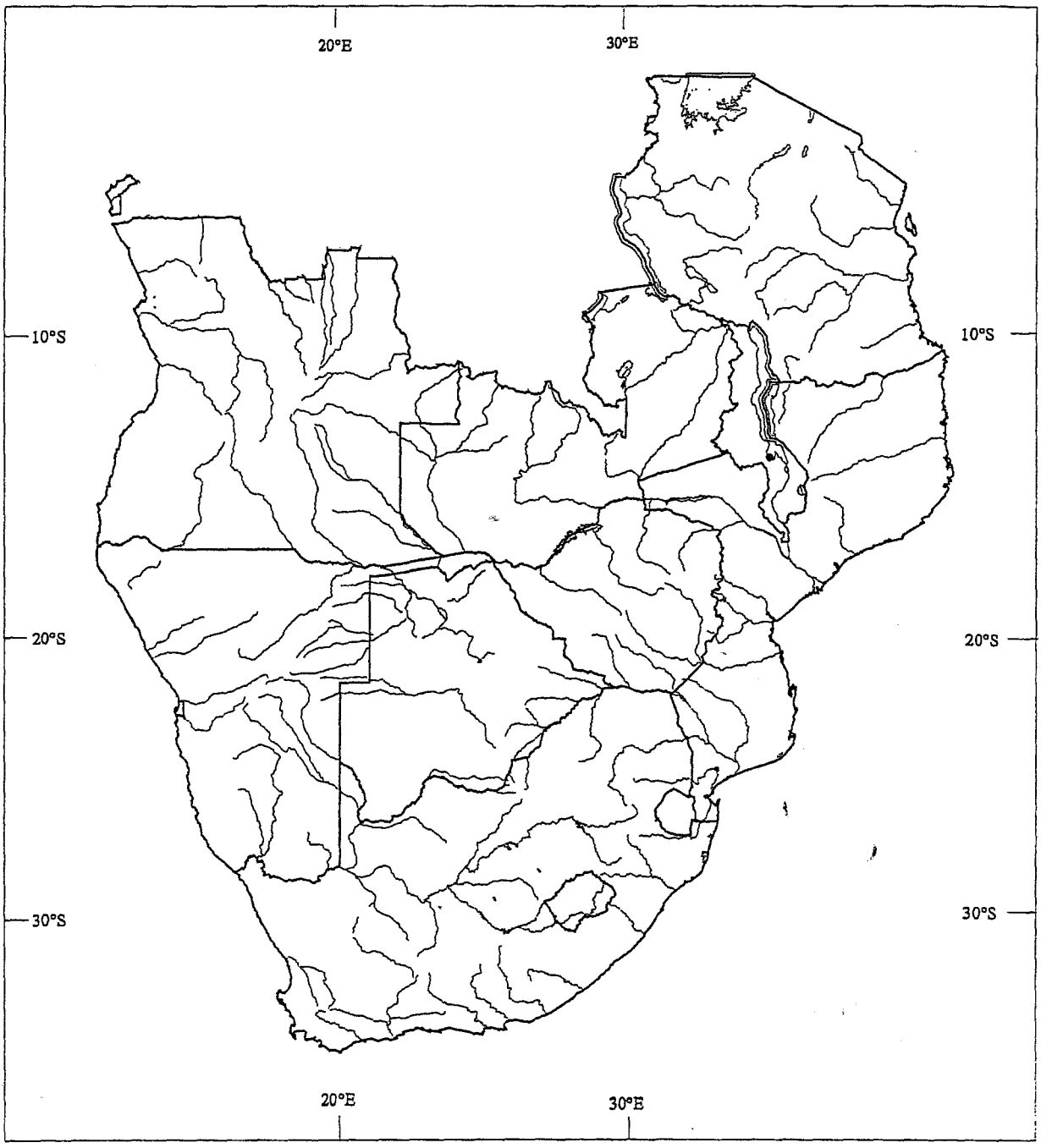


Figure F.206. Point distribution of *Copadichromis chrysonotus*. Scale approximately 1:25 000 000

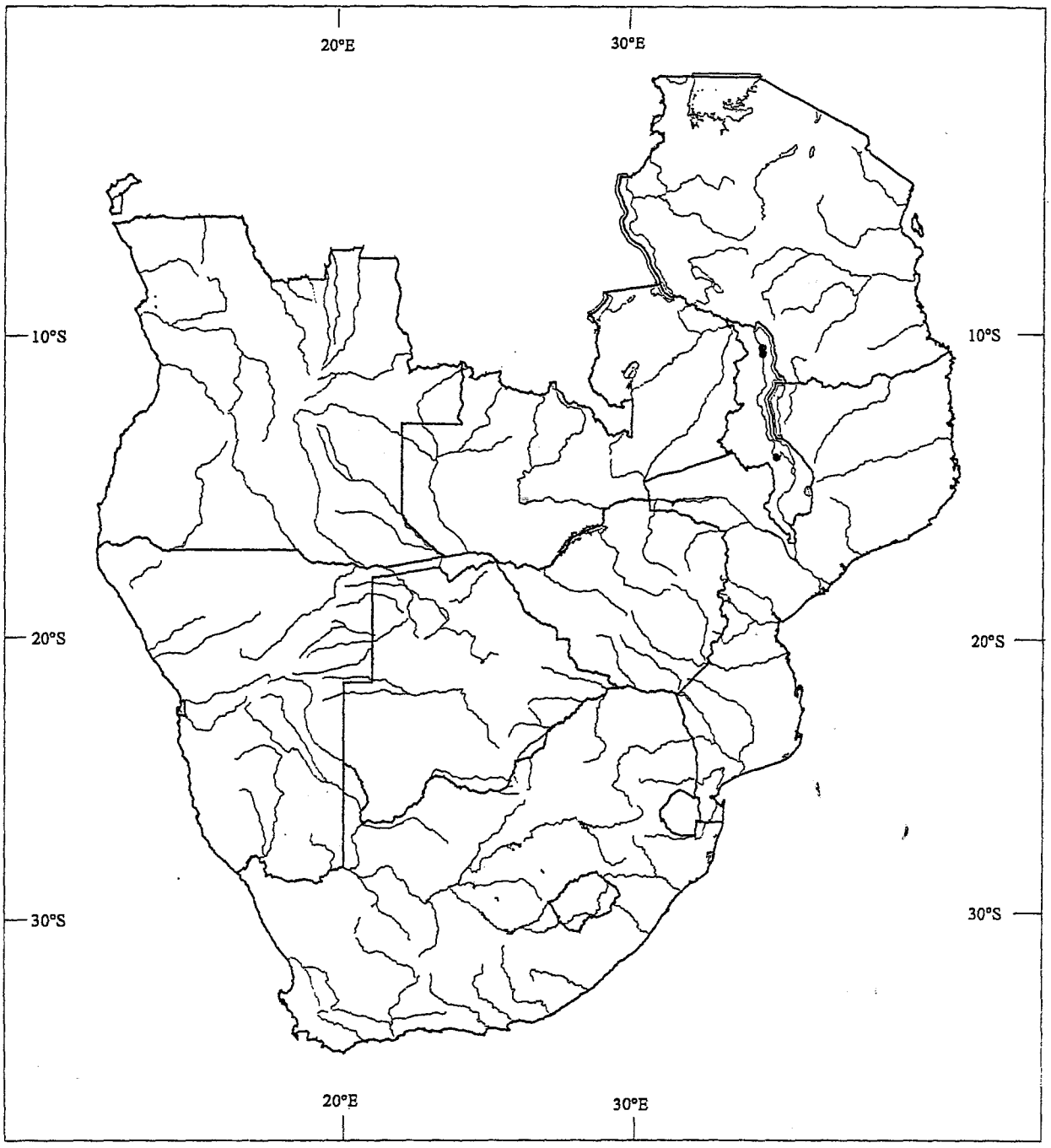


Figure F.207. Point distribution of *Copadichromis eucinostomus*. Scale approximately 1:25 000 000

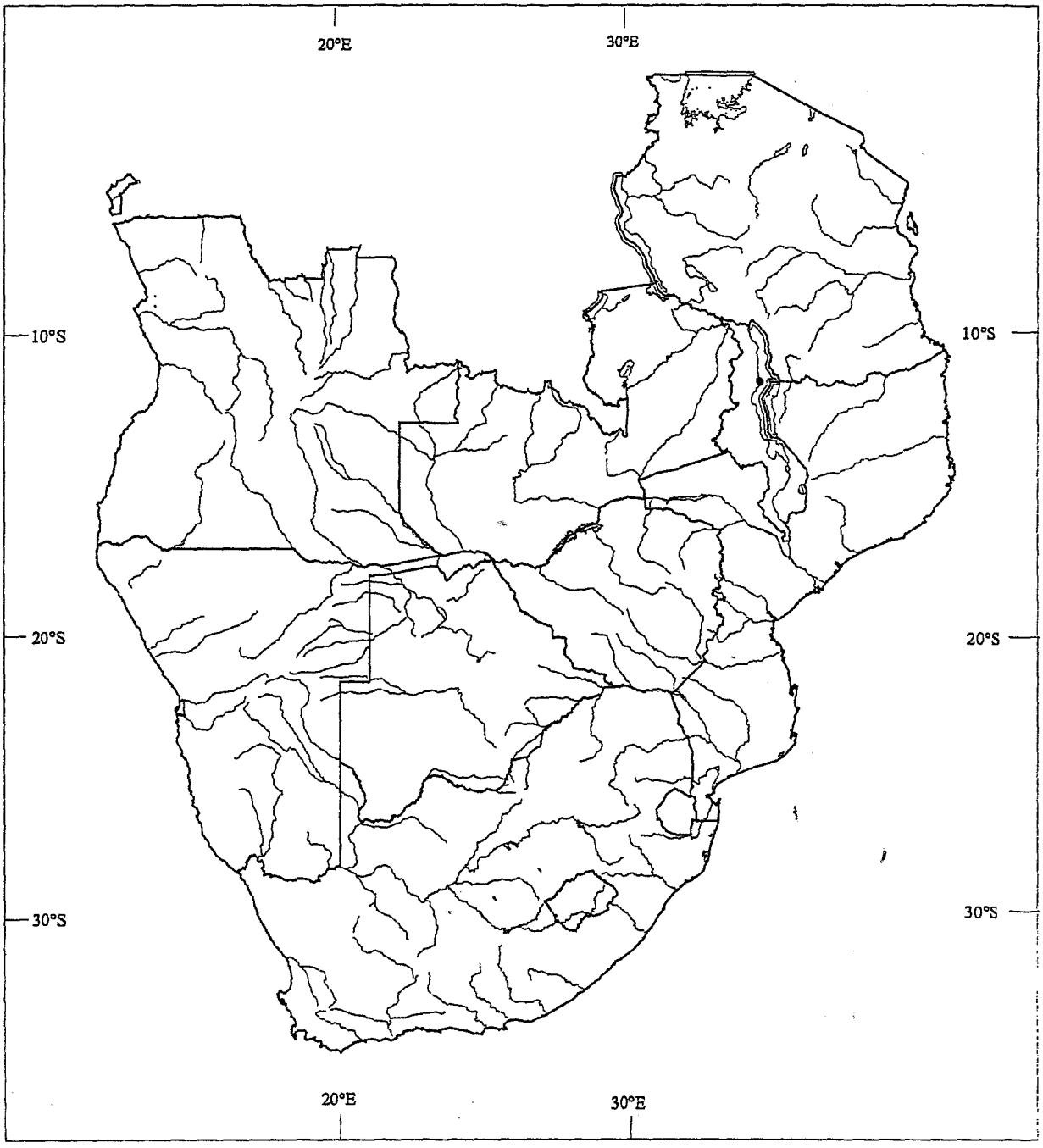


Figure F.208. Point distribution of *Copadichromis jacksoni*. Scale approximately 1:25 000 000

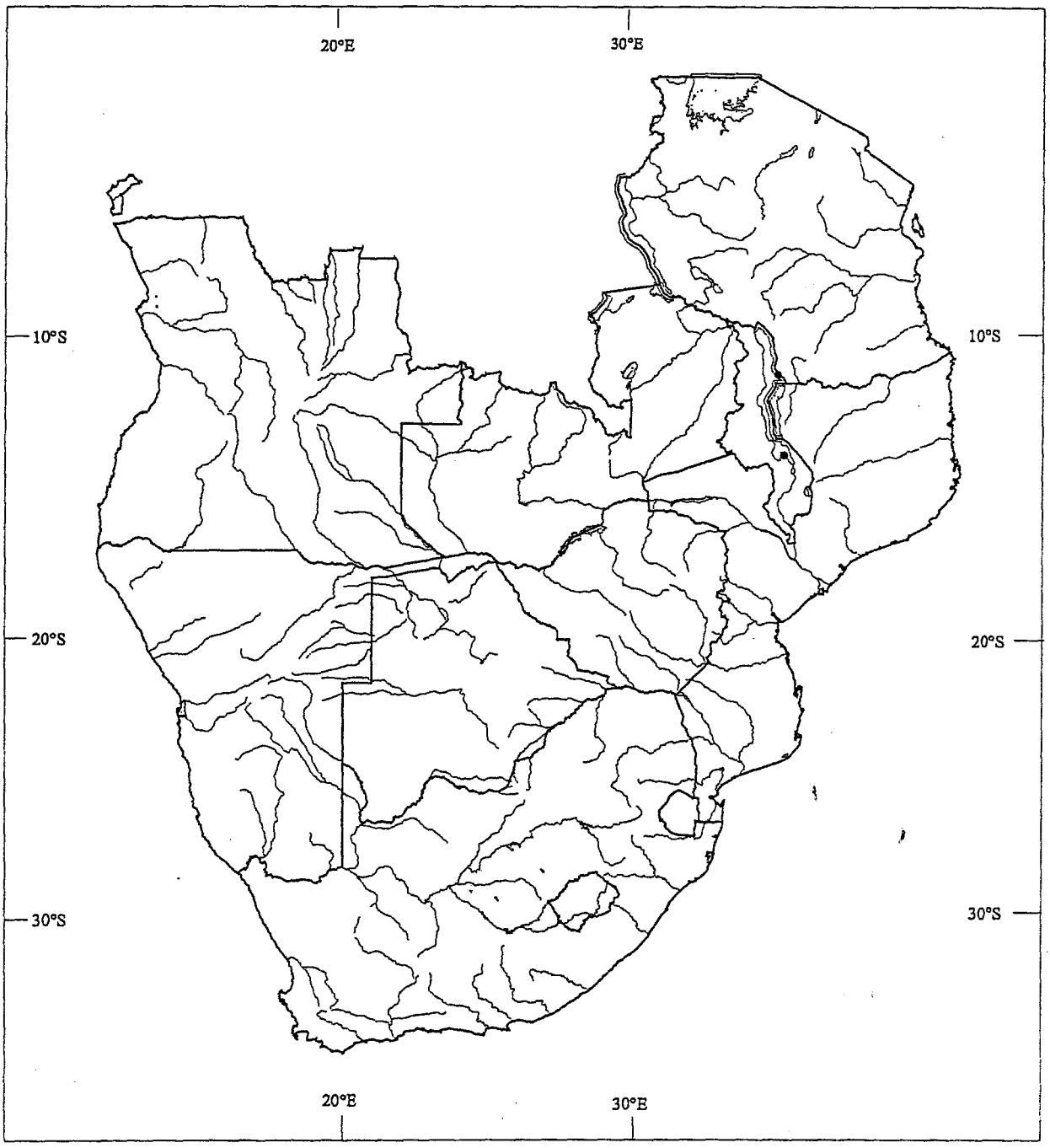


Figure F.209. Point distribution of *Copadichromis mloto*. Scale approximately 1:25 000 000

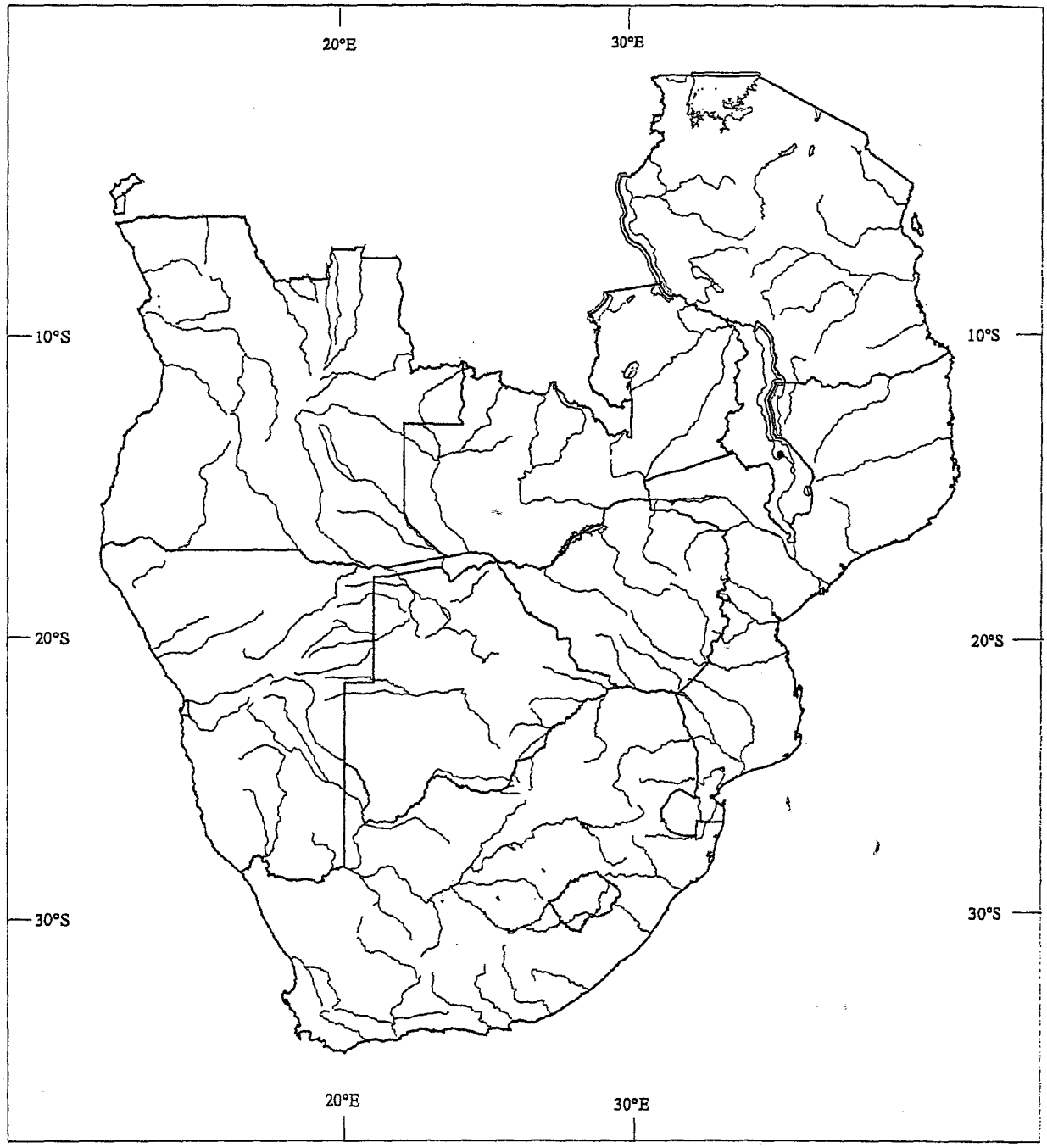


Figure F.210. Point distribution of *Copadichromis pleurostigma*. Scale approximately 1:25 000 000

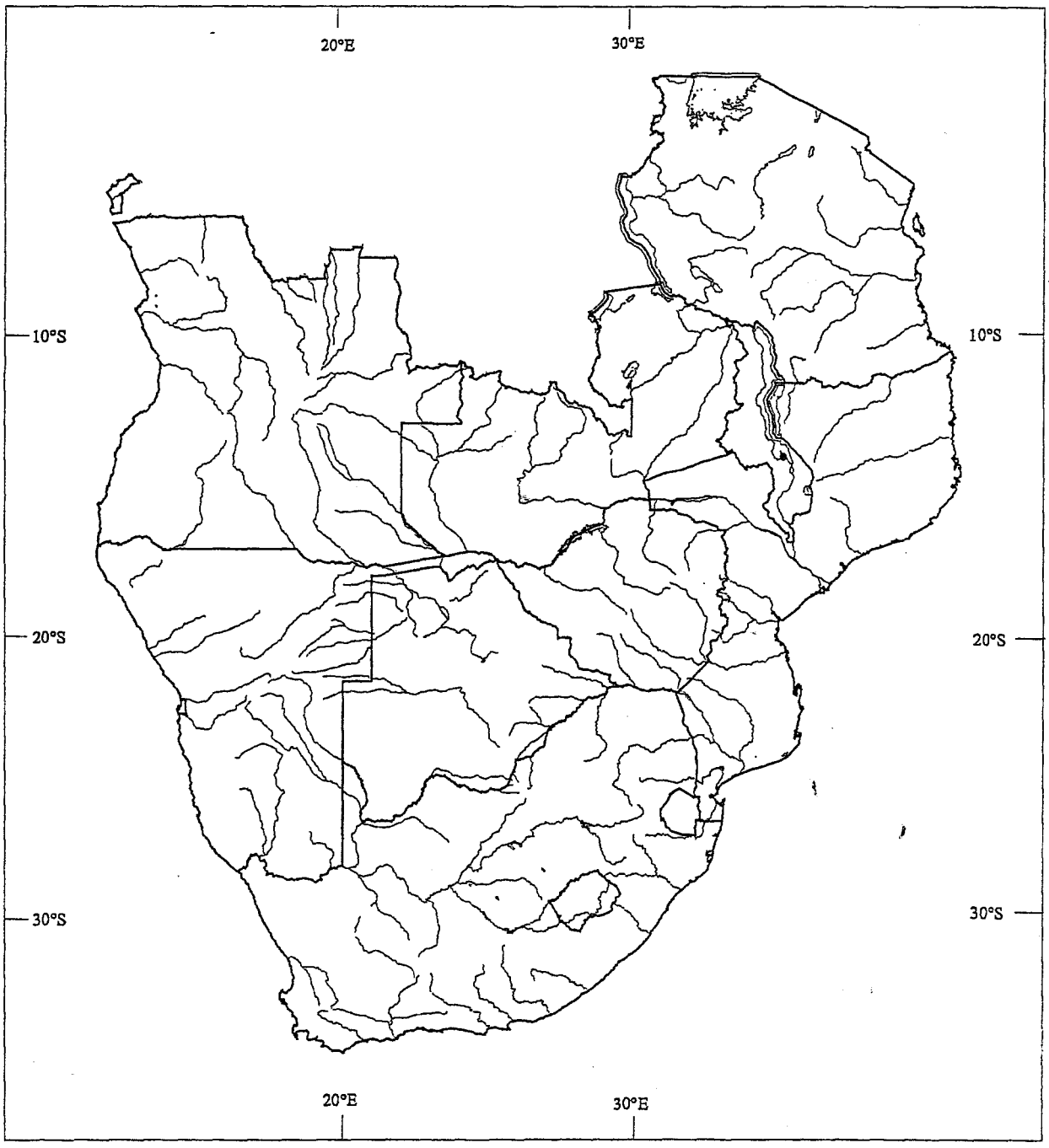


Figure F.211. Point distribution of *Copadichromis prostoma*. Scale approximately 1:25 000 000

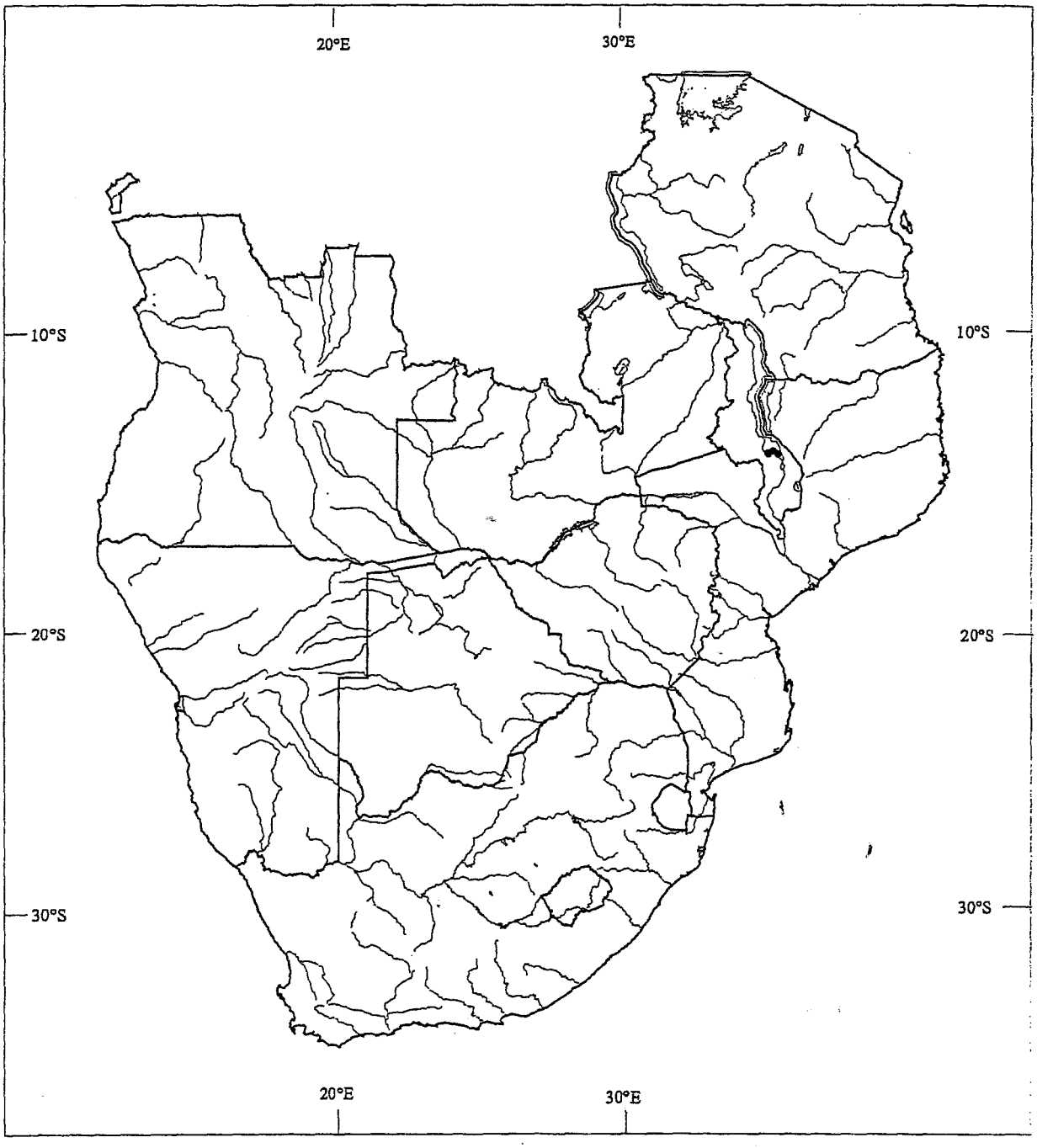


Figure F.212. Point distribution of *Copadichromis quadrimaculatus*. Scale approximately 1:25 000 000

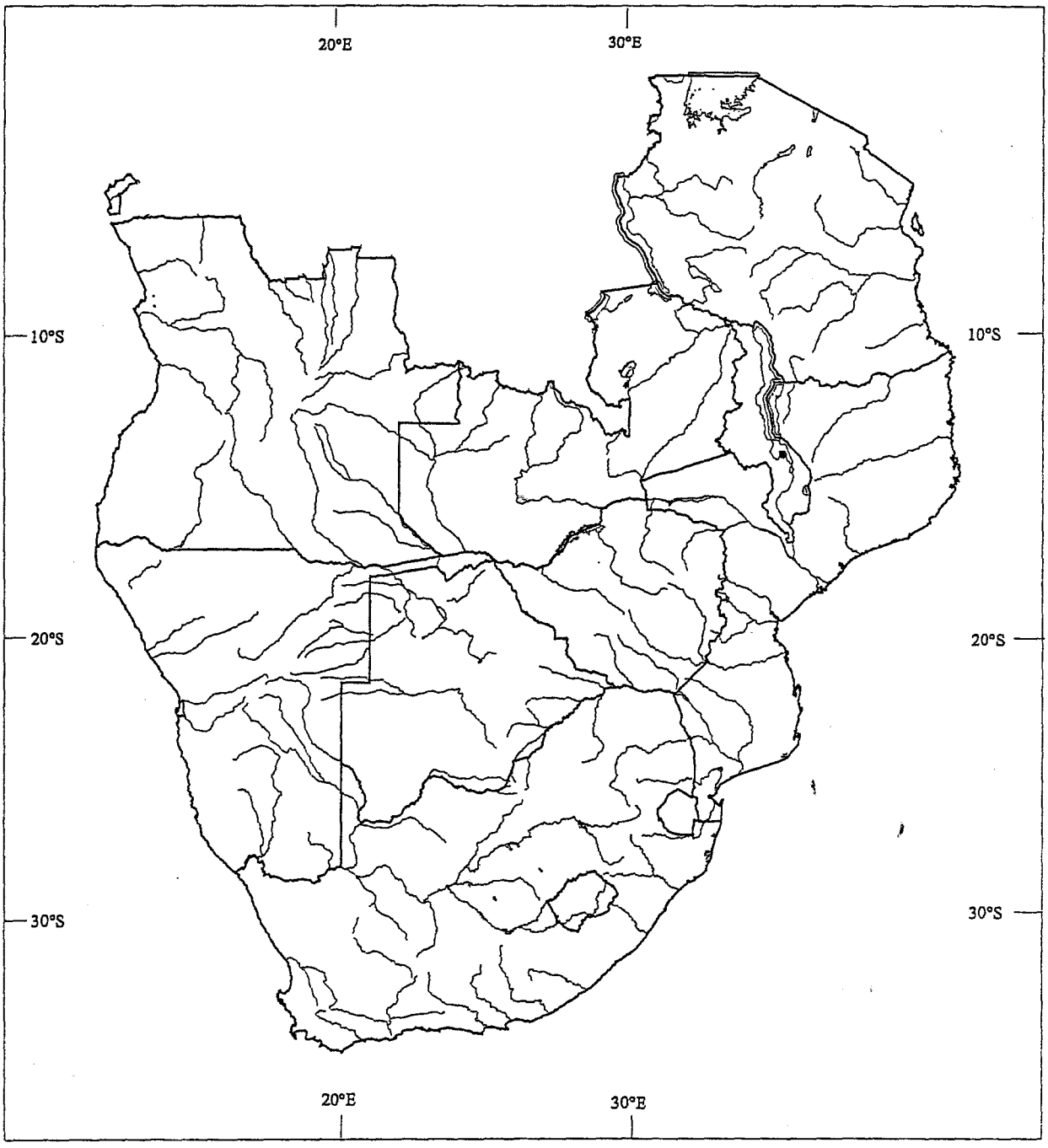


Figure F.213. Point distribution of *Copadichromis trimaculatus*. Scale approximately 1:25 000 000

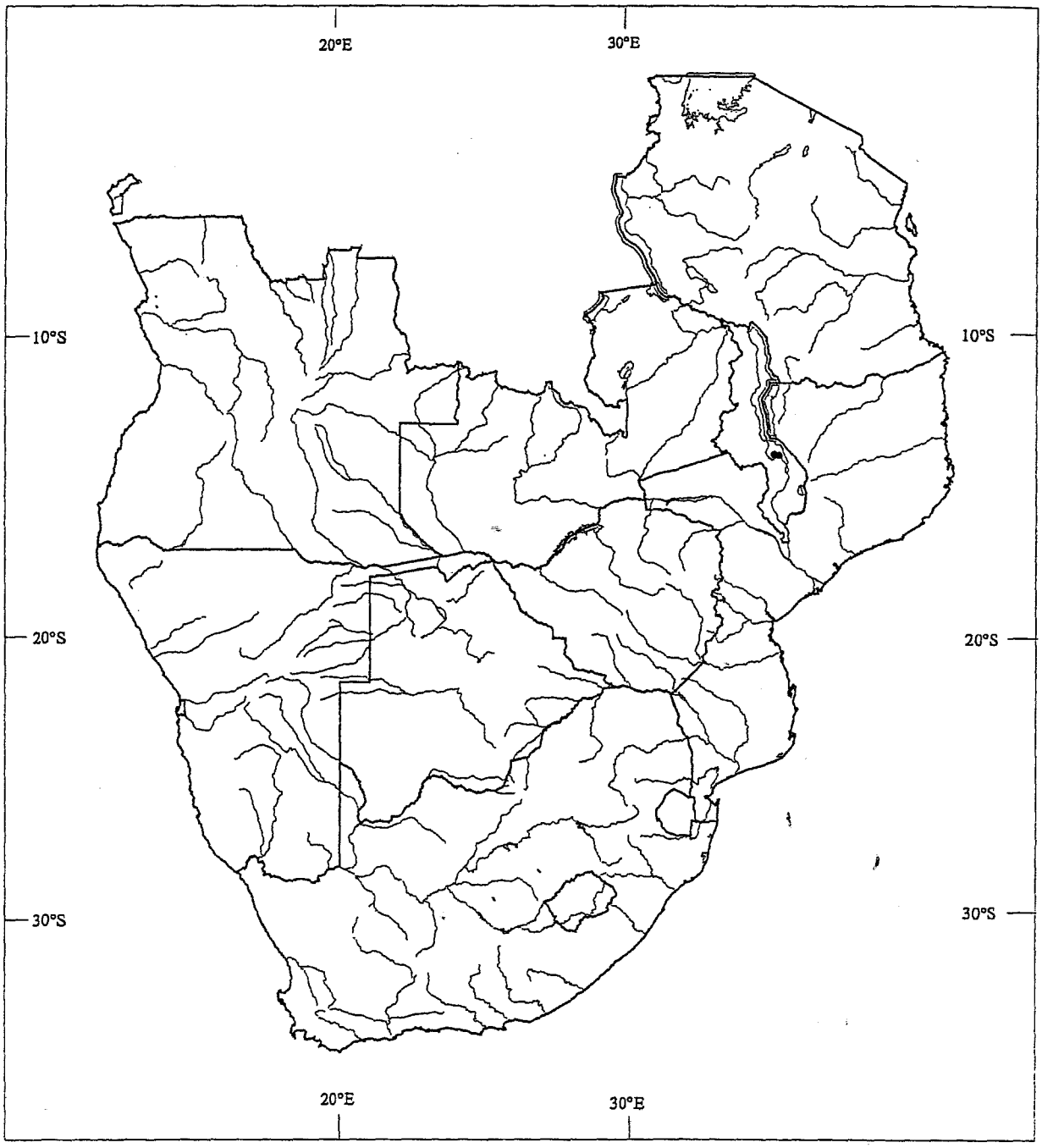


Figure F.214. Point distribution of *Copadichromis virginalis*. Scale approximately 1:25 000 000

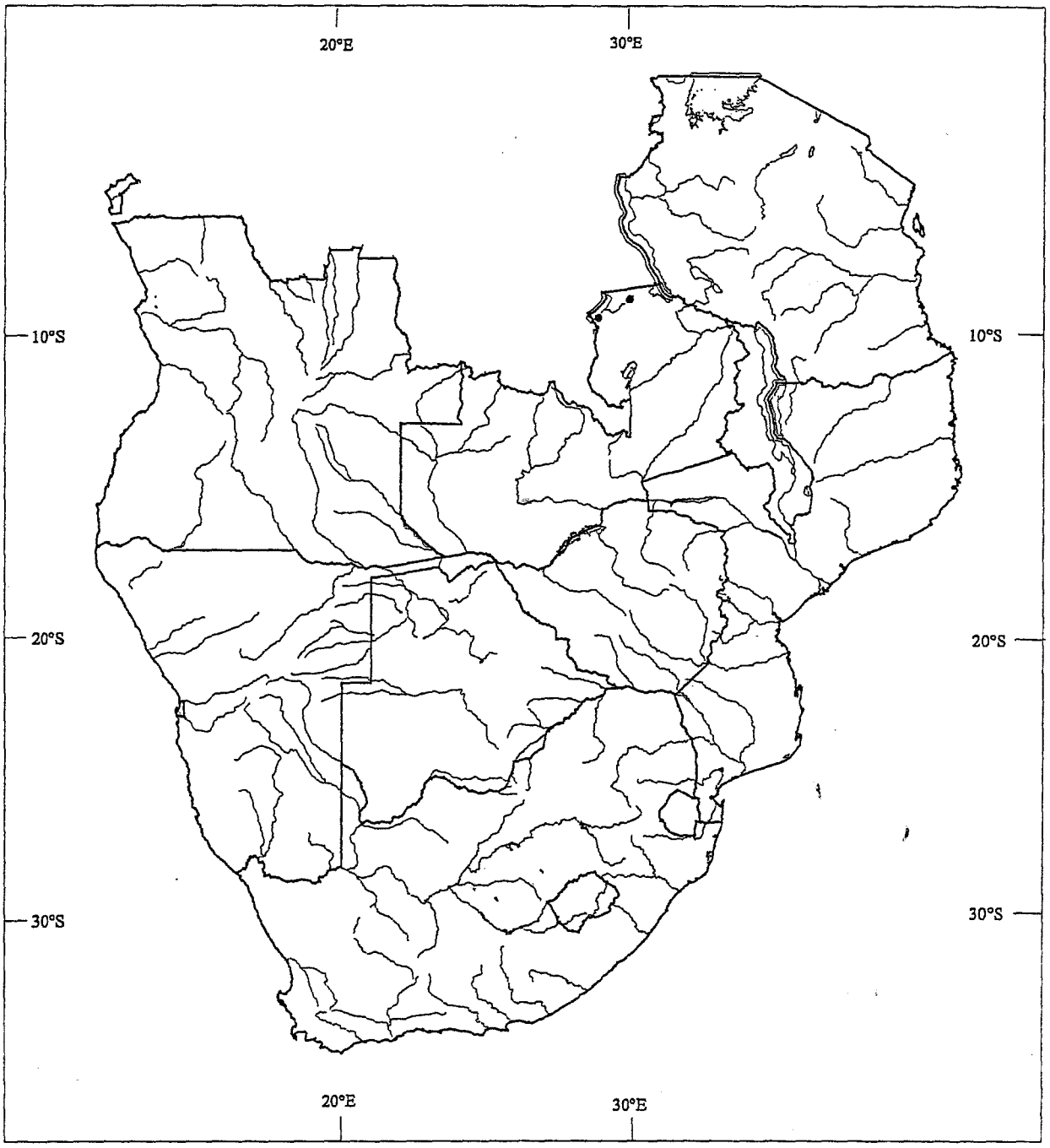


Figure F.215. Point distribution of *Coptostomabarbus bellcrossi*. Scale approximately 1:25 000 000

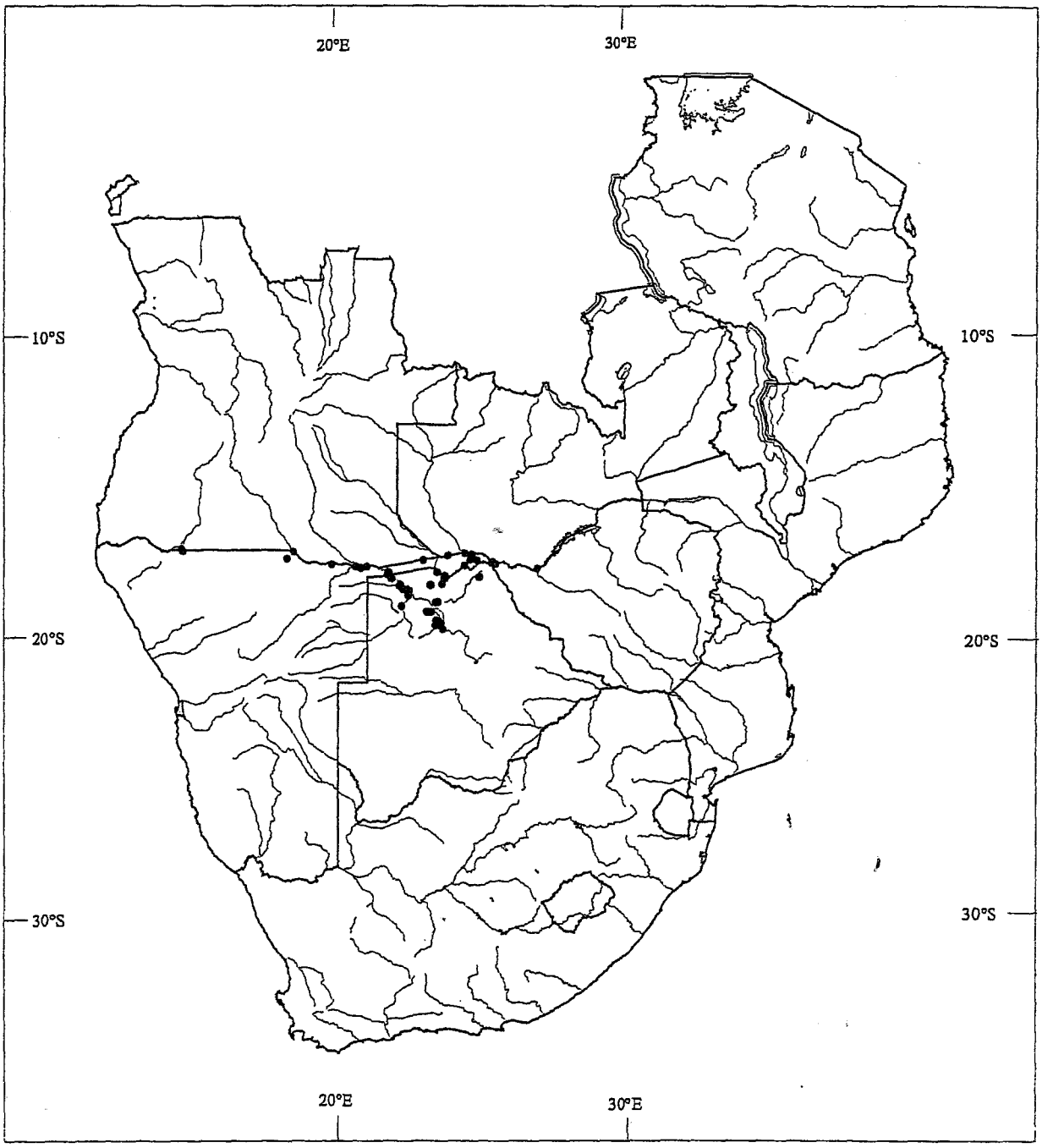


Figure F.216. Point distribution of *Coptostomabarbus wittei*. Scale approximately 1:25 000 000

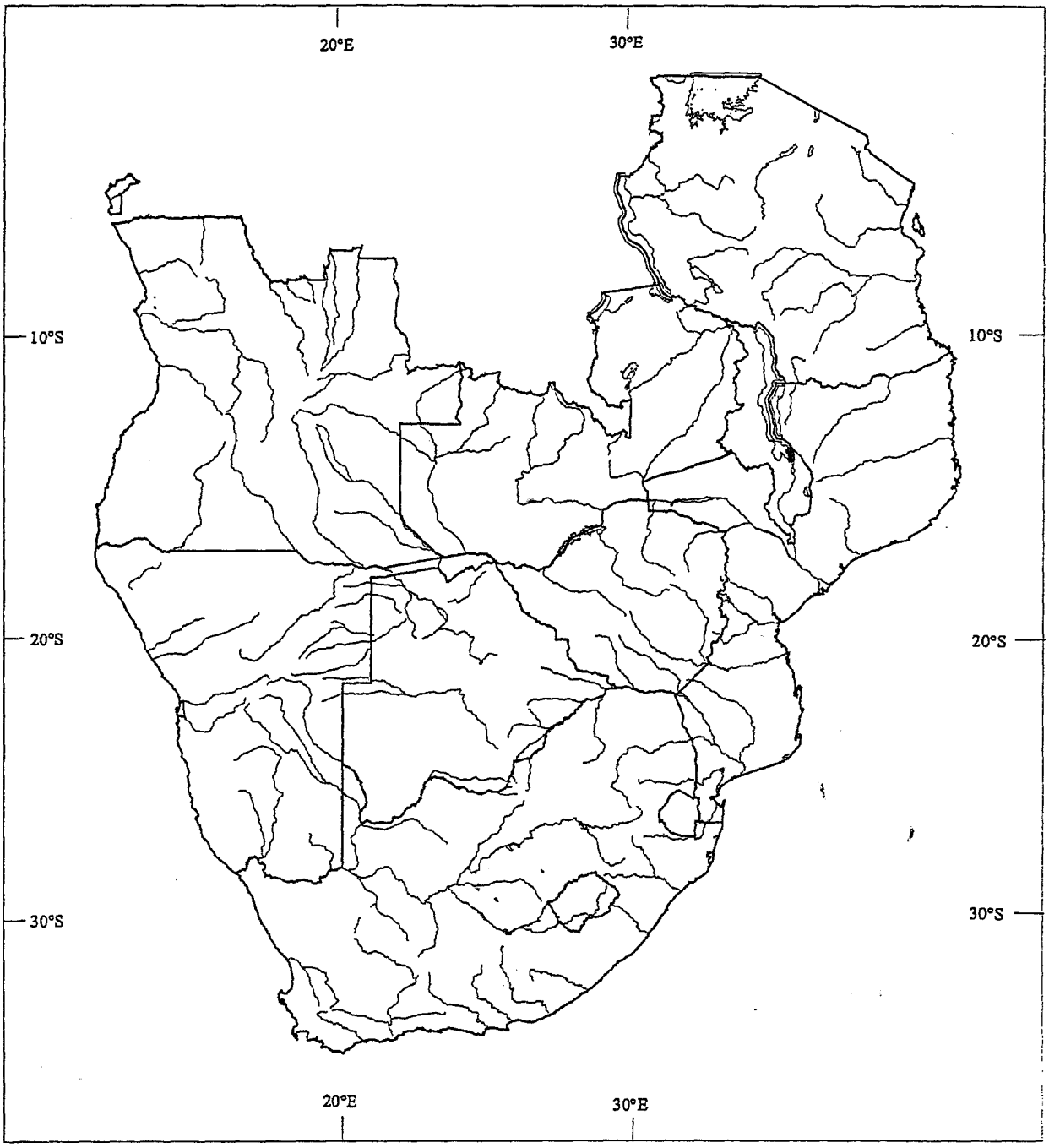


Figure F.217. Point distribution of *Corematodus shiranus*. Scale approximately 1:25 000 000

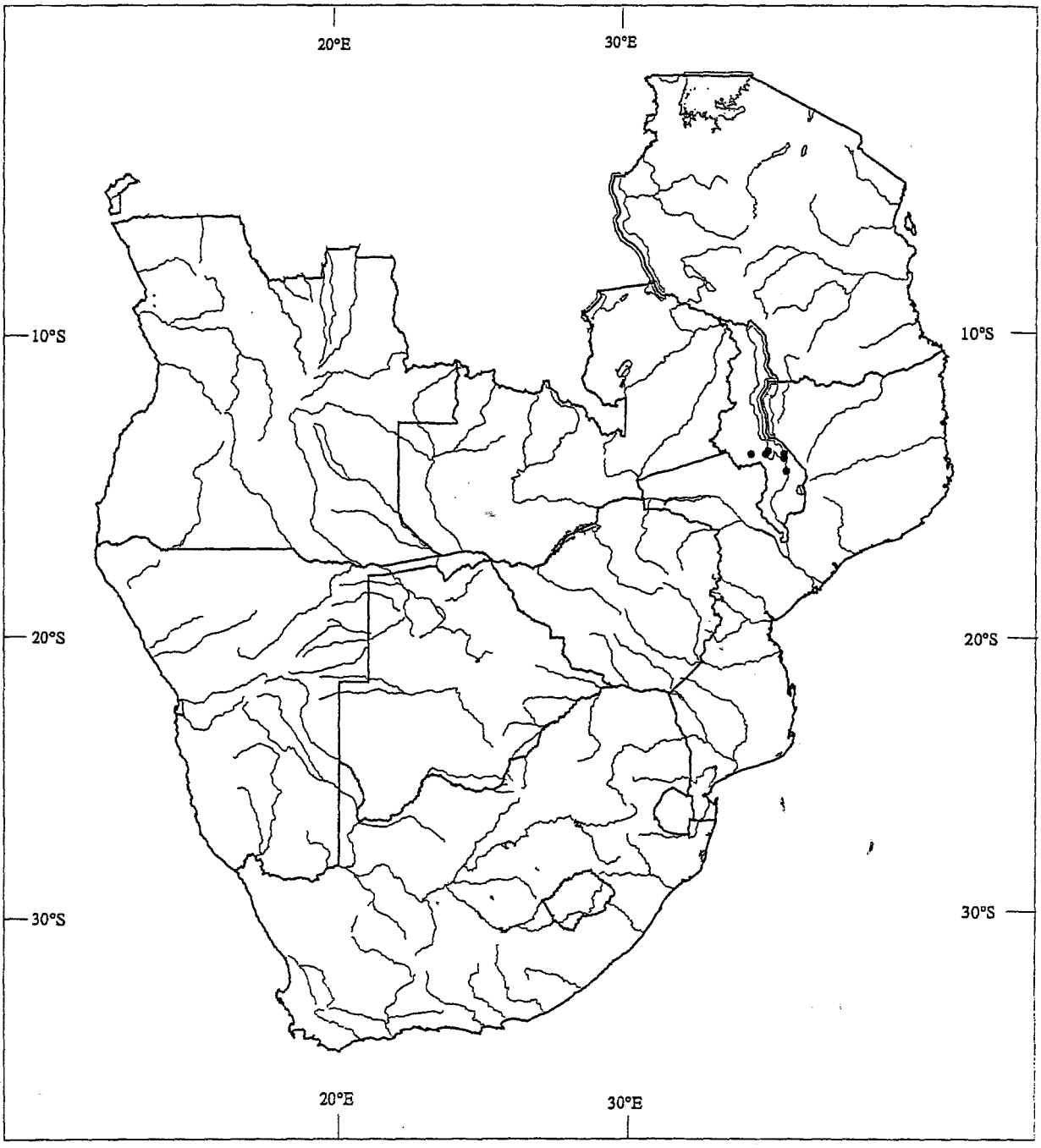


Figure F.218. Point distribution of *Corematodus taeniatus*. Scale approximately 1:25 000 000

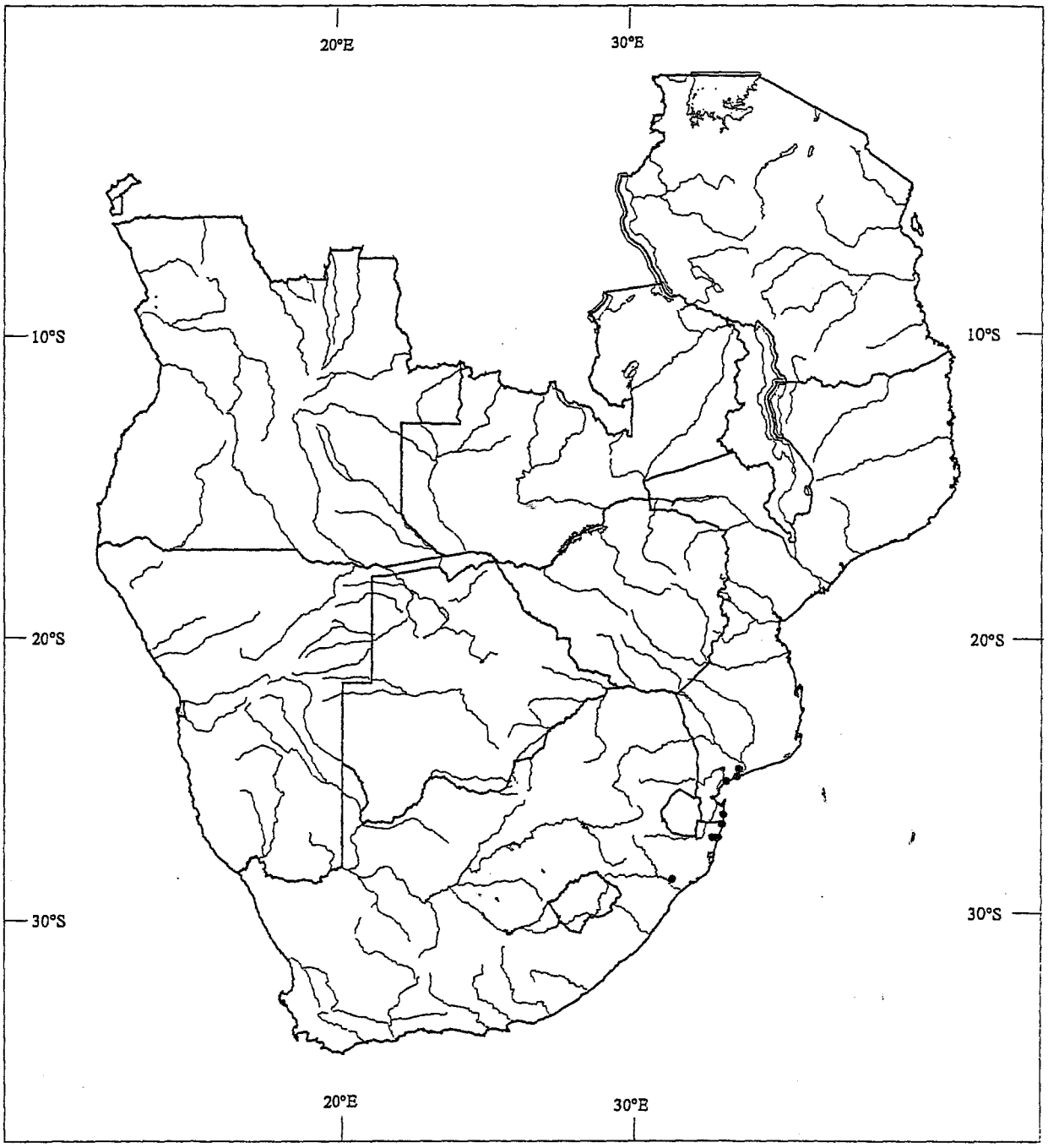


Figure F.219. Point distribution of *Croilia mossambica*. Scale approximately 1:25 000 000

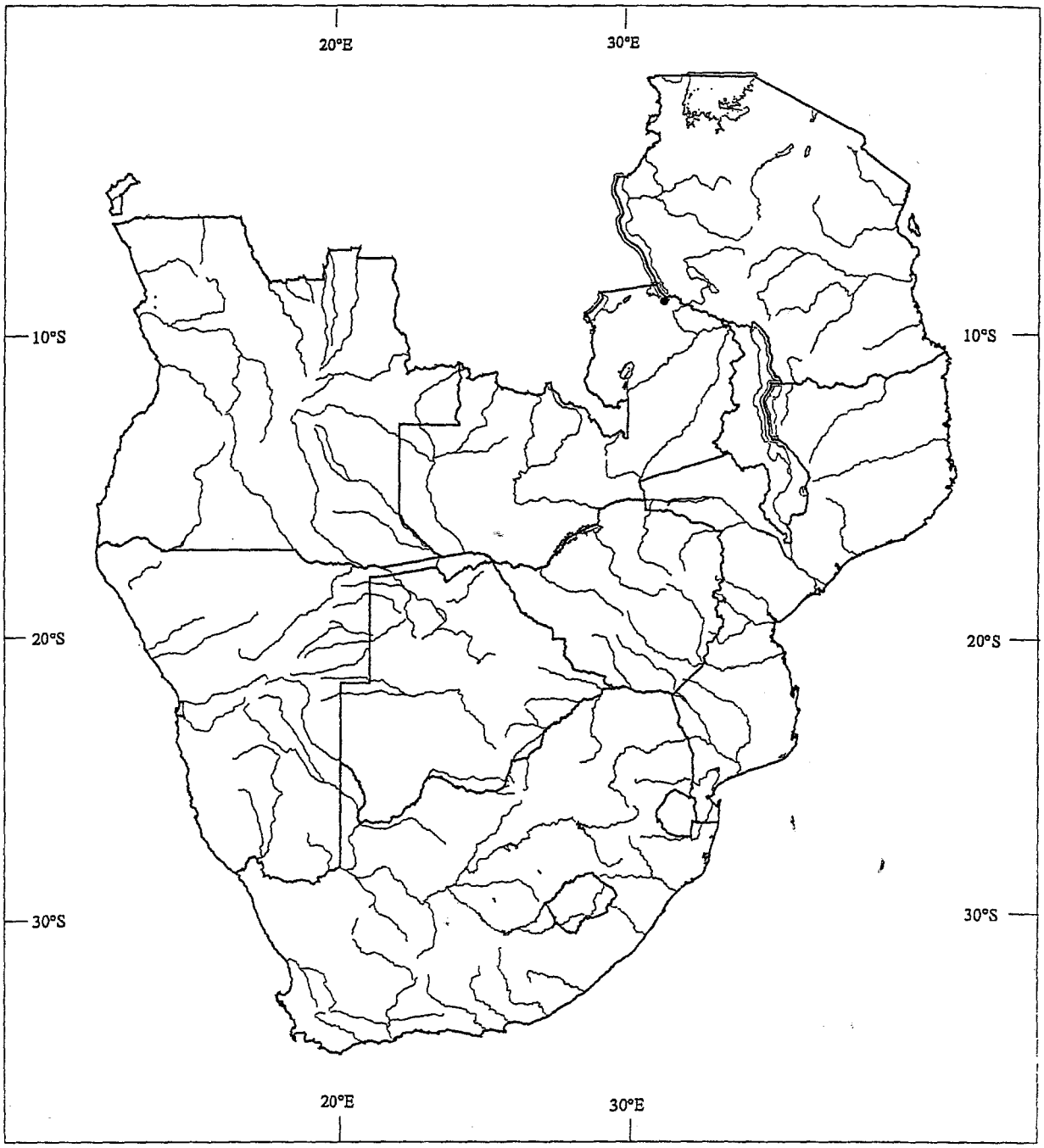


Figure F.220. Point distribution of *Ctenochromis benthicola.* Scale approximately 1:25 000 000

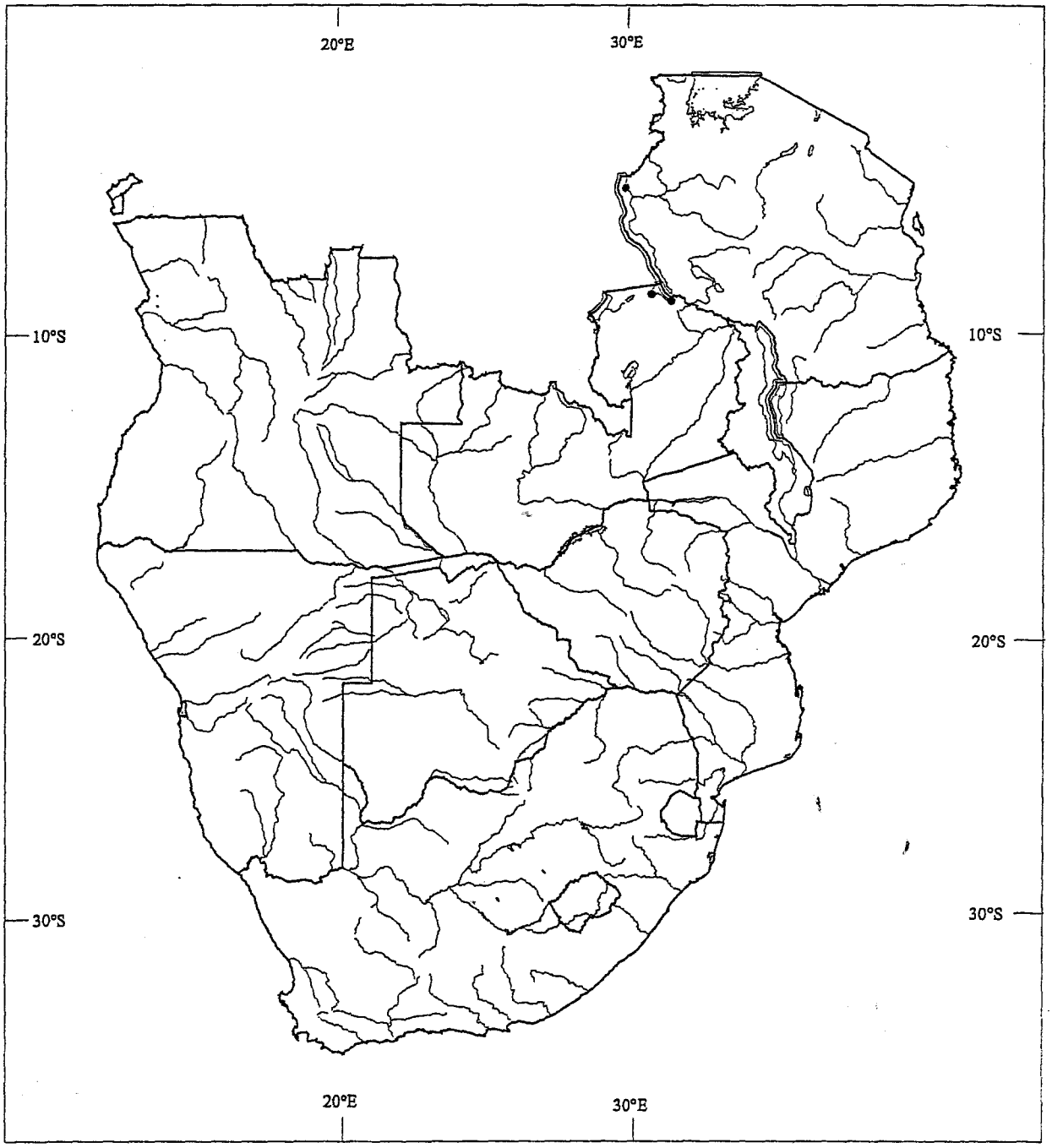


Figure F.221. Point distribution of *Ctenochromis horei*. Scale approximately 1:25 000 000

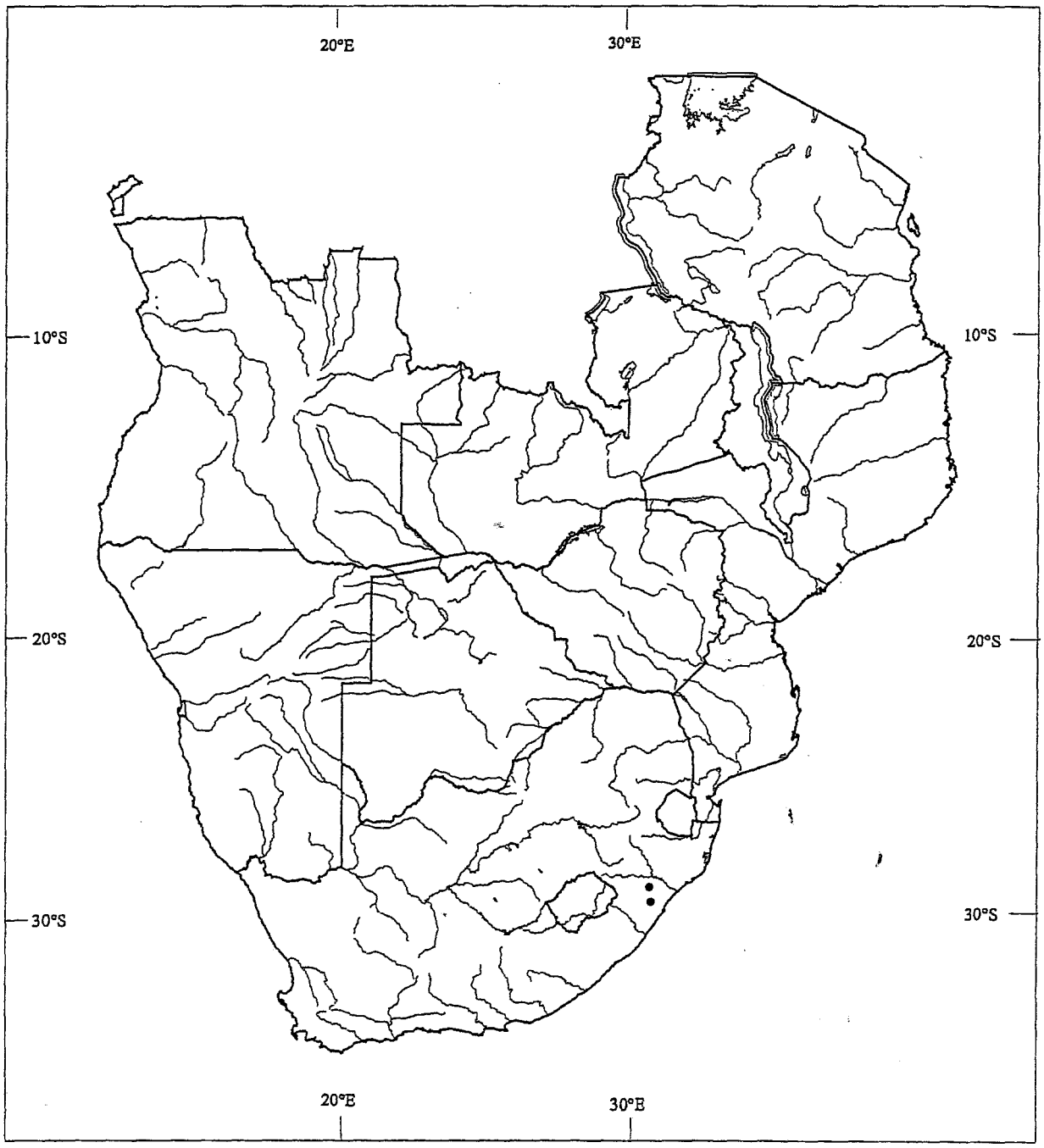


Figure F.222. Point distribution of *Ctenopharyngodon idella*. Scale approximately 1:25 000 000

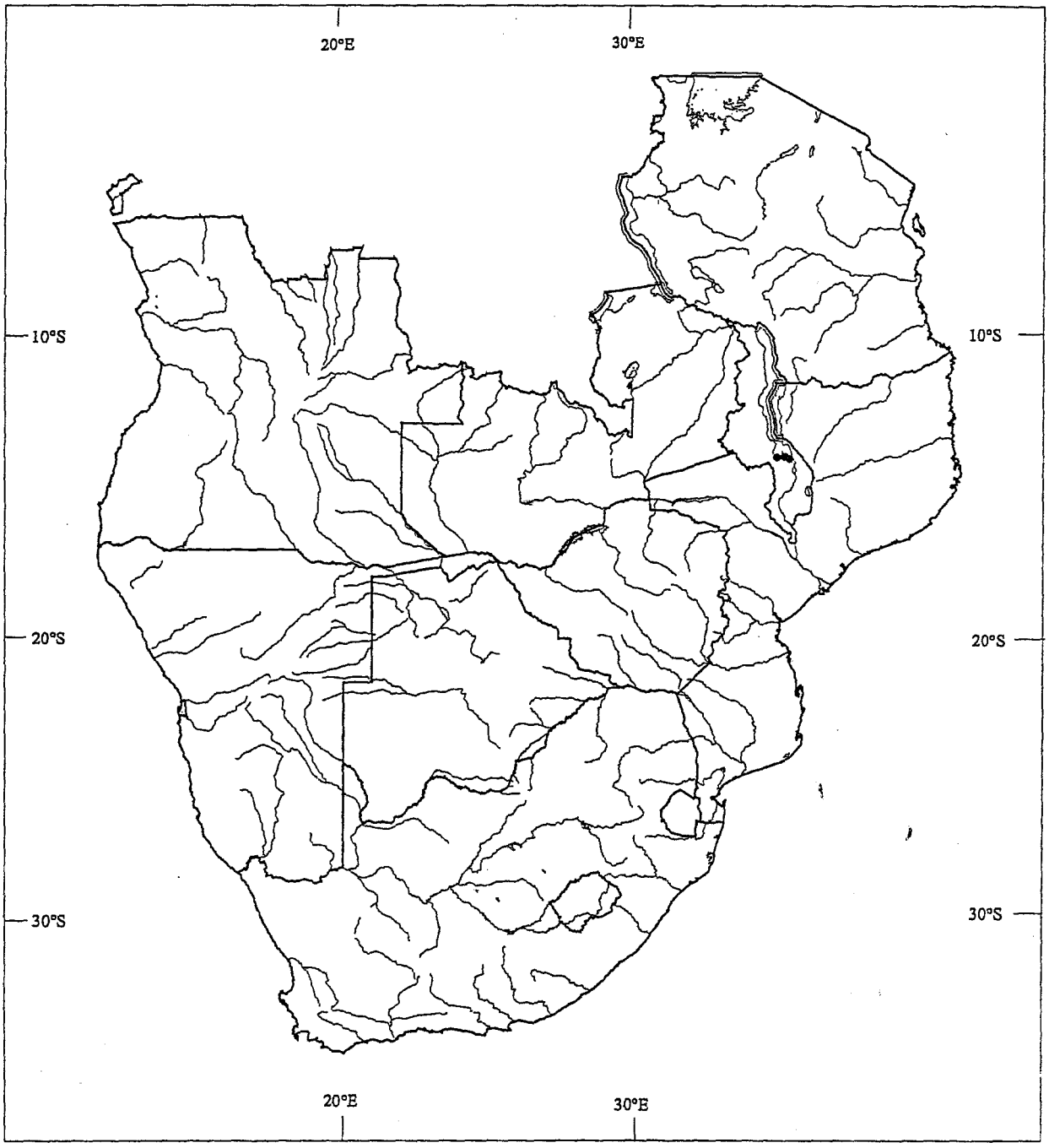


Figure F.223. Point distribution of *Ctenopharynx intermedius*. Scale approximately 1:25 000 000

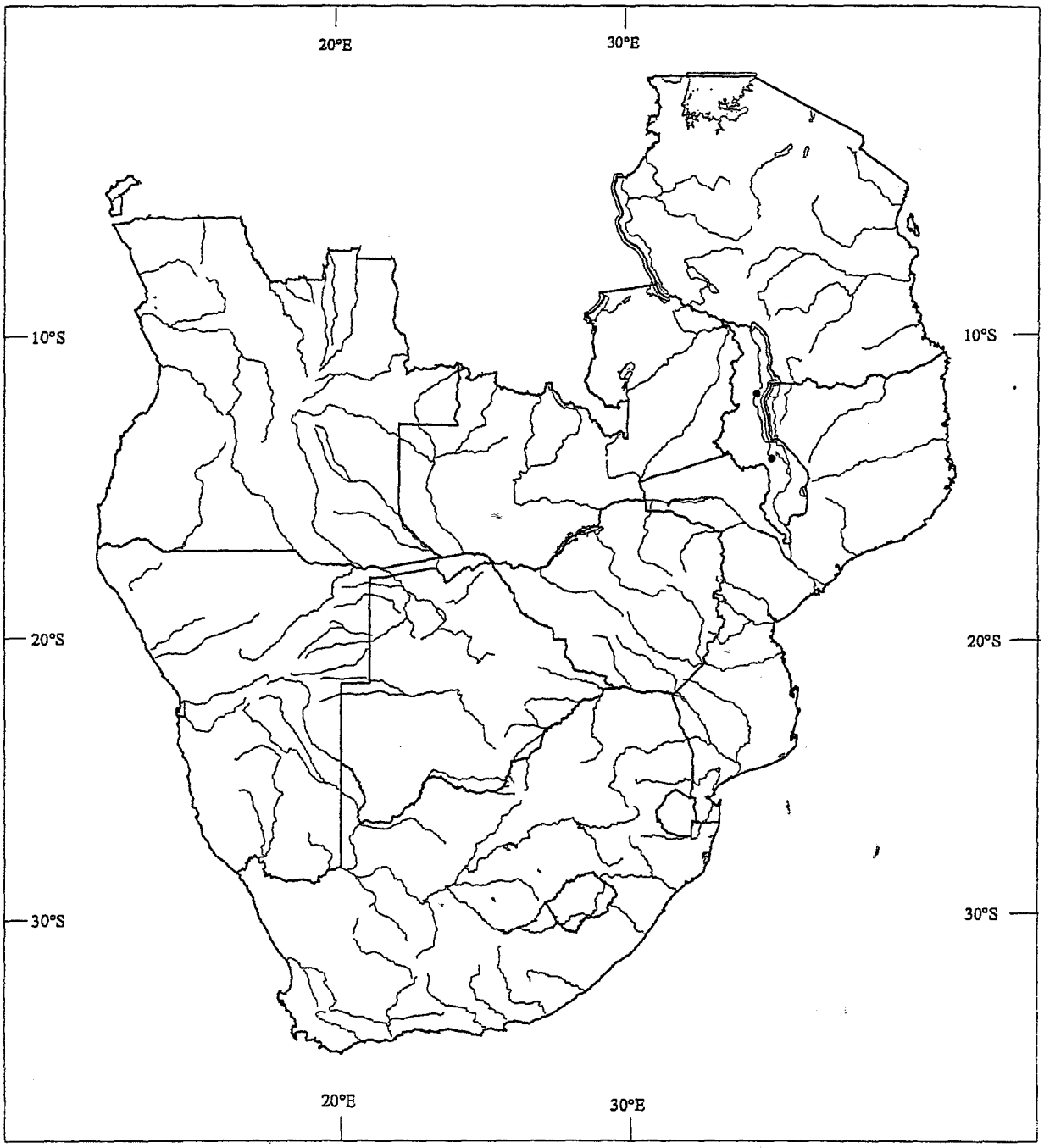


Figure F.224. Point distribution of *Ctenopharynx nitidus*. Scale approximately 1:25 000 000

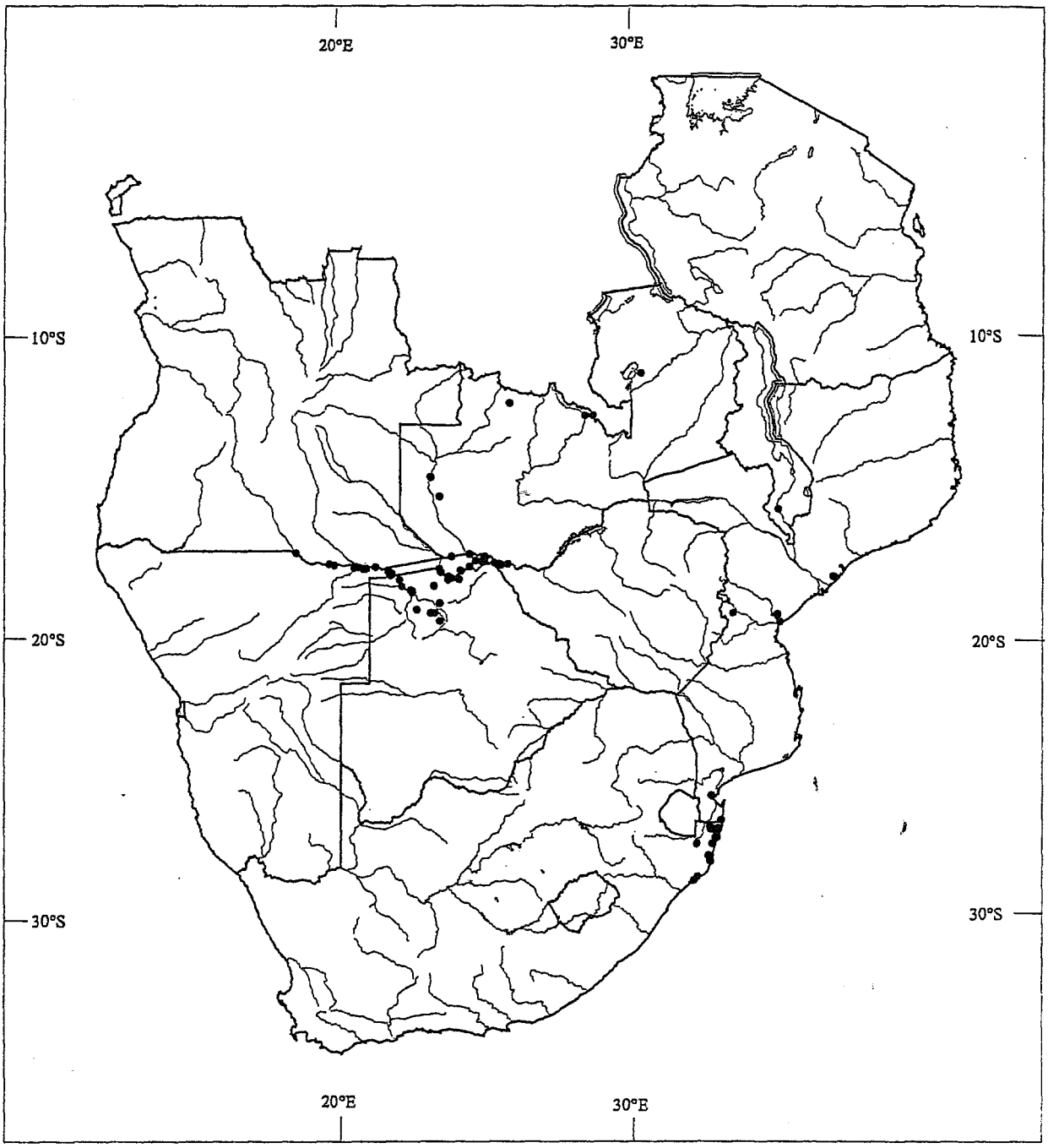


Figure F.225. Point distribution of *Ctenopoma multispine*. Scale approximately 1:25 000 000

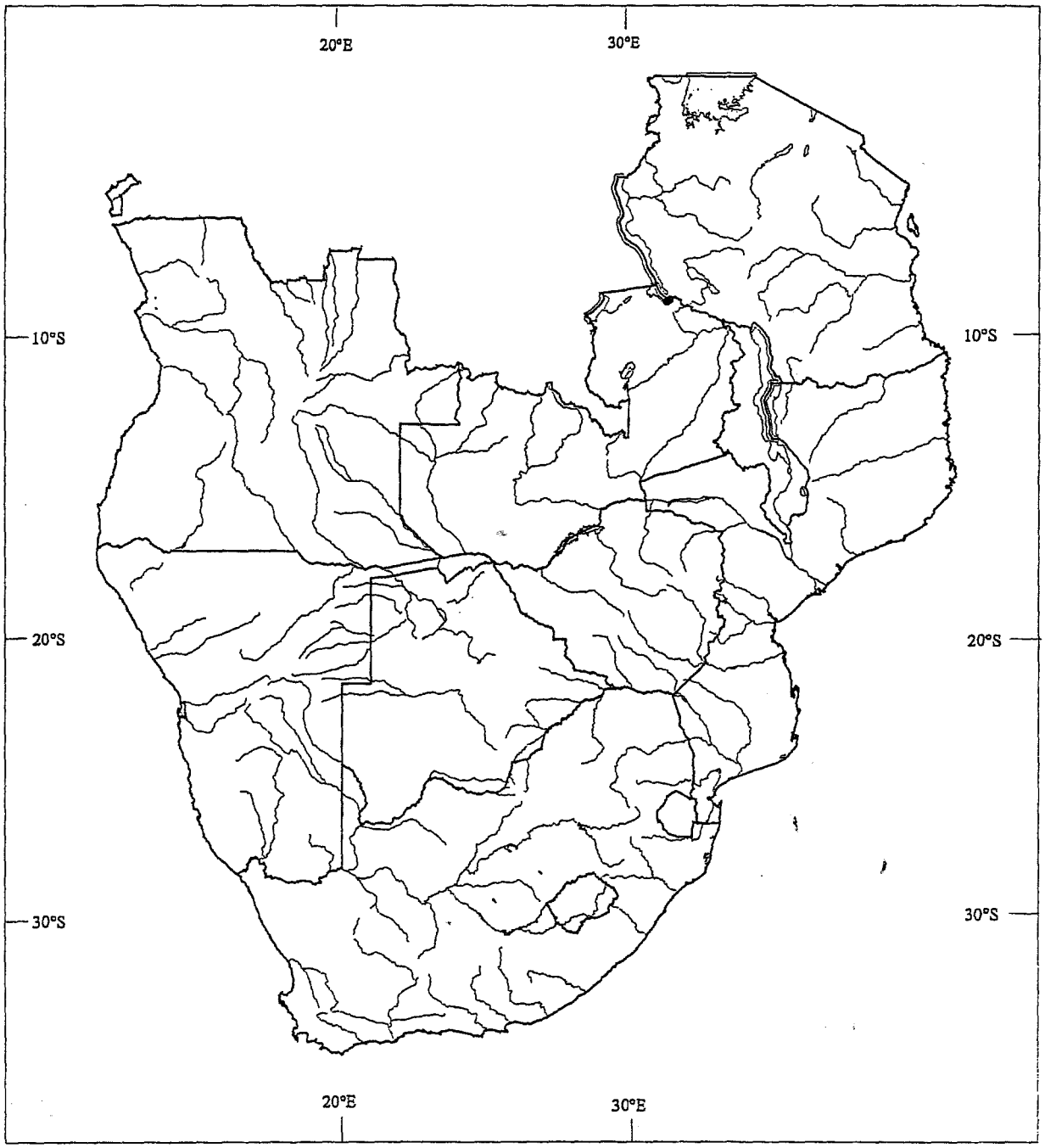


Figure F.226. Point distribution of *Cunningtonia longiventralis*. Scale approximately 1:25 000 000

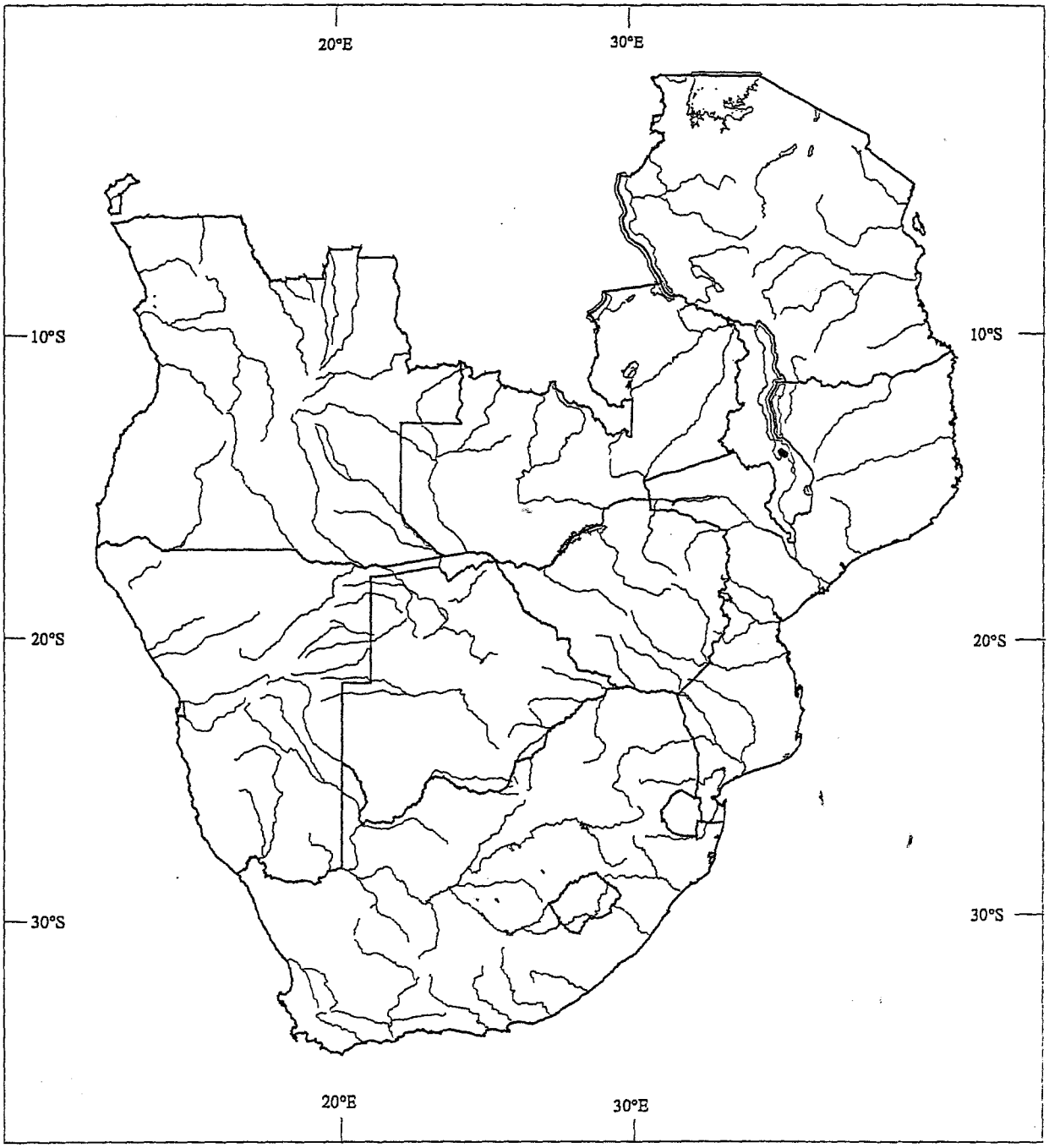


Figure F.227. Point distribution of *Cyathochromis obliquidens*. Scale approximately 1:25 000 000

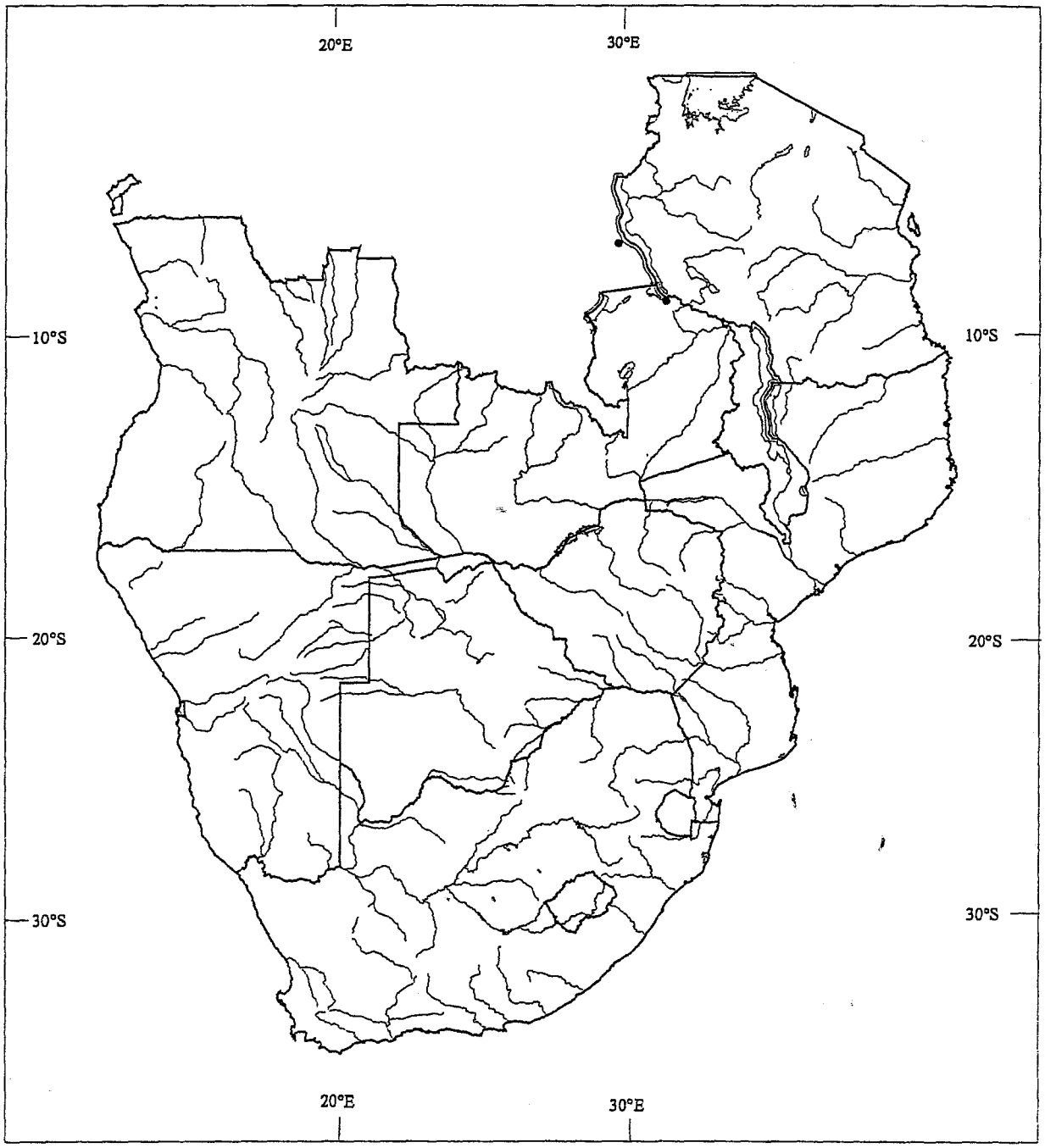


Figure F.228. Point distribution of *Cyathopharynx furcifer*. Scale approximately 1:25 000 000

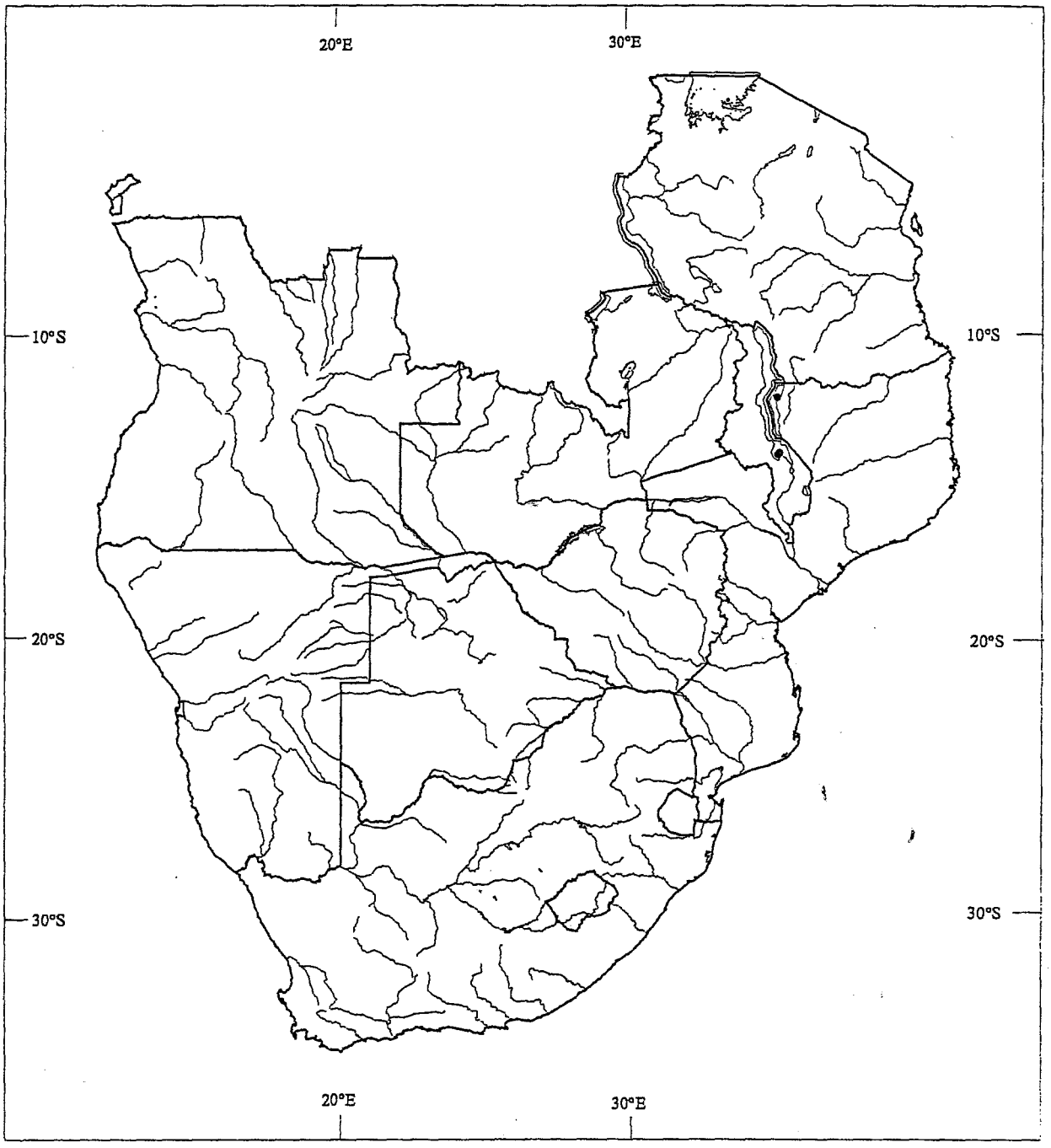


Figure F.229. Point distribution of *Cynotilapia afra*. Scale approximately 1:25 000 000

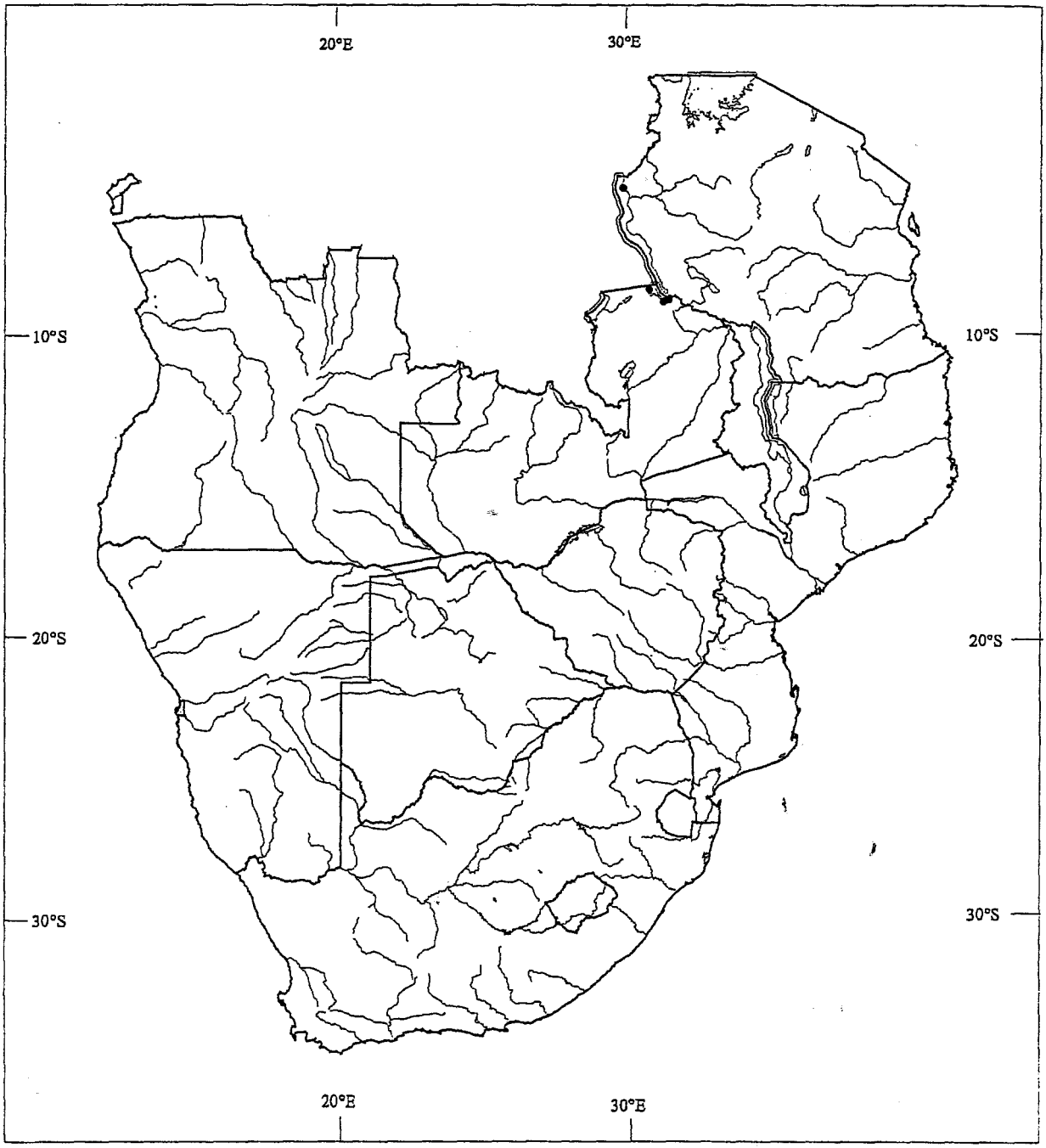


Figure F.230. Point distribution of *Cynotilapia frontosa*. Scale approximately 1:25 000 000

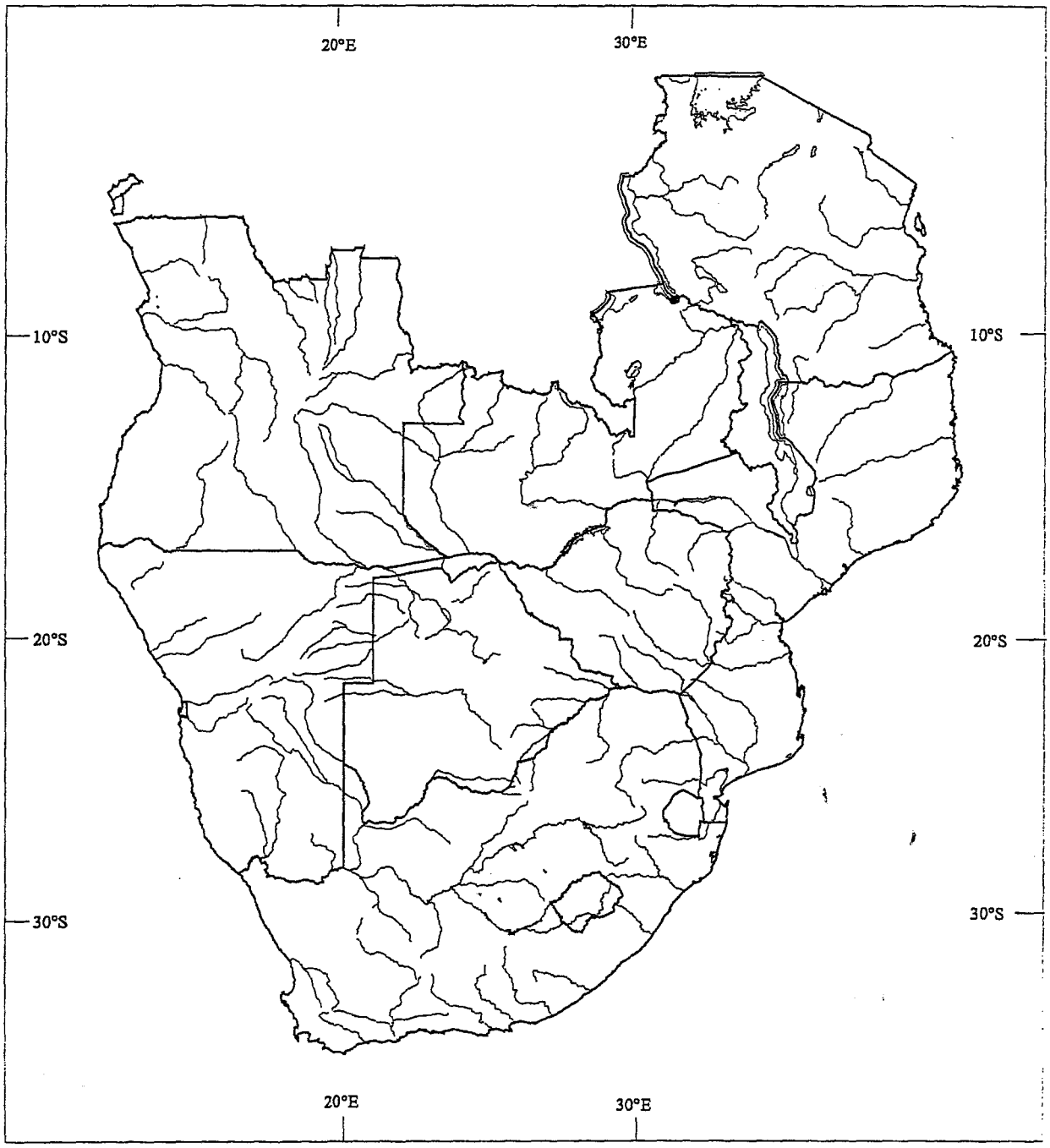


Figure F.231. Point distribution of *Cyprichromis leptosoma*. Scale approximately 1:25 000 000

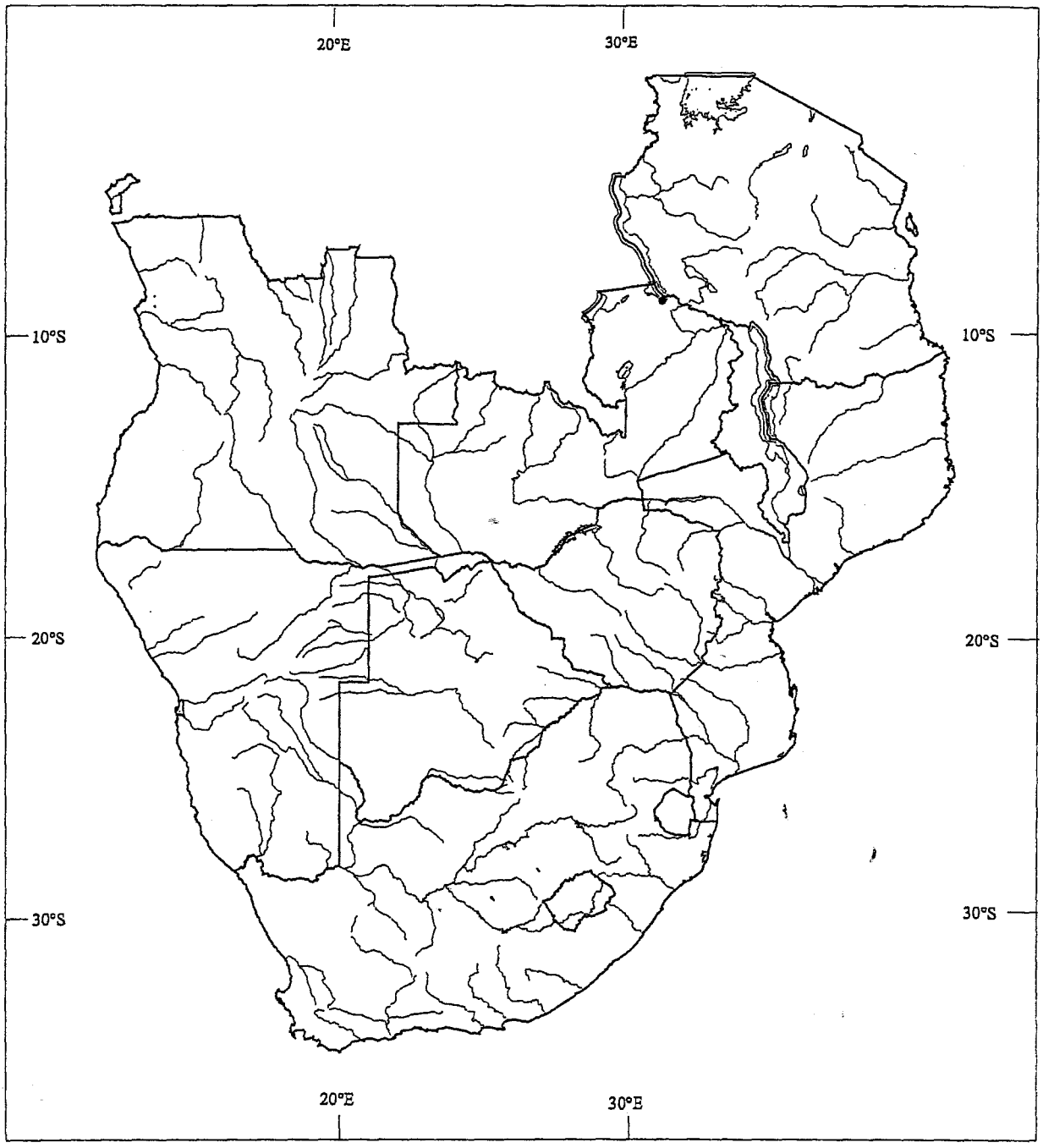


Figure F.232. Point distribution of *Cyprichromis pavo*. Scale approximately 1:25 000 000

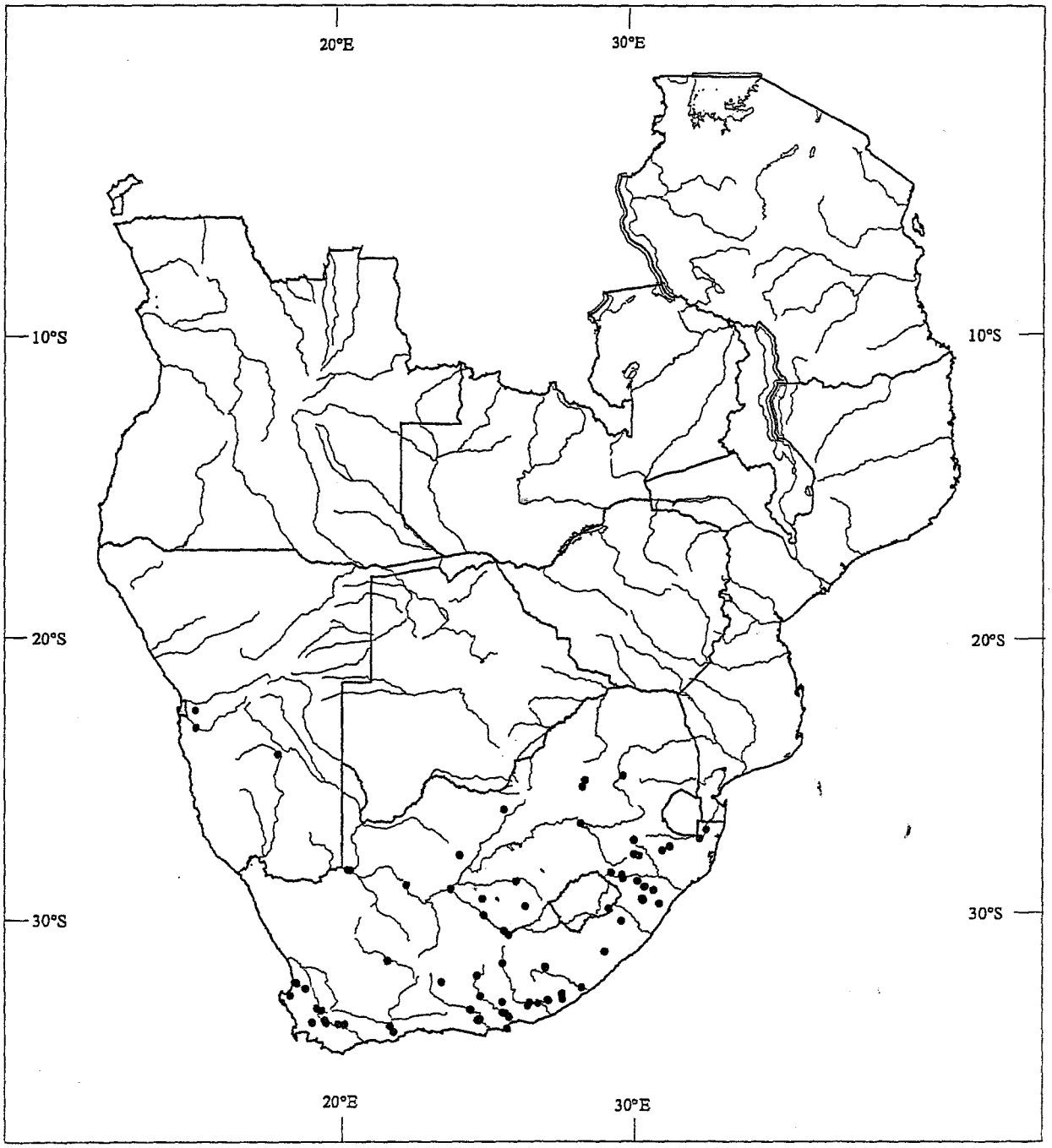


Figure F.233. Point distribution of *Cyprinus carpio*. Scale approximately 1:25 000 000

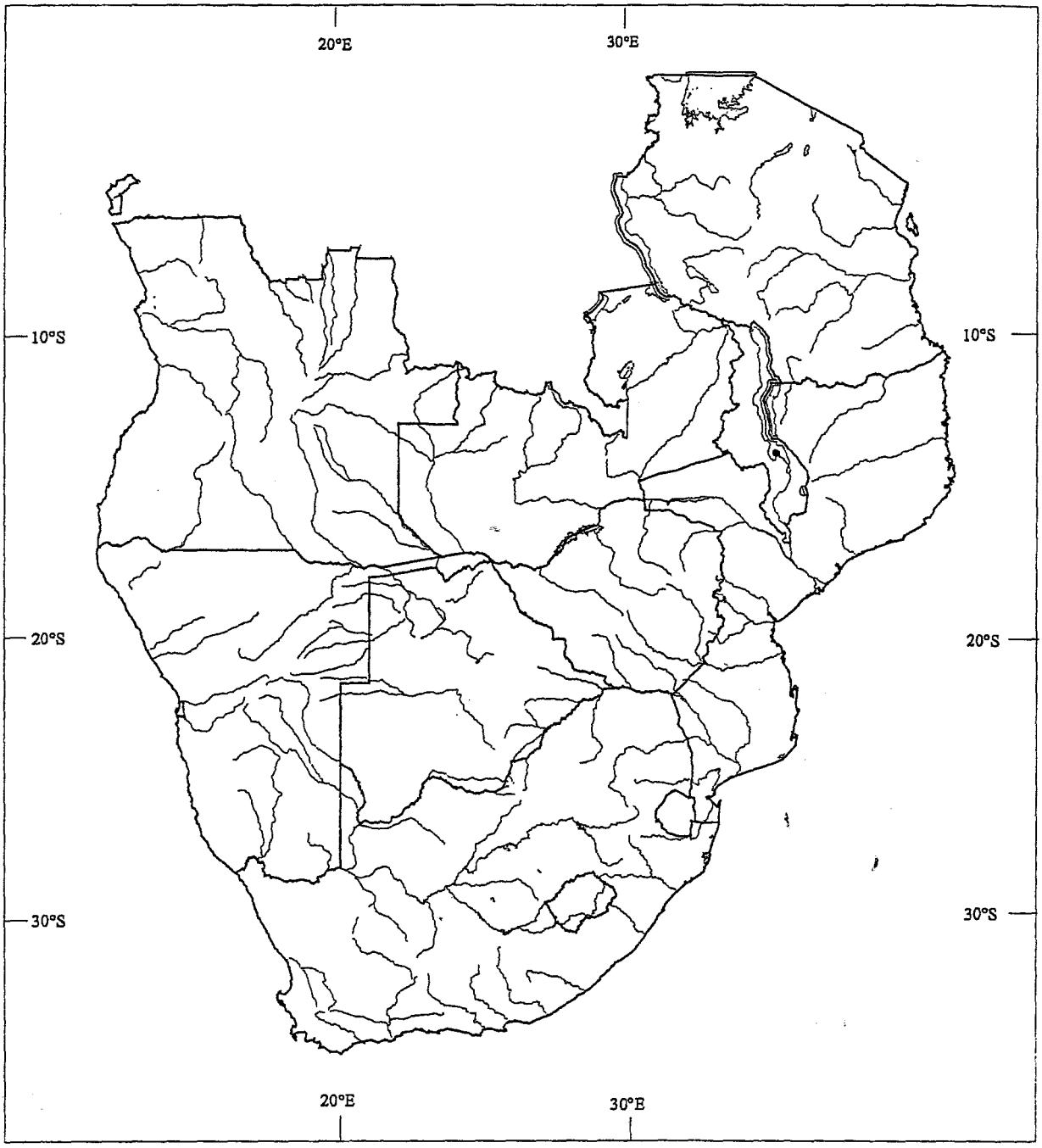


Figure F.234. Point distribution of *Cyrtocara anaphyrmus*. Scale approximately 1:25 000 000

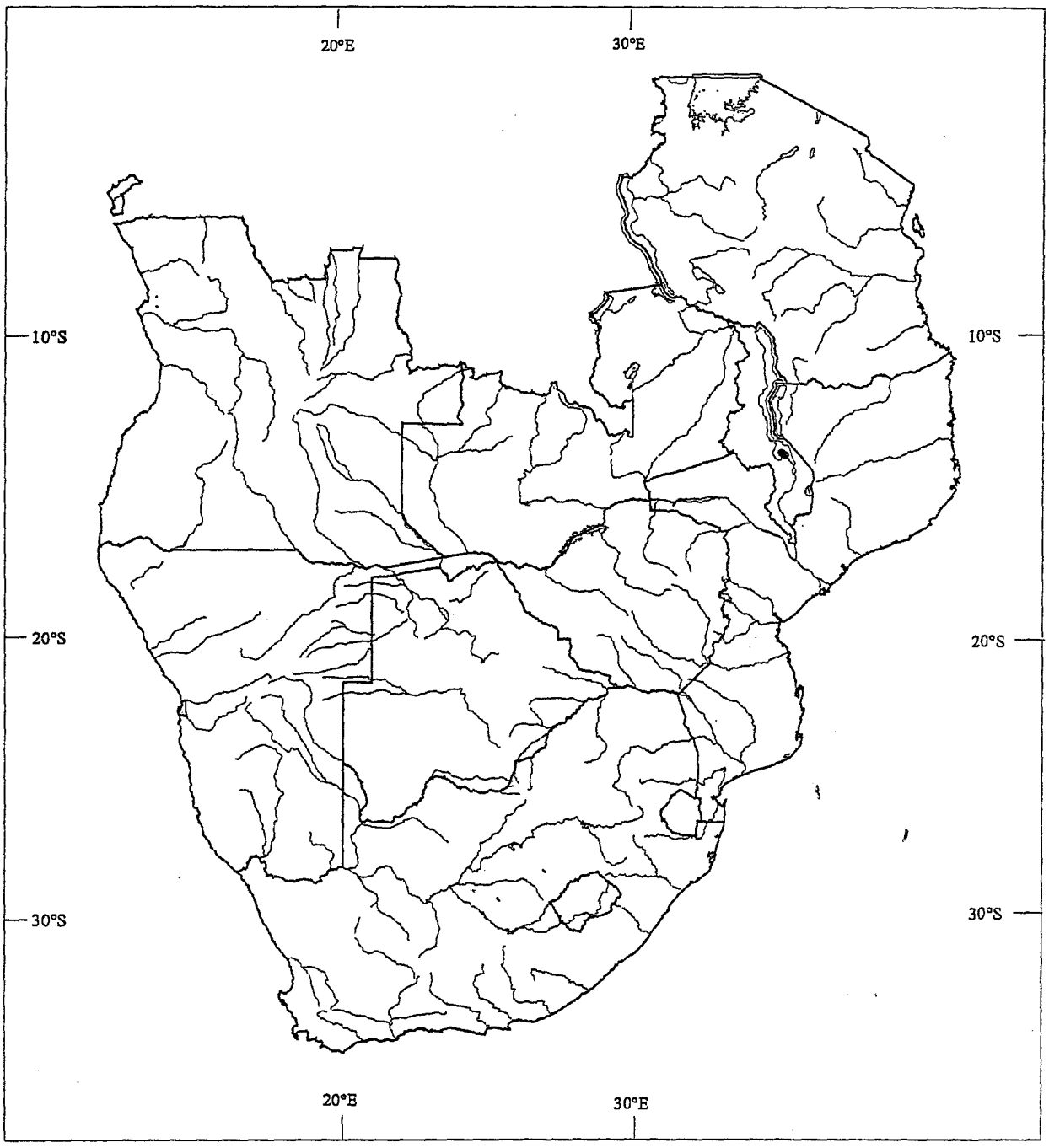


Figure F.235. Point distribution of *Cyrtocara compressiceps*. Scale approximately 1:25 000 000

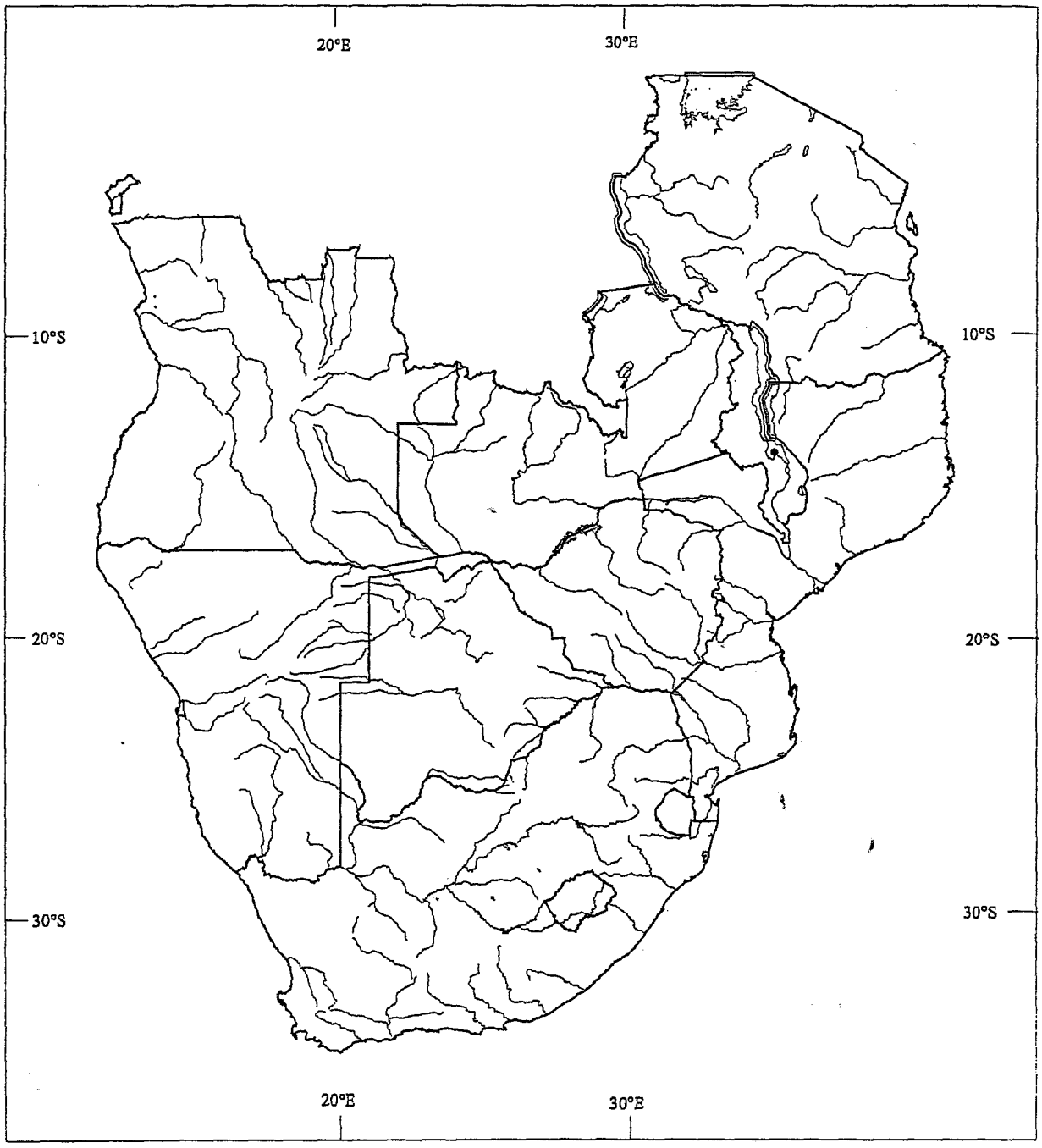


Figure F.236. Point distribution of *Cyrtocara euchilus*. Scale approximately 1:25 000 000

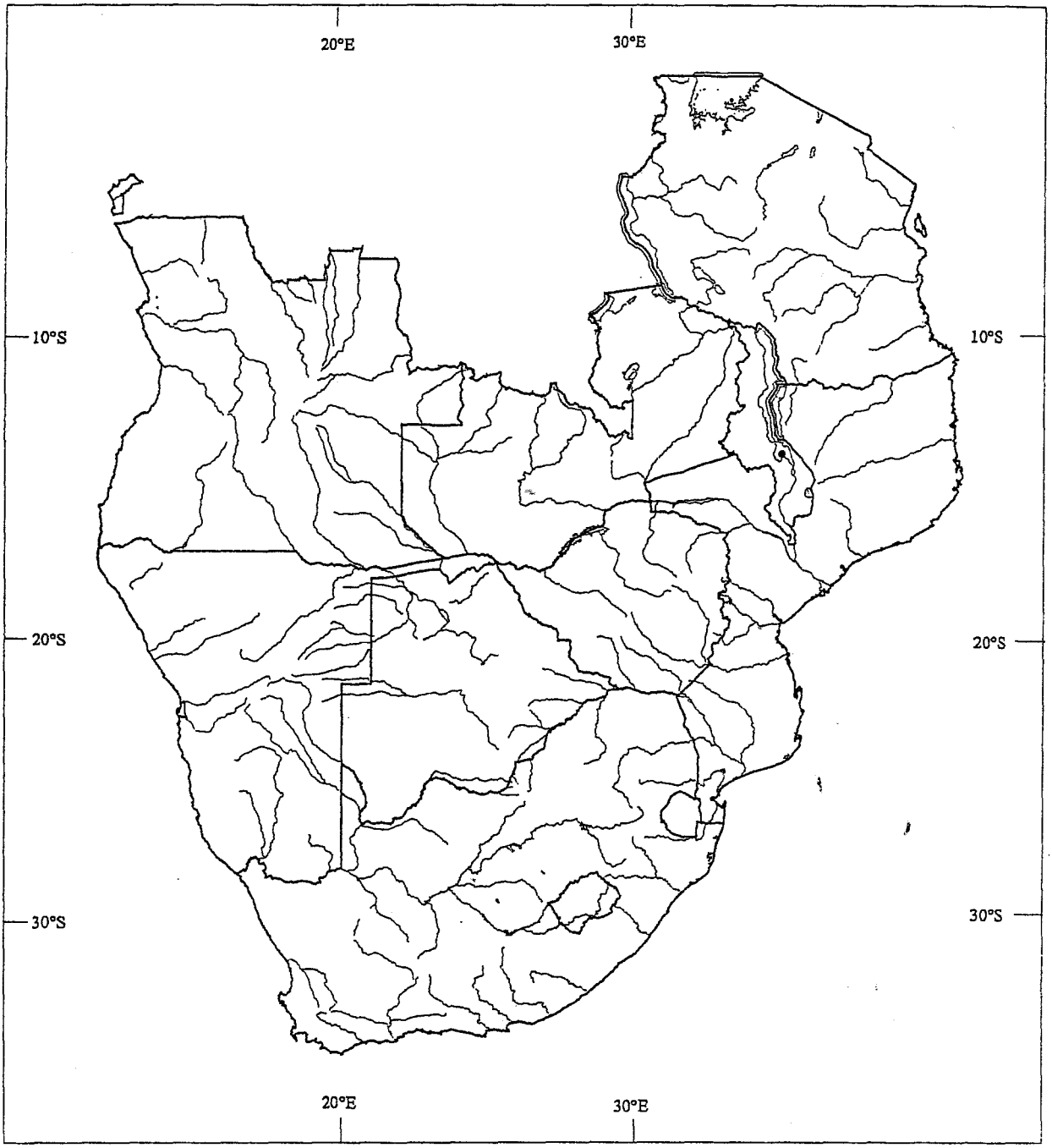


Figure F.237. Point distribution of *Cyrtocara eucinostomus*. Scale approximately 1:25 000 000

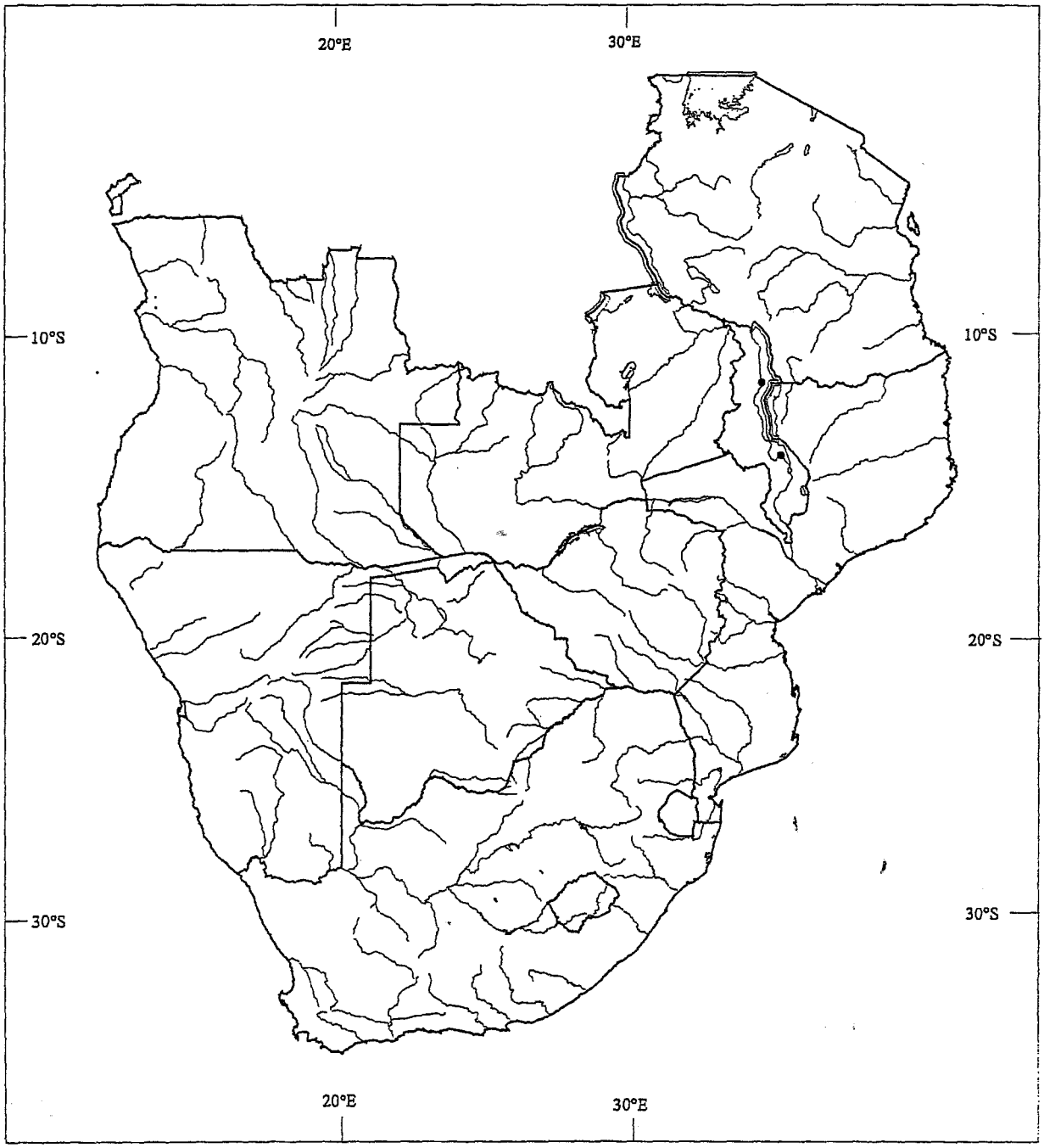


Figure F.238. Point distribution of *Cyrtocara fenestratus*. Scale approximately 1:25 000 000

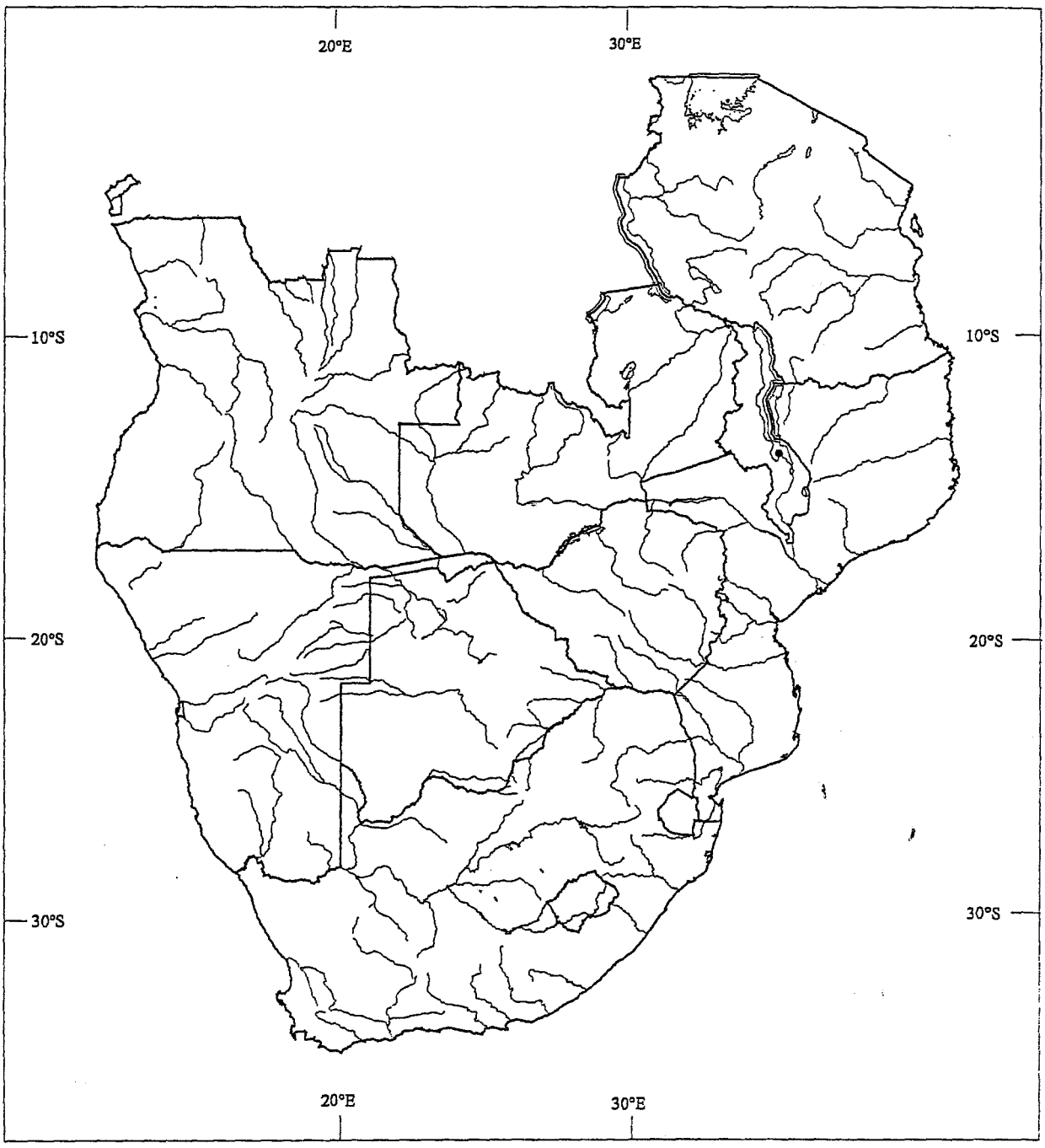


Figure F.239. Point distribution of *Cyrtocara intermedia*. Scale approximately 1:25 000 000

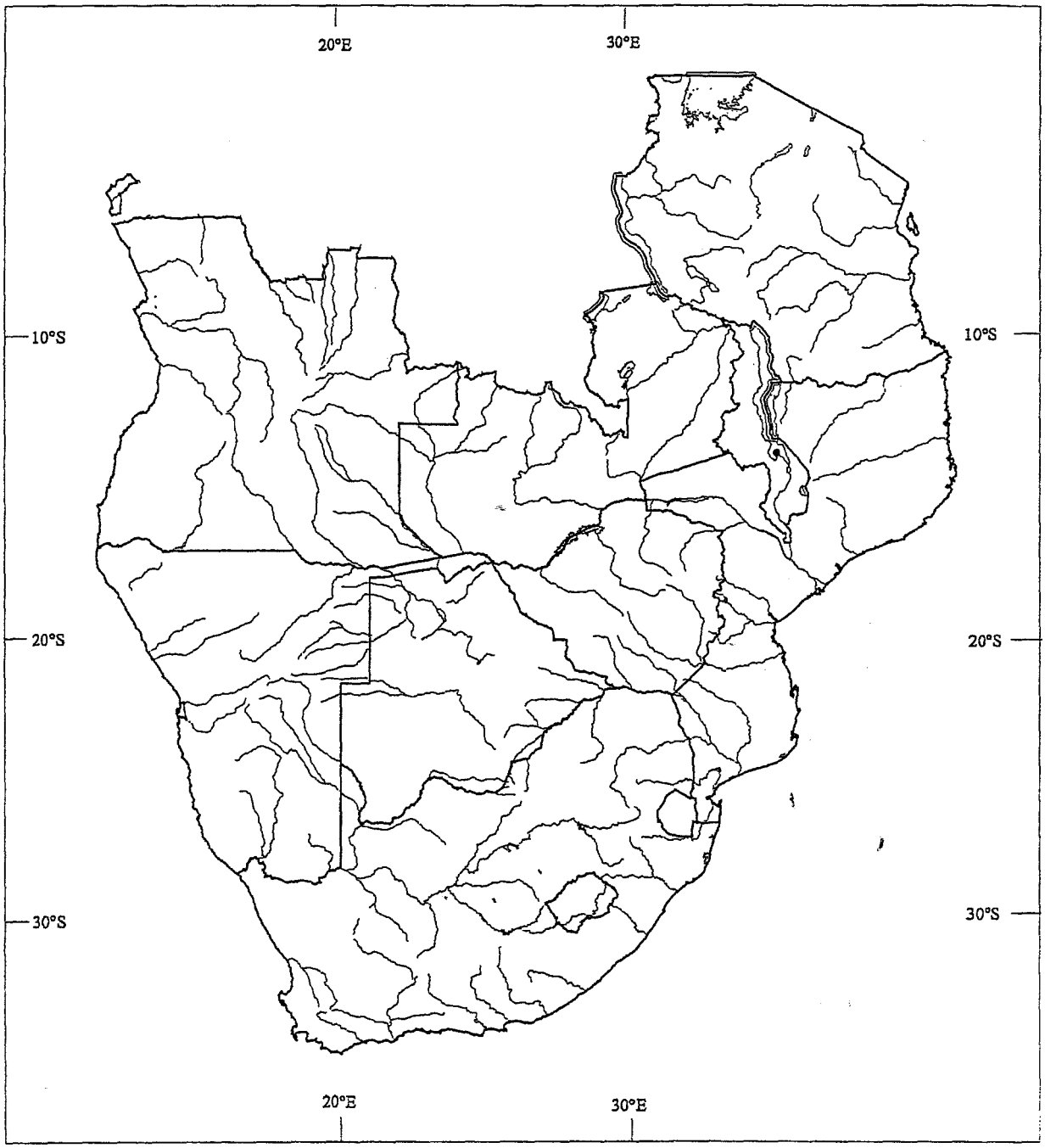


Figure F.240. Point distribution of *Cyrtocara johnstonii*. Scale approximately 1:25 000 000

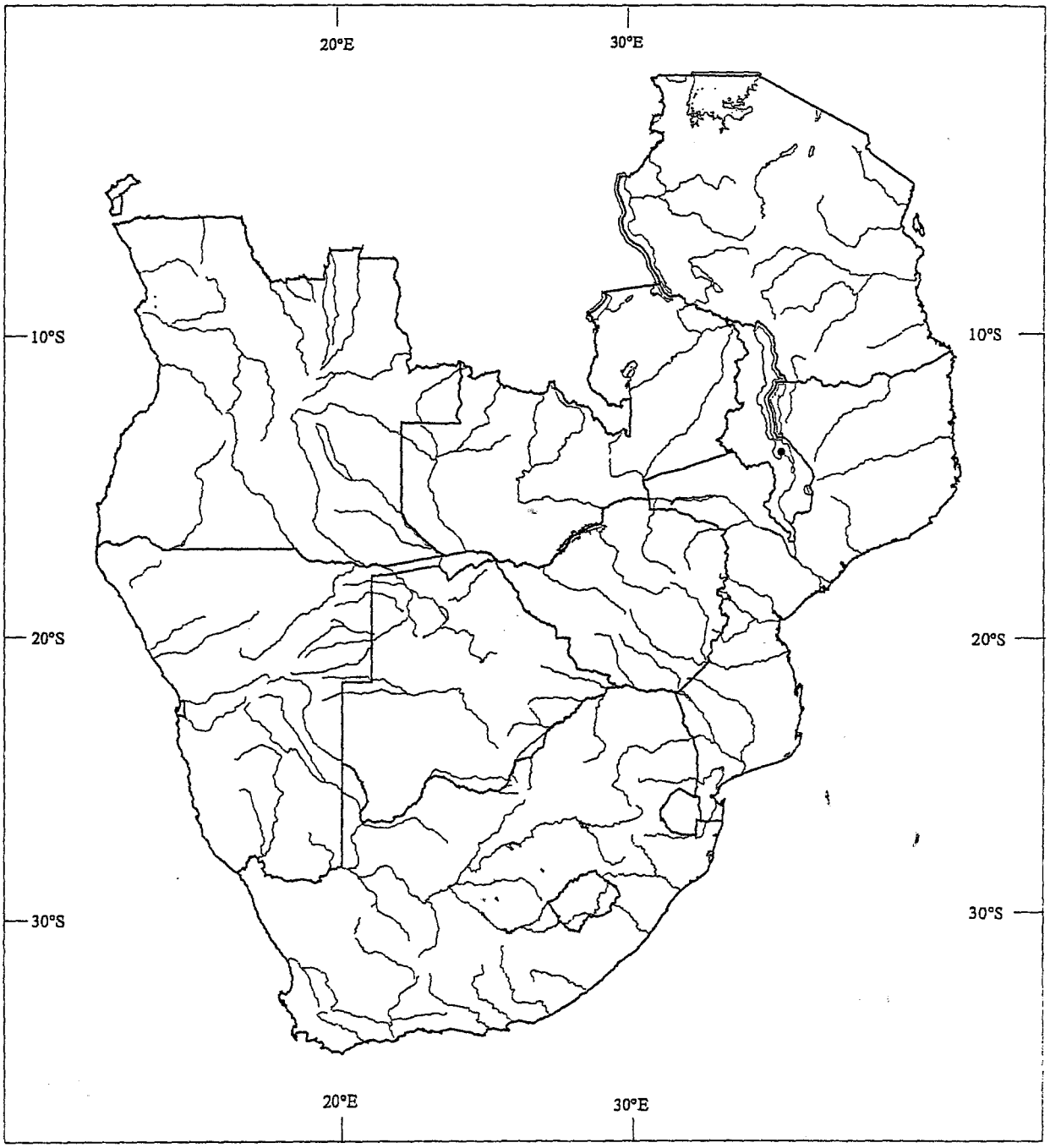


Figure F.241. Point distribution of *Cyrtocara kiwinge*. Scale approximately 1:25 000 000

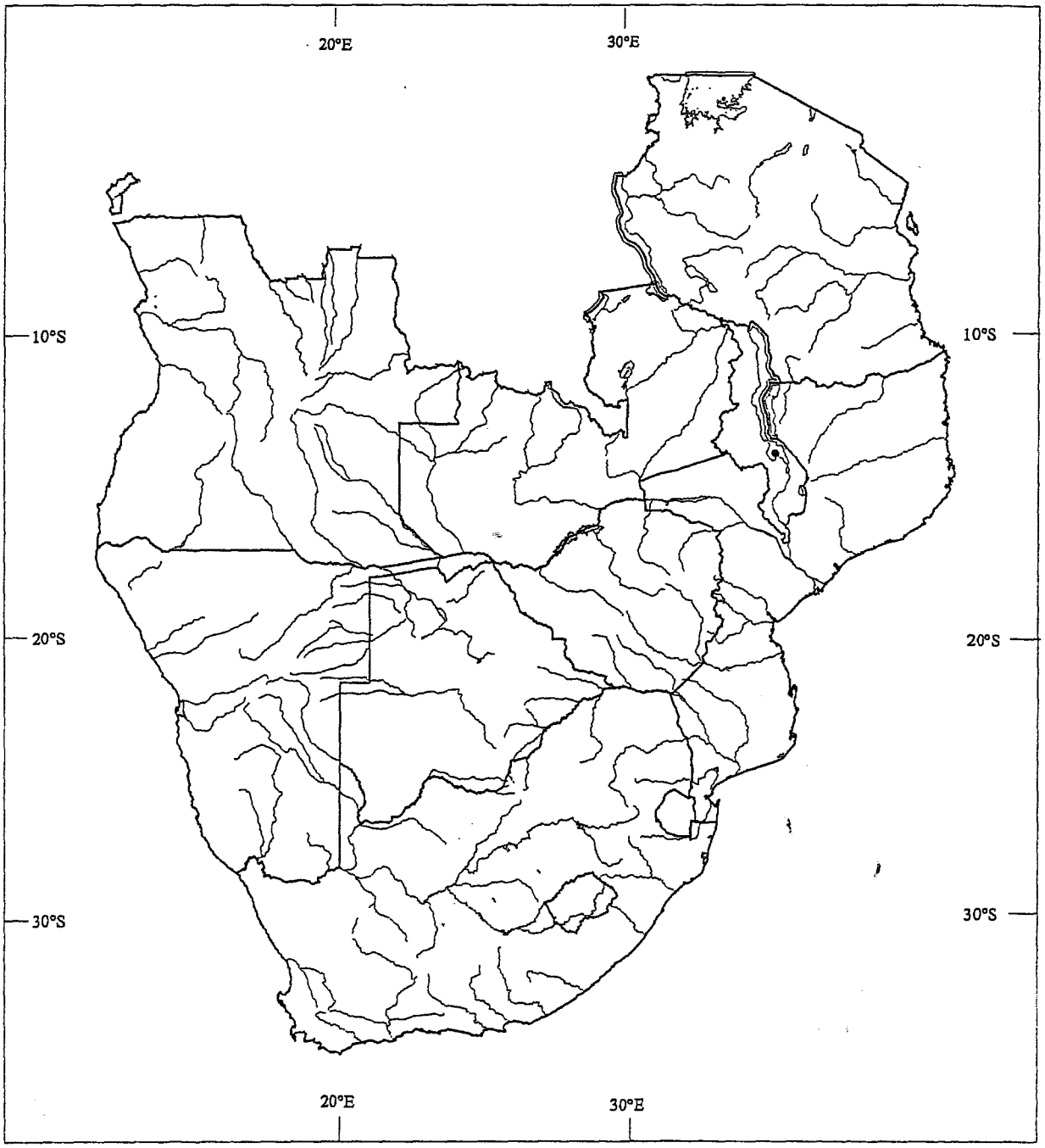


Figure F.242. Point distribution of *Cyrtocara lepteris*. Scale approximately 1:25 000 000

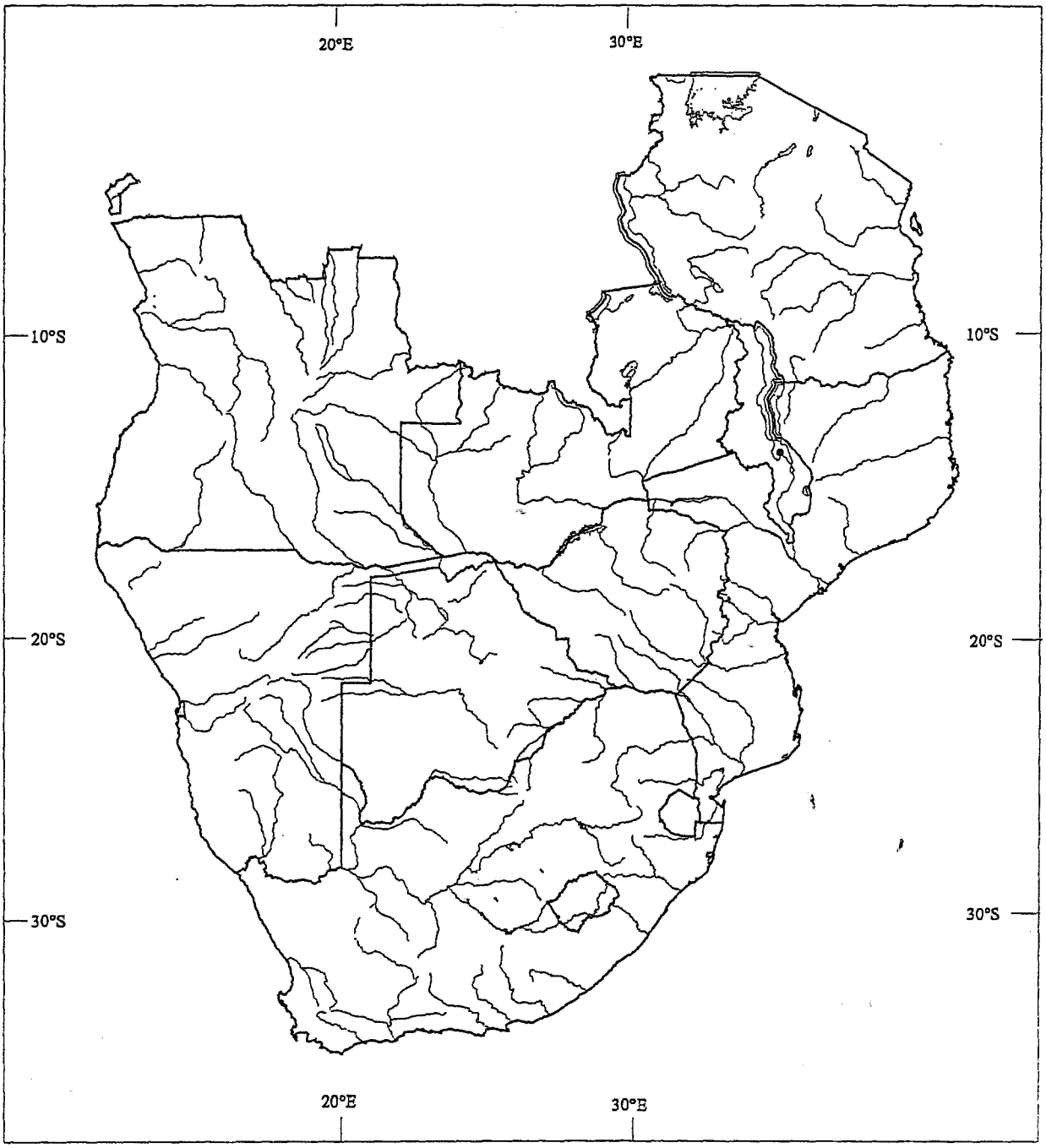


Figure F.243. Point distribution of *Cyrtocara livingstonii*. Scale approximately 1:25 000 000

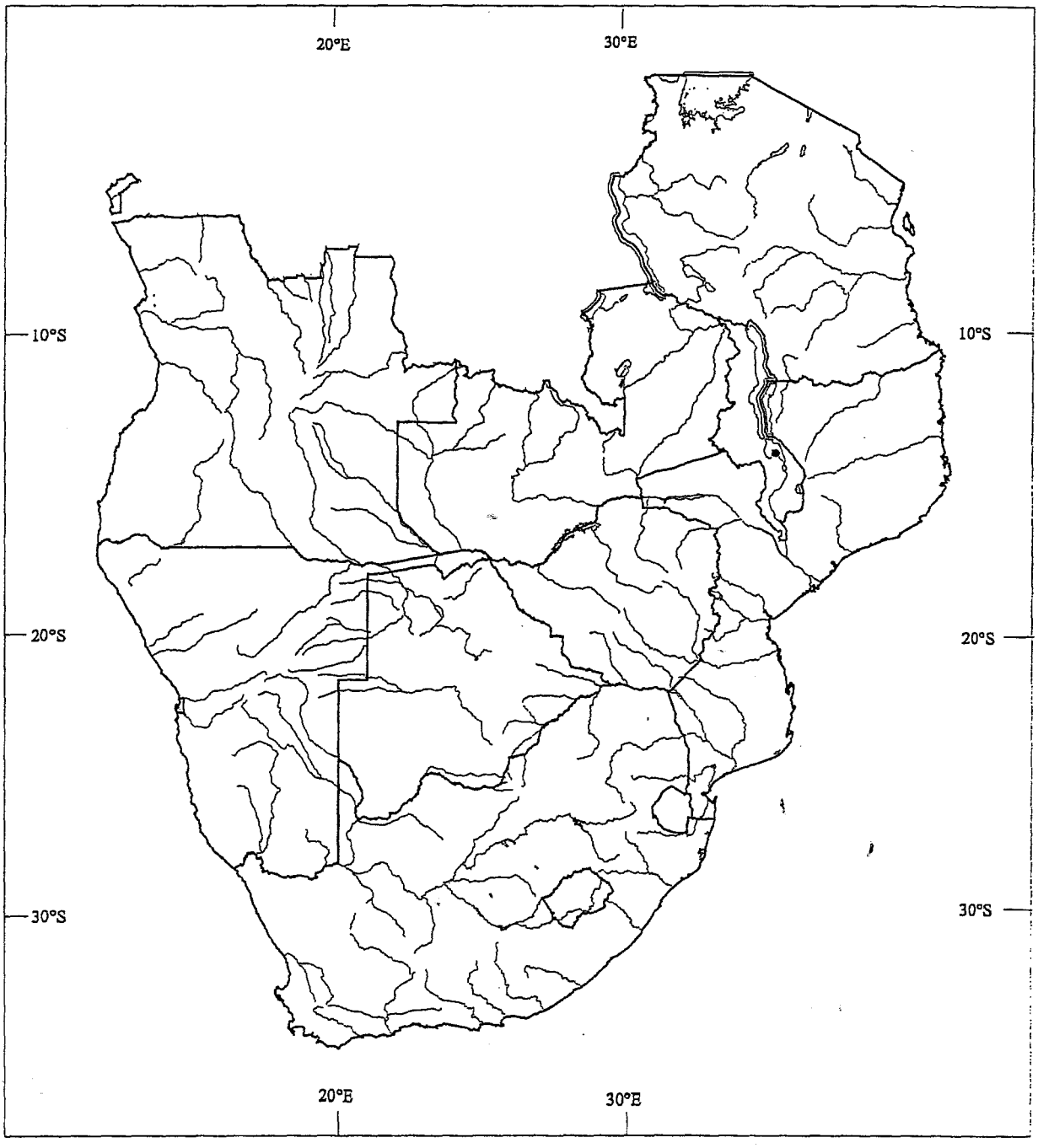


Figure F.244. Point distribution of *Cyrtocara mola*. Scale approximately 1:25 000 000

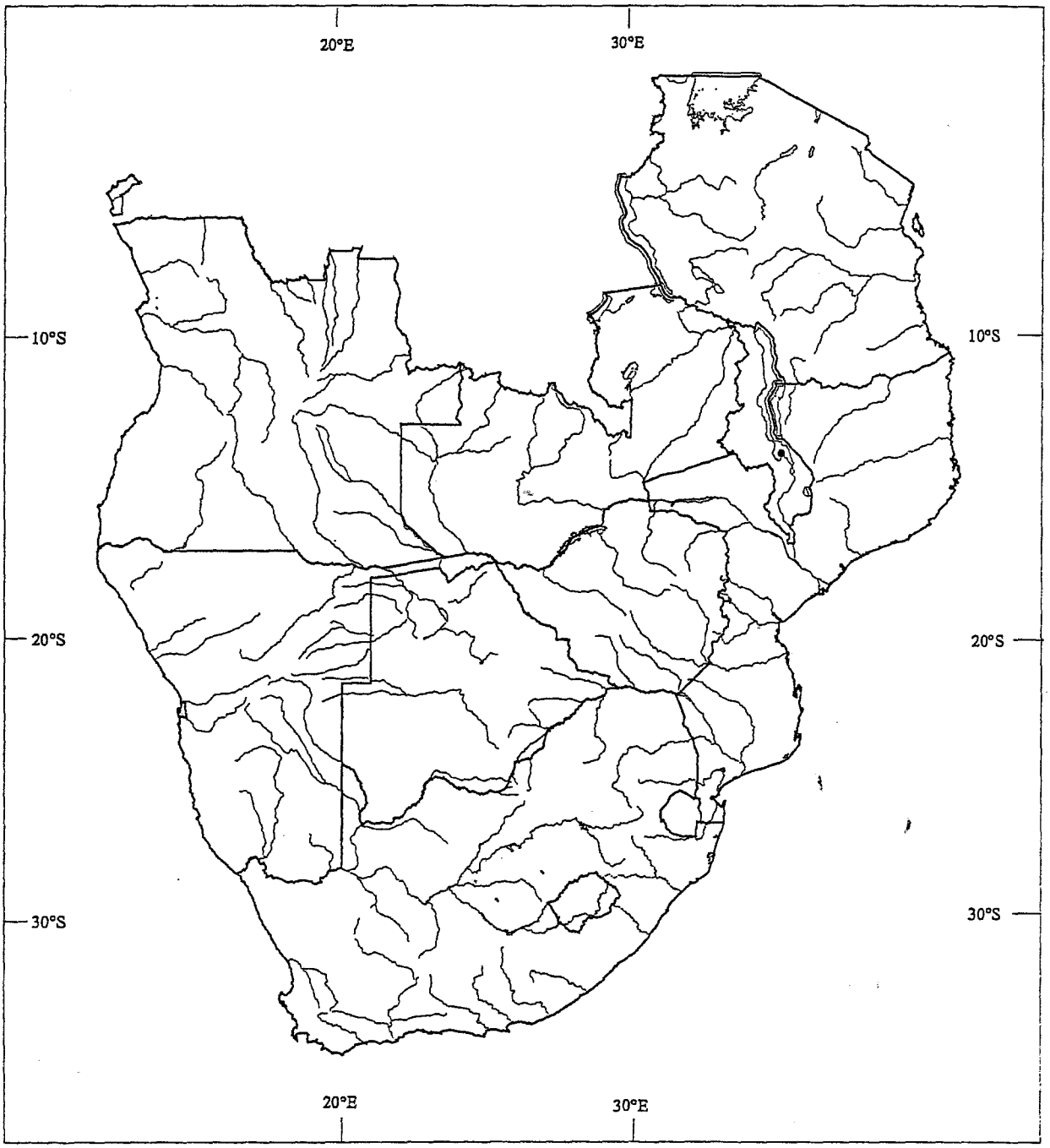


Figure F.245. Point distribution of *Cyrtocara moorii*. Scale approximately 1:25 000 000

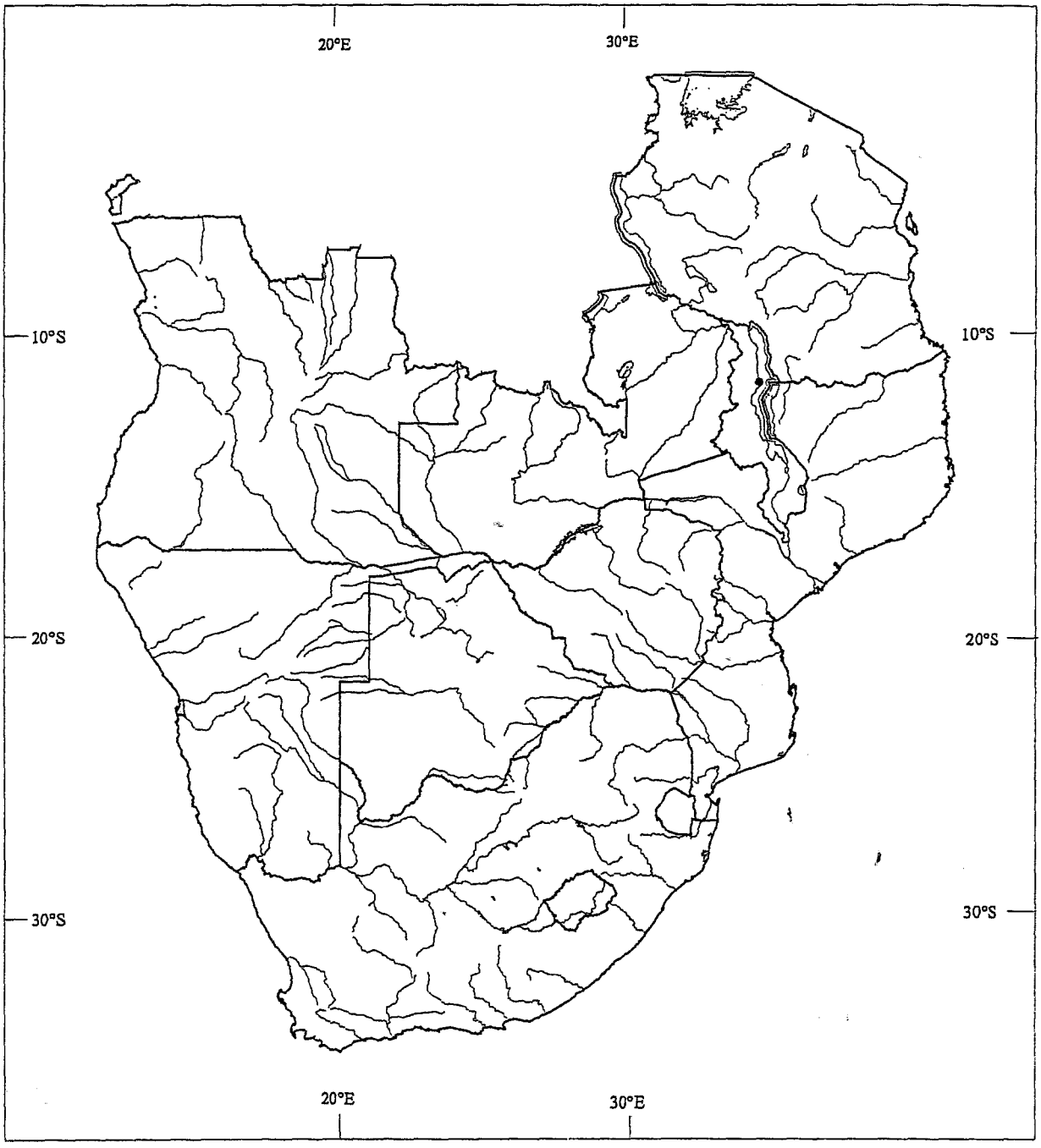


Figure F.246. Point distribution of *Cyrtocara ornatus*. Scale approximately 1:25 000 000

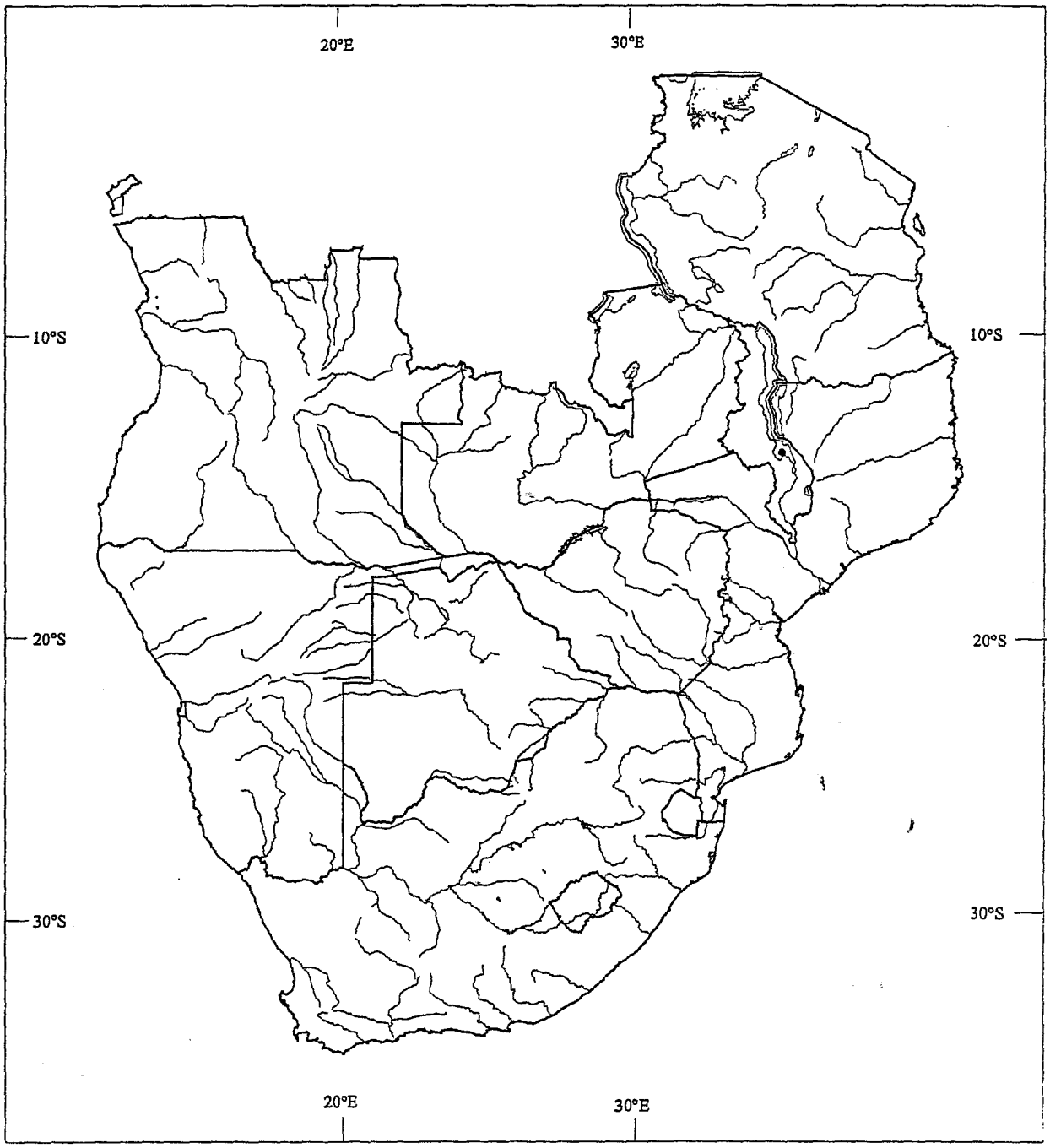


Figure F.247. Point distribution of *Cyrtocara orthognathus*. Scale approximately 1:25 000 000

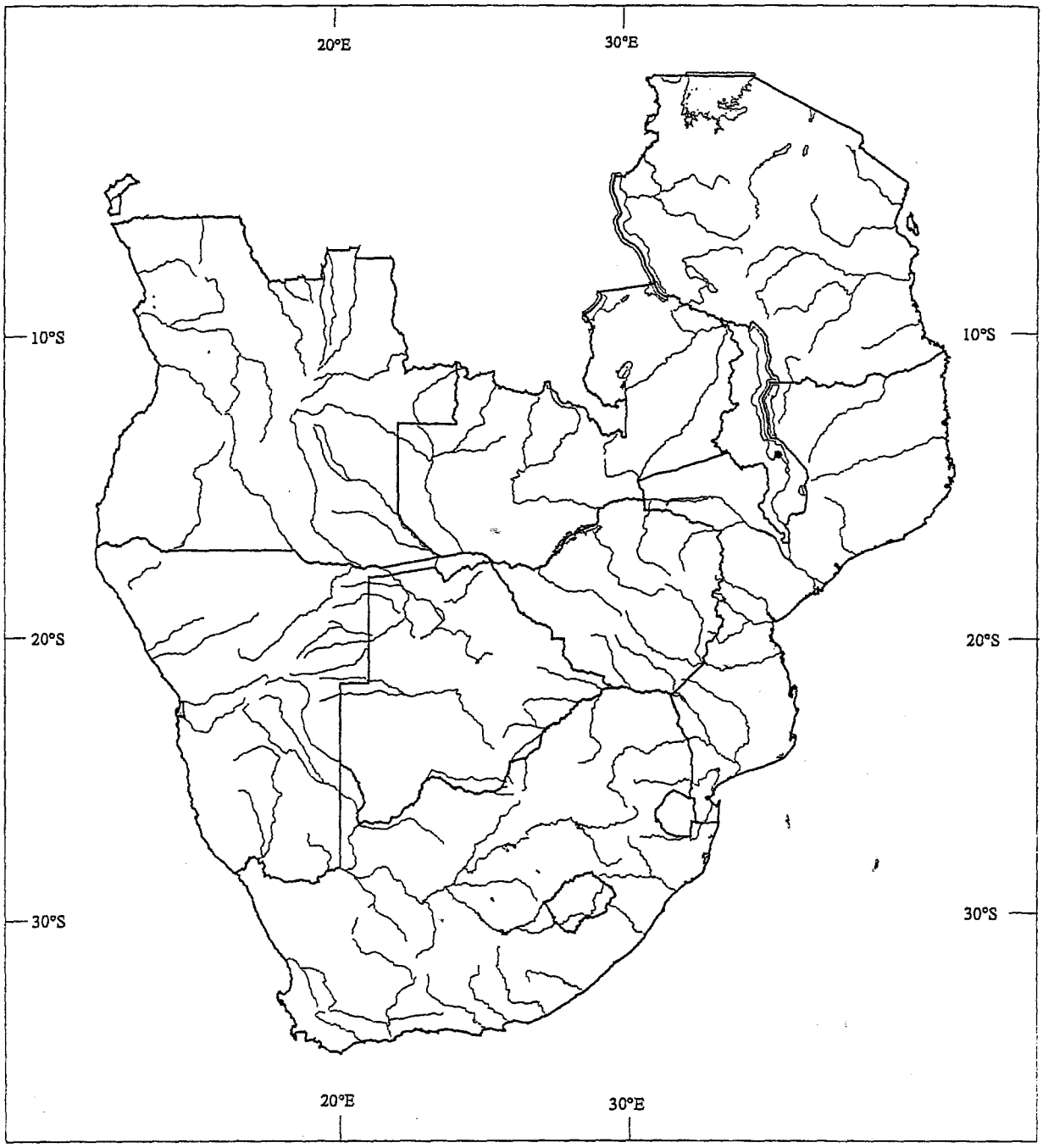


Figure F.248. Point distribution of *Cyrtocara pictus*. Scale approximately 1:25 000 000

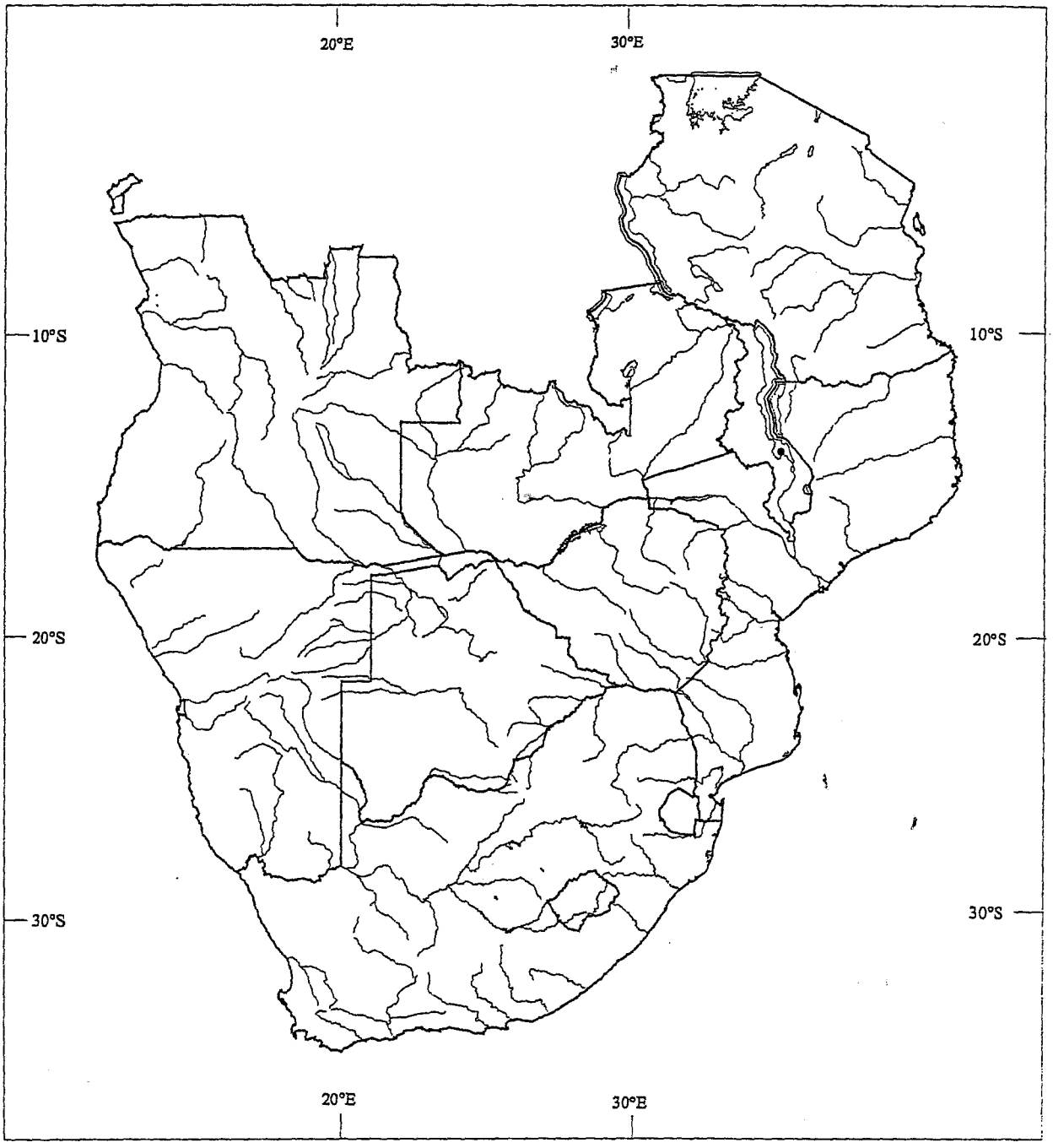


Figure F.249. Point distribution of *Cyrtocara placodon*. Scale approximately 1:25 000 000

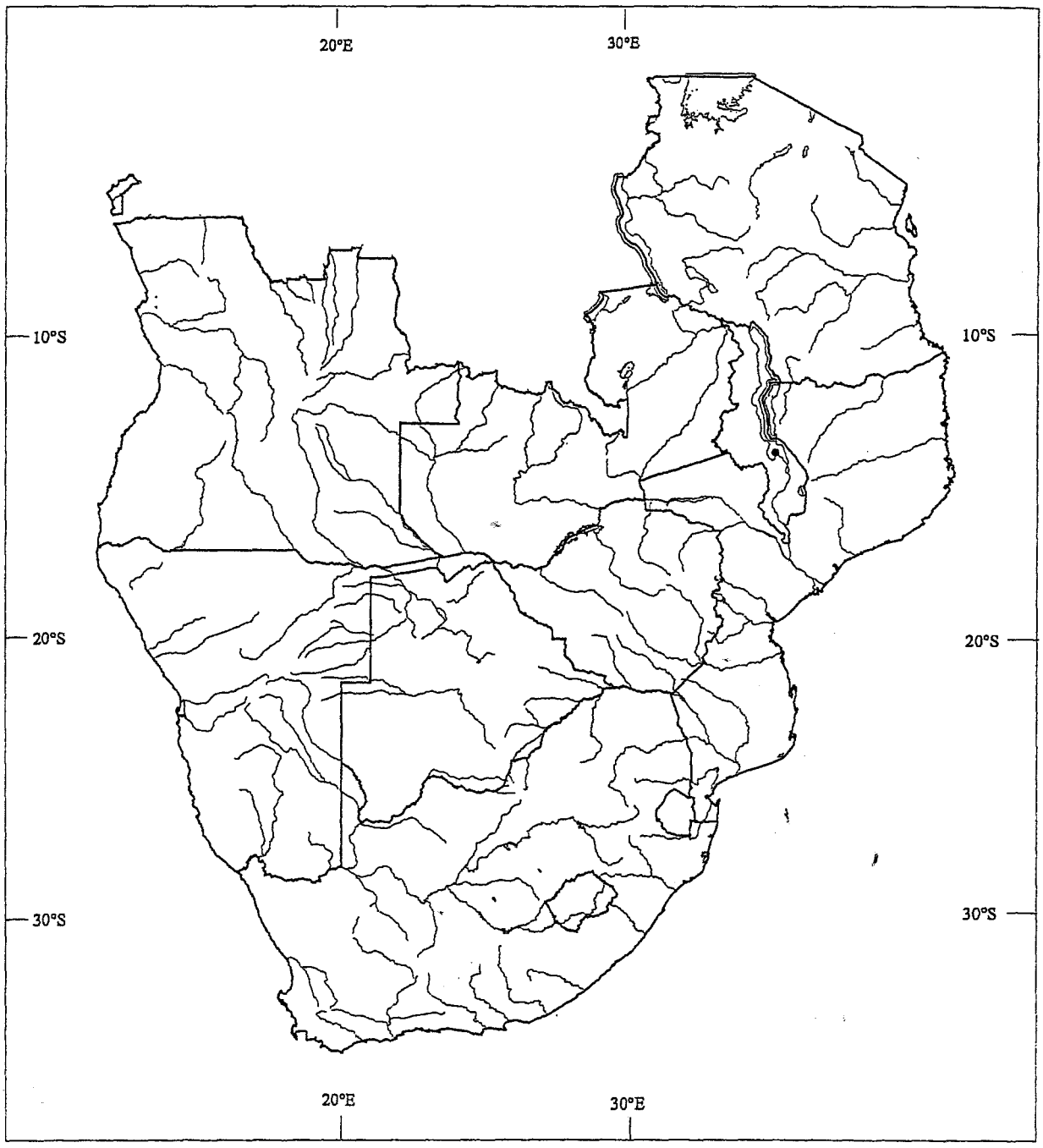


Figure F.250. Point distribution of *Cyrtocara polystigma*. Scale approximately 1:25 000 000

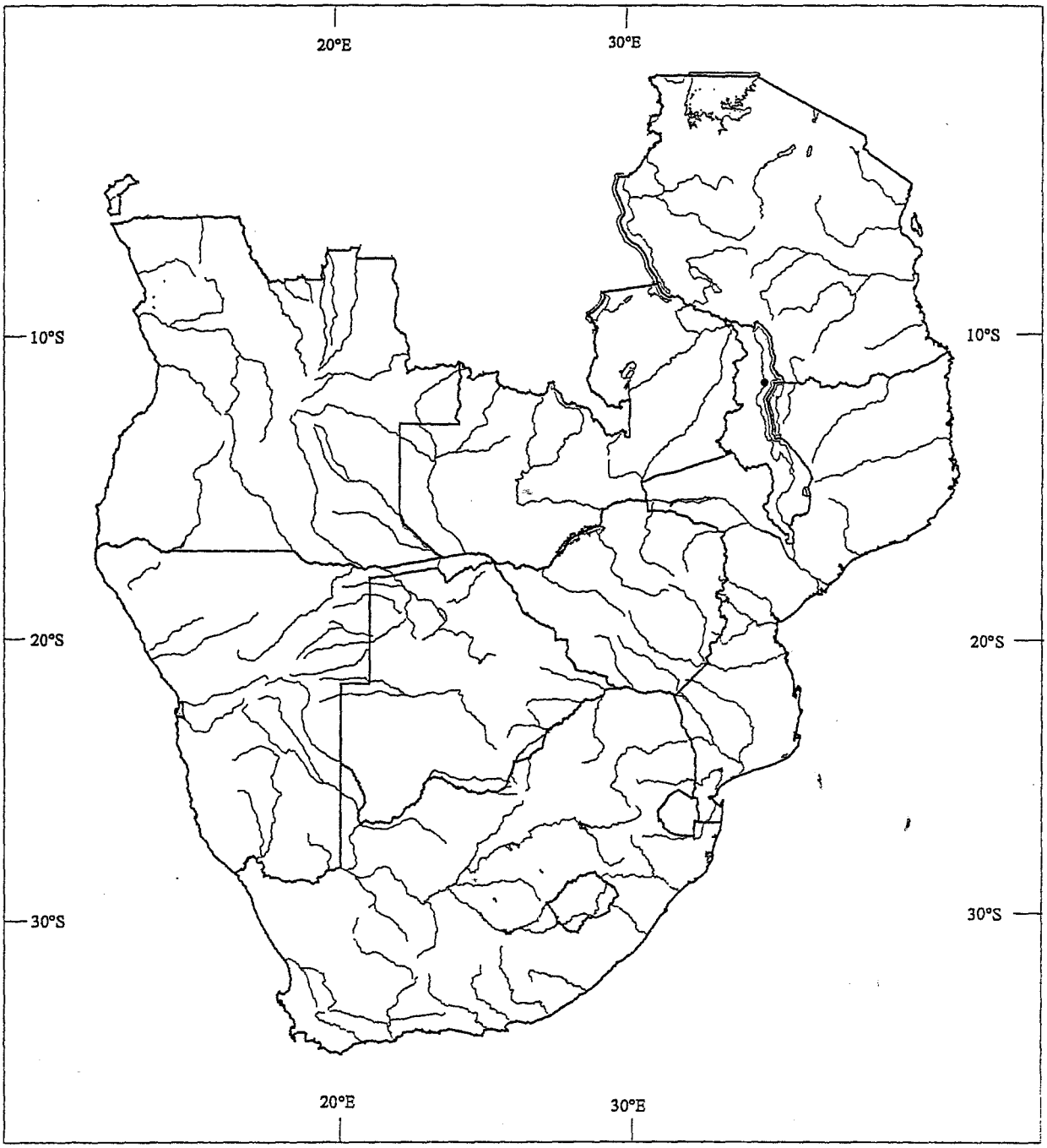


Figure F.251. Point distribution of *Cyrtocara rostratus*. Scale approximately 1:25 000 000

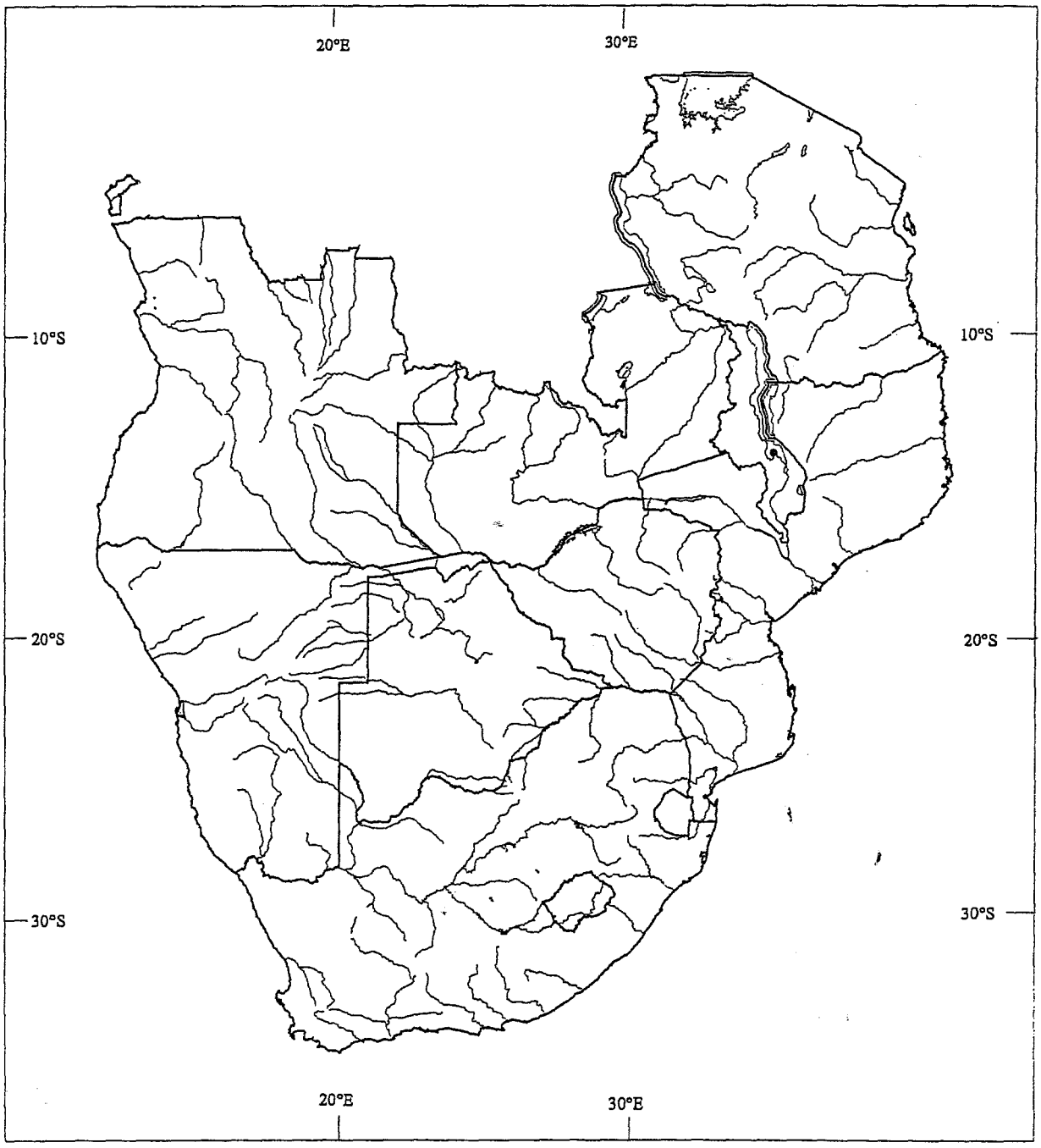


Figure F.252. Point distribution of *Cyrtocara virgatus*. Scale approximately 1:25 000 000

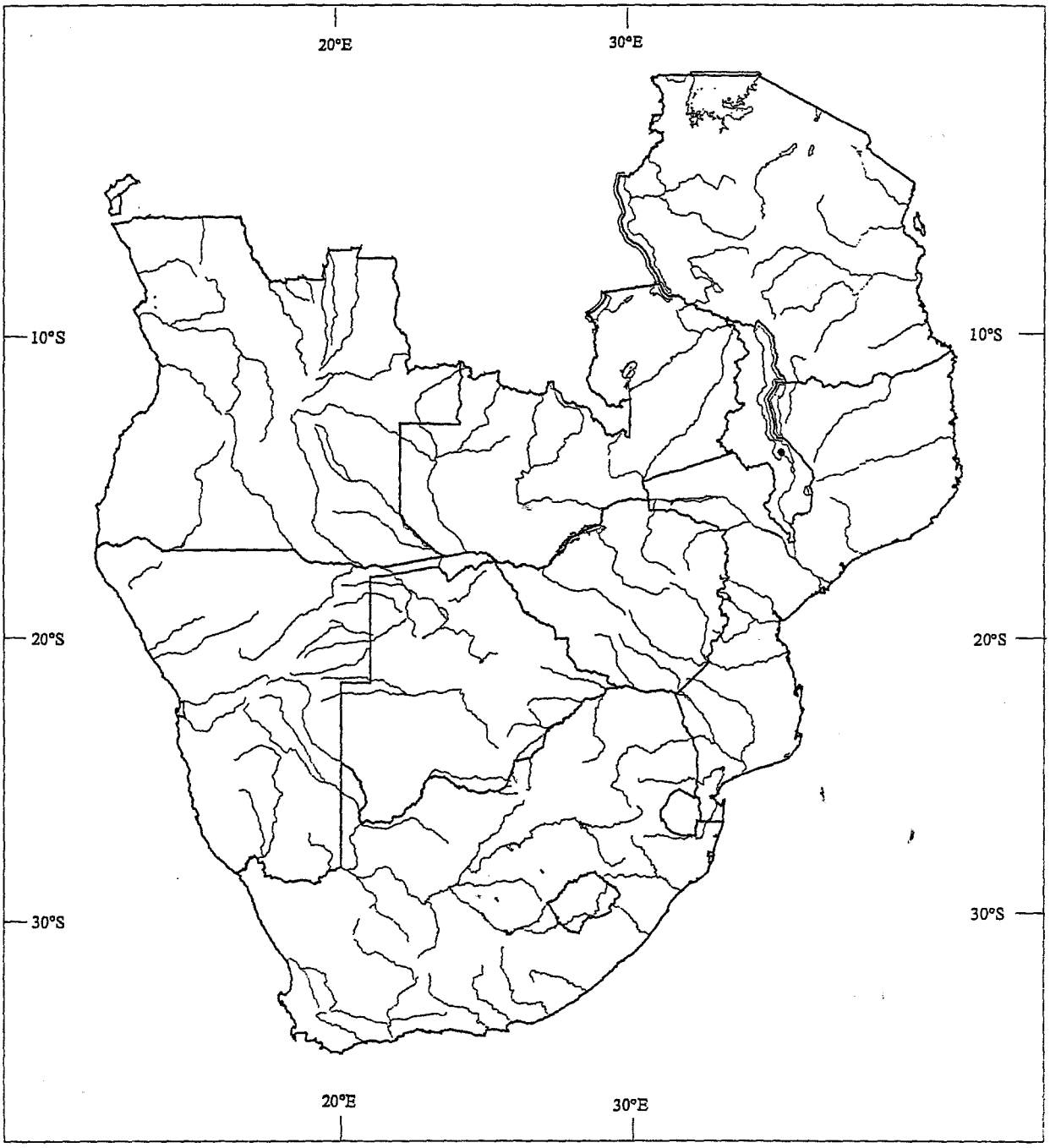


Figure F.253. Point distribution of *Cyrtocara woodi*. Scale approximately 1:25 000 000

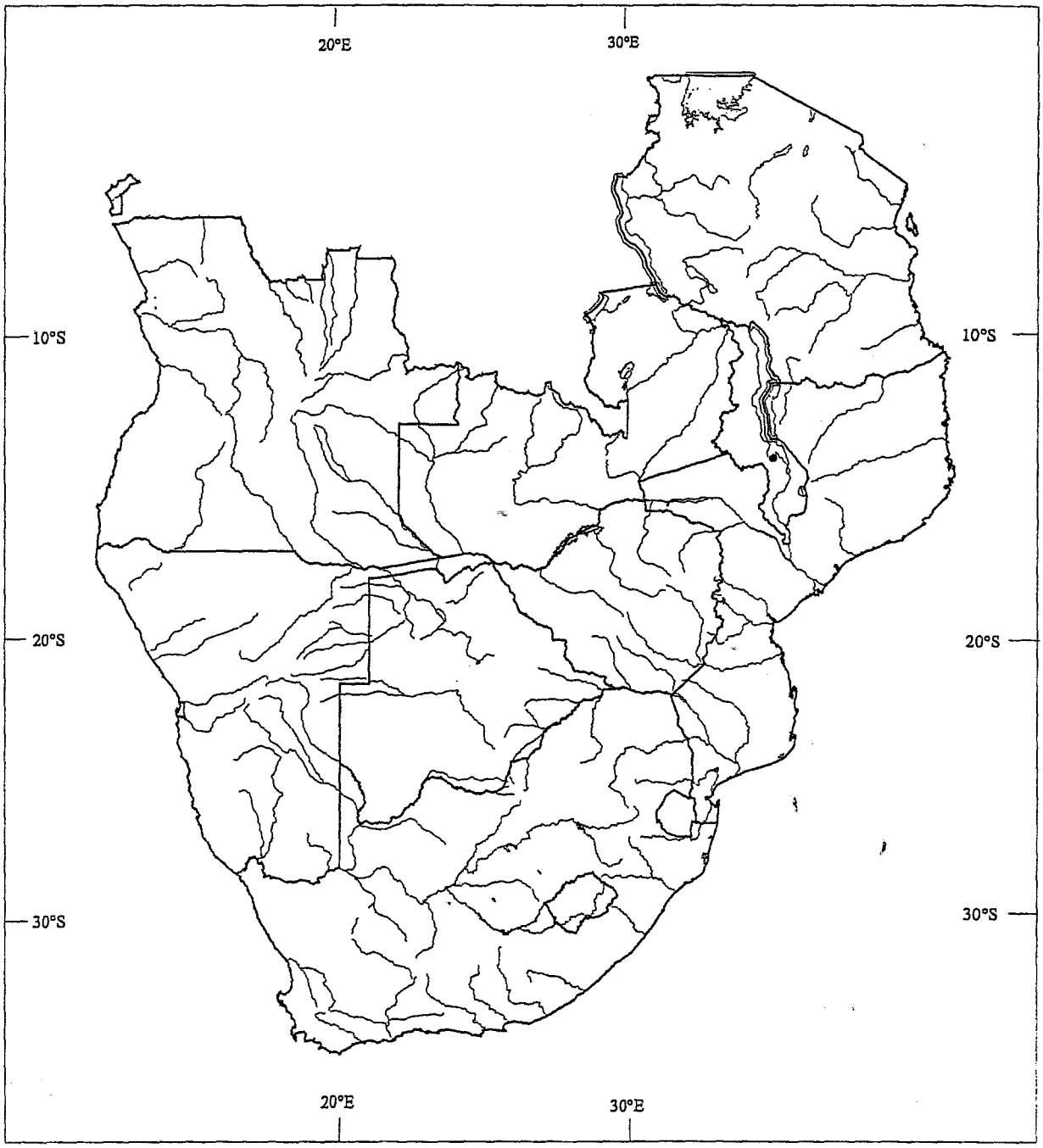


Figure F.254. Point distribution of *Dimidiochromis dimidiatus*. Scale approximately 1:25 000 000

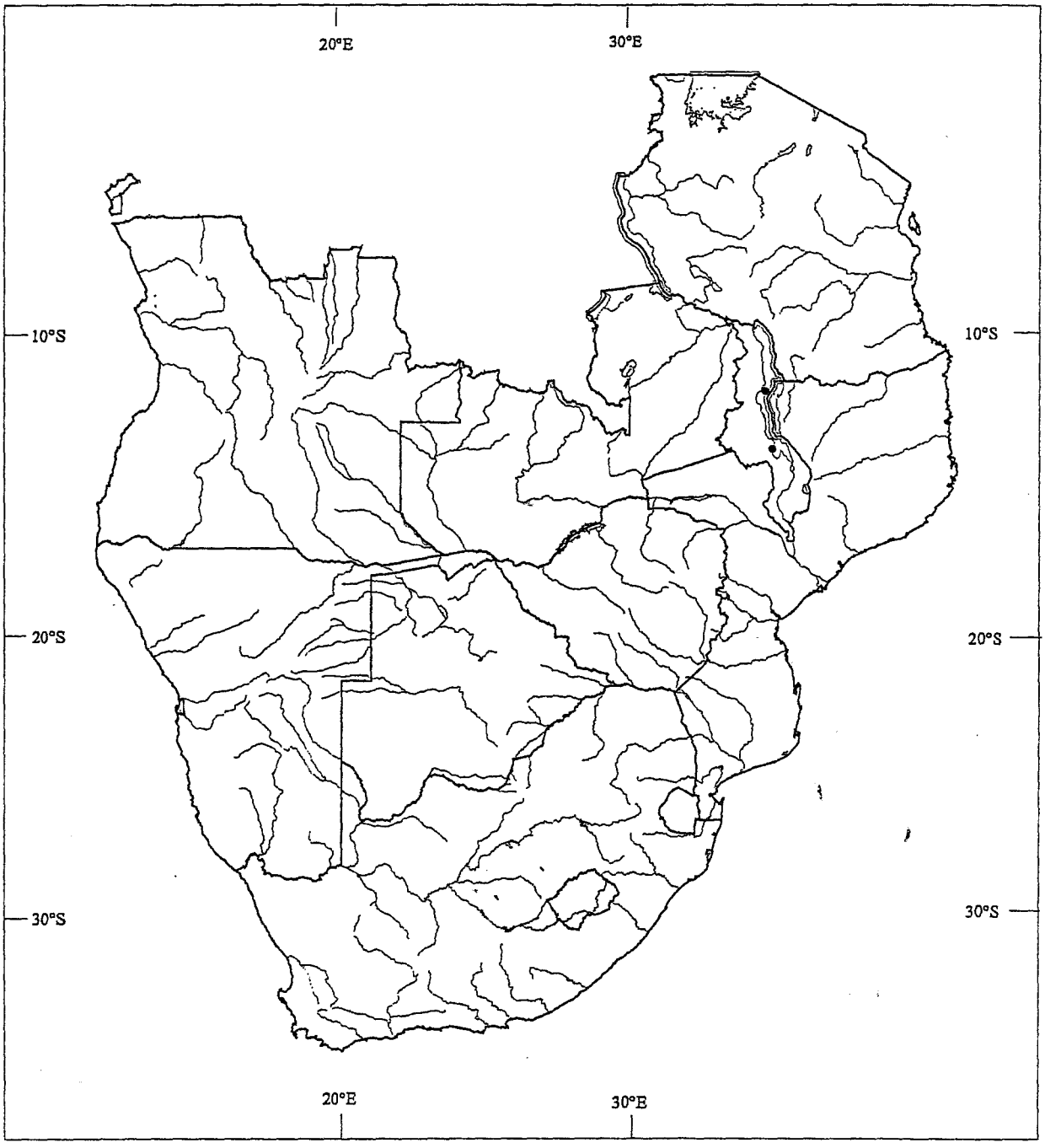


Figure F.255. Point distribution of *Dimidiochromis kiwinge*. Scale approximately 1:25 000 000

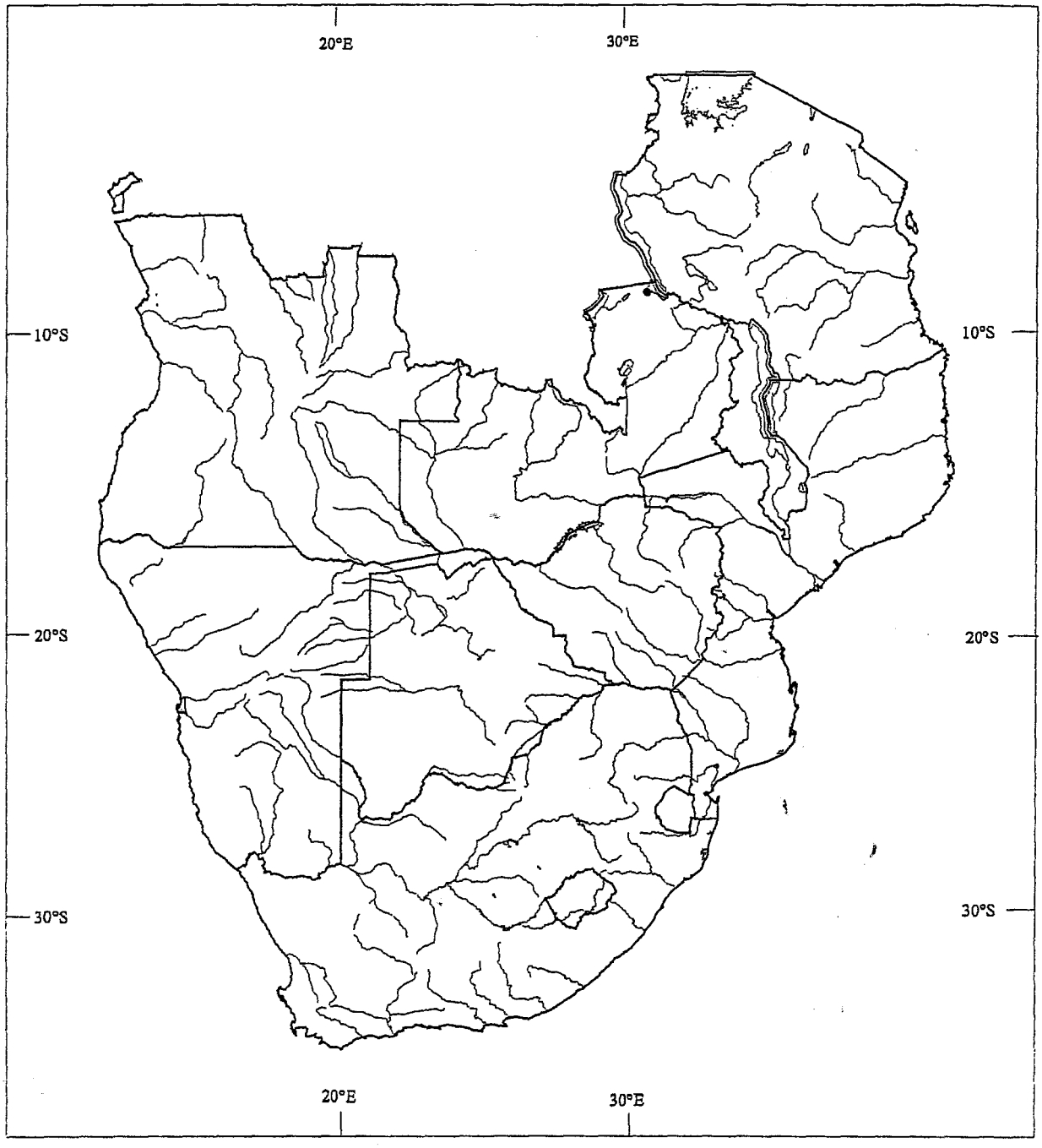


Figure F.256. Point distribution of *Dinotopterus cunningtoni*. Scale approximately 1:25 000 000

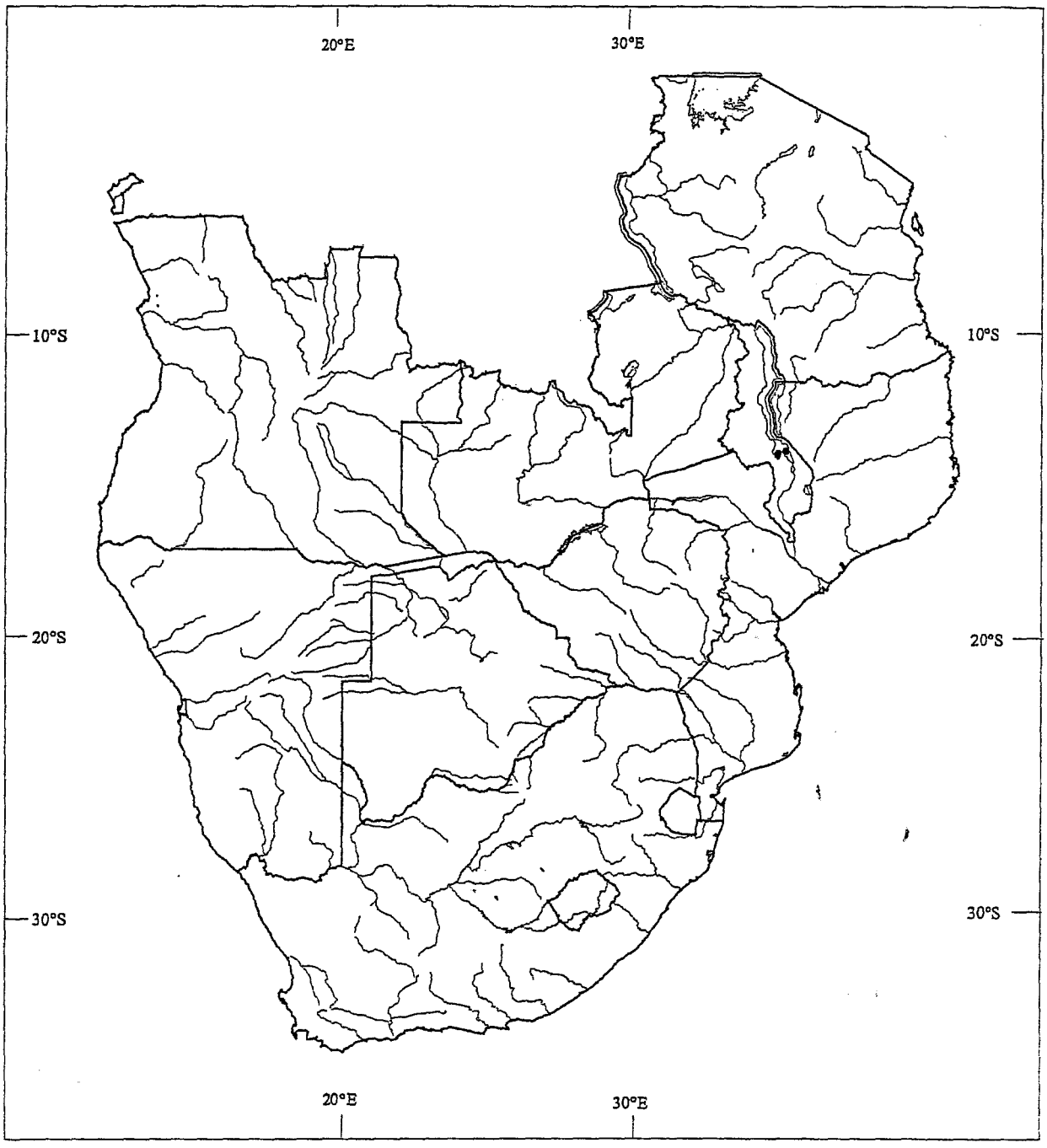


Figure F.257. Point distribution of *Diplotaxodon argenteus*. Scale approximately 1:25 000 000

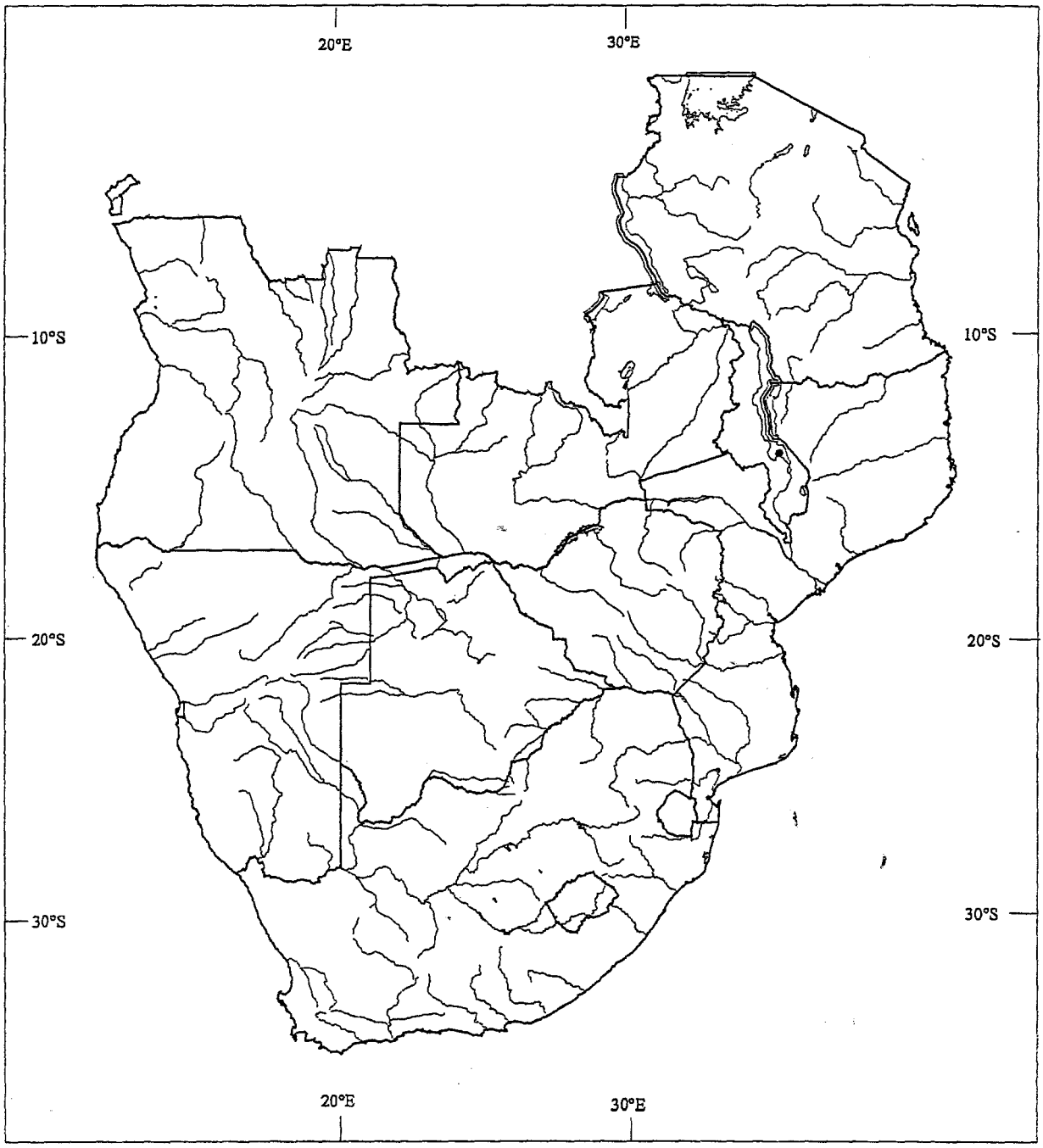


Figure F.258. Point distribution of *Diplotaxodon greenwoodi*. Scale approximately 1:25 000 000

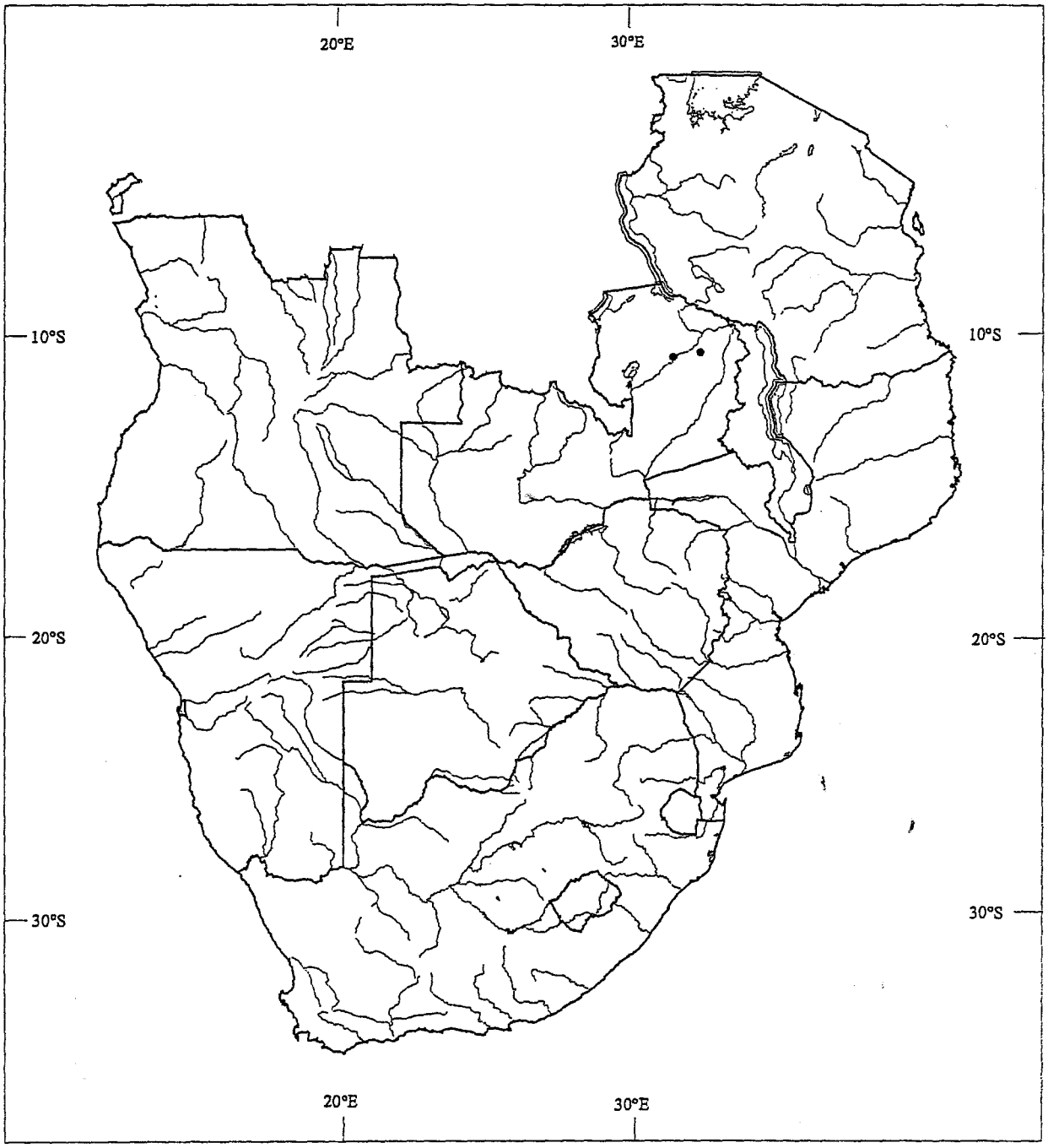


Figure F.259. Point distribution of *Distichodus maculatus*. Scale approximately 1:25 000 000

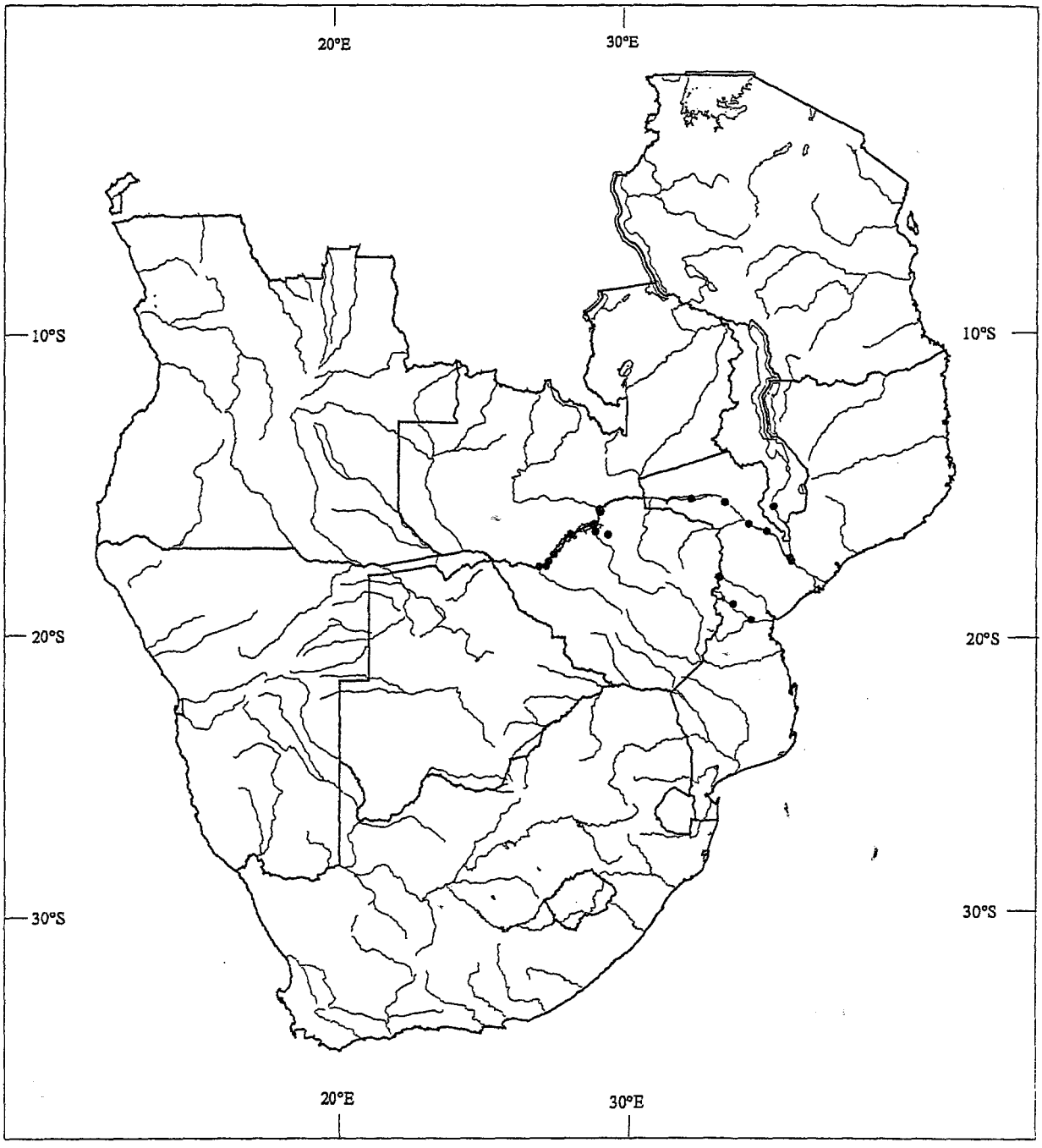


Figure F.260. Point distribution of *Distichodus mossambicus*. Scale approximately 1:25 000 000

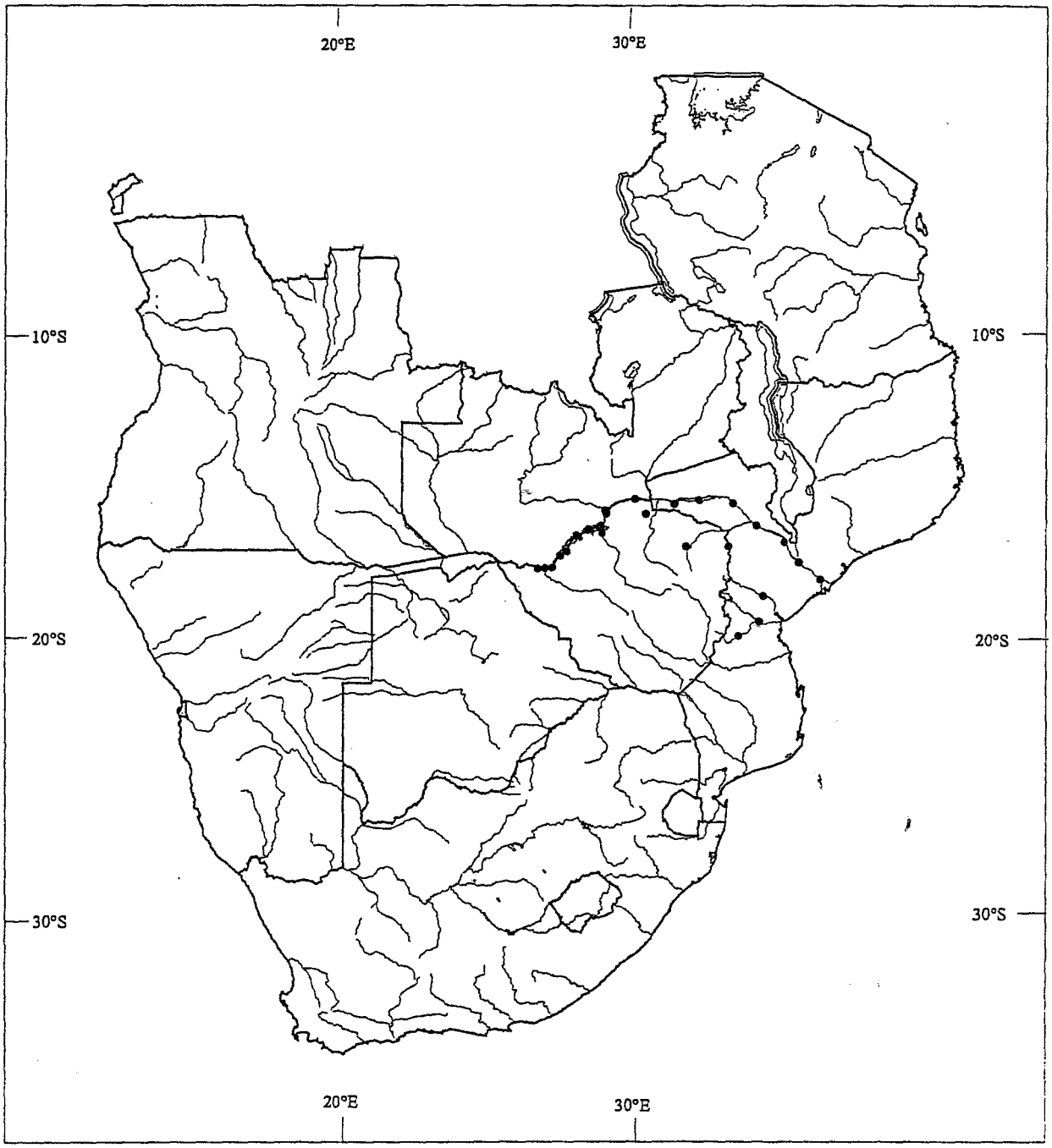


Figure F.261. Point distribution of *Distichodus schenga*. Scale approximately 1:25 000 000

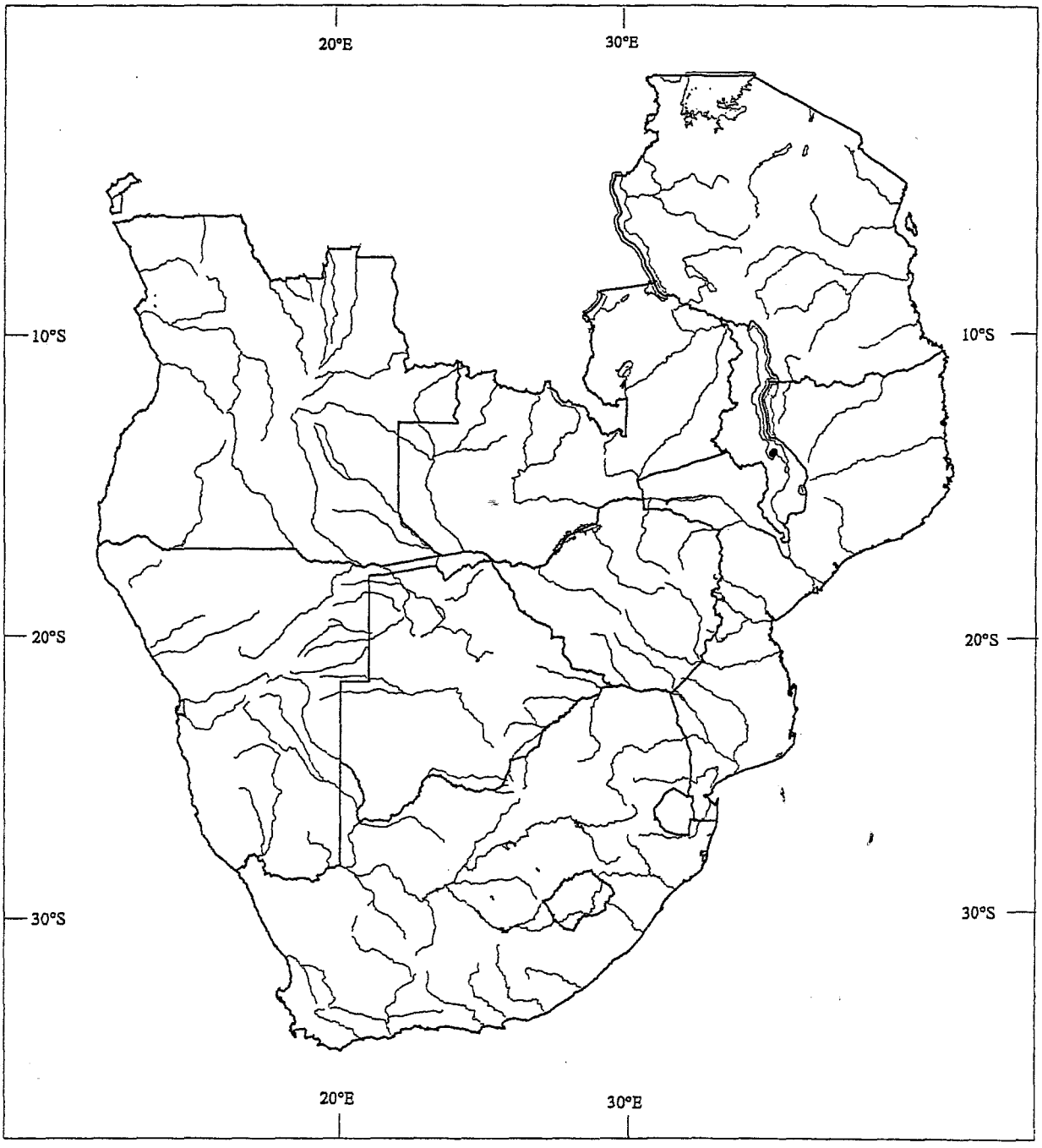


Figure F.262. Point distribution of *Docimodus evelynae*. Scale approximately 1:25 000 000

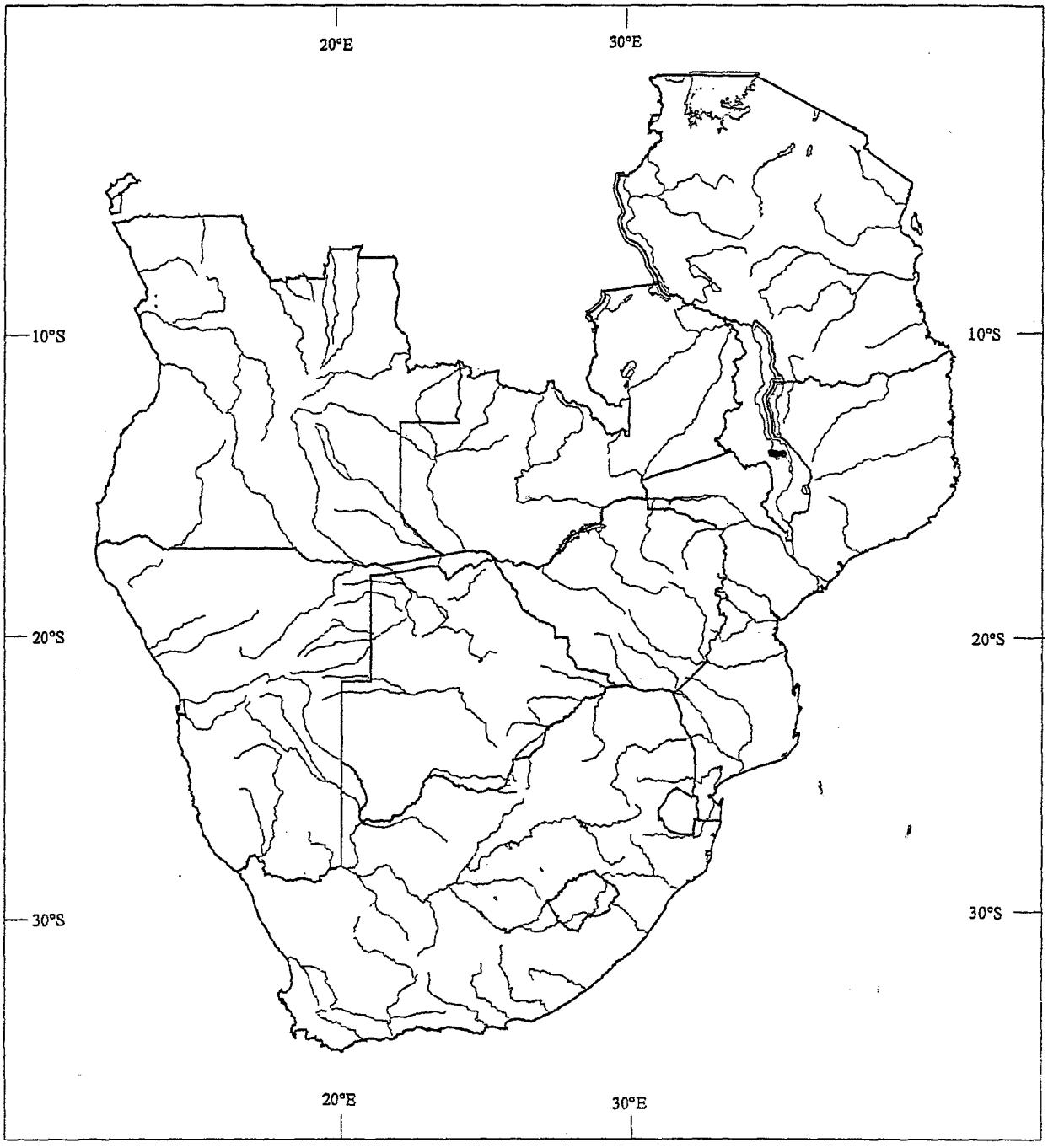


Figure F.263. Point distribution of *Docimodus johnstoni*. Scale approximately 1:25 000 000

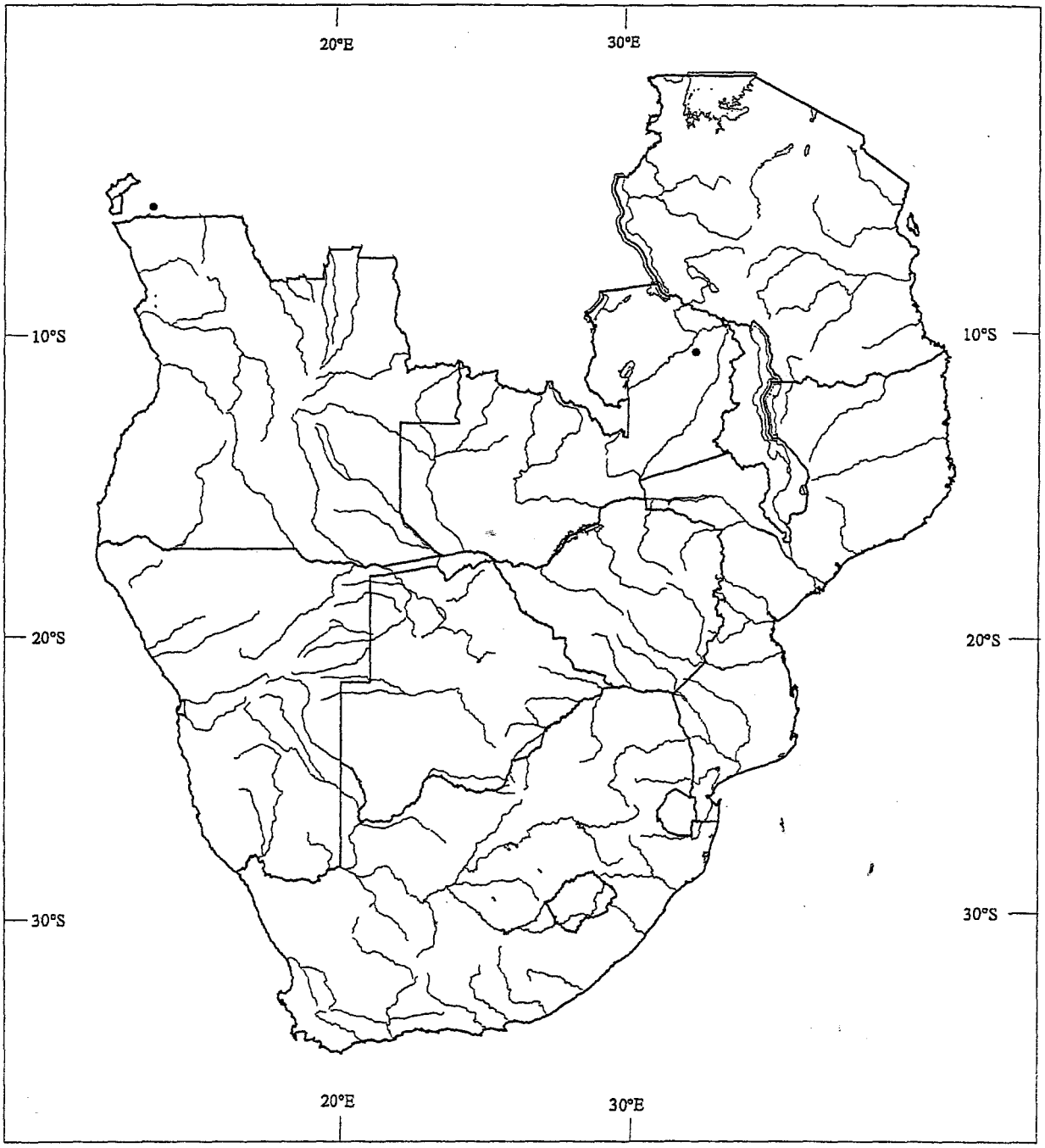


Figure F.264. Point distribution of *Doumea alula*. Scale approximately 1:25 000 000

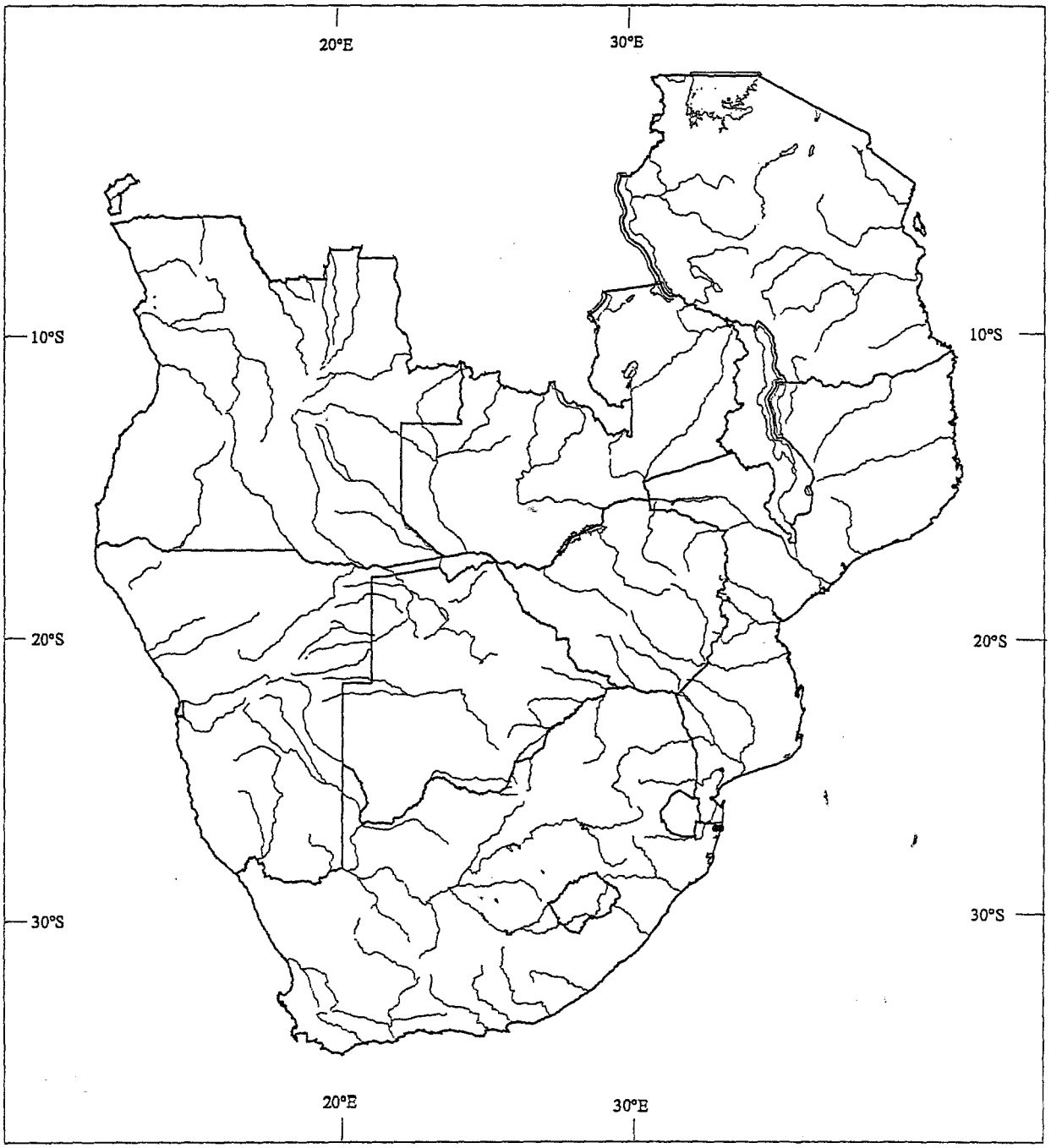


Figure F.265. Point distribution of *Dules rupestris*. Scale approximately 1:25 000 000

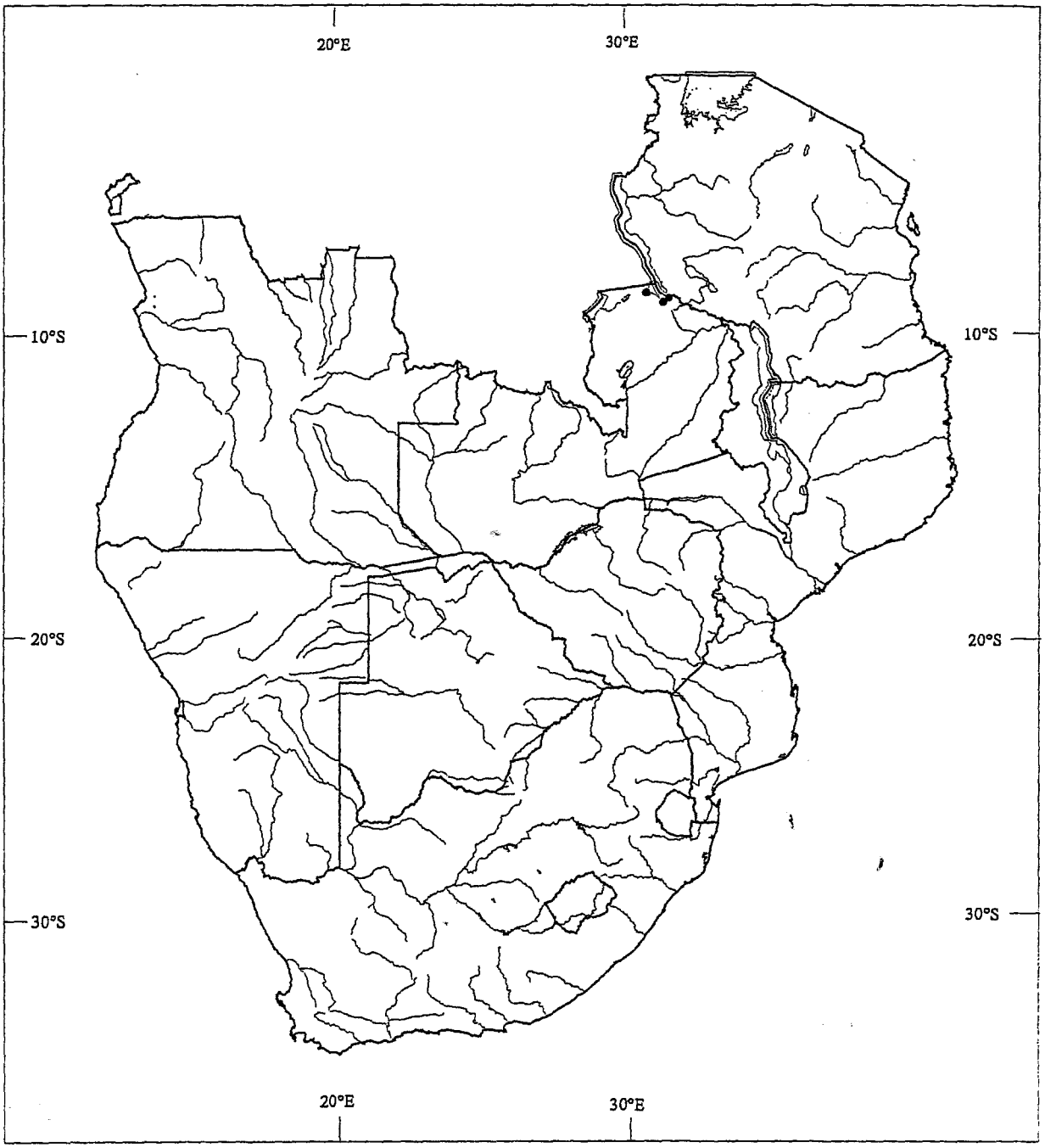


Figure F.266. Point distribution of *Ectodus descampsi*. Scale approximately 1:25 000 000

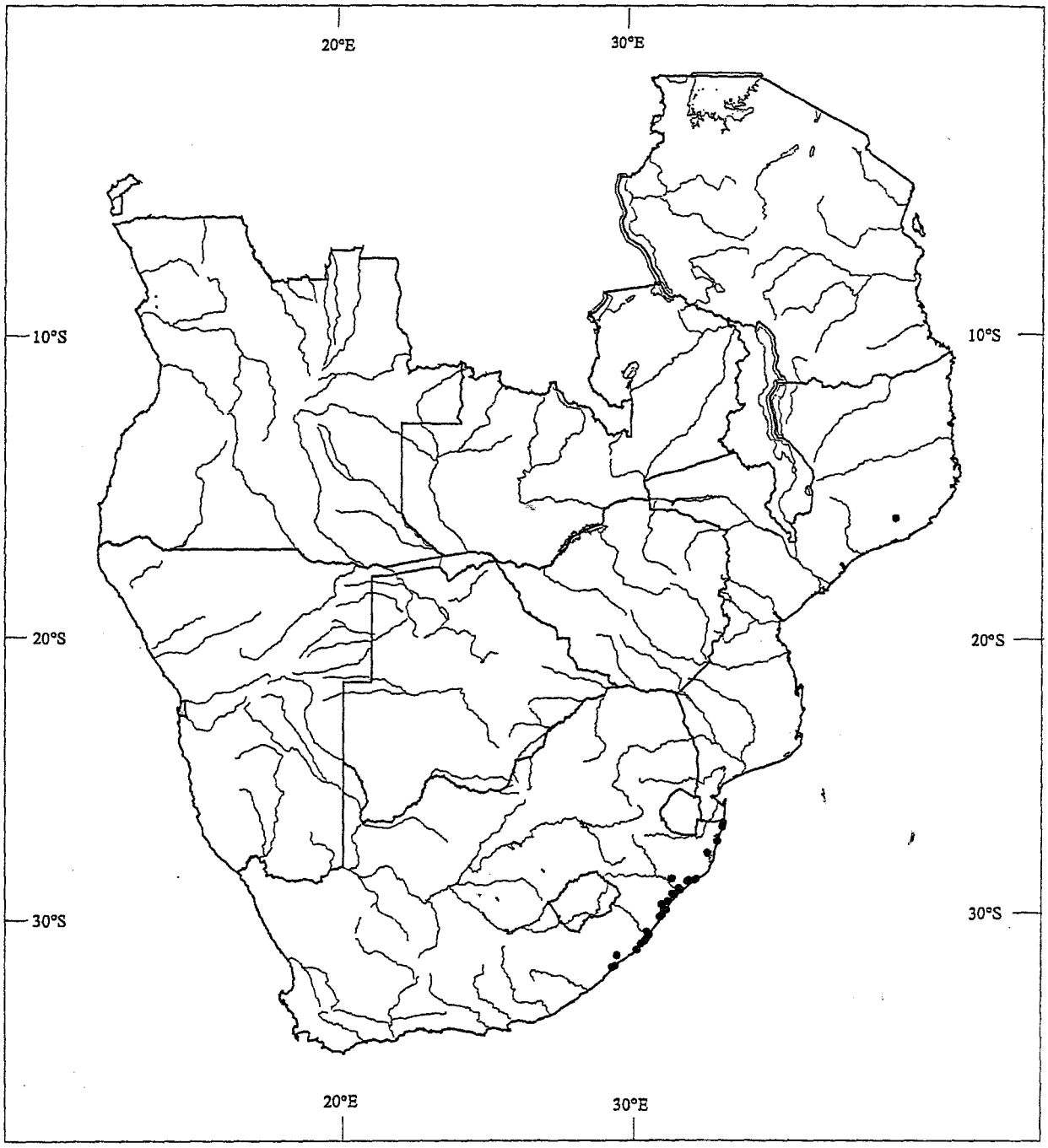


Figure F.267. Point distribution of *Eleotris fusca*. Scale approximately 1:25 000 000

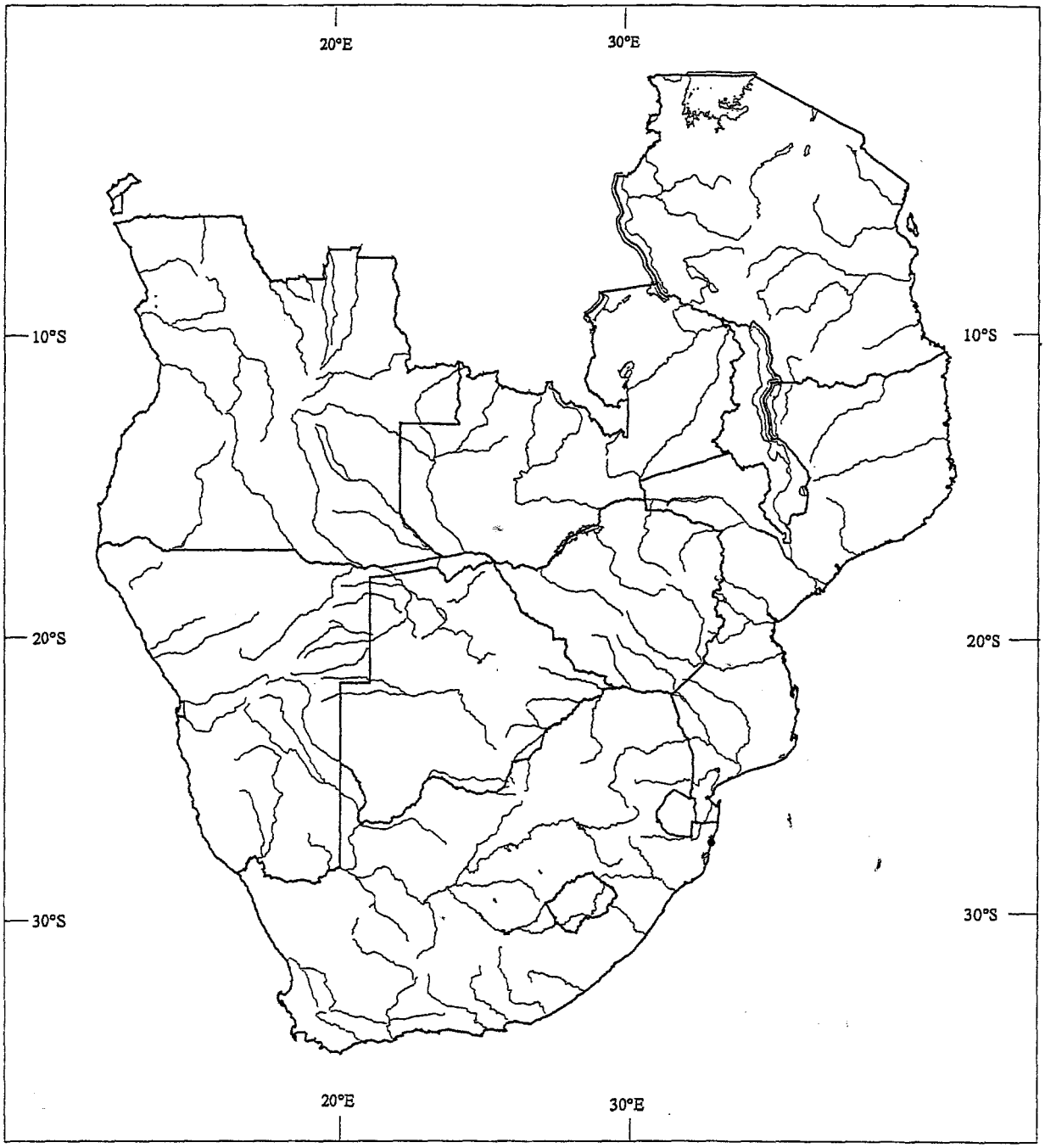


Figure F.268. Point distribution of *Eleotris melanosoma*. Scale approximately 1:25 000 000

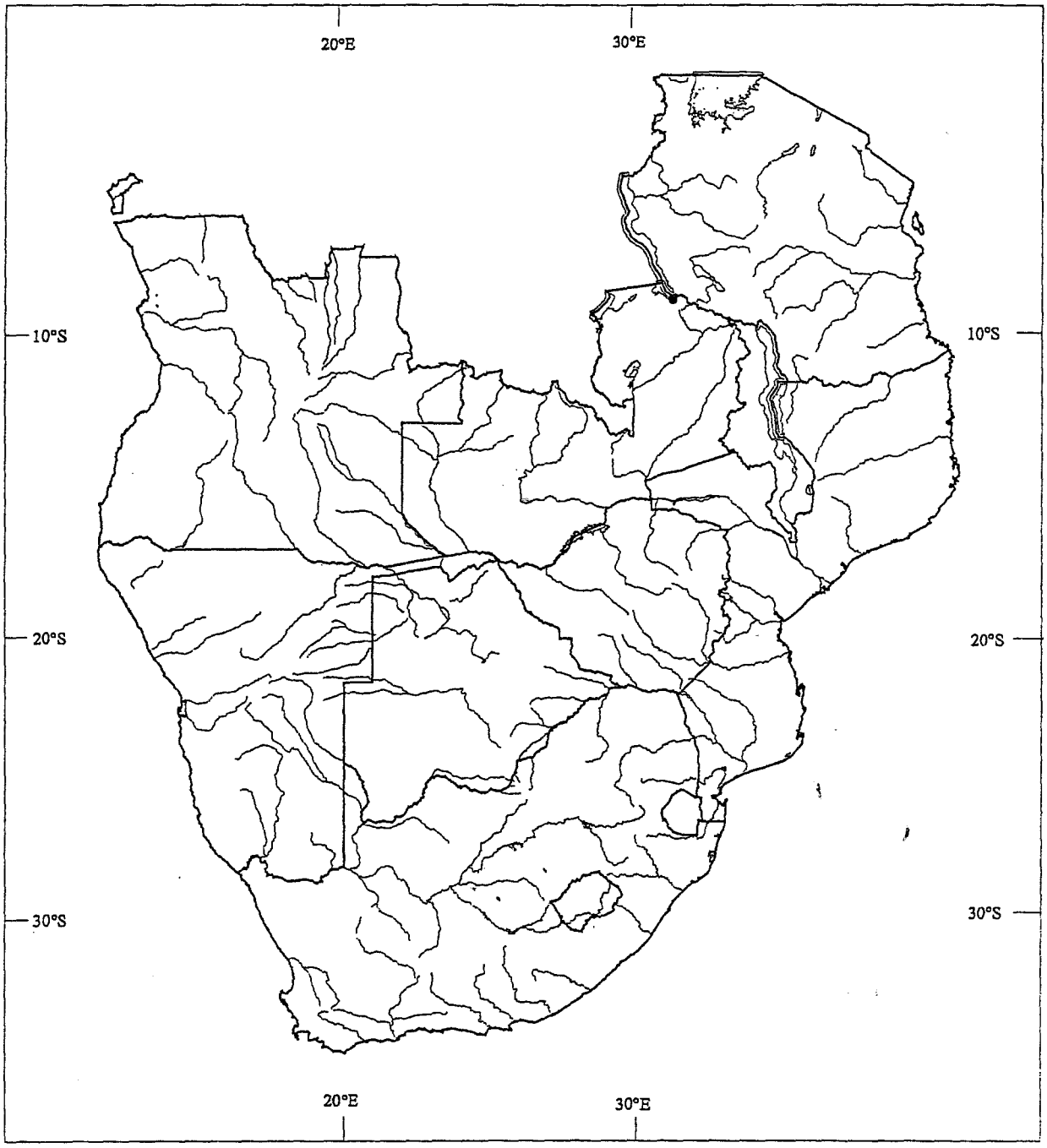


Figure F.269. Point distribution of *Enantiopus melanogenys*. Scale approximately 1:25 000 000

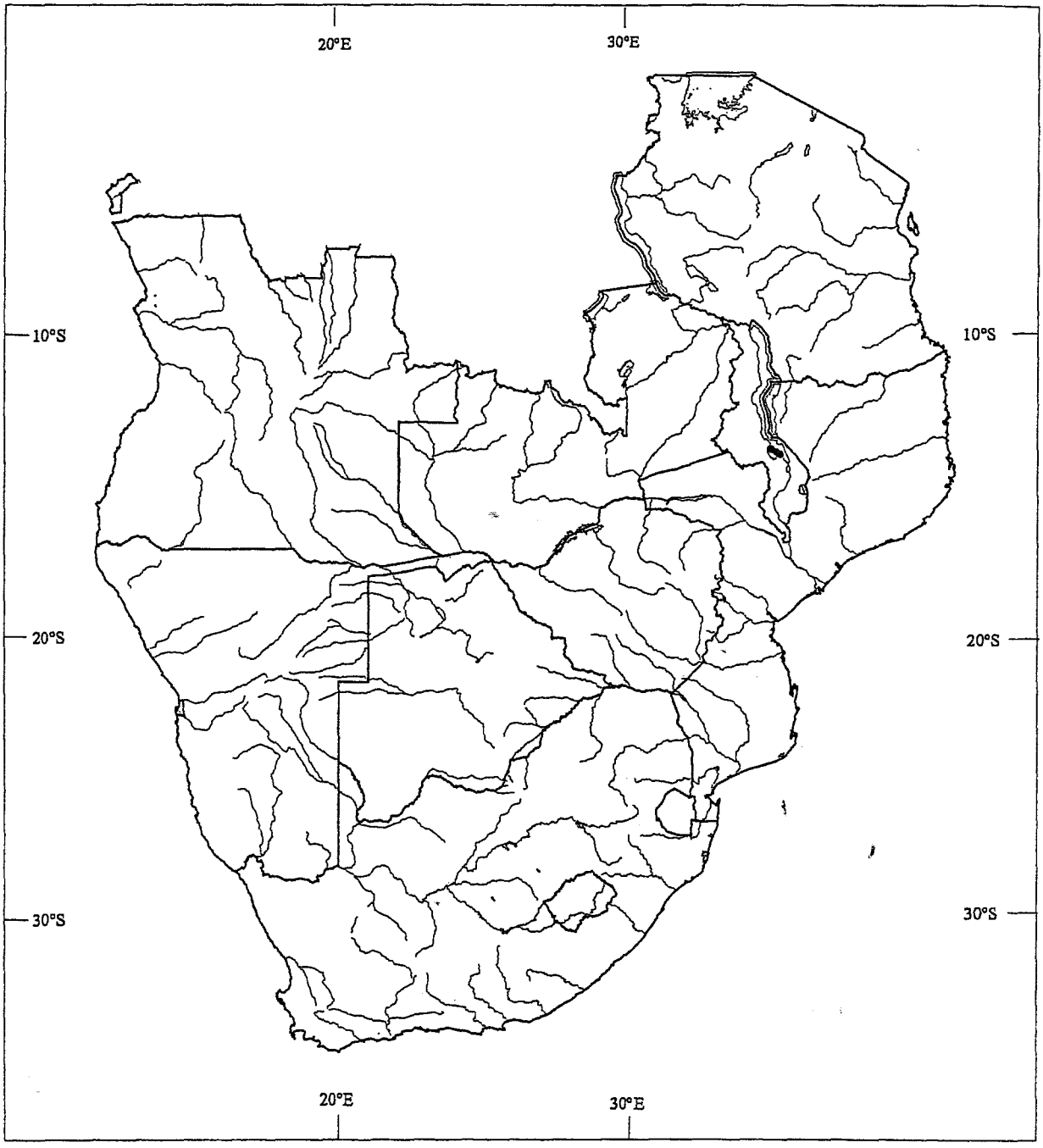


Figure F.270. Point distribution of *Engraulicypris sardella*. Scale approximately 1:25 000 000

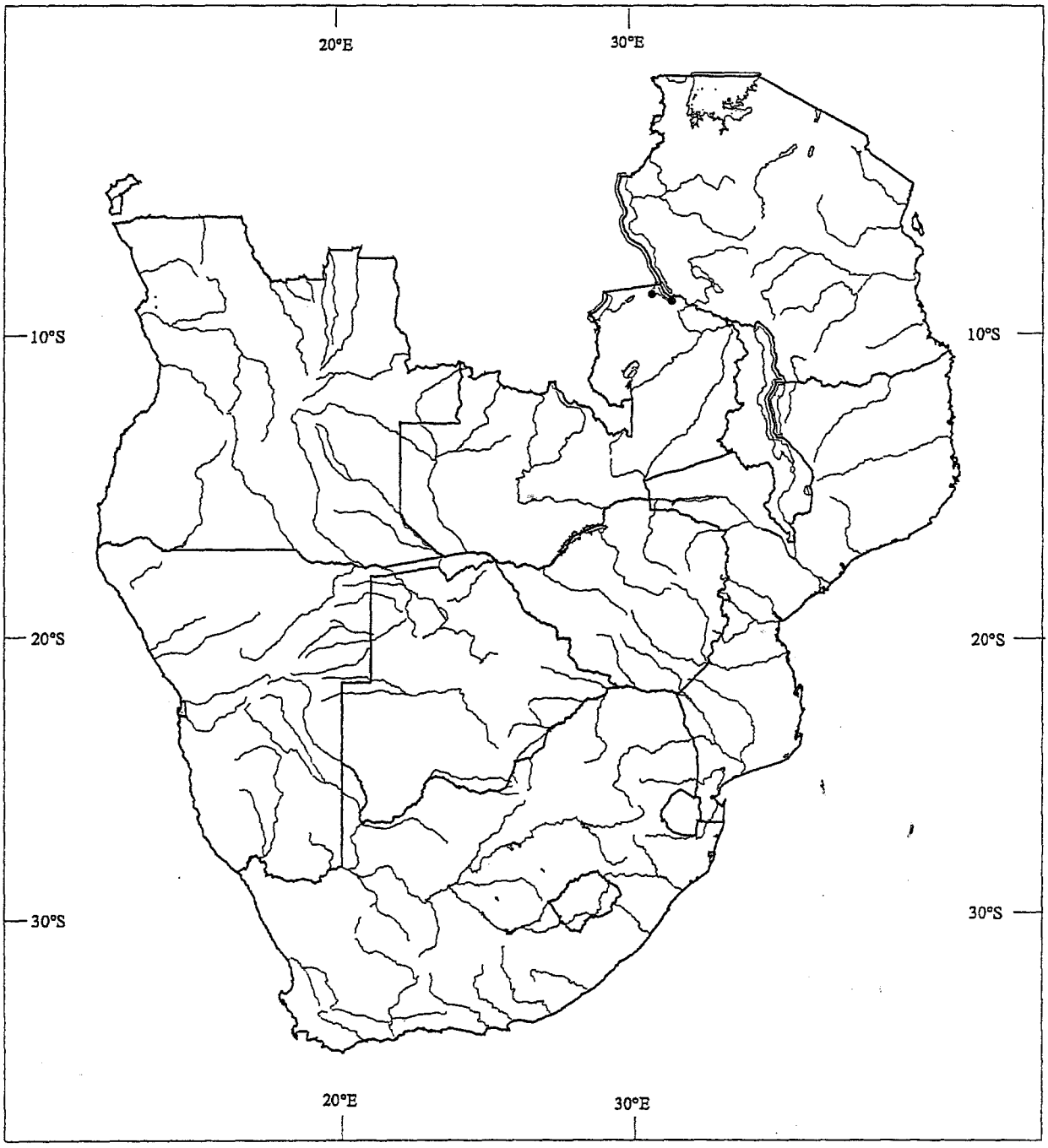


Figure F.271. Point distribution of *Eretmodus cyanostictus*. Scale approximately 1:25 000 000

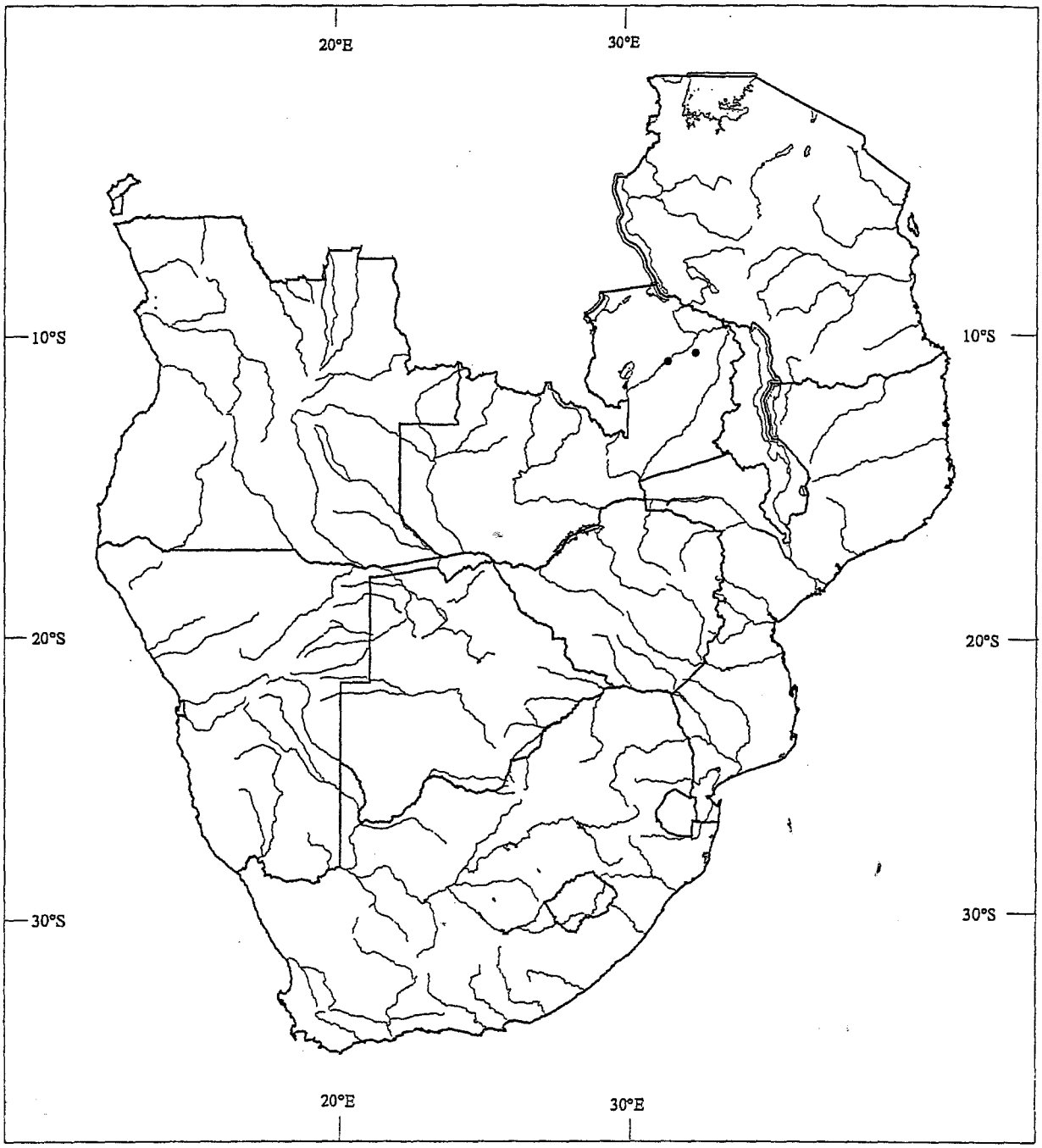


Figure F.272. Point distribution of *Euchilichthys guentheri*. Scale approximately 1:25 000 000

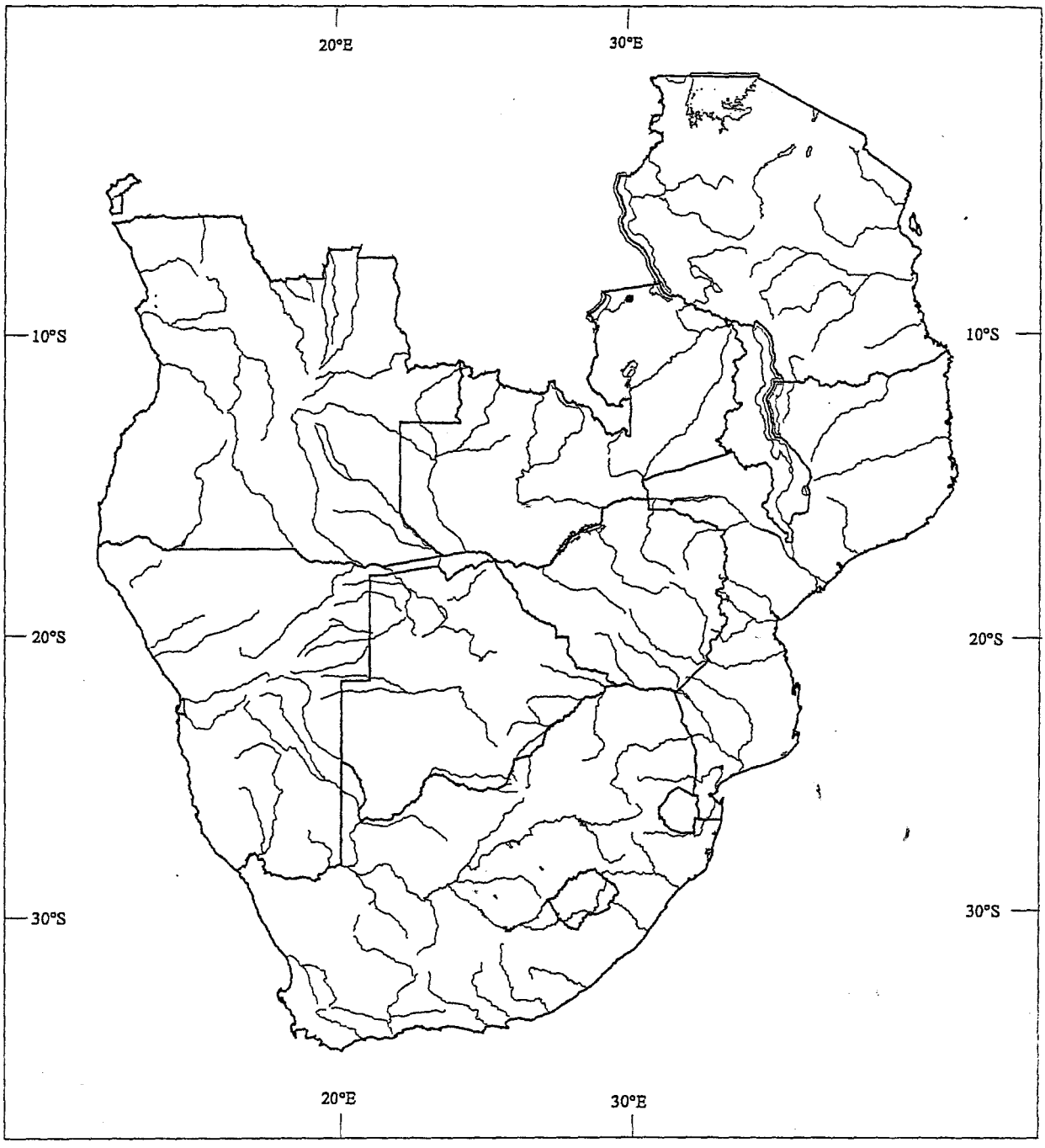


Figure F.273. Point distribution of *Euchilichthys royauxi*. Scale approximately 1:25 000 000

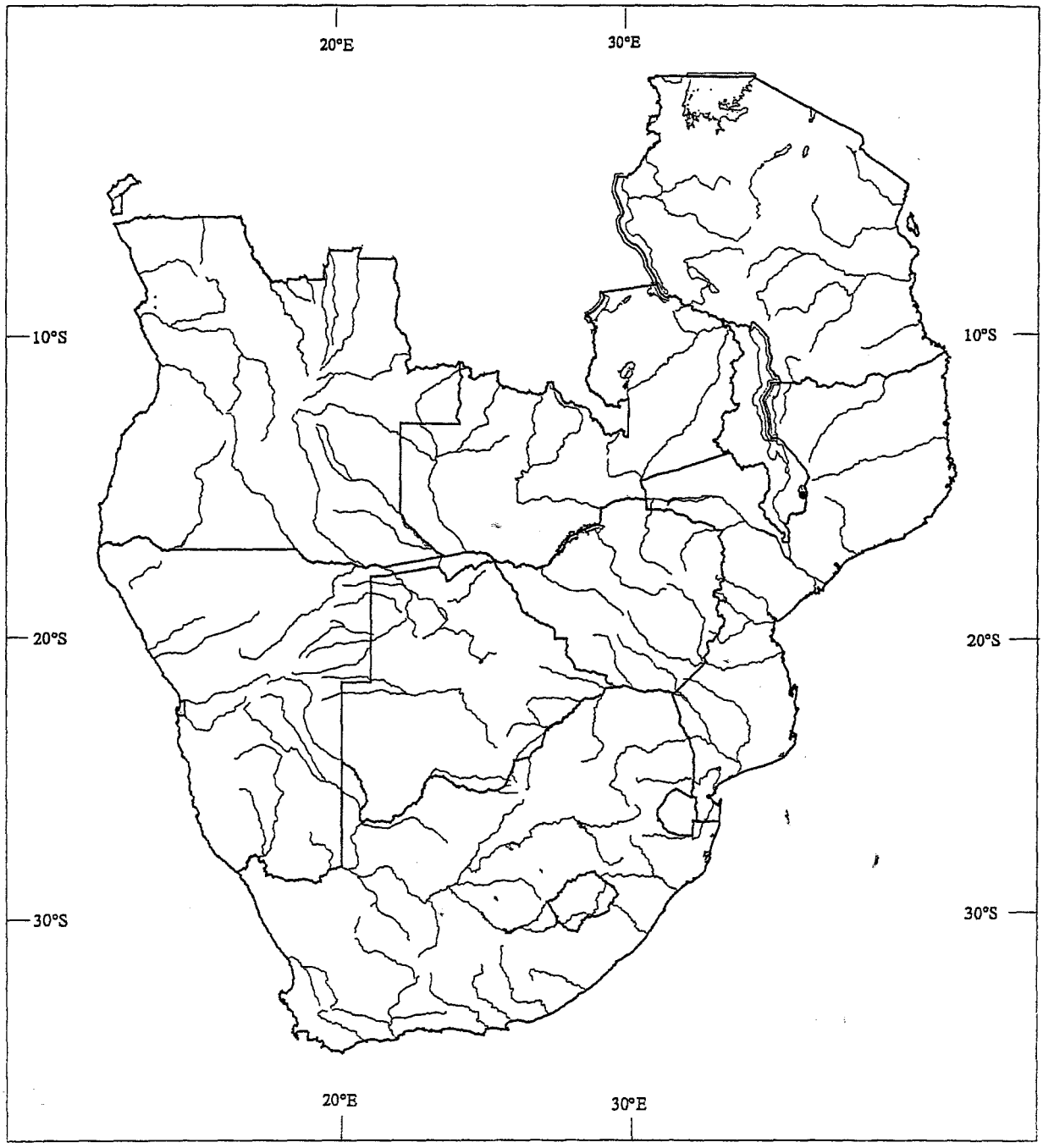


Figure F.274. Point distribution of *Eutropiellus longifilis*. Scale approximately 1:25 000 000

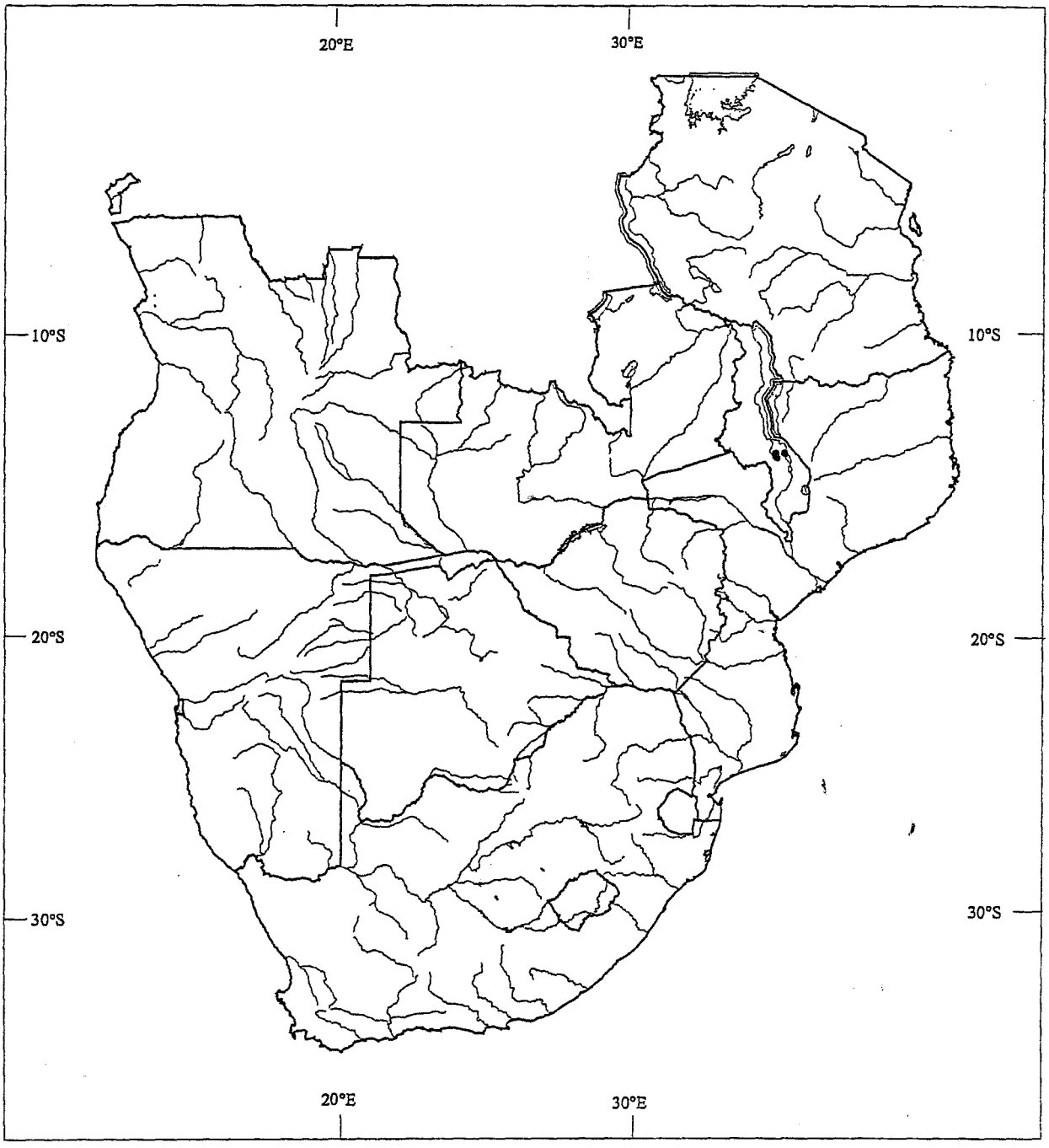


Figure F.275. Point distribution of *Exochochromis anagenys*. Scale approximately 1:25 000 000

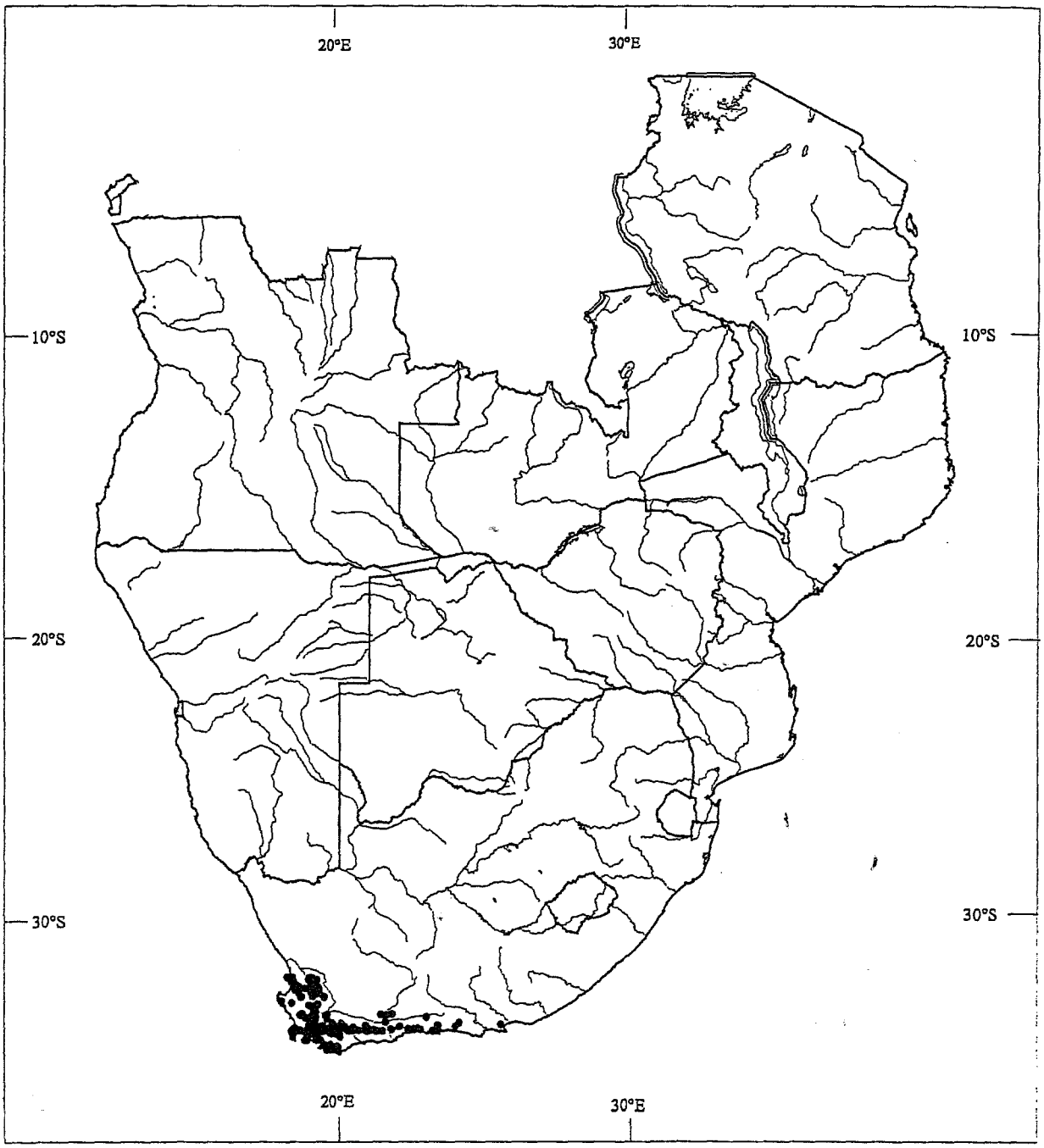


Figure F.276. Point distribution of *Galaxias zebratus*. Scale approximately 1:25 000 000

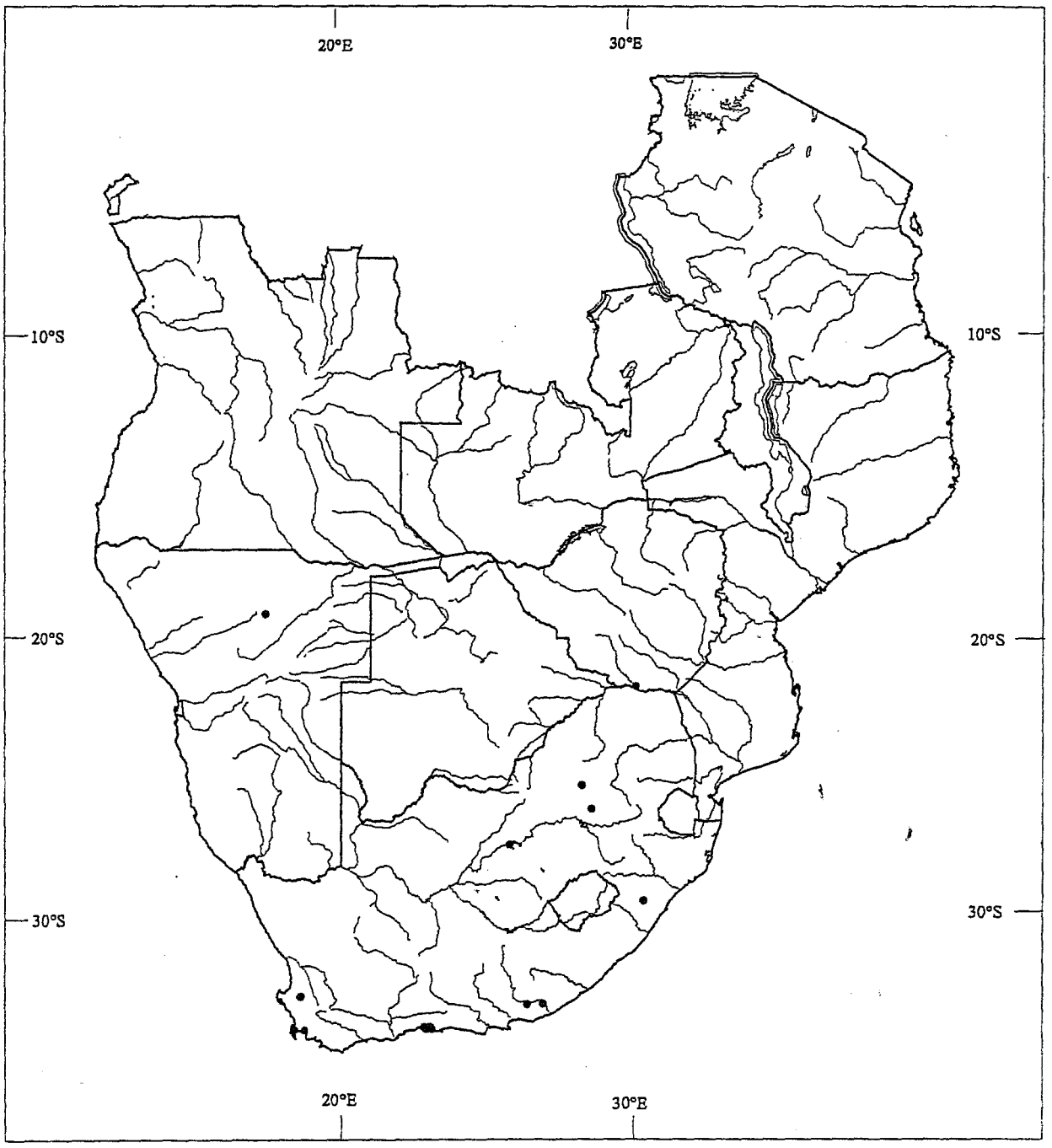


Figure F.277. Point distribution of *Gambusia affinis*. Scale approximately 1:25 000 000

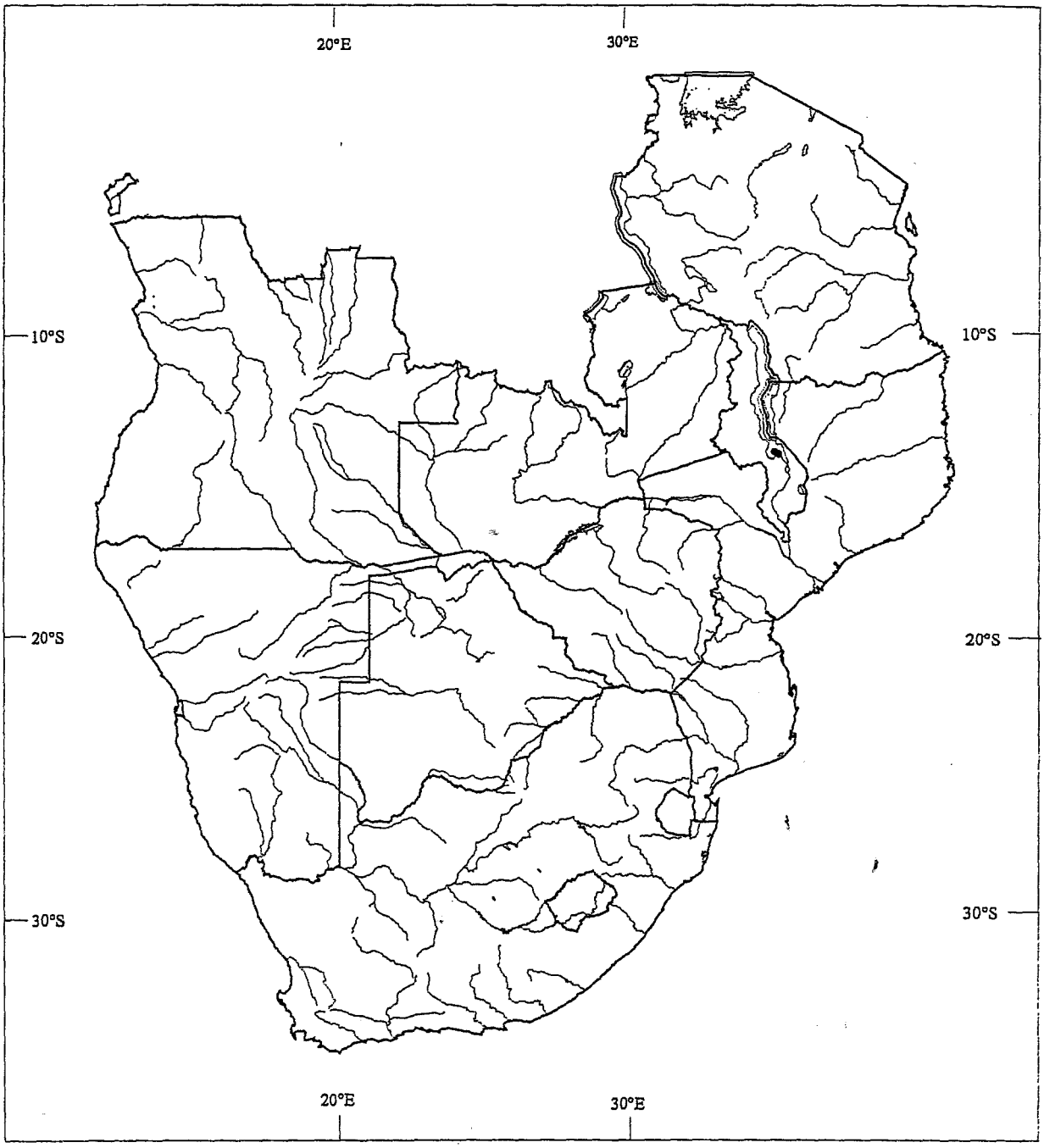


Figure F.278. Point distribution of *Genyochromis mento*. Scale approximately 1:25 000 000

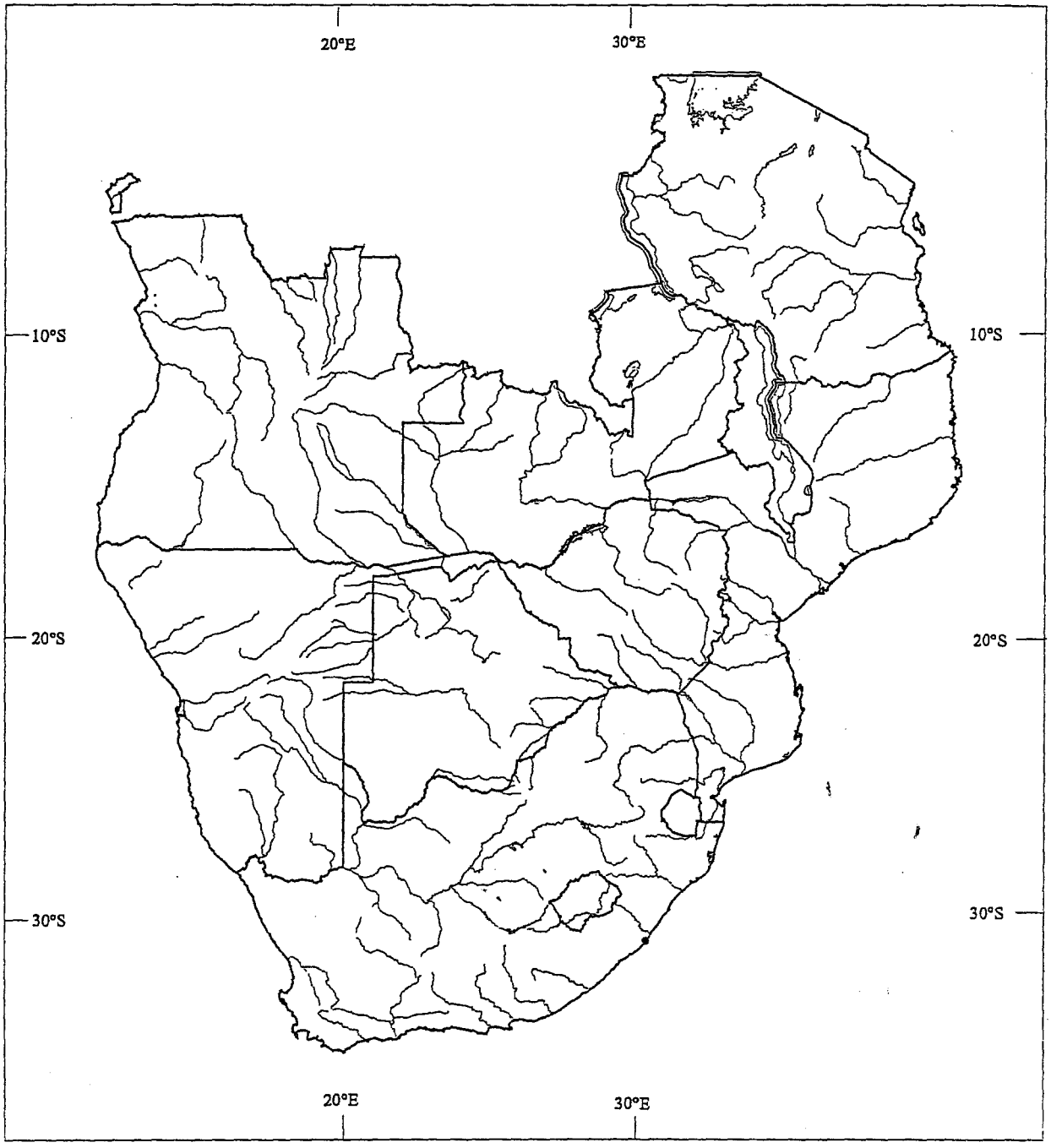


Figure F.279. Point distribution of *Gerres acinaces*. Scale approximately 1:25 000 000

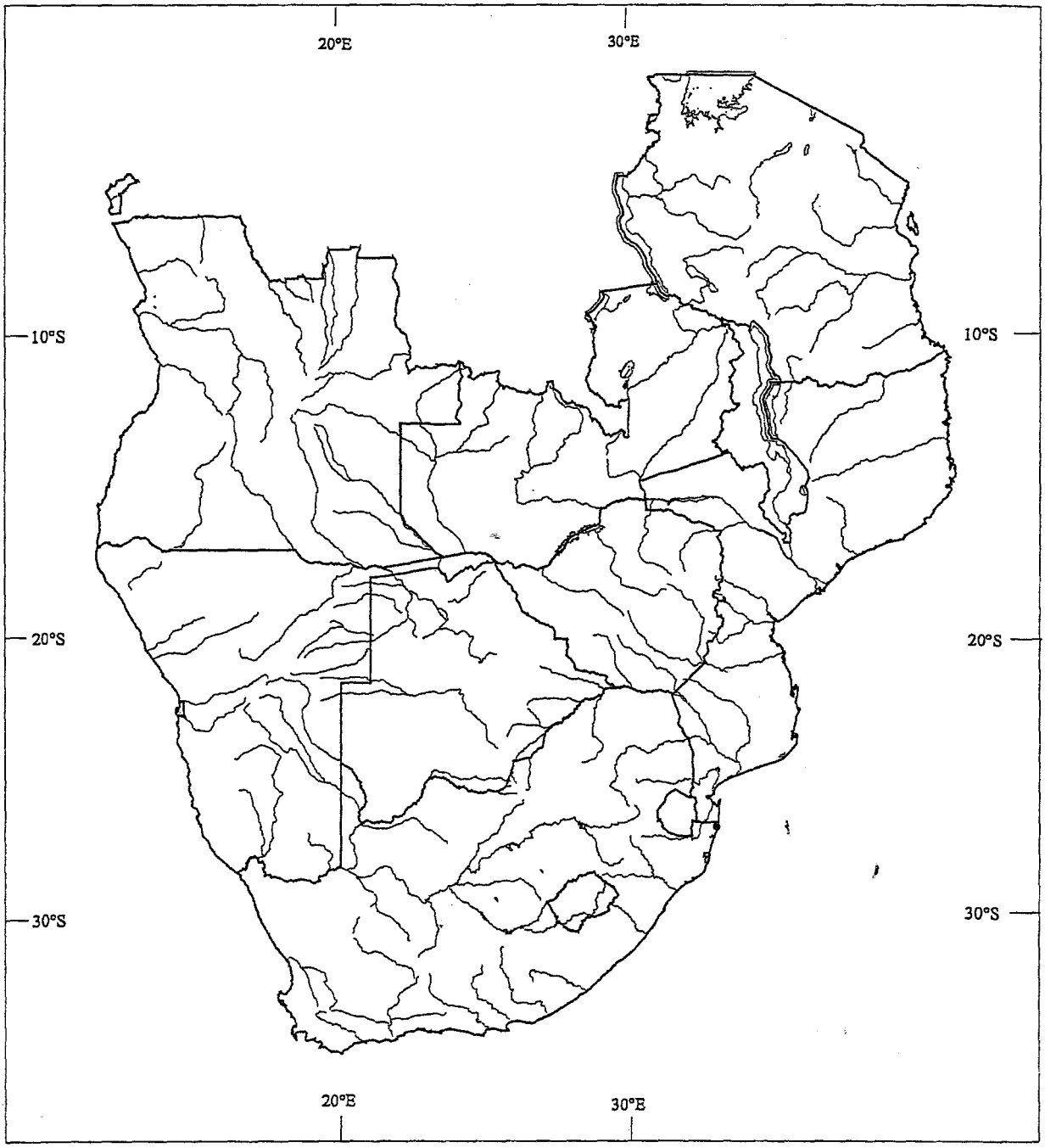


Figure F.280. Point distribution of *Gerres rappi*. Scale approximately 1:25 000 000

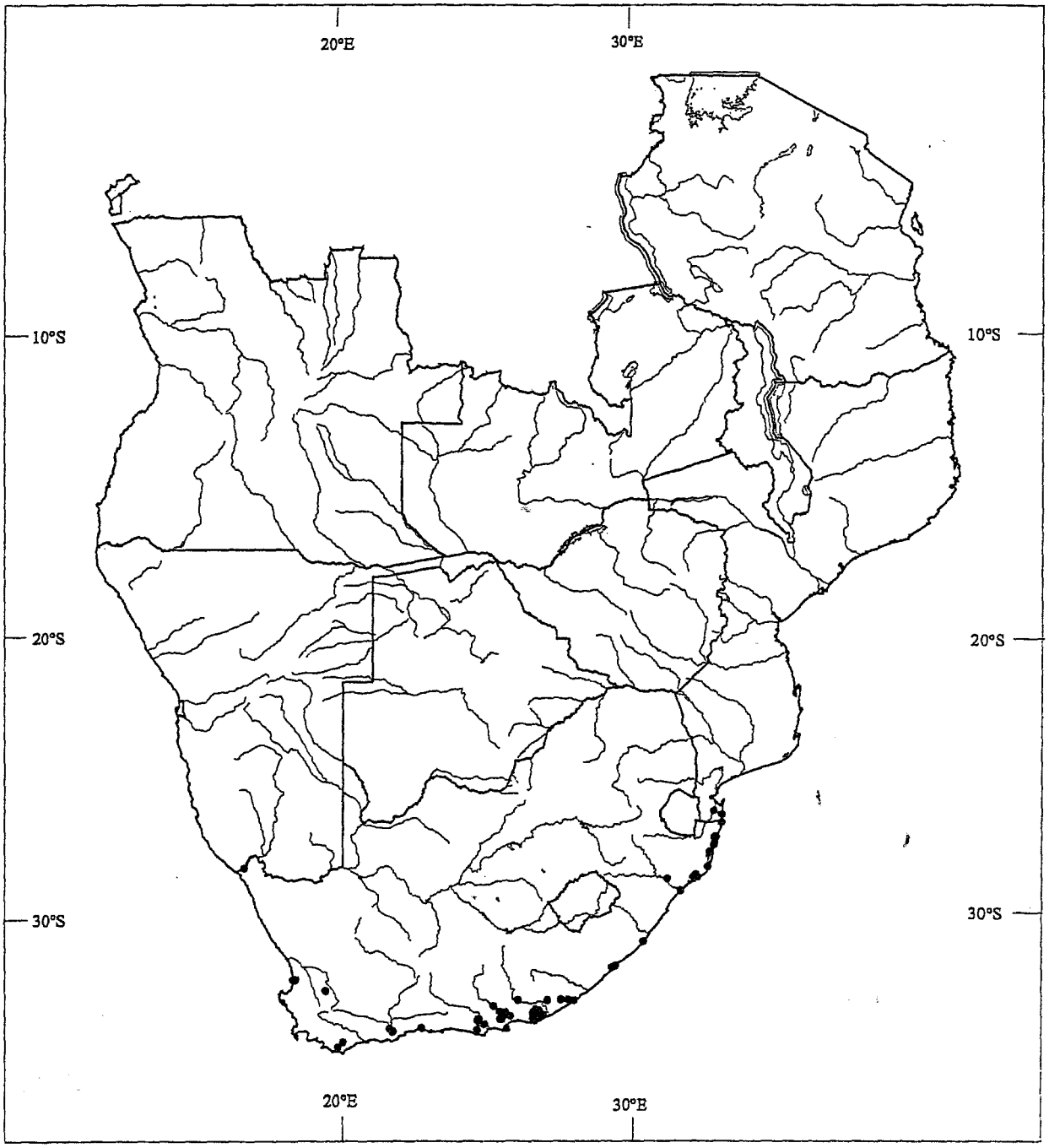


Figure F.281. Point distribution of *Gilchristella aestuaria*. Scale approximately 1:25 000 000

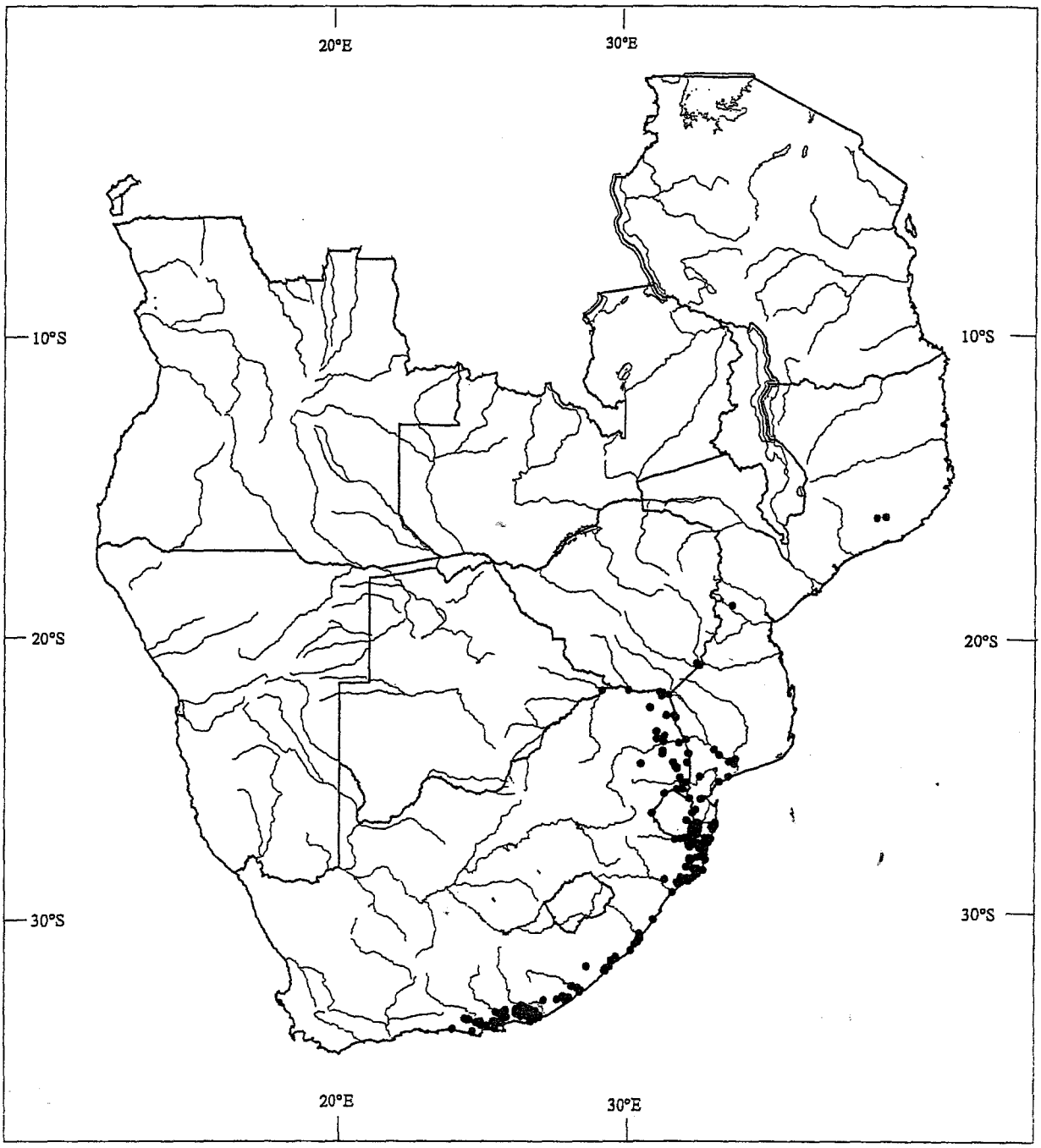


Figure F.282. Point distribution of *Glossogobius callidus*. Scale approximately 1:25 000 000

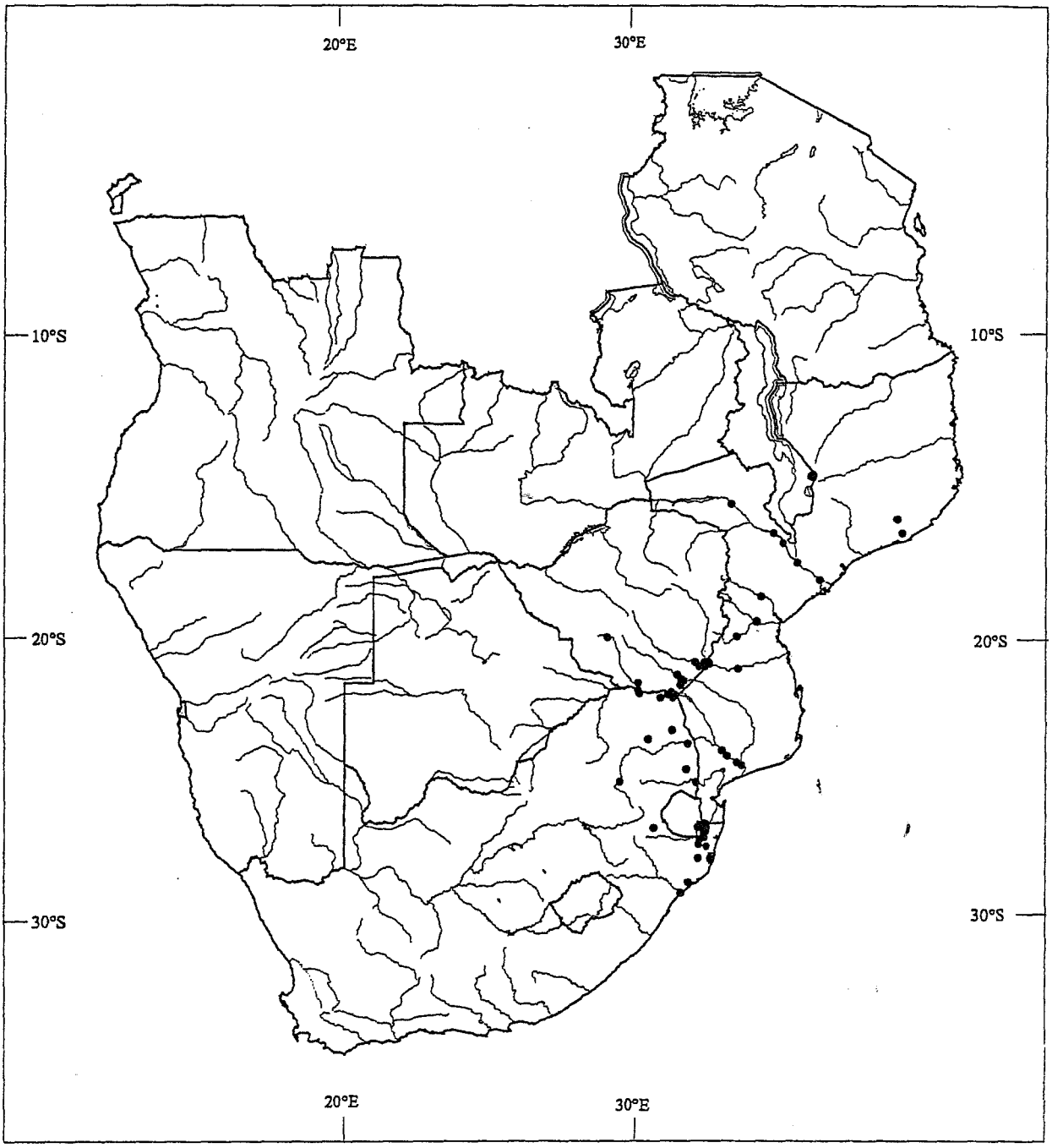


Figure F.283. Point distribution of *Glossogobius giuris*. Scale approximately 1:25 000 000

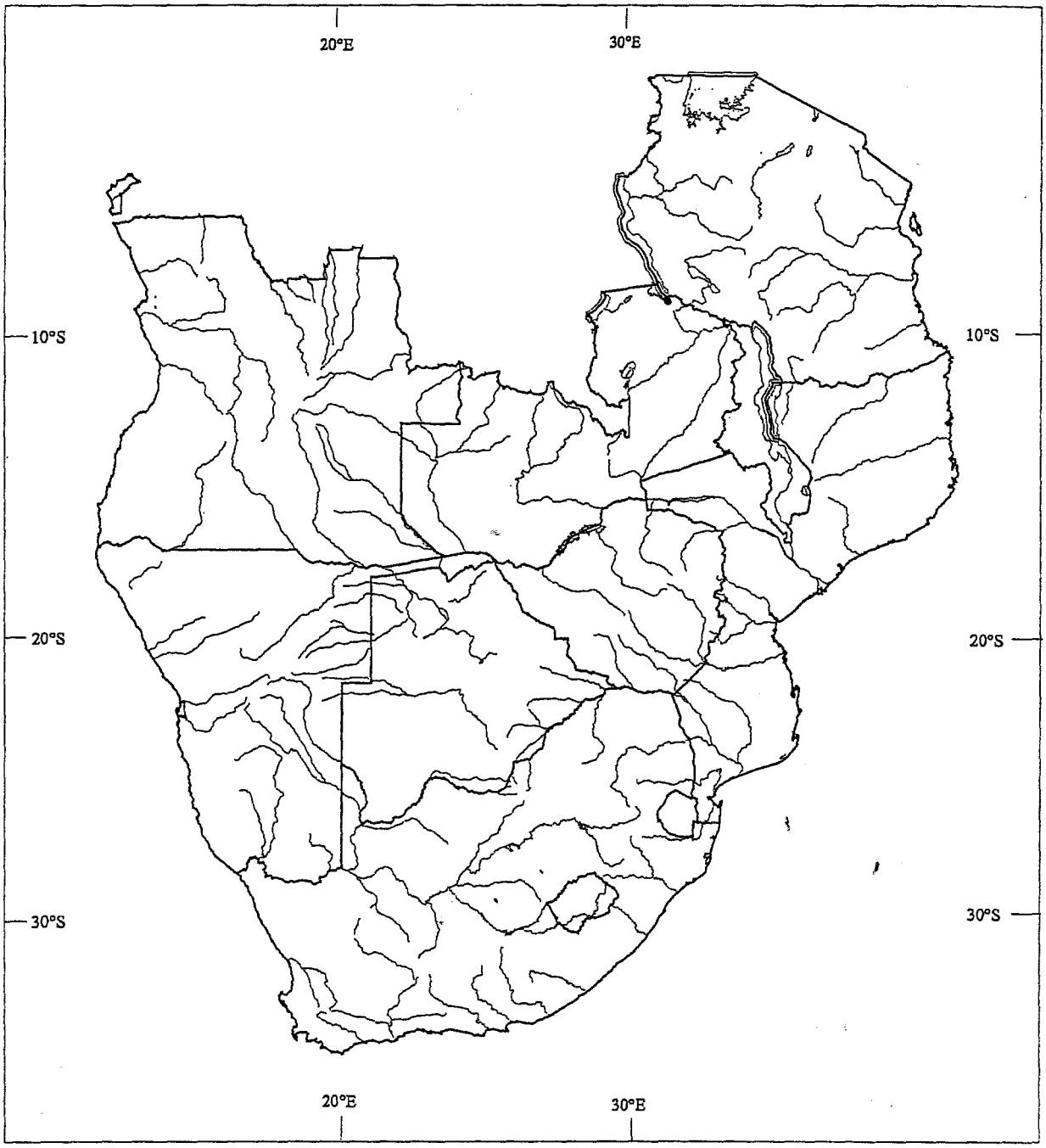


Figure F.284. Point distribution of *Gnathochromis permaxillaris*. Scale approximately 1:25 000 000

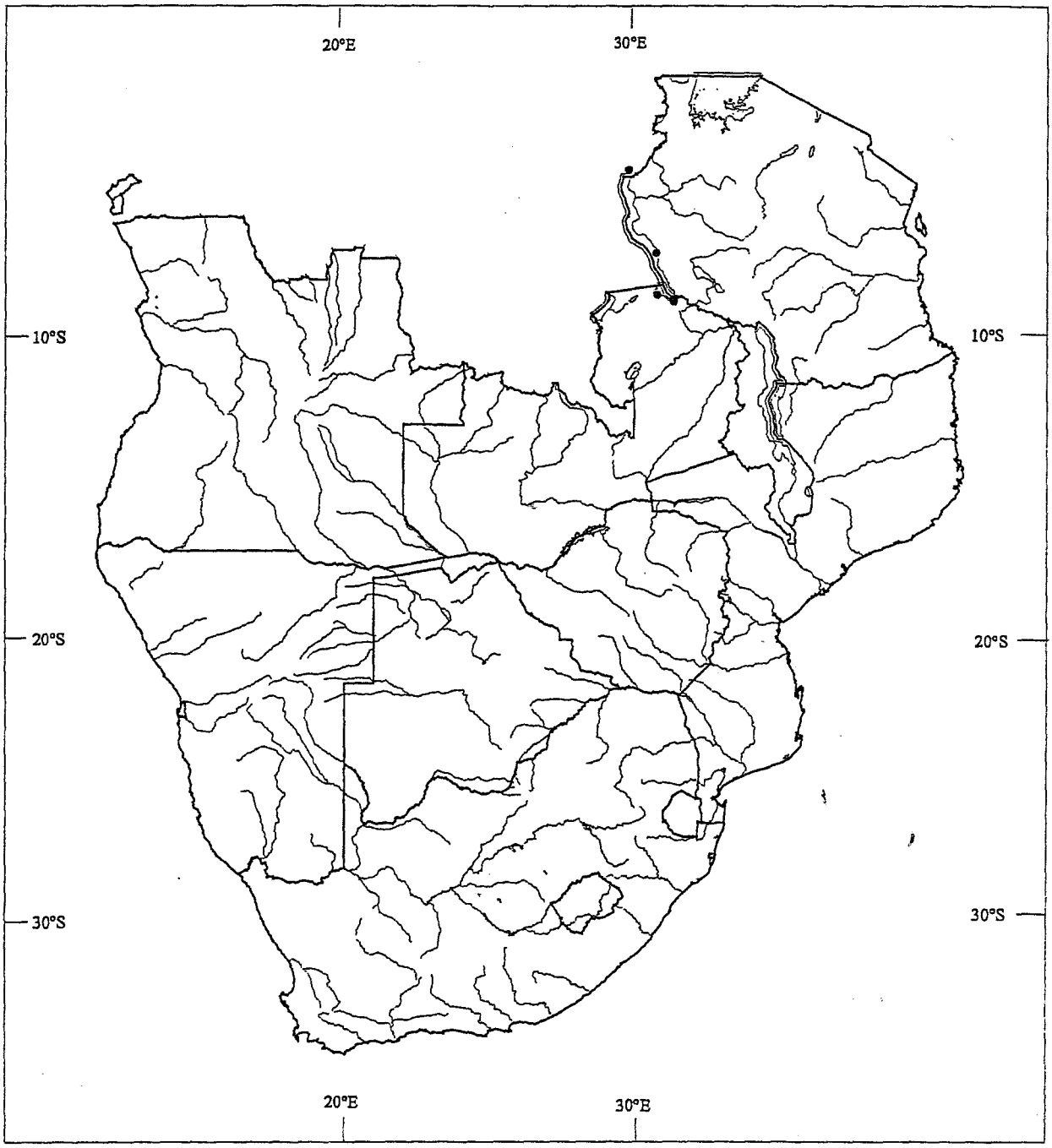


Figure F.285. Point distribution of *Gnathochromis pfefferi*. Scale approximately 1:25 000 000

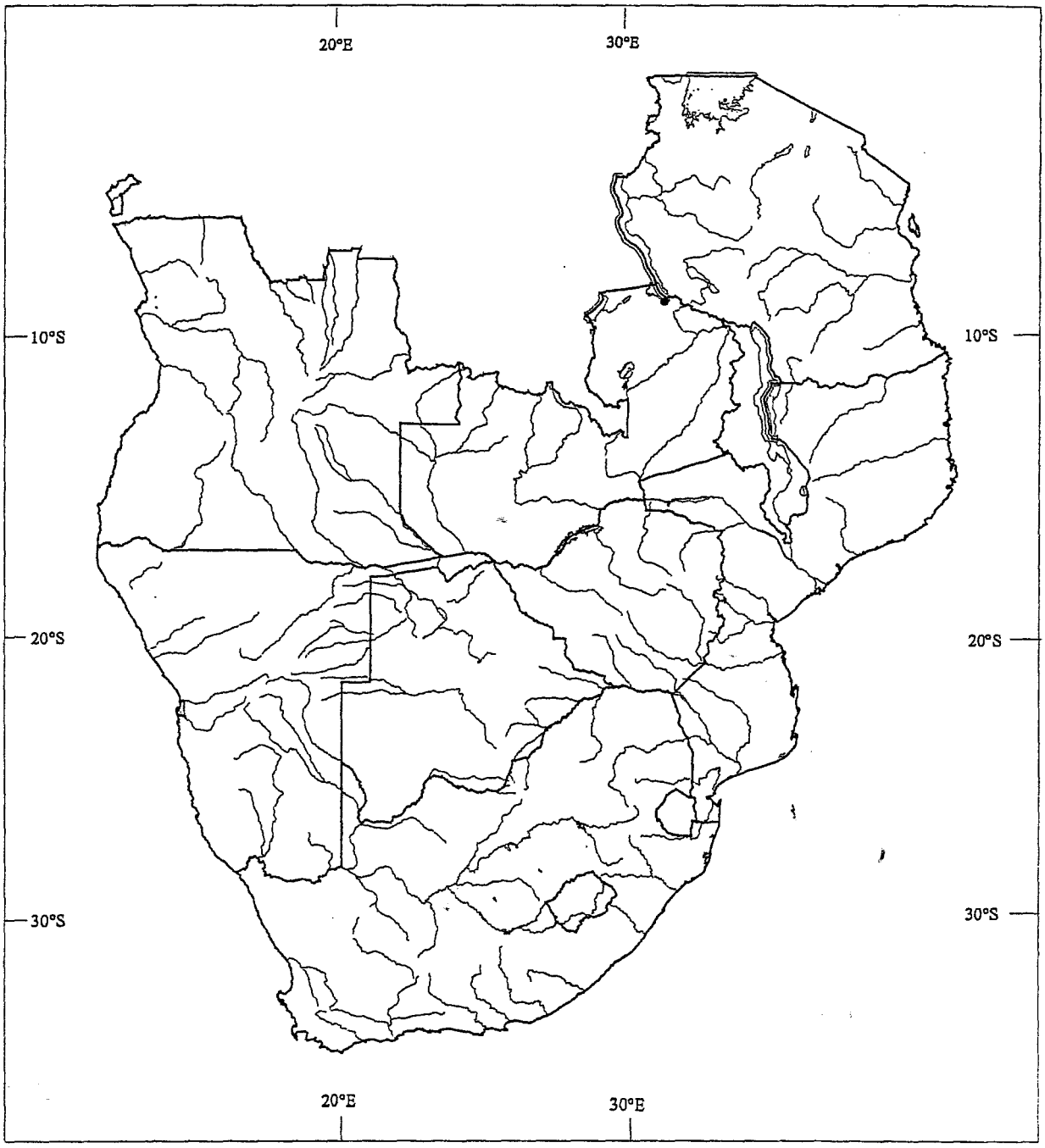


Figure F.286. Point distribution of *Grammatotria lemairii*. Scale approximately 1:25 000 000

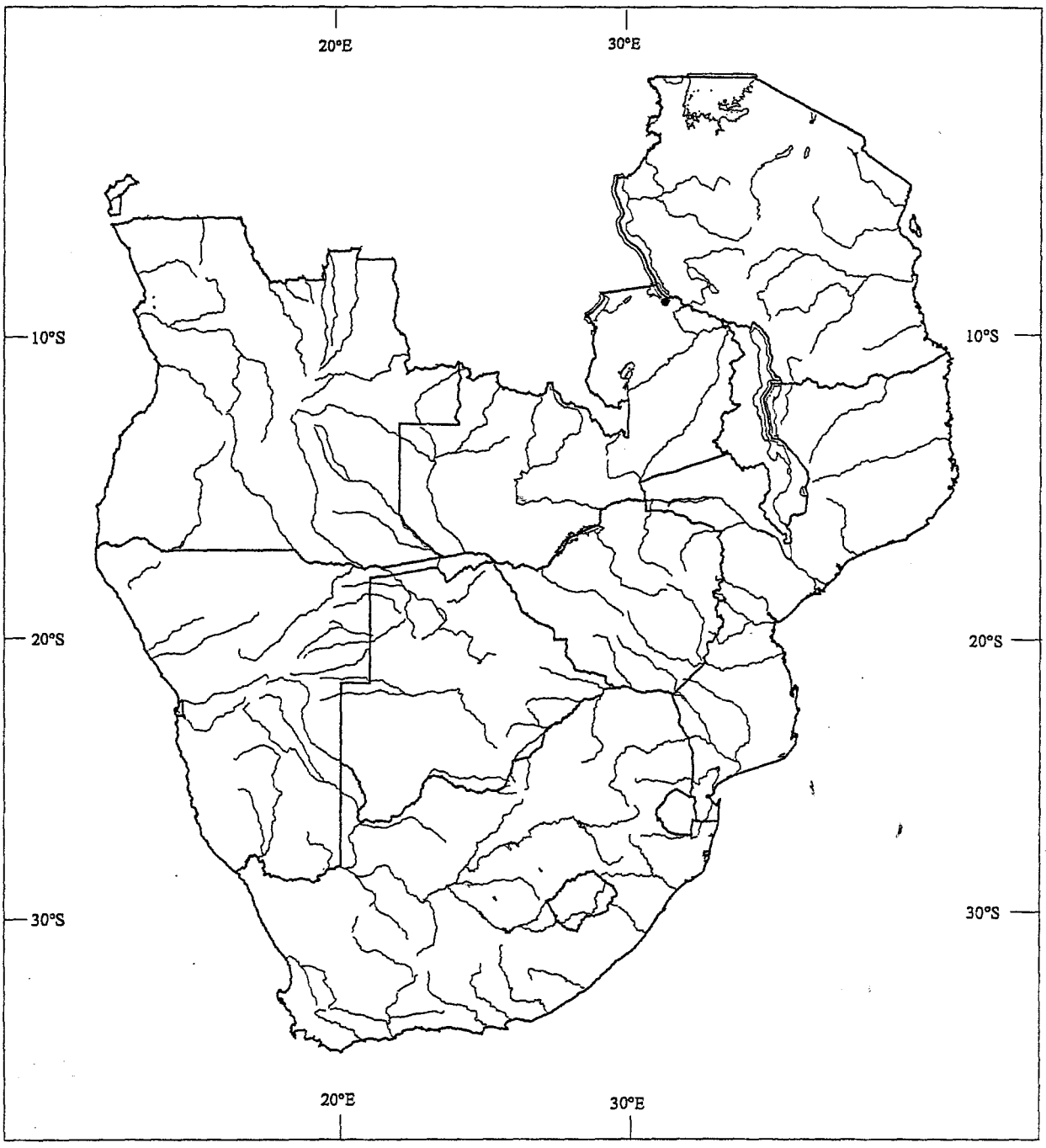


Figure F.287. Point distribution of *Greenwoodochromis bellcrossi*. Scale approximately 1:25 000 000

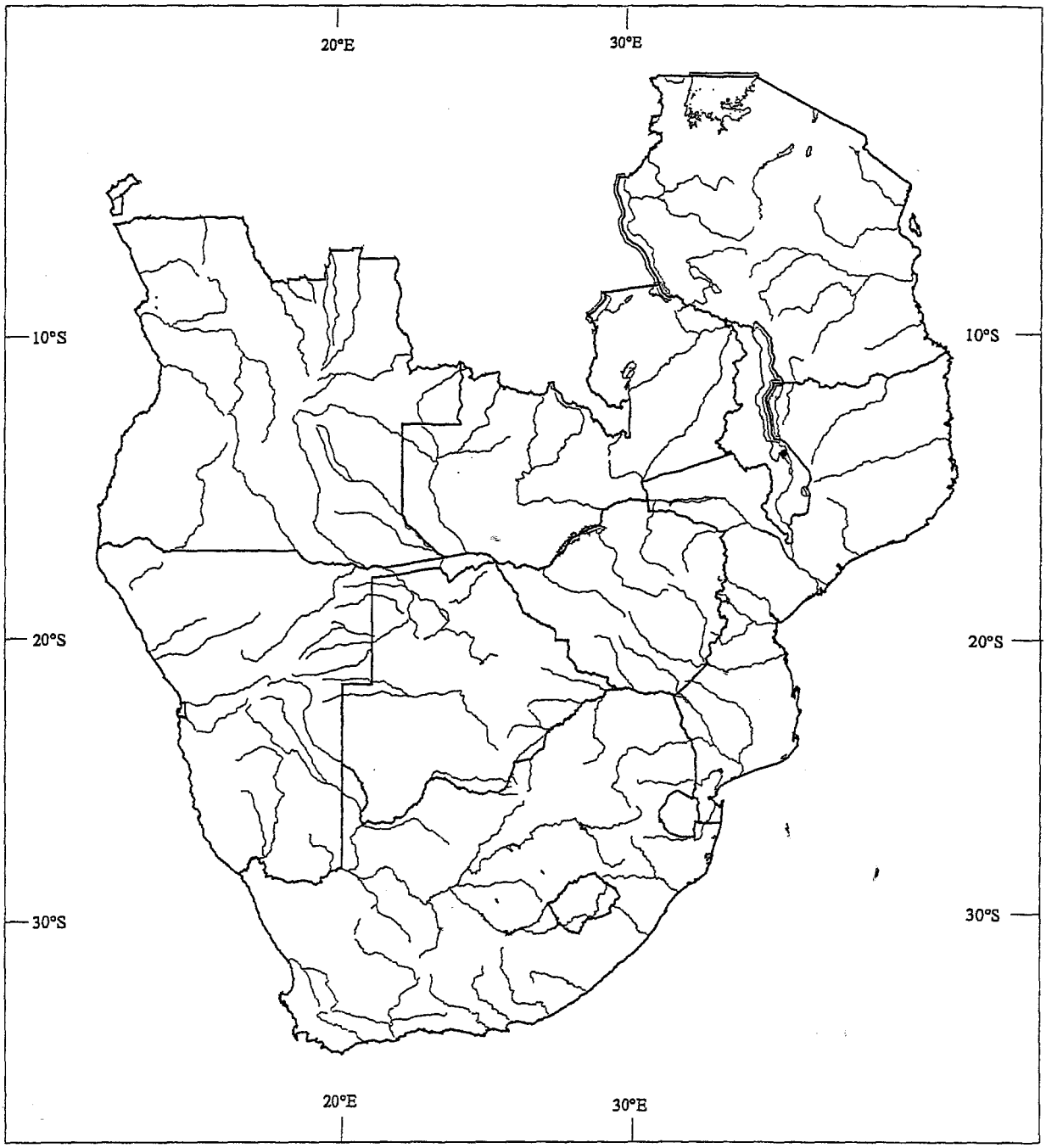


Figure F.288. Point distribution of *Haplochromis acutidens*. Scale approximately 1:25 000 000

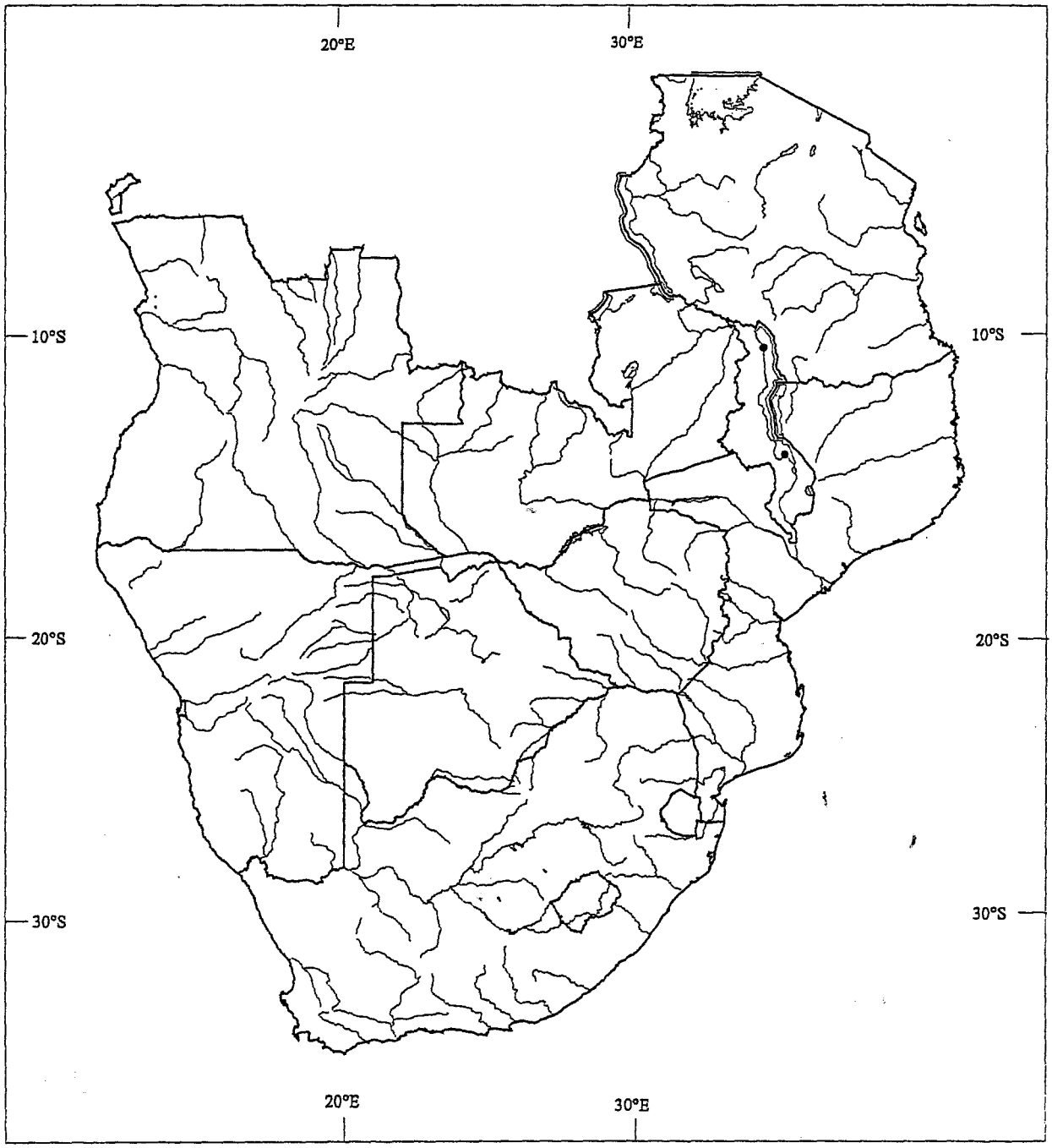


Figure F.289. Point distribution of *Haplochromis argyrosoma*. Scale approximately 1:25 000 000

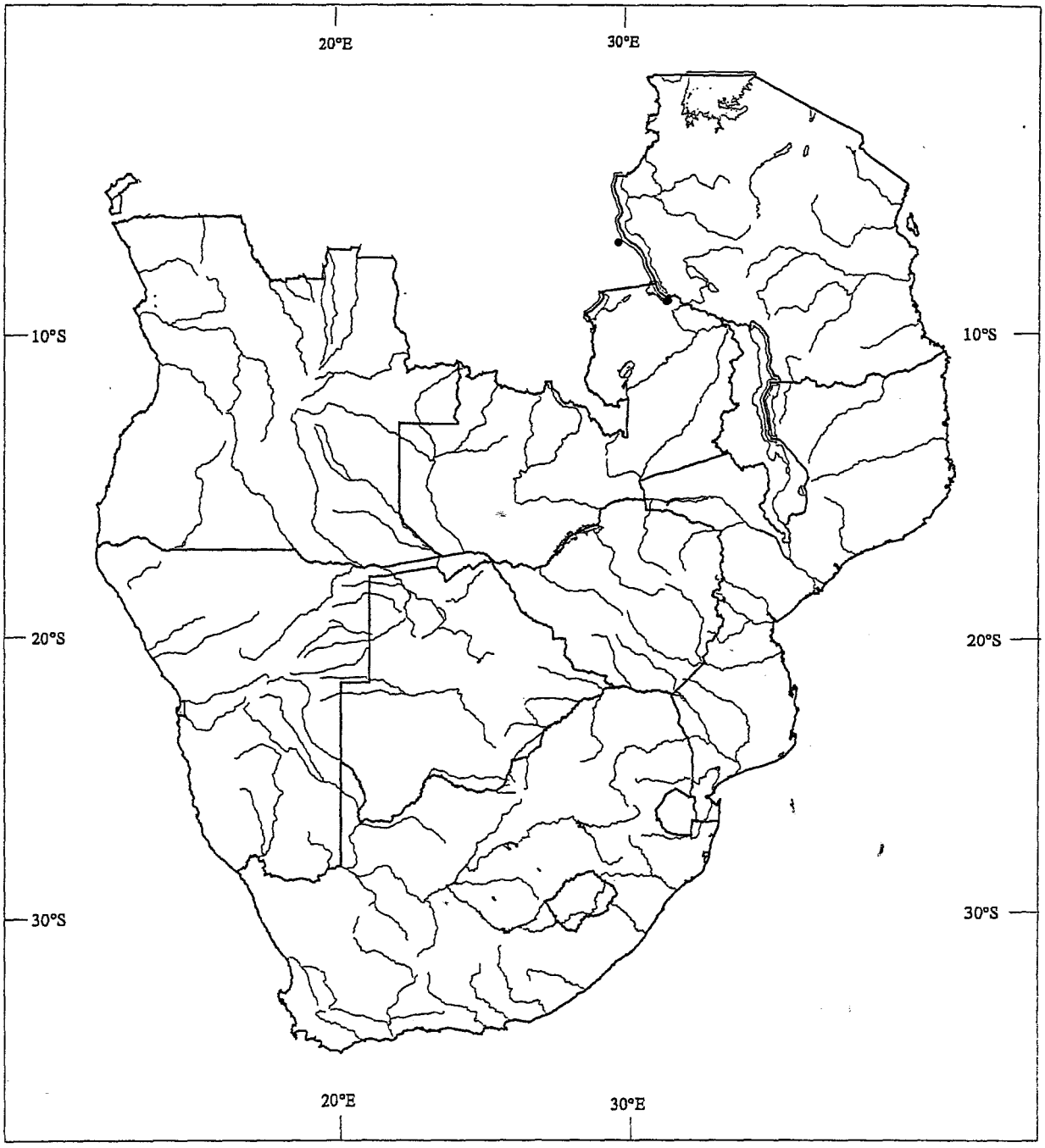


Figure F.290. Point distribution of *Haplochromis burtoni*. Scale approximately 1:25 000 000

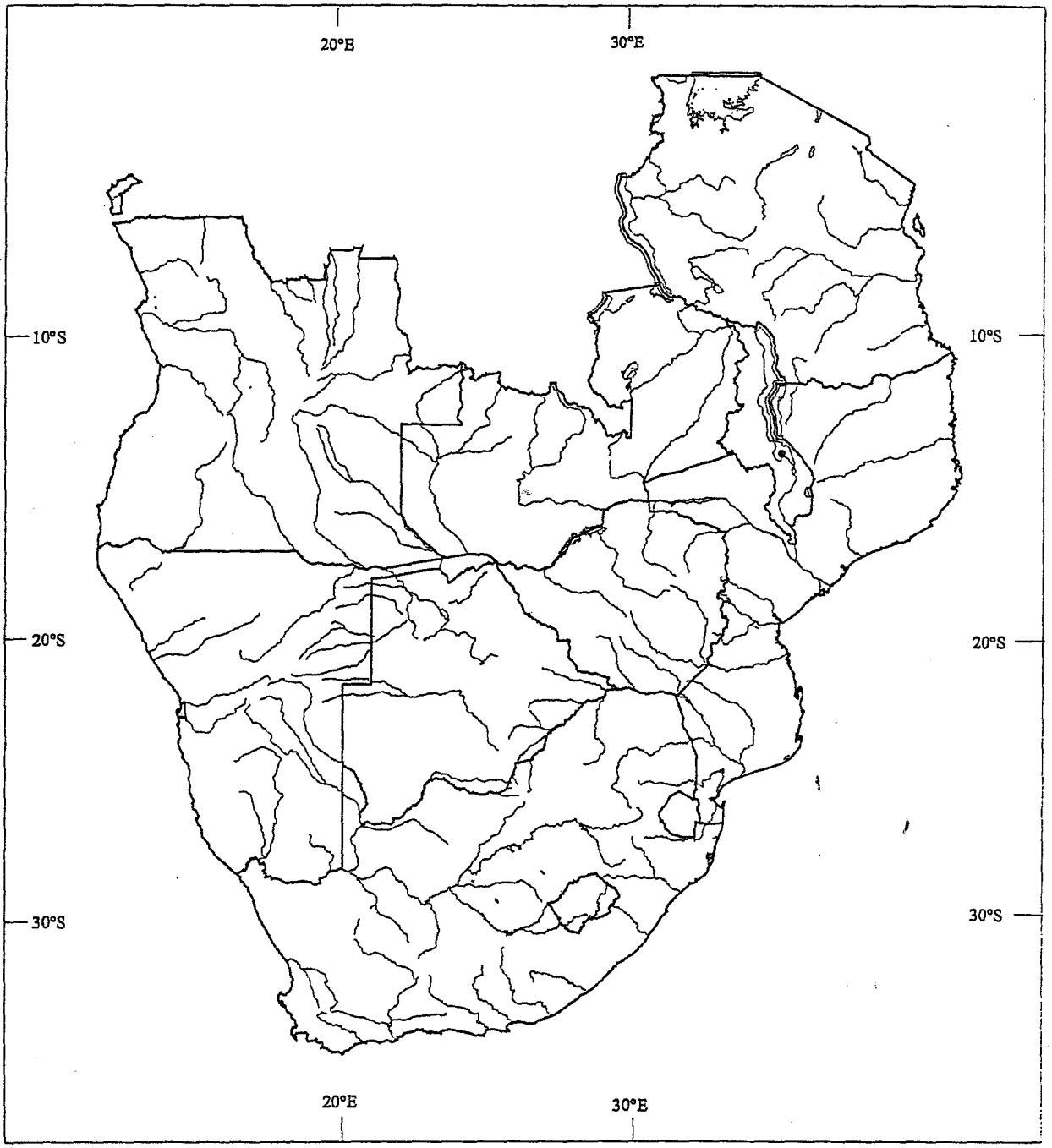


Figure F.291. Point distribution of *Haplochromis caeruleus*. Scale approximately 1:25 000 000

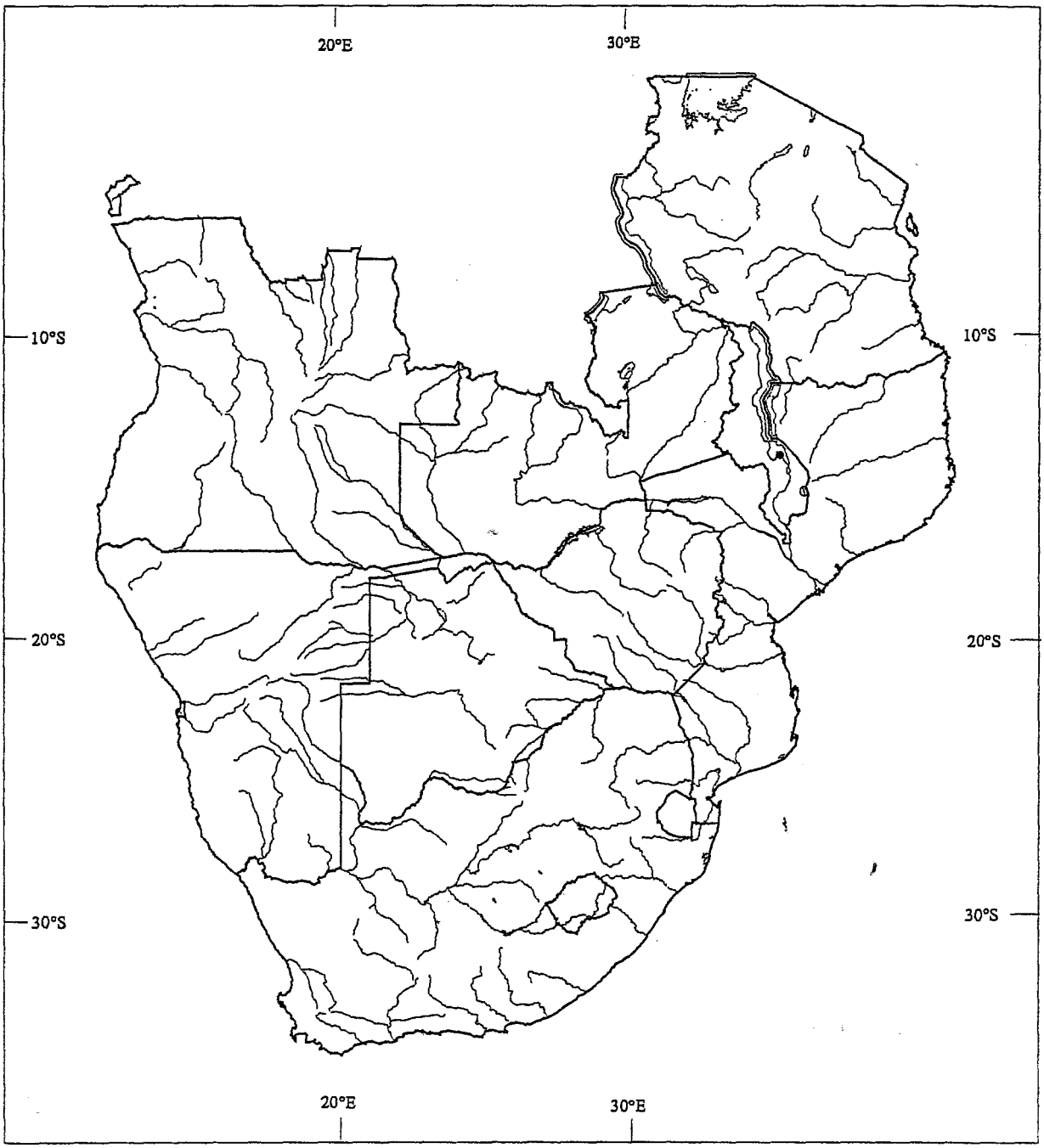


Figure F.292. Point distribution of *Haplochromis chrysonotus*. Scale approximately 1:25 000 000

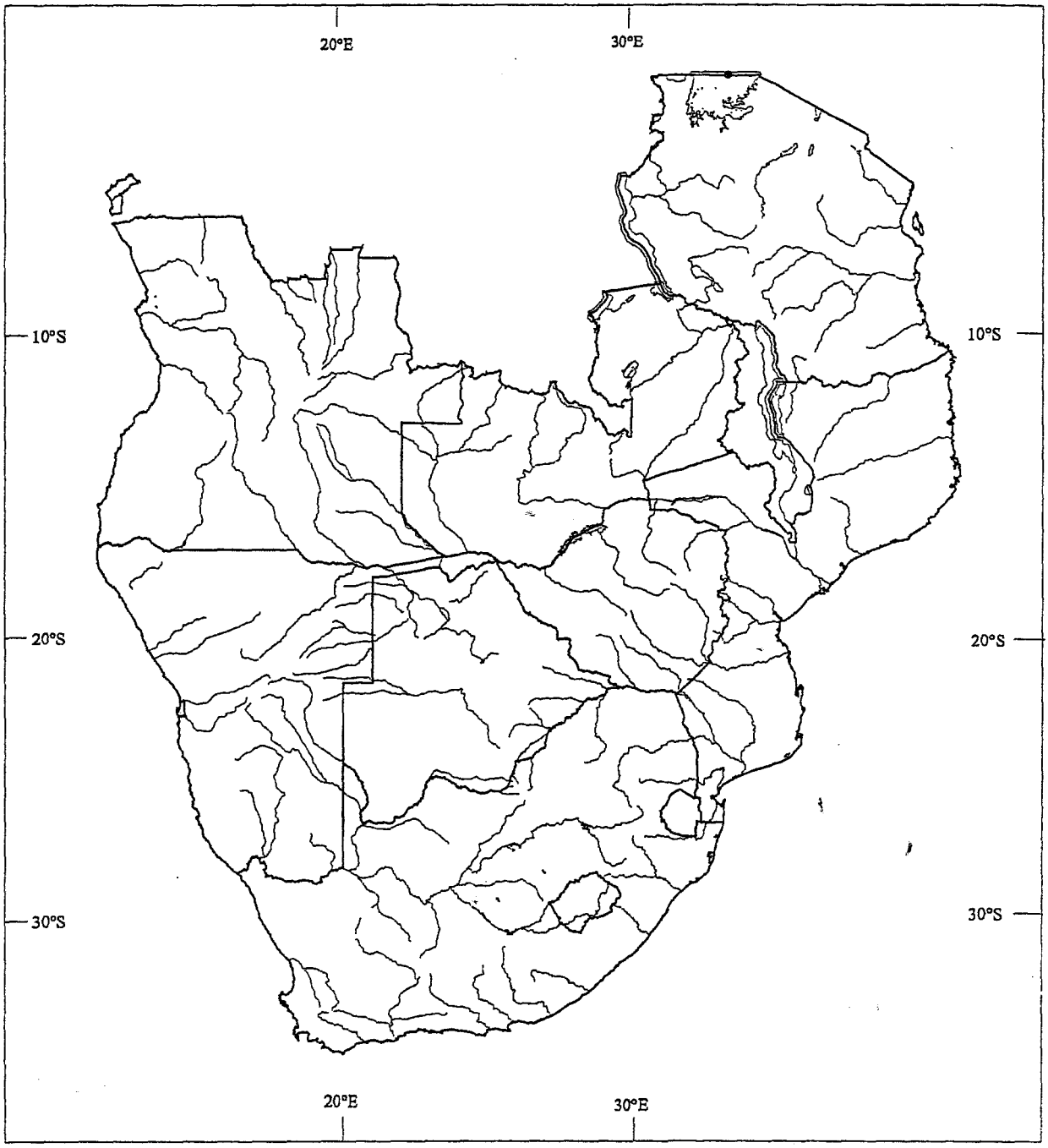


Figure F.293. Point distribution of *Haplochromis cinereus*. Scale approximately 1:25 000 000

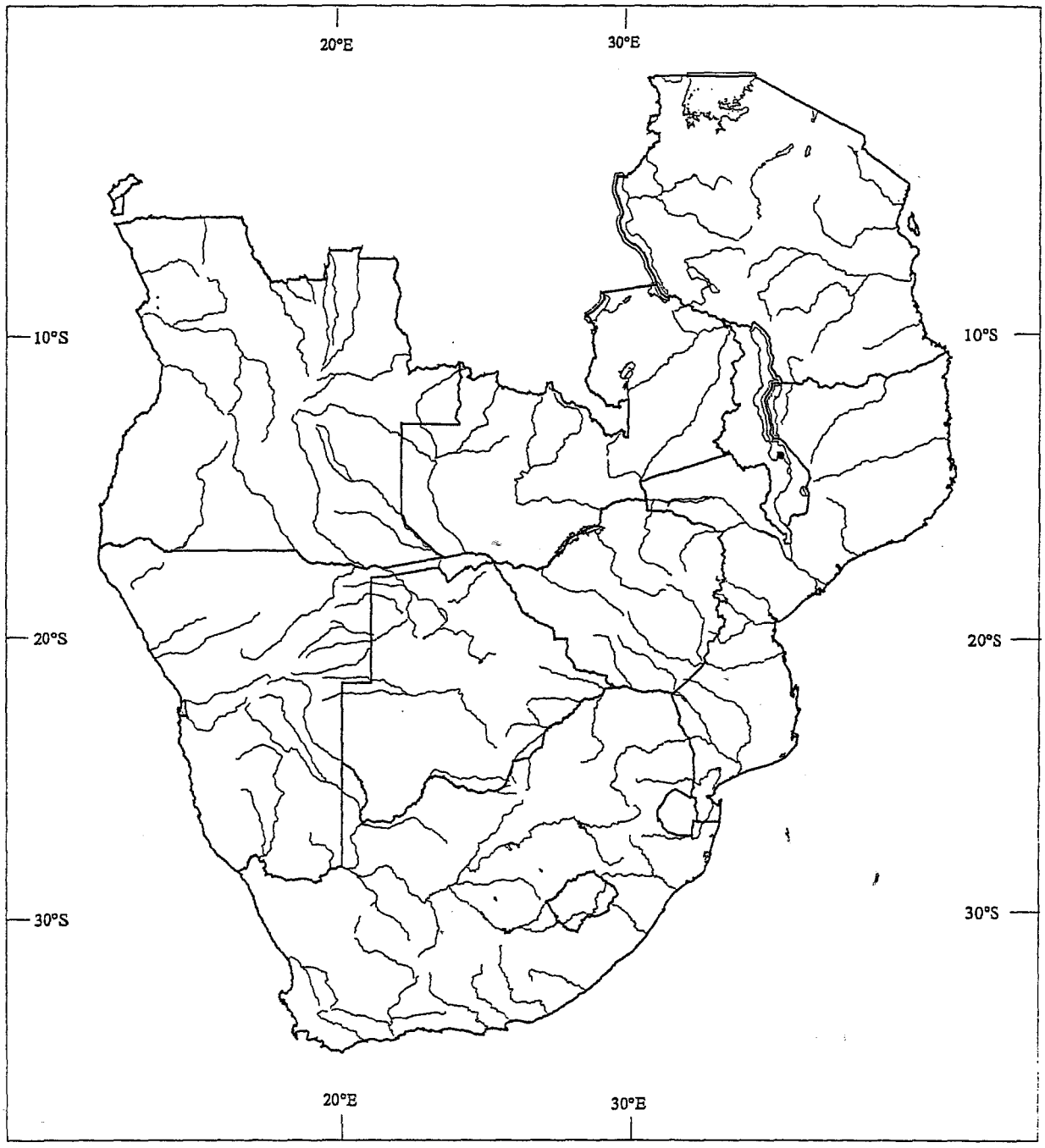


Figure F.294. Point distribution of *Haplochromis compressiceps*. Scale approximately 1:25 000 000

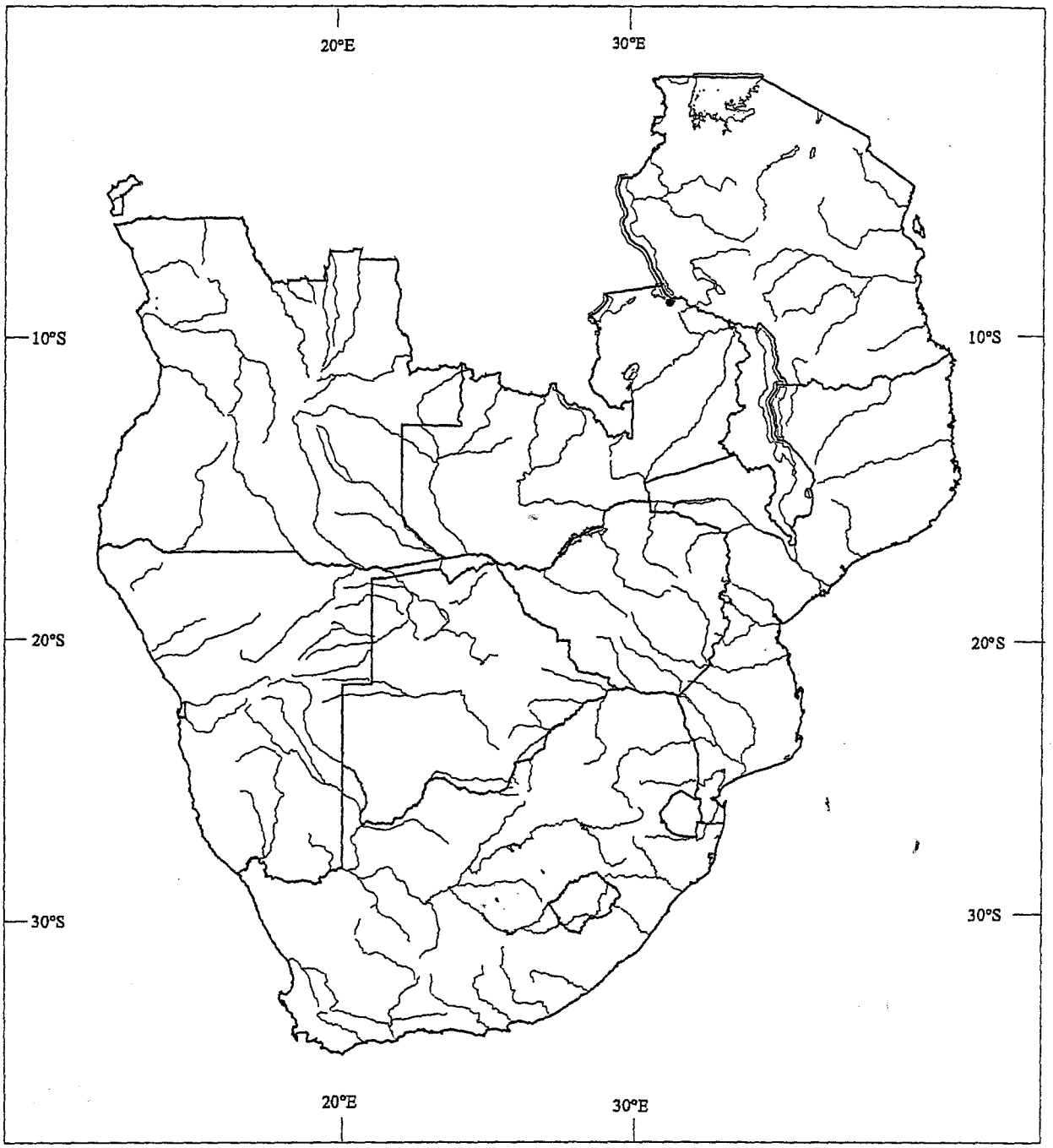


Figure F.295. Point distribution of *Haplochromis horei*. Scale approximately 1:25 000 000

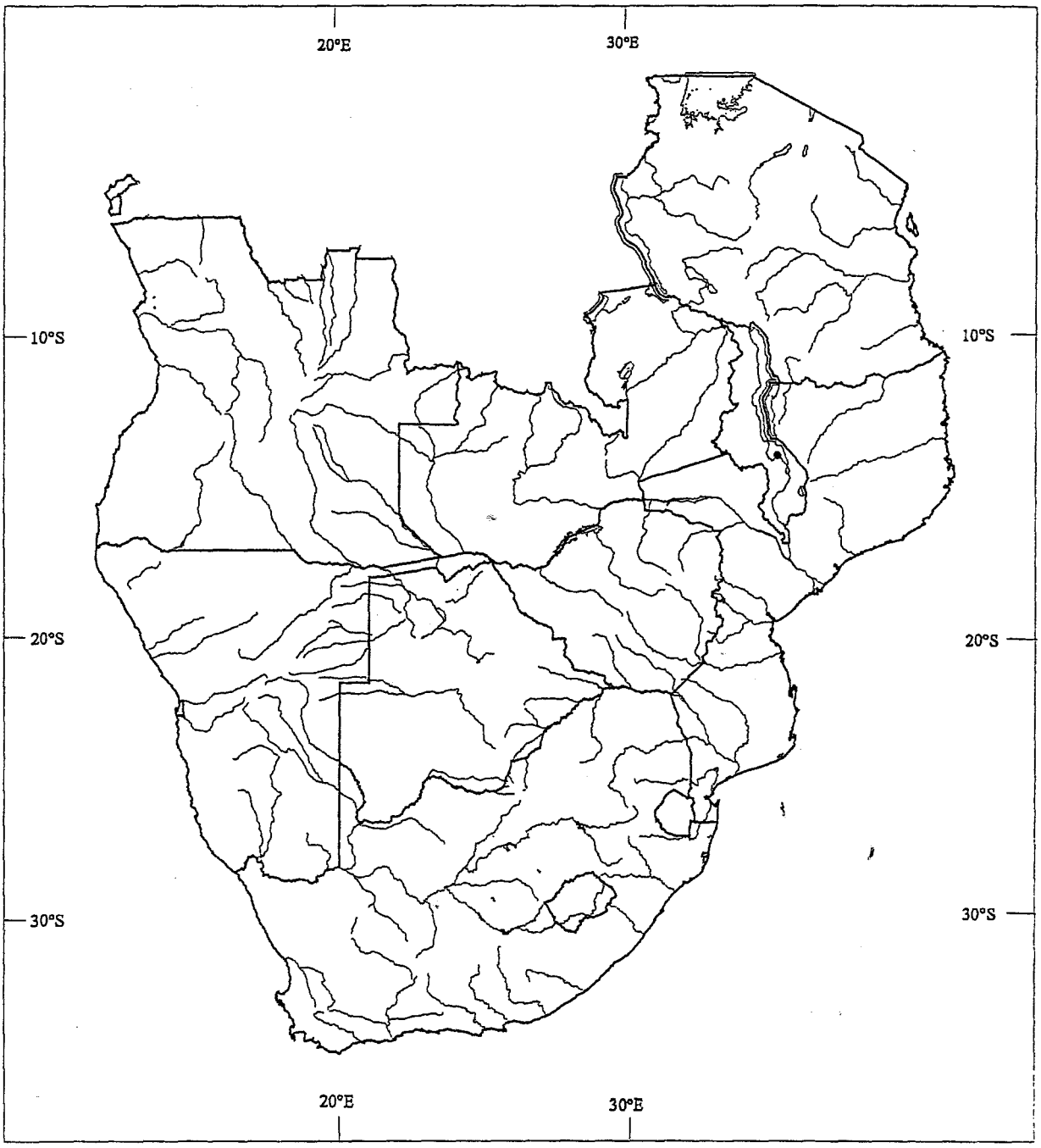


Figure F.296. Point distribution of *Haplochromis inornatus*. Scale approximately 1:25 000 000

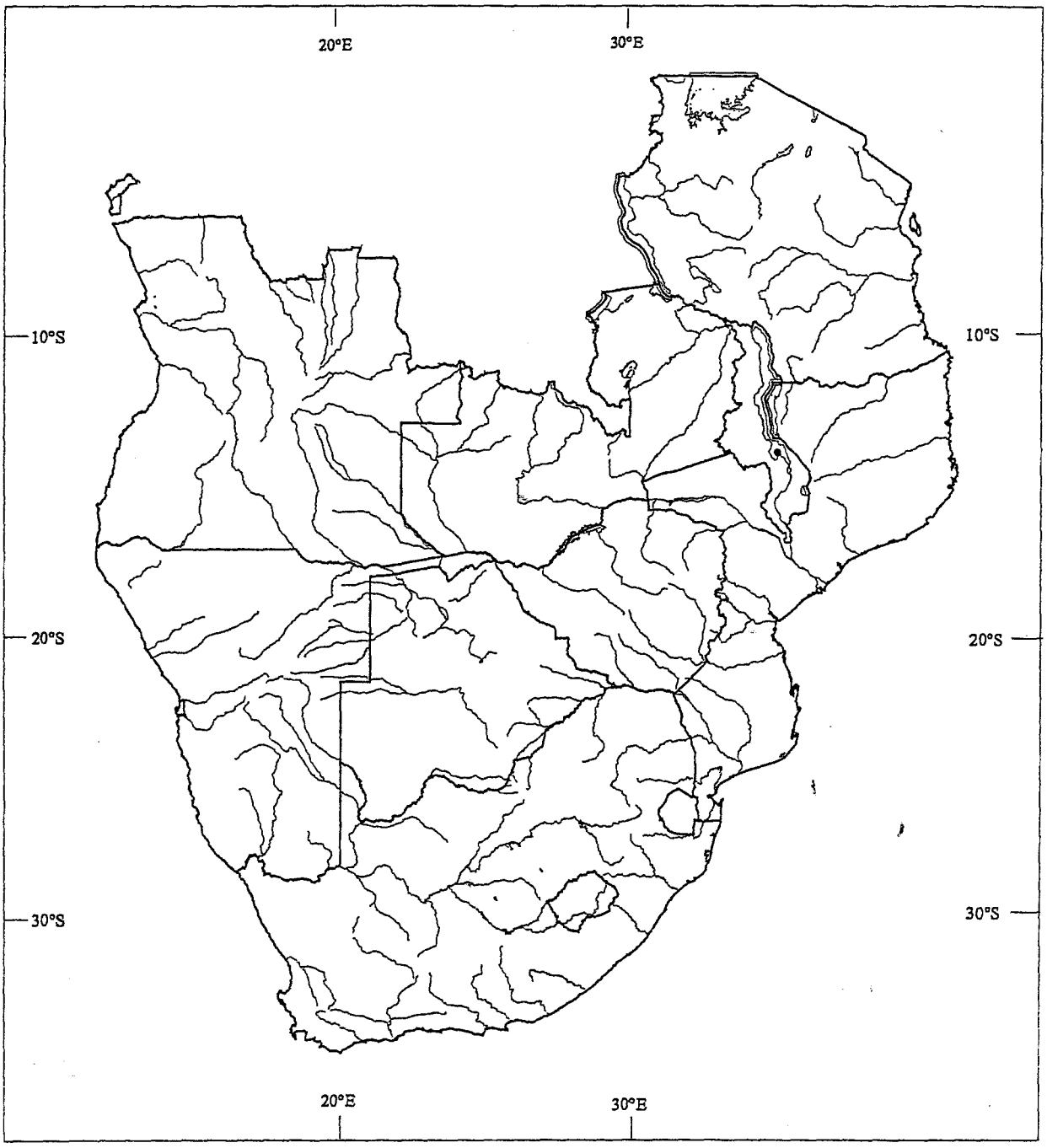


Figure F.297. Point distribution of *Haplochromis intermedius*. Scale approximately 1:25 000 000

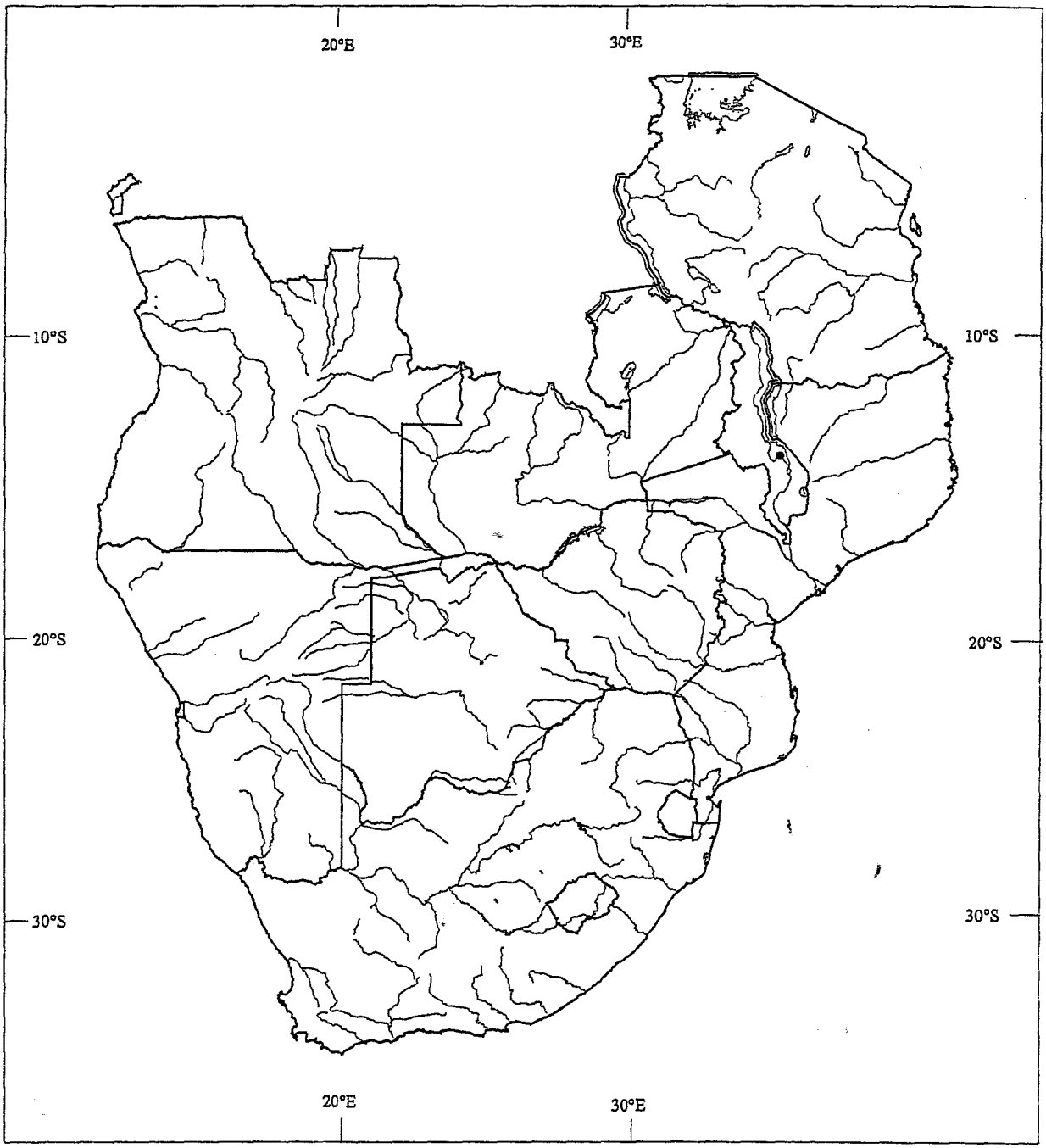


Figure F.298. Point distribution of *Haplochromis kirkii*. Scale approximately 1:25 000 000

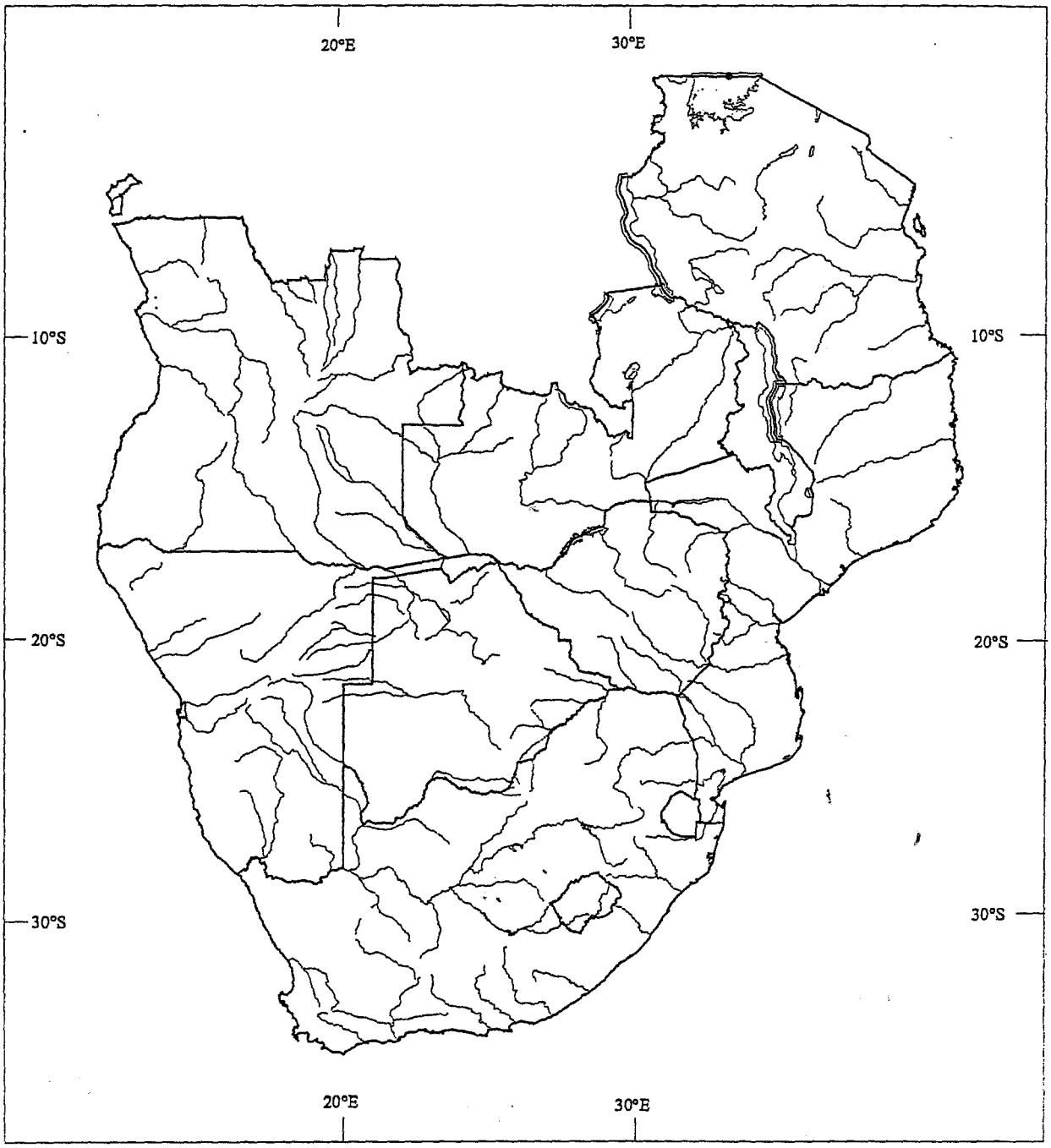


Figure F.299. Point distribution of *Haplochromis lacrimosus*. Scale approximately 1:25 000 000

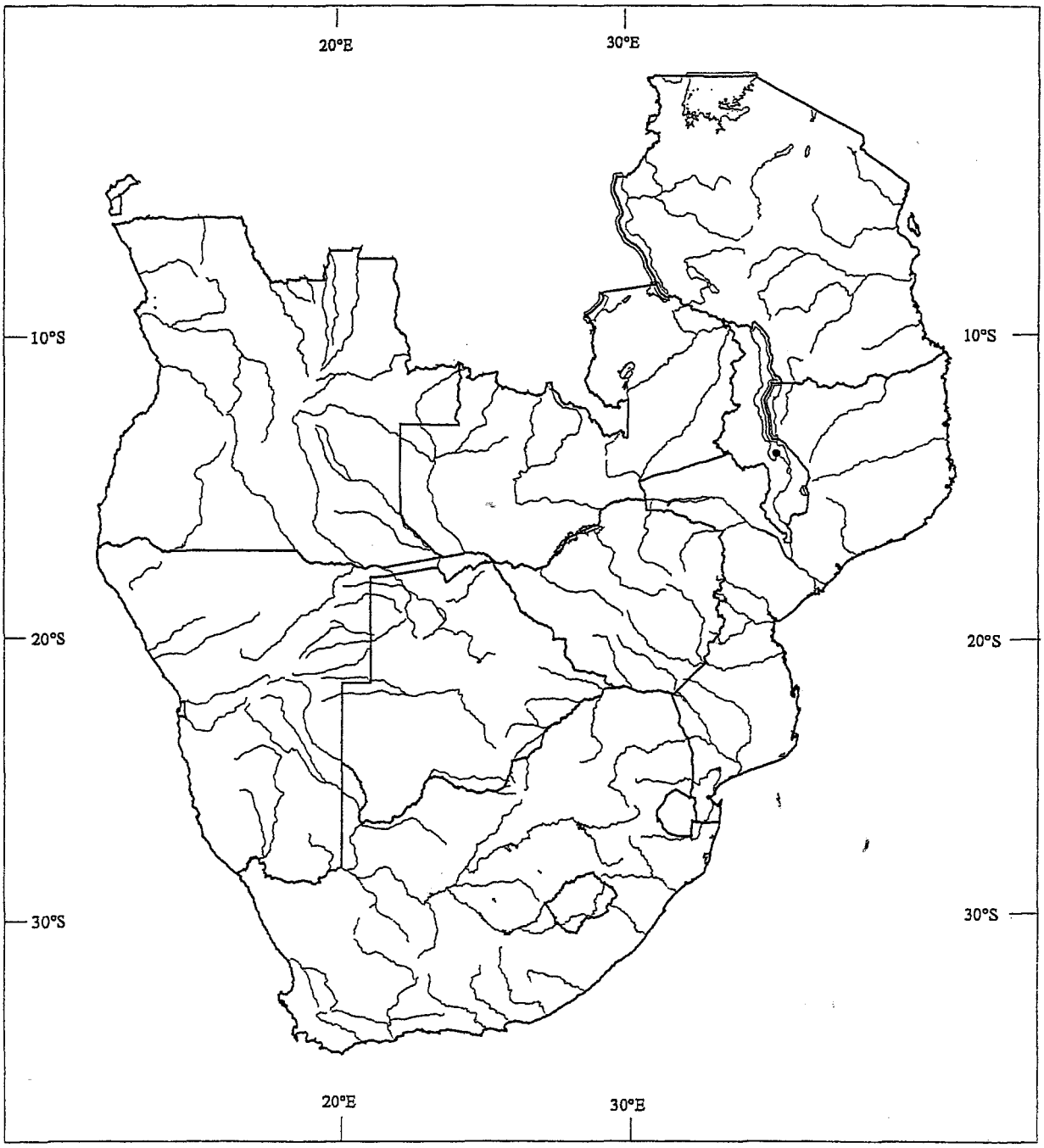


Figure F.300. Point distribution of *Haplochromis loweae*. Scale approximately 1:25 000 000

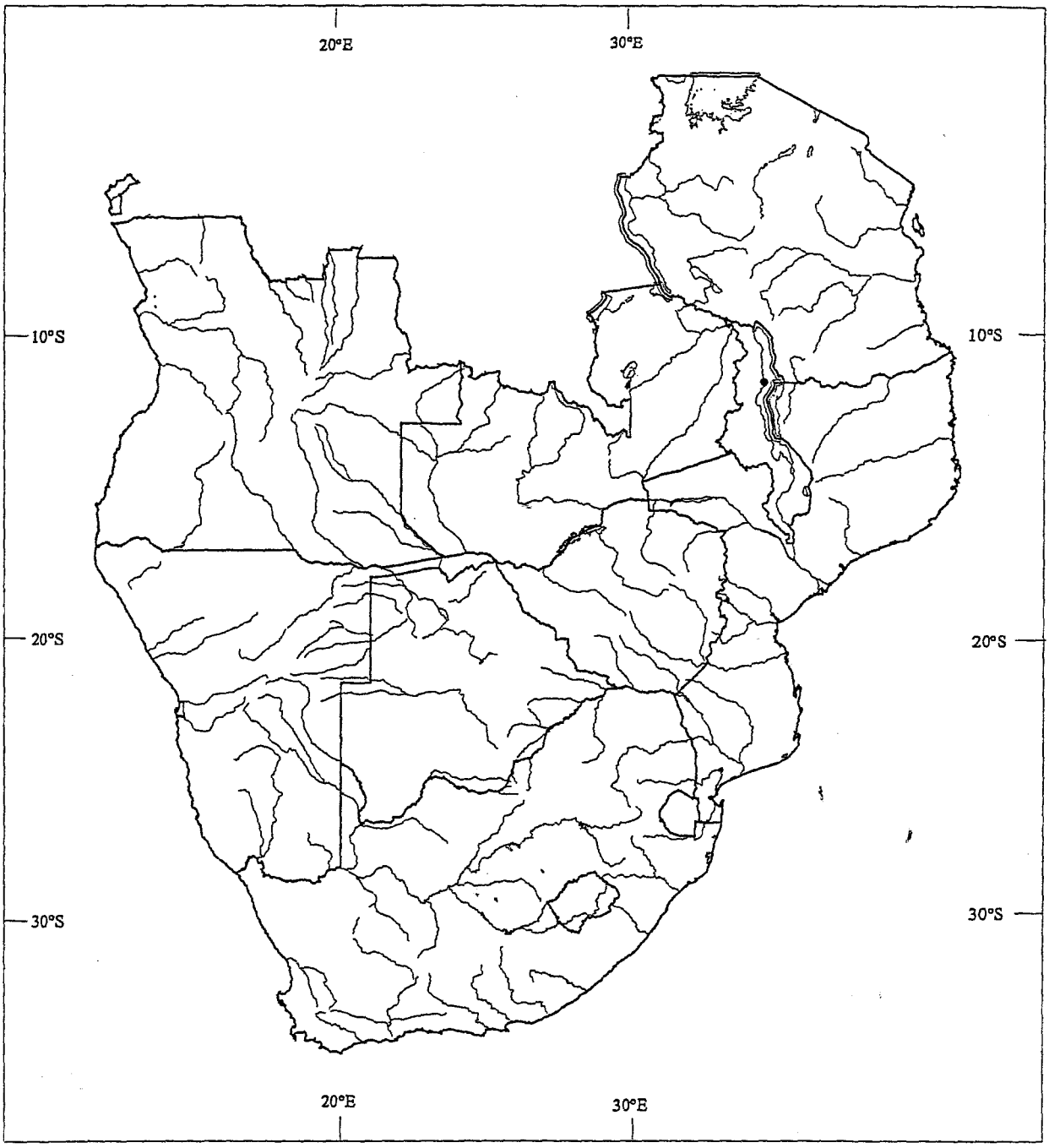


Figure F.301. Point distribution of *Haplochromis moorii*. Scale approximately 1:25 000 000

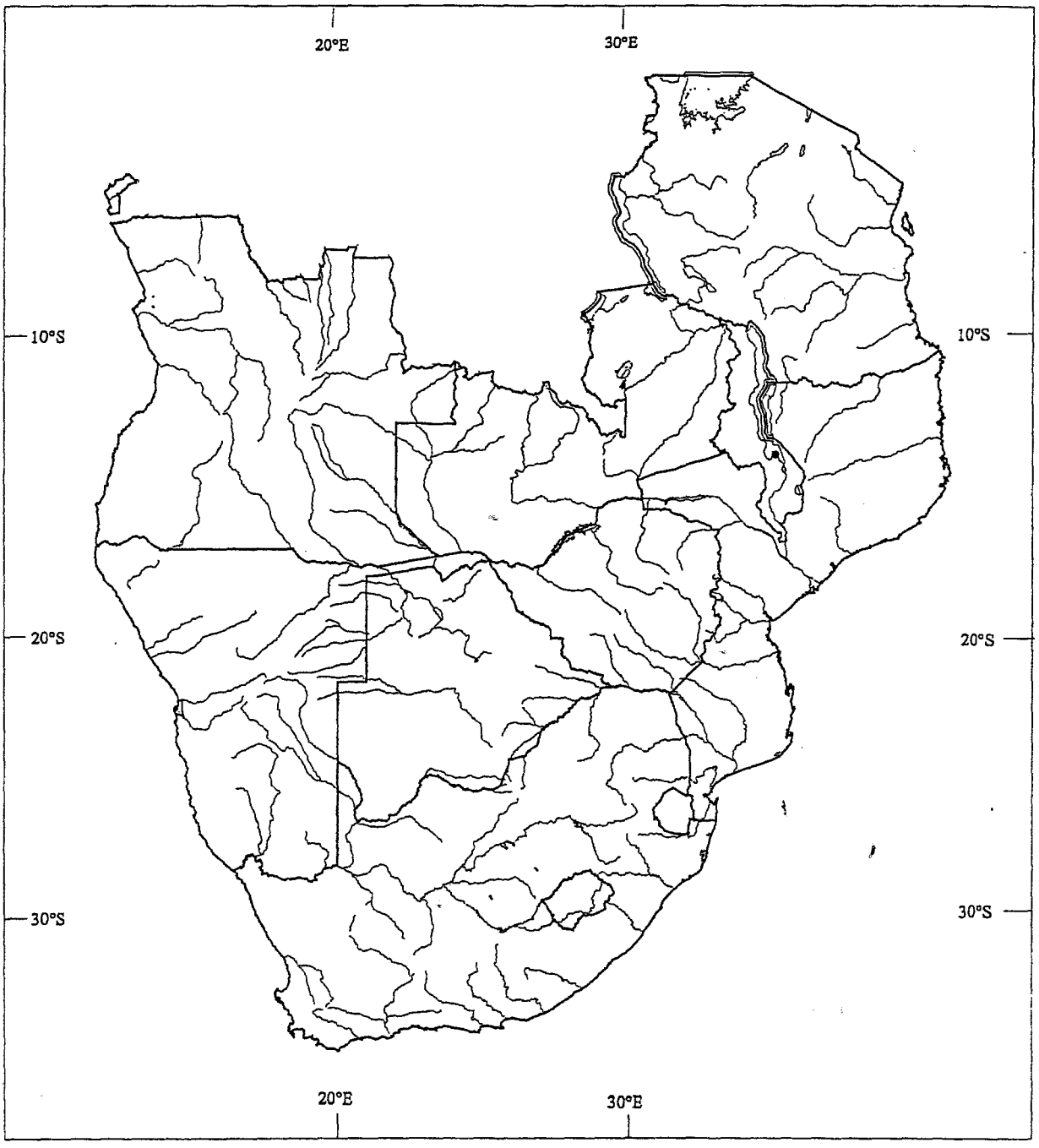


Figure F.302. Point distribution of *Haplochromis nototaenia*. Scale approximately 1:25 000 000

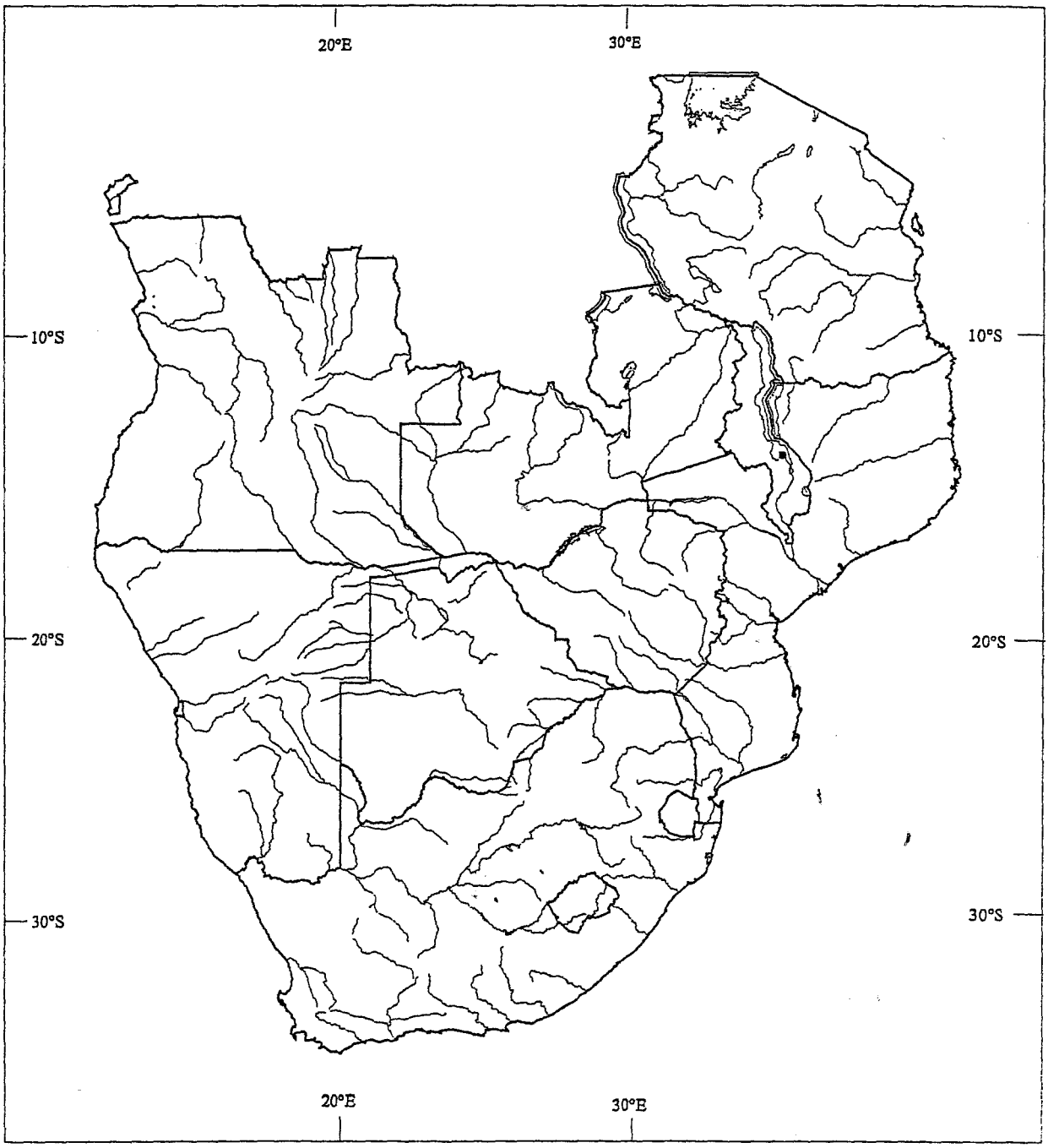


Figure F.303. Point distribution of *Haplochromis prodromus*. Scale approximately 1:25 000 000

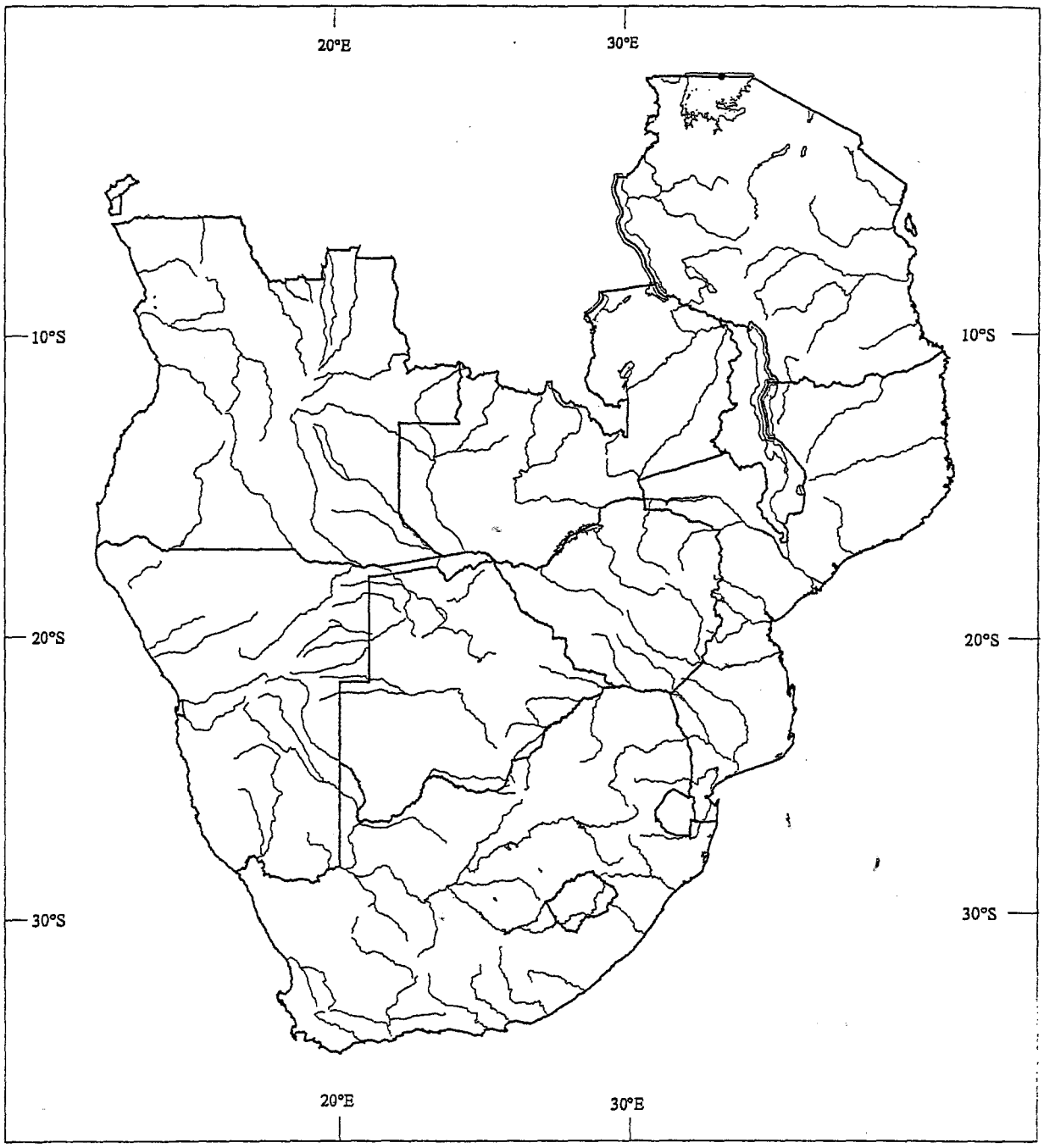


Figure F.304. Point distribution of *Haplochromis riponiarus*. Scale approximately 1:25 000 000

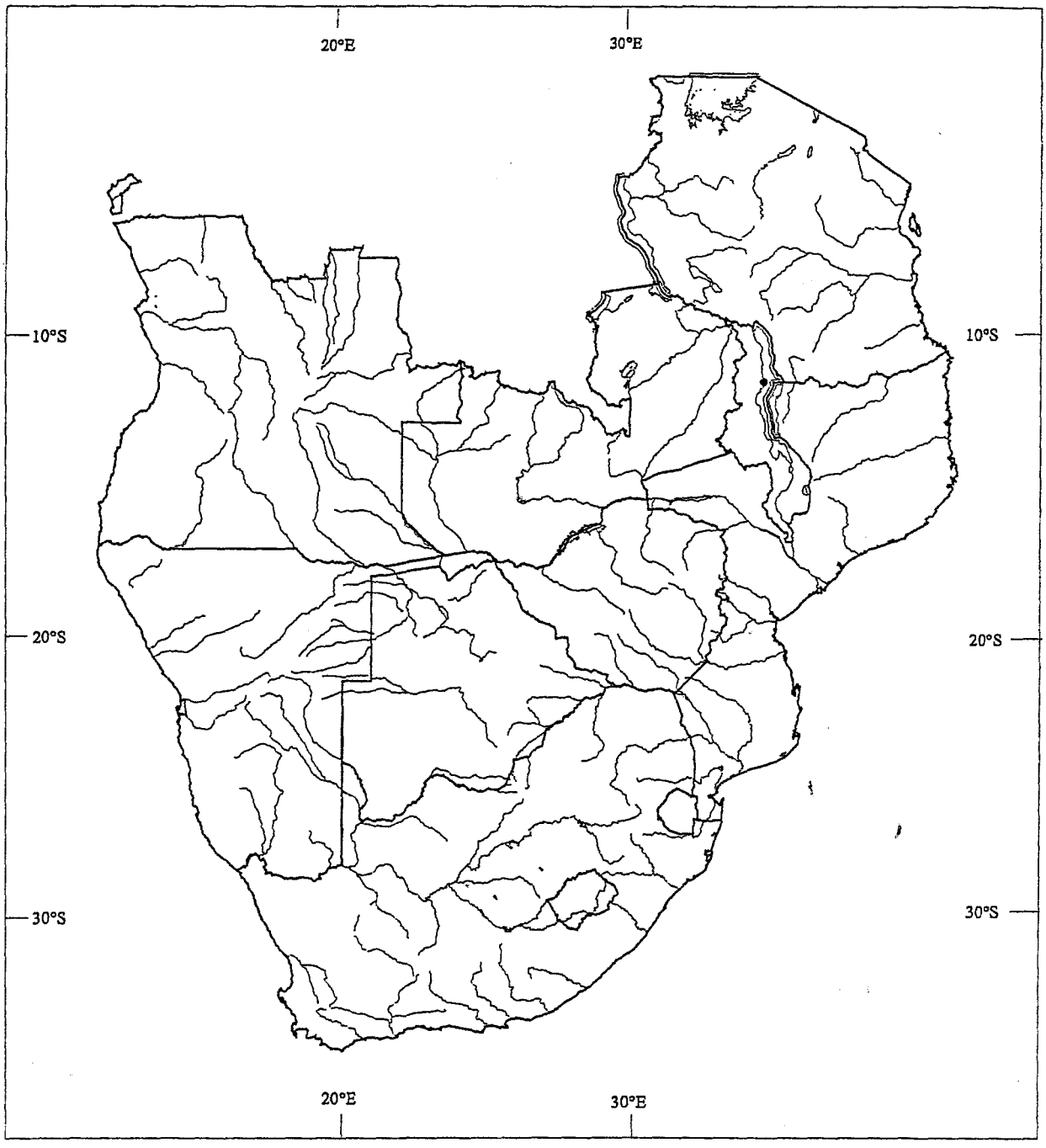


Figure F.305. Point distribution of *Haplochromis rostratus*. Scale approximately 1:25 000 000

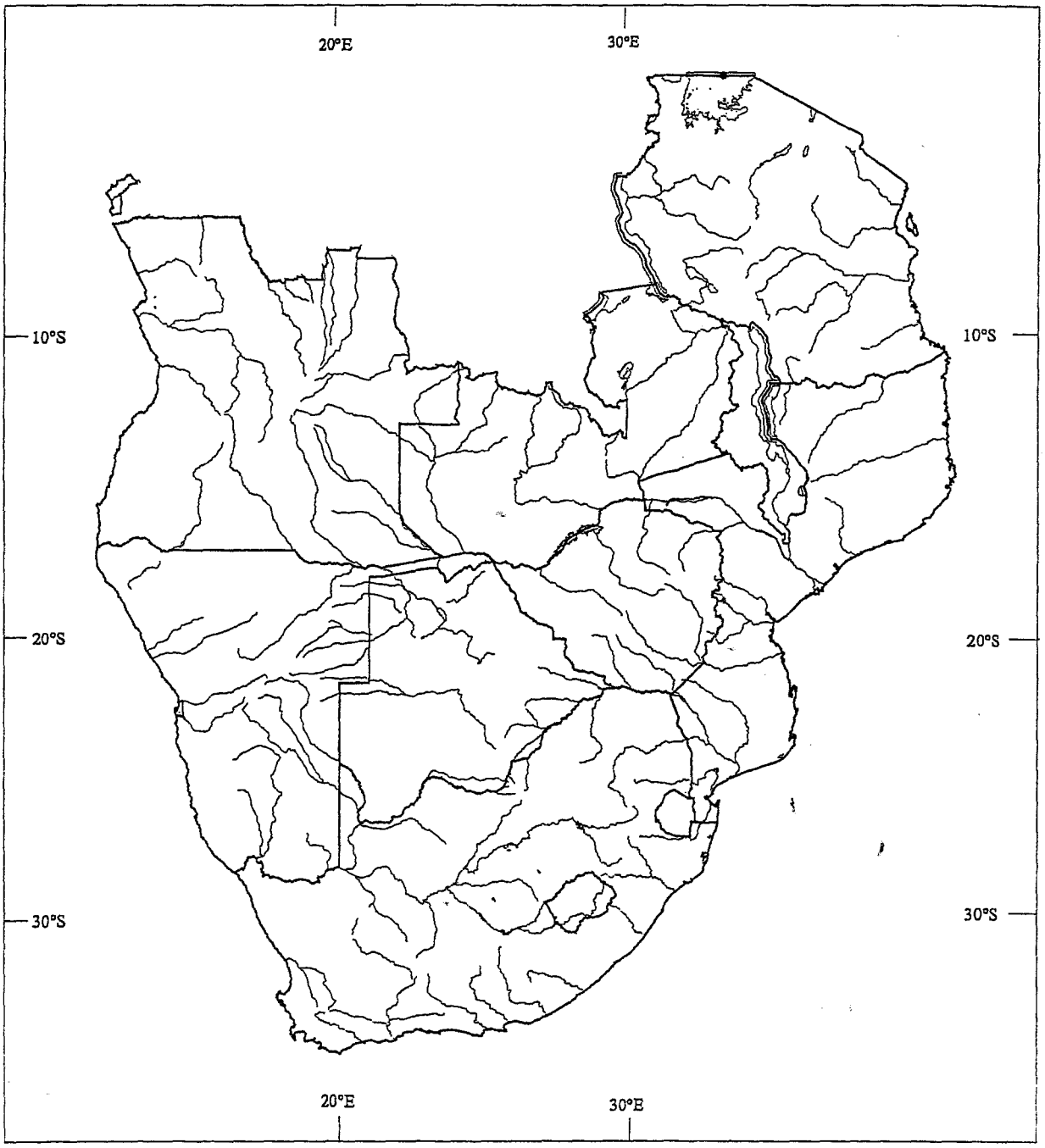


Figure F.306. Point distribution of *Haplochromis sauvagei*. Scale approximately 1:25 000 000

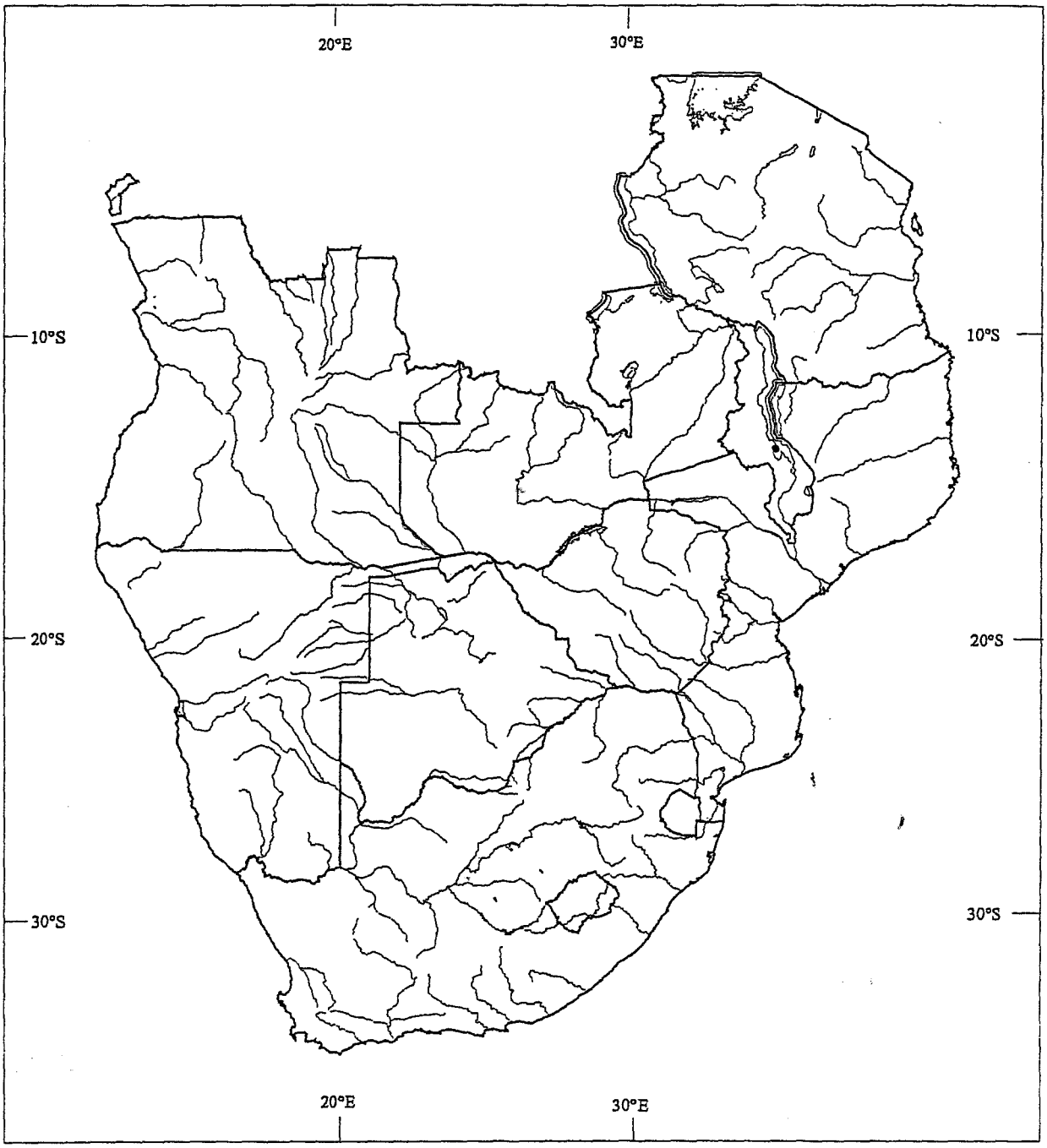


Figure F.307. Point distribution of *Haplochromis selenurus*. Scale approximately 1:25 000 000

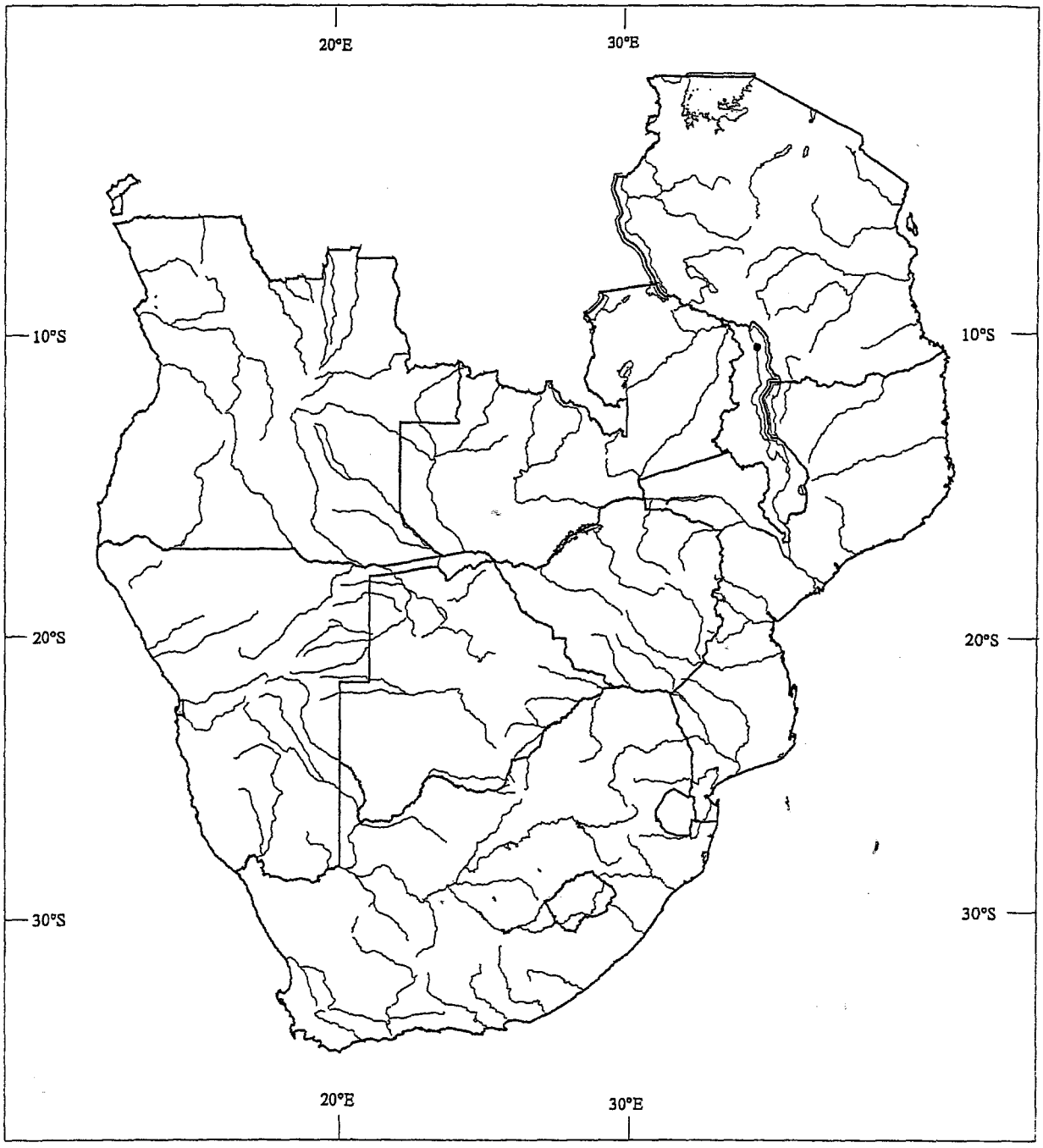


Figure F.308. Point distribution of *Haplochromis triaenodon*. Scale approximately 1:25 000 000

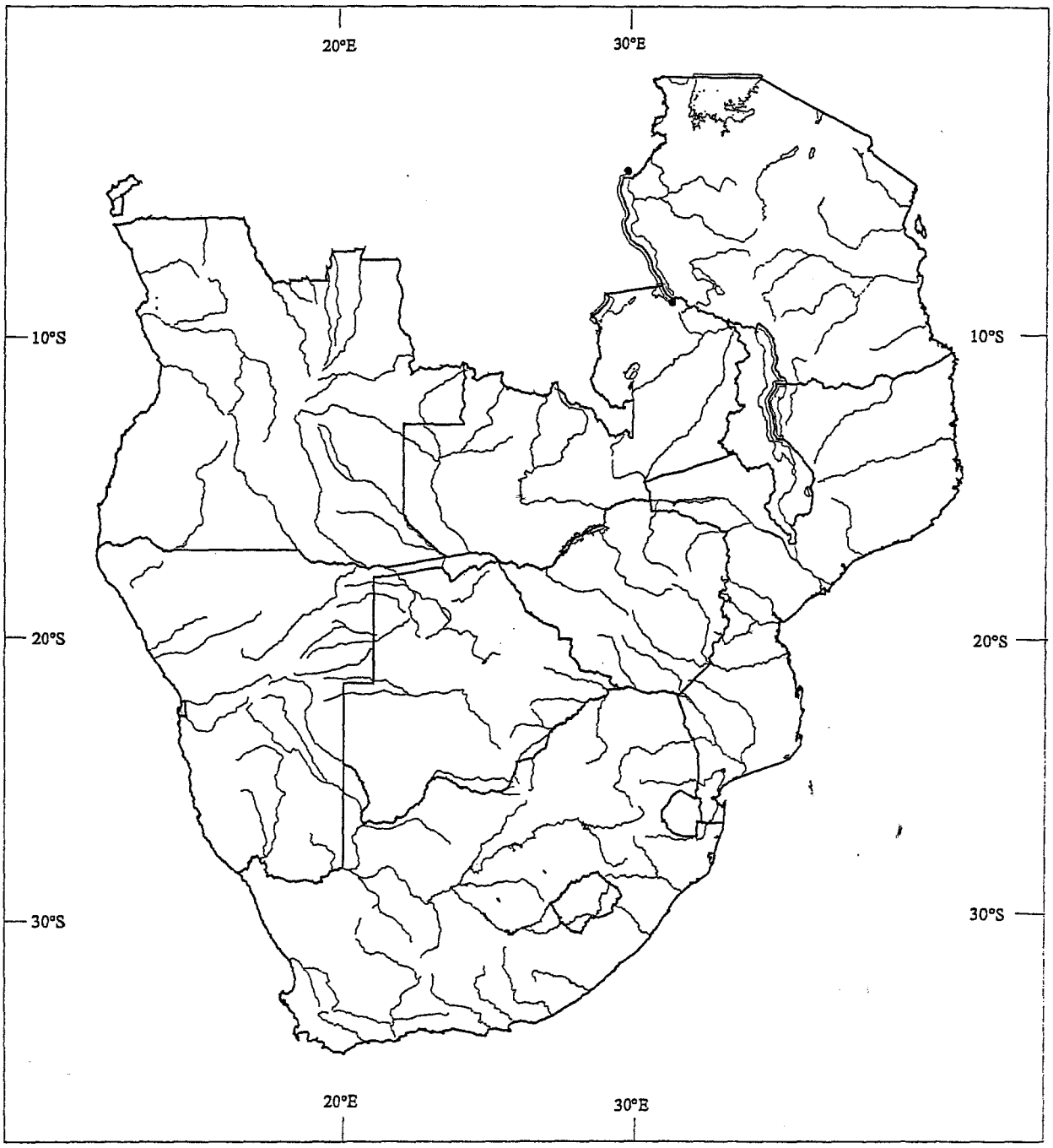


Figure F.309. Point distribution of *Haplotaxodon microlepis*. Scale approximately 1:25 000 000

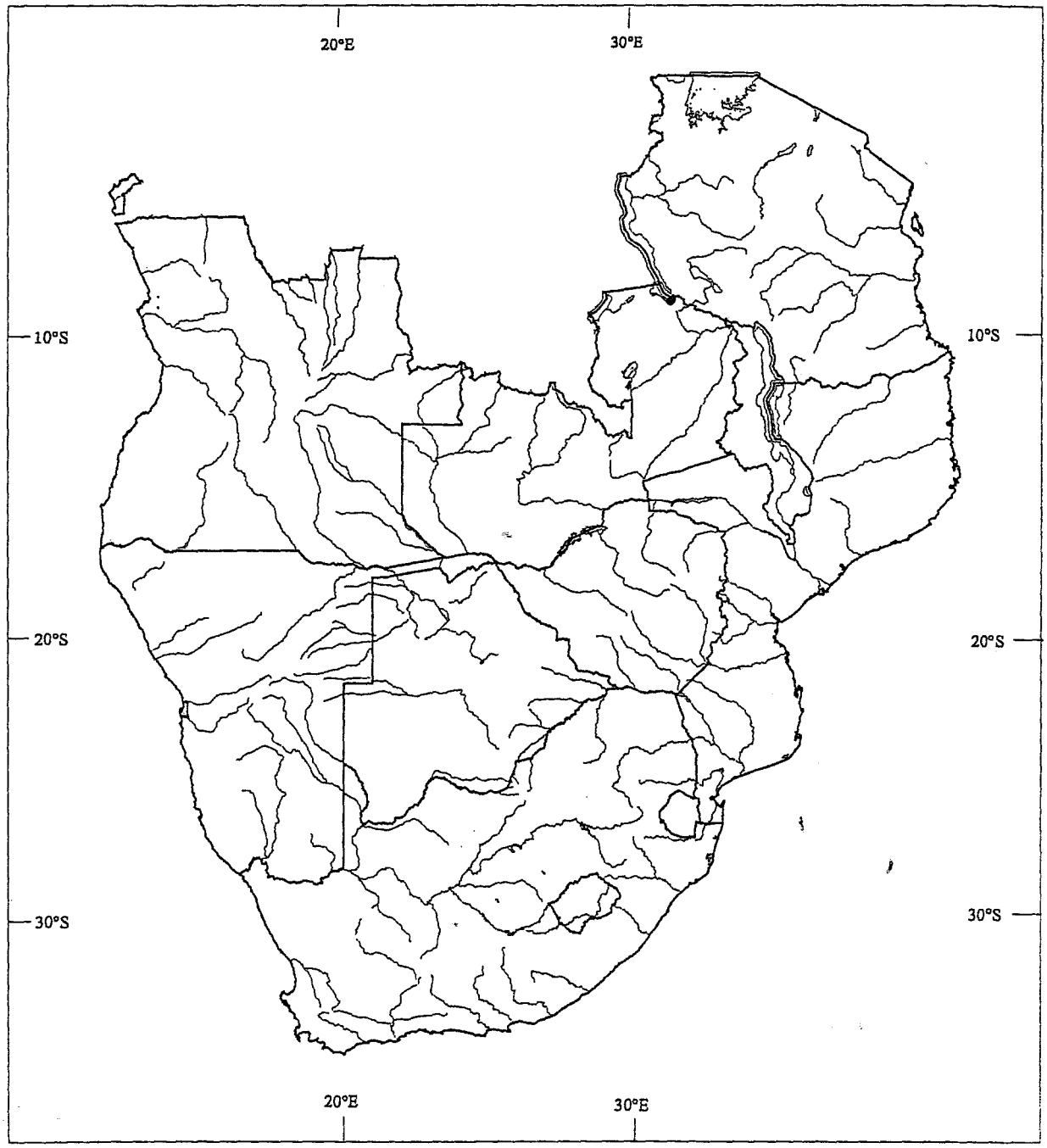


Figure F.310. Point distribution of *Hemibates stenosoma*. Scale approximately 1:25 000 000

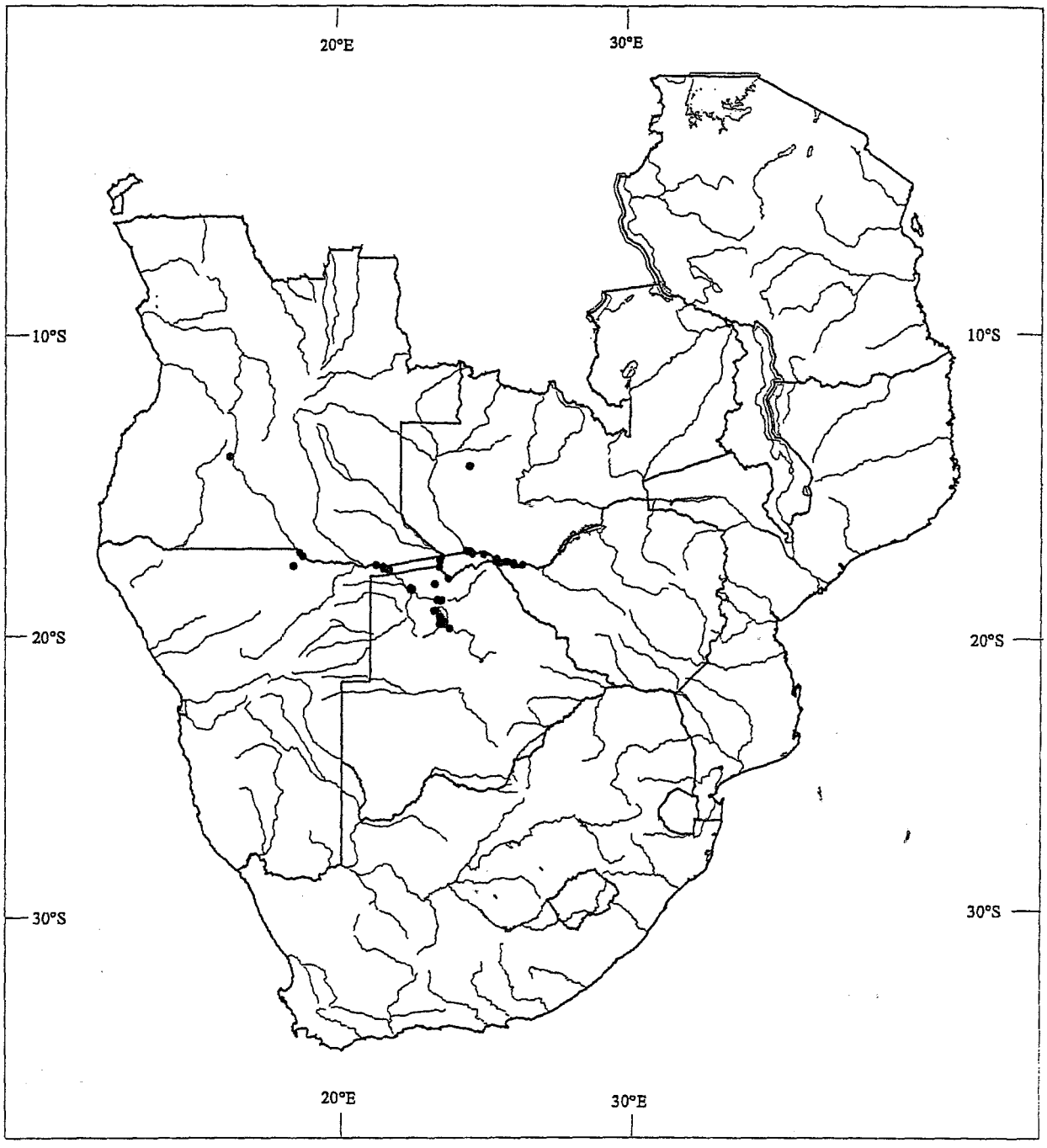


Figure F.311. Point distribution of *Hemichromis elongatus*. Scale approximately 1:25 000 000

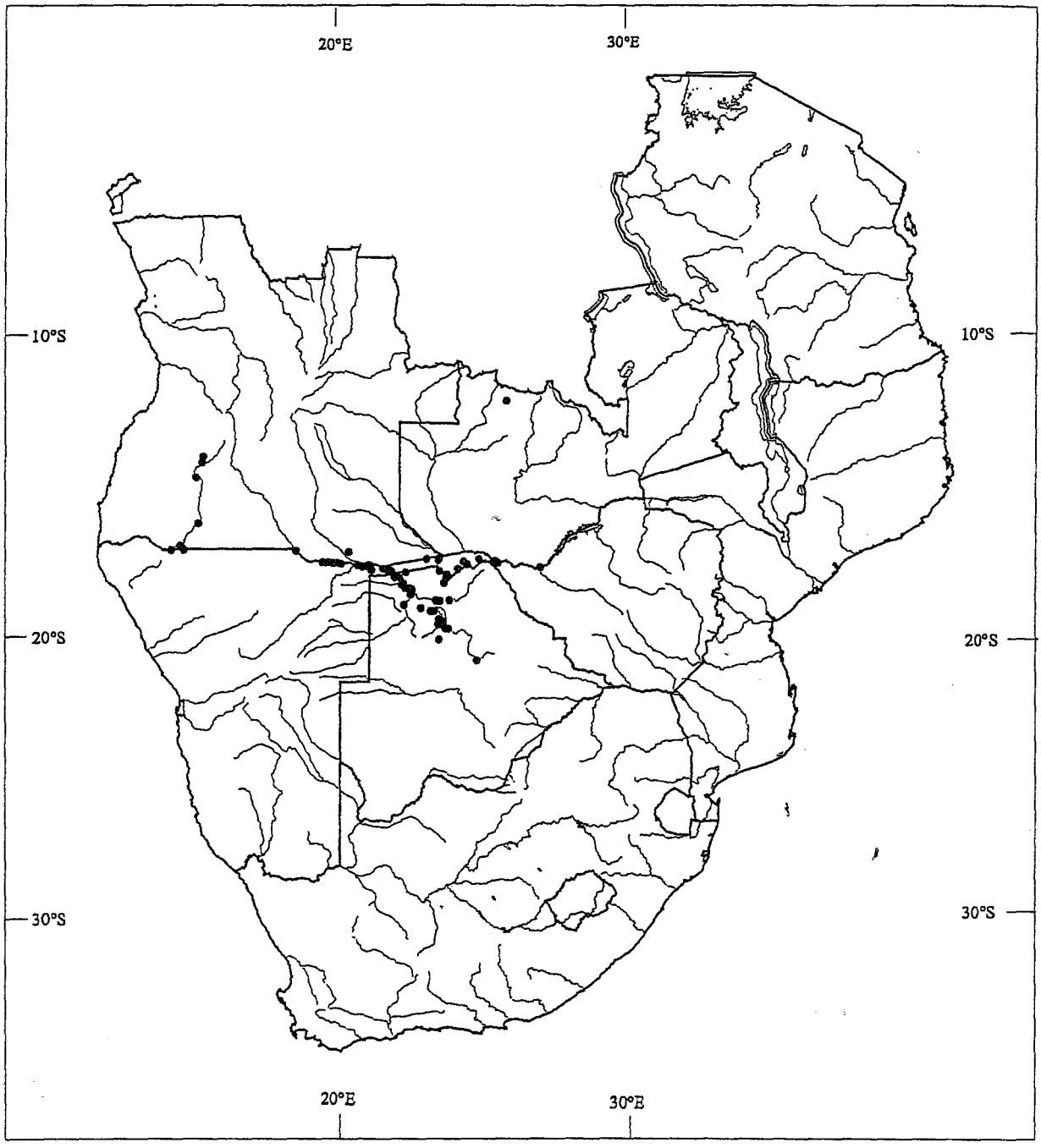


Figure F.312. Point distribution of *Hemigrammocharax machadoi*. Scale approximately 1:25 000 000

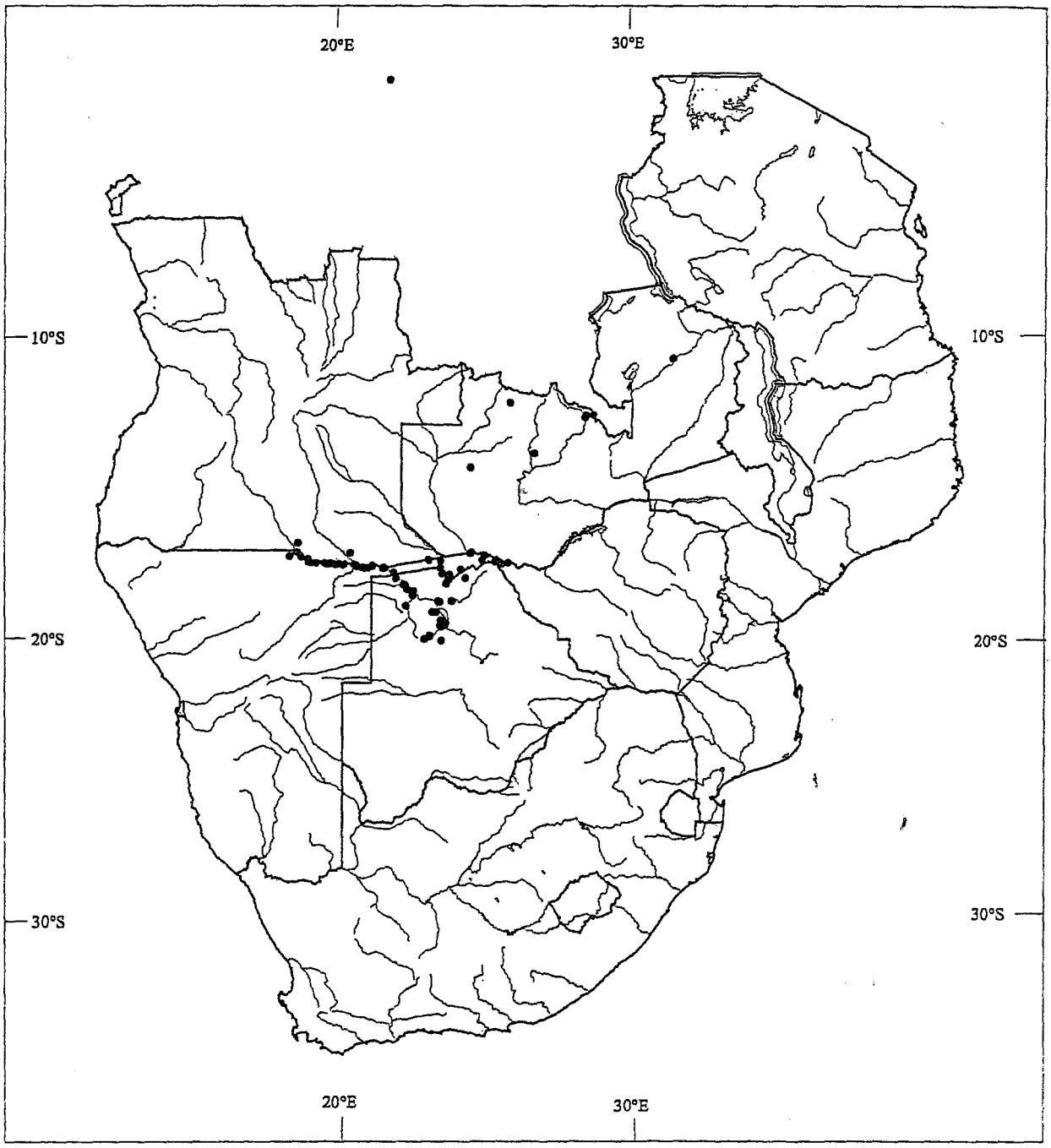


Figure F.313. Point distribution of *Hemigrammocharax multifasciatus*. Scale approximately 1:25 000 000

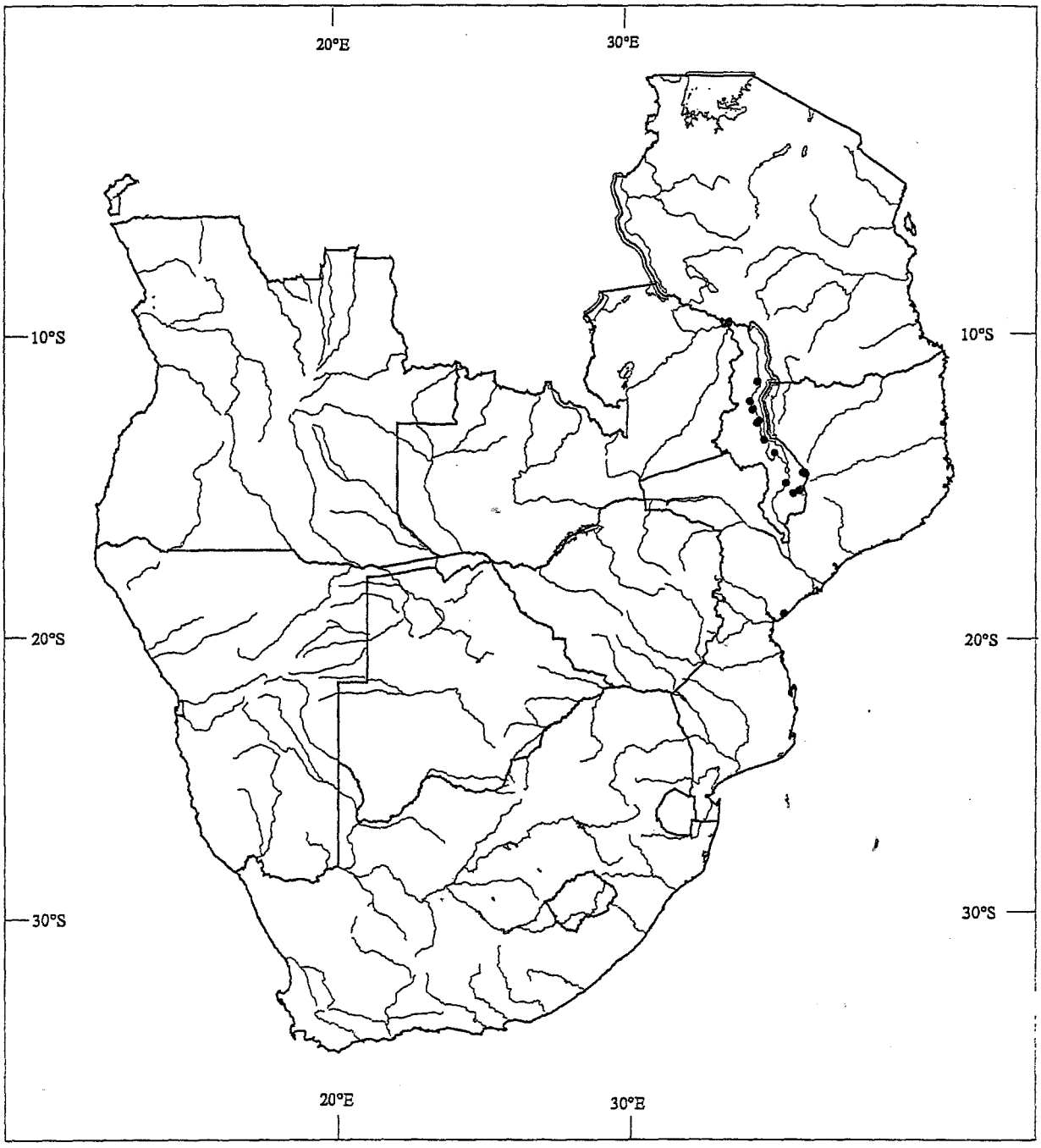


Figure F.314. Point distribution of *Hemigrammopetersius barnardi*. Scale approximately 1:25 000 000

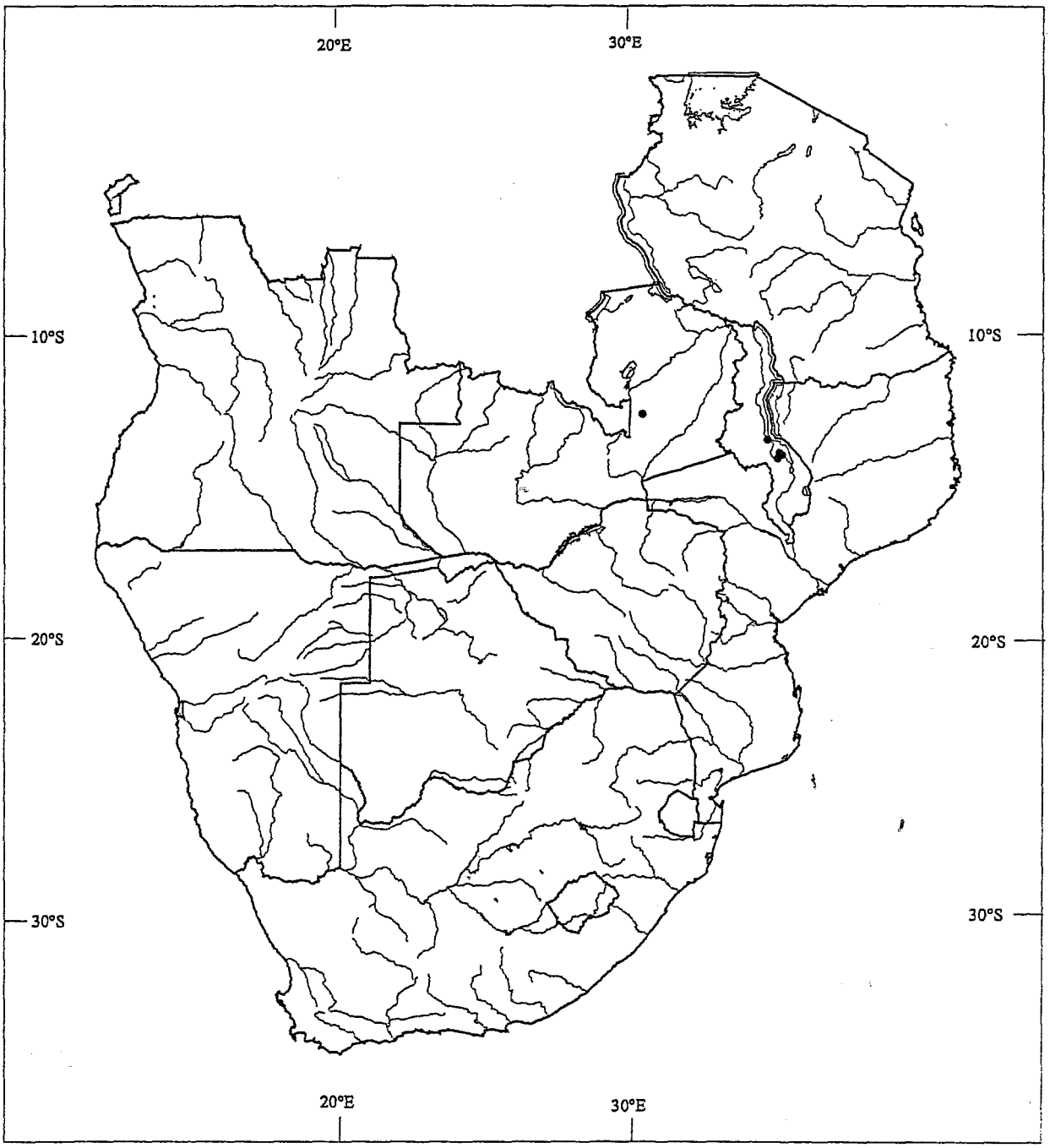


Figure F.315. Point distribution of *Hemitaeniochromis urotaenia*. Scale approximately 1:25 000 000

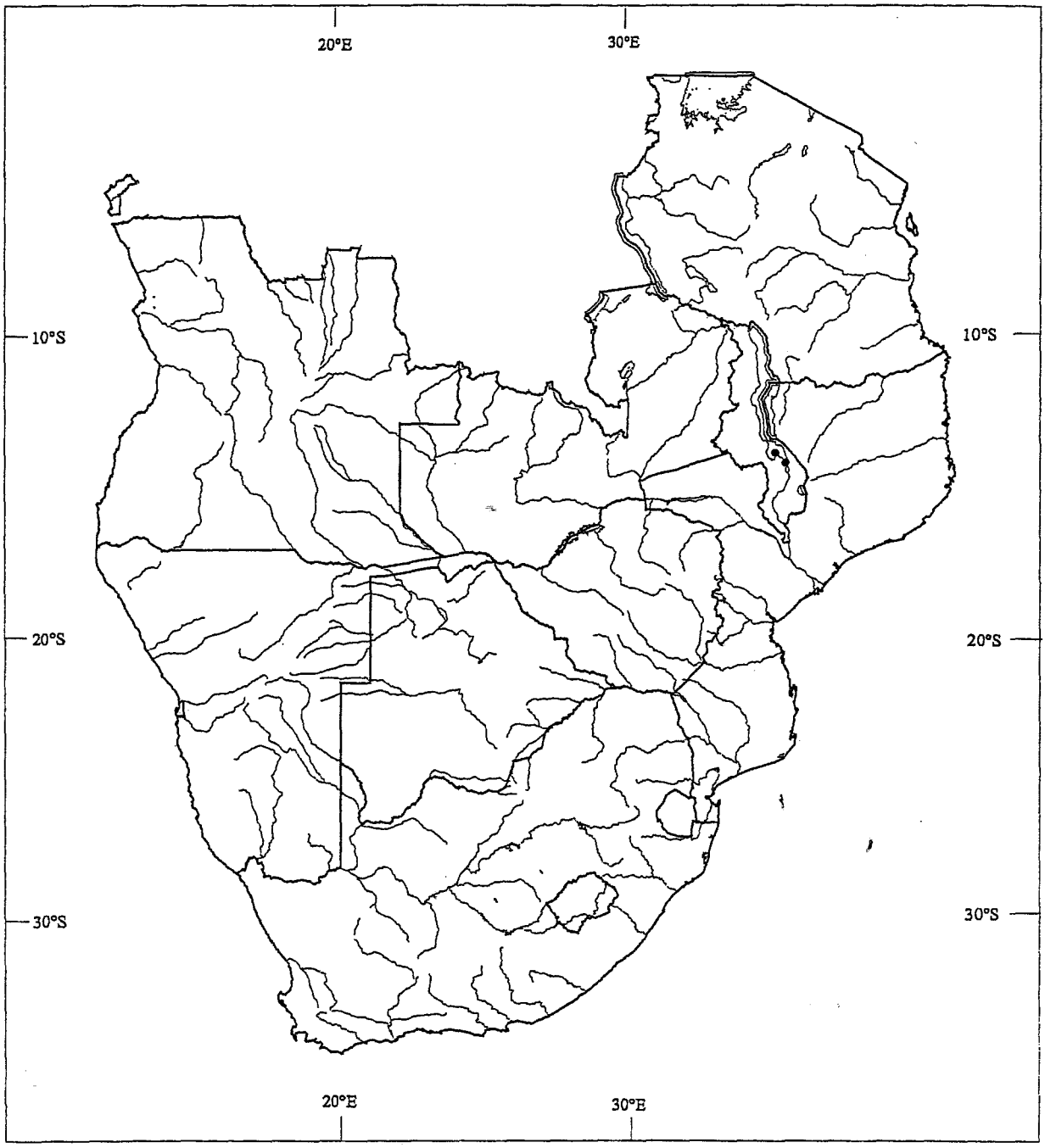


Figure F.316. Point distribution of *Hemitilapia oxyrhyncha*. Scale approximately 1:25 000 000

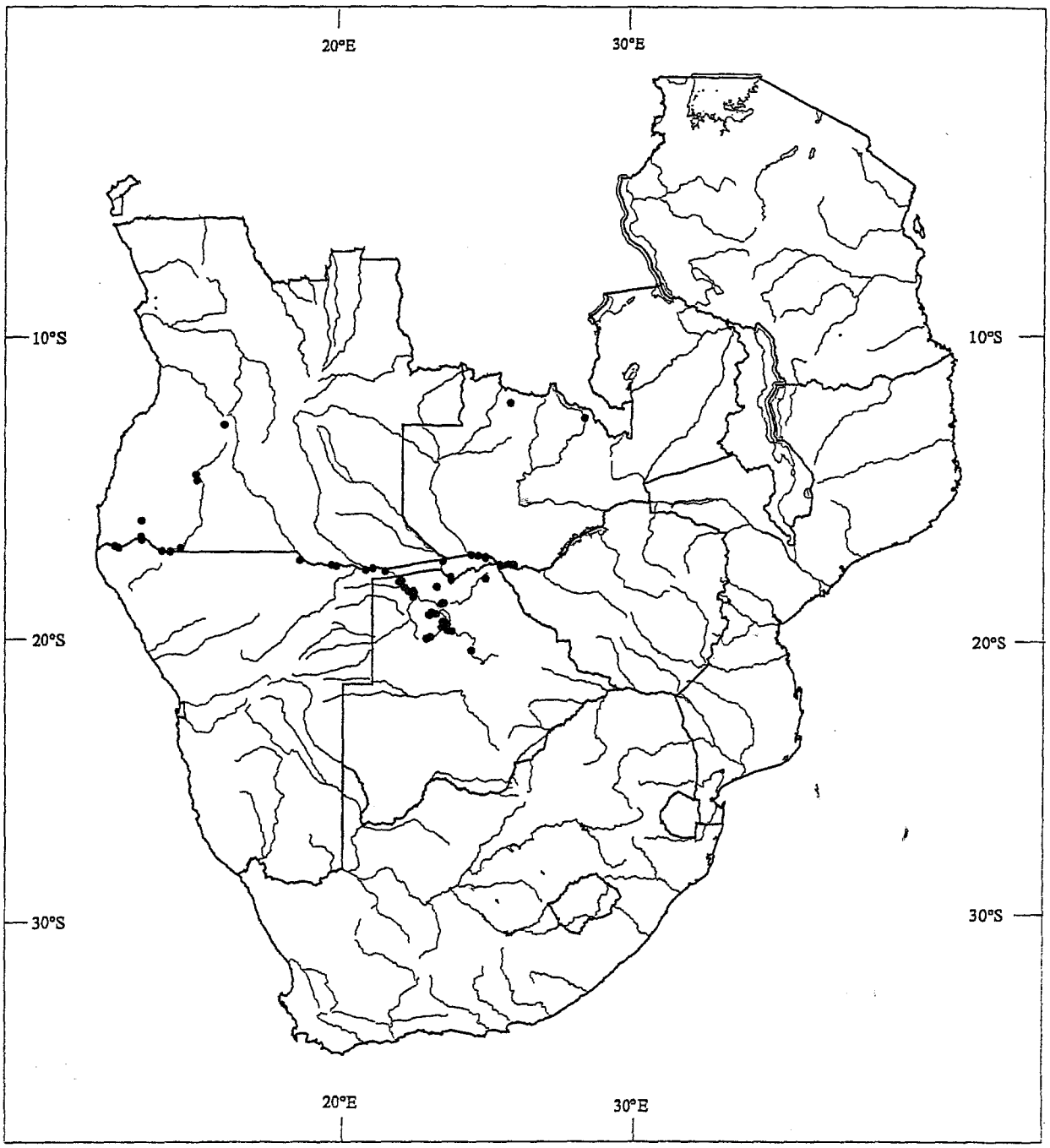


Figure F.317. Point distribution of *Hepsetus odoe*. Scale approximately 1:25 000 000

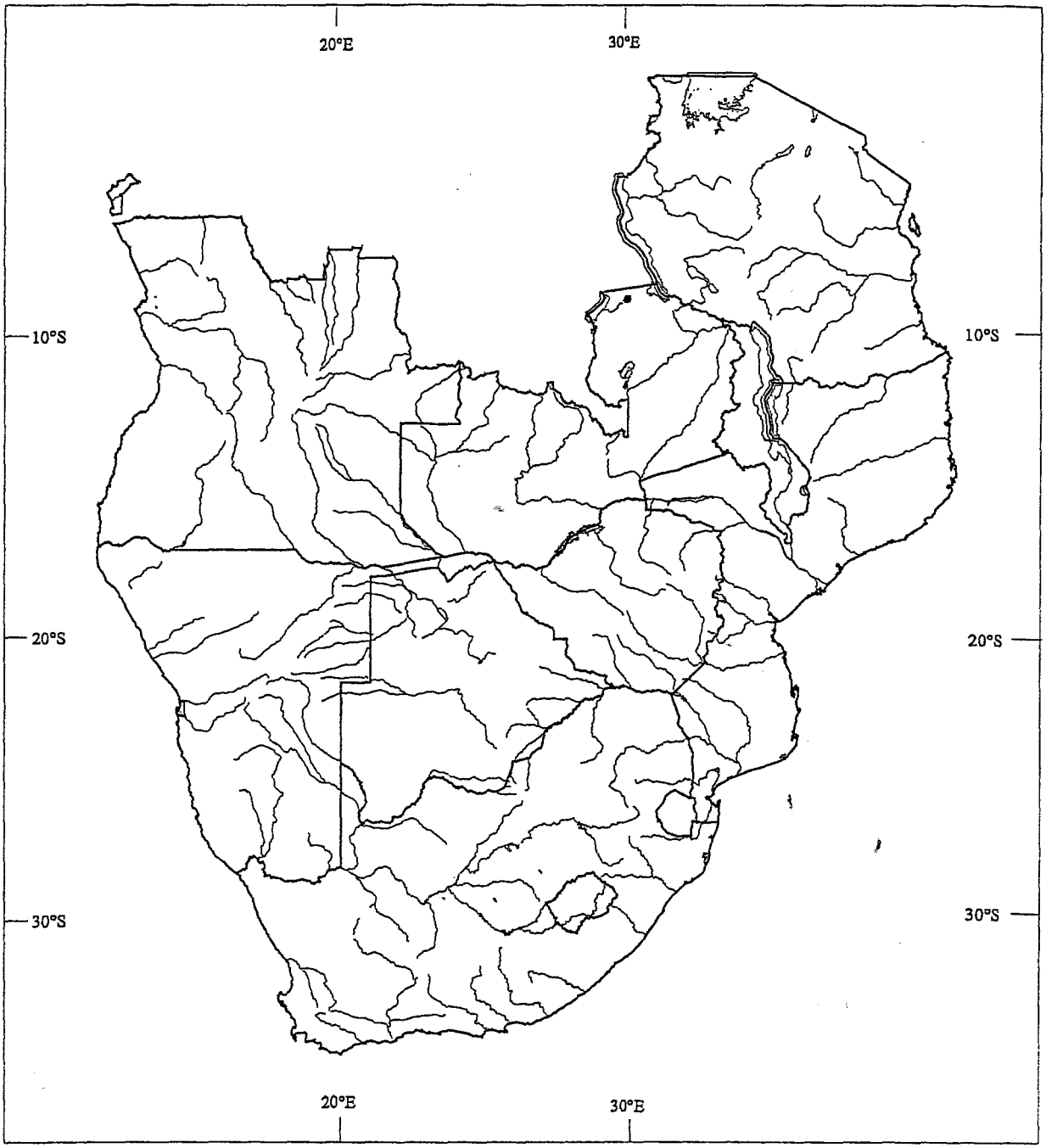


Figure F.318. Point distribution of *Heterobranchus boulengeri*. Scale approximately 1:25 000 000

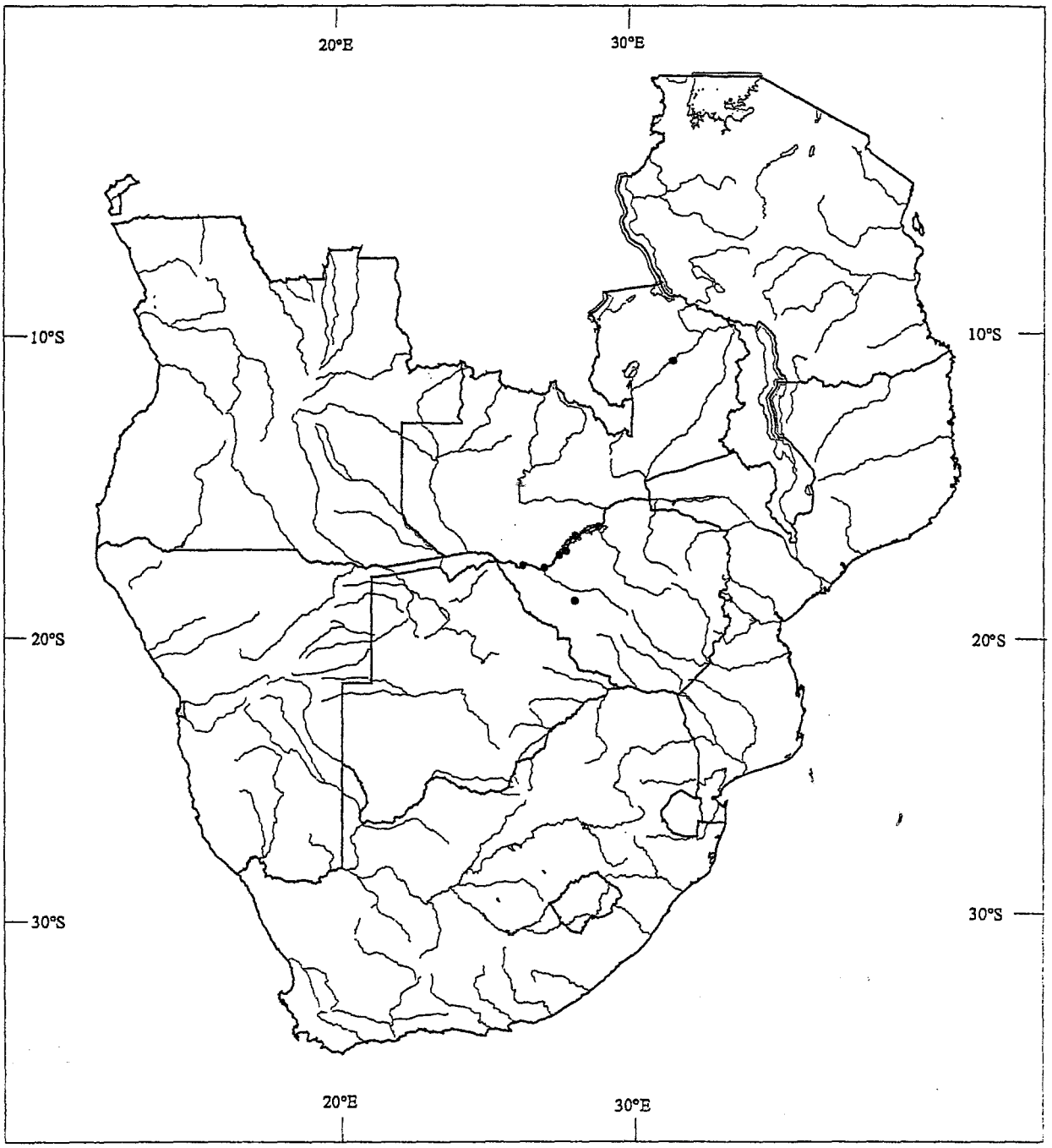


Figure F.319. Point distribution of *Heterobranchus longifilis*. Scale approximately 1:25 000 000

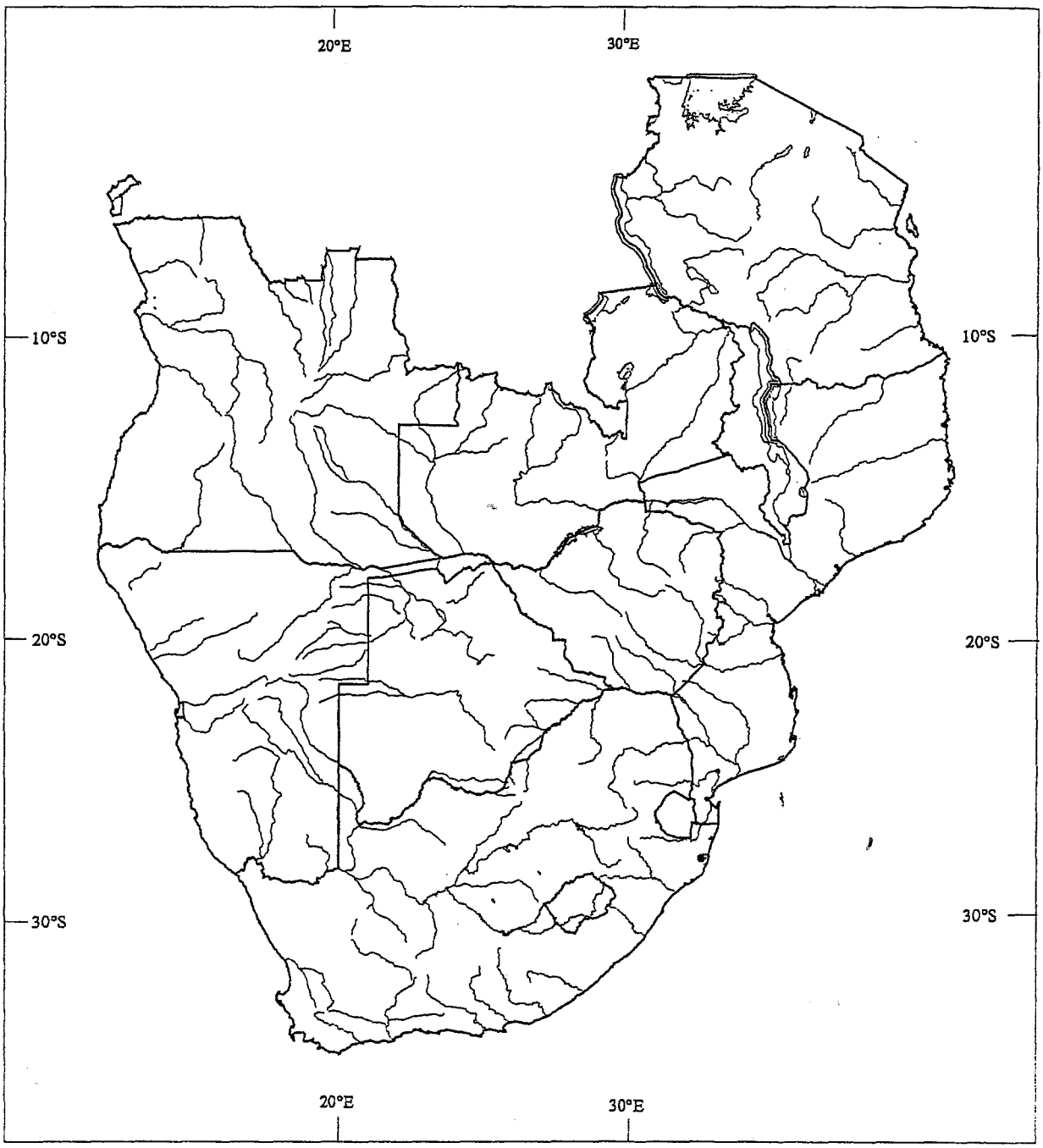


Figure F.320. Point distribution of *Hippichthys heptagonus*. Scale approximately 1:25 000 000

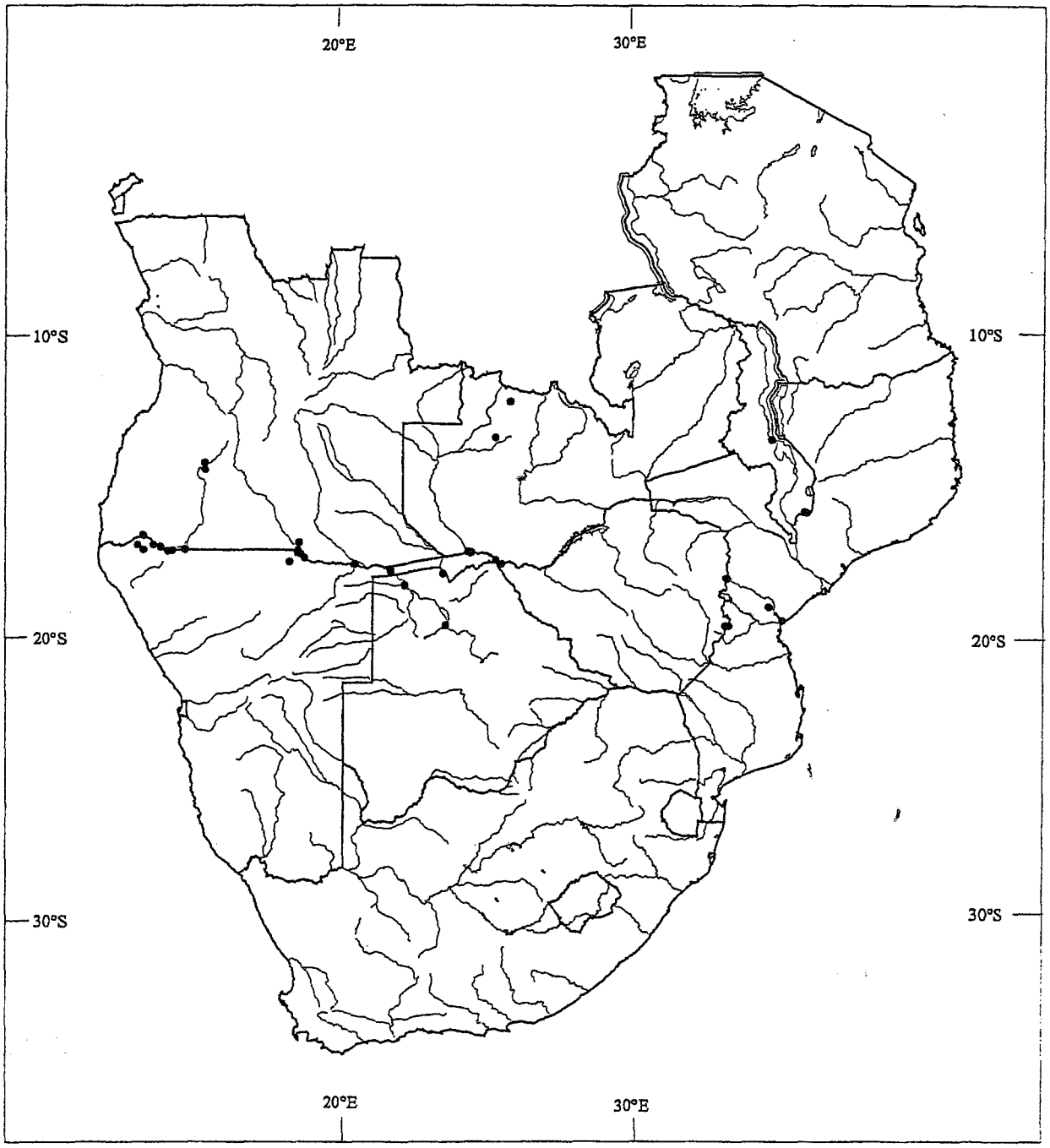


Figure F.321. Point distribution of *Hippopotamyrus ansorgii*. Scale approximately 1:25 000 000

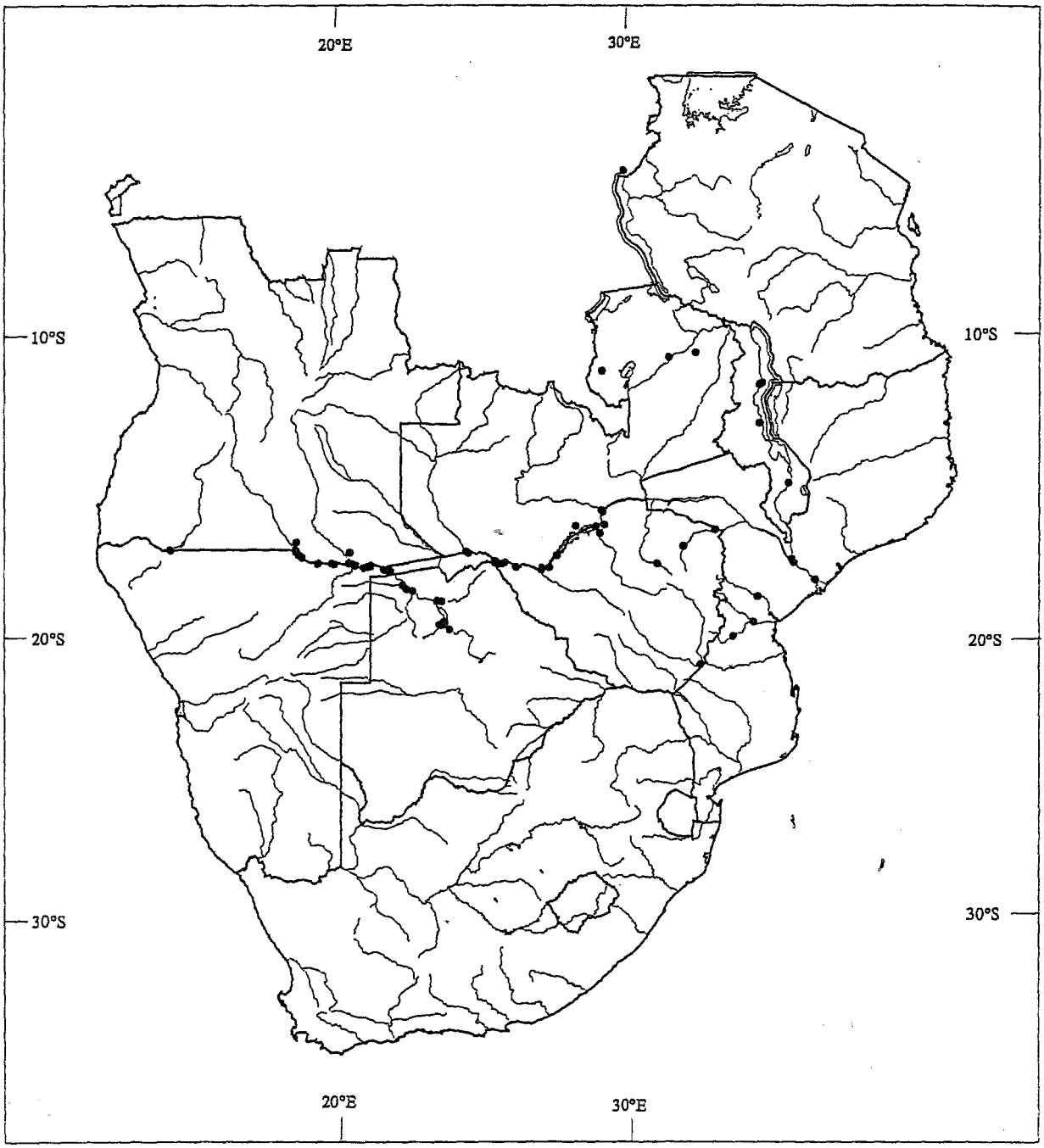


Figure F.322. Point distribution of *Hippopotamyrus discorhynchus*. Scale approximately 1:25 000 000

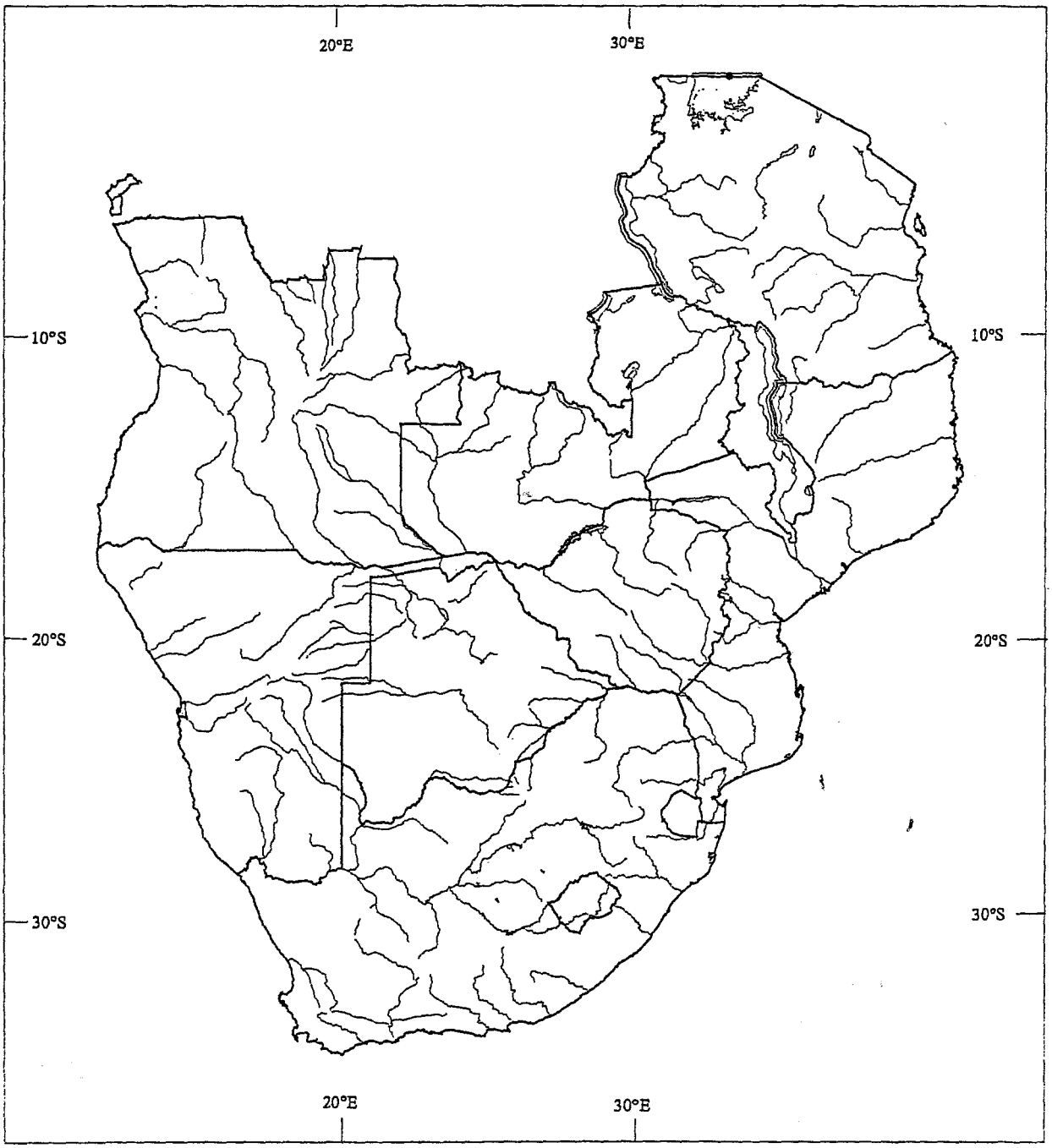


Figure F.323. Point distribution of *Hoplotilapia retrodens*. Scale approximately 1:25 000 000

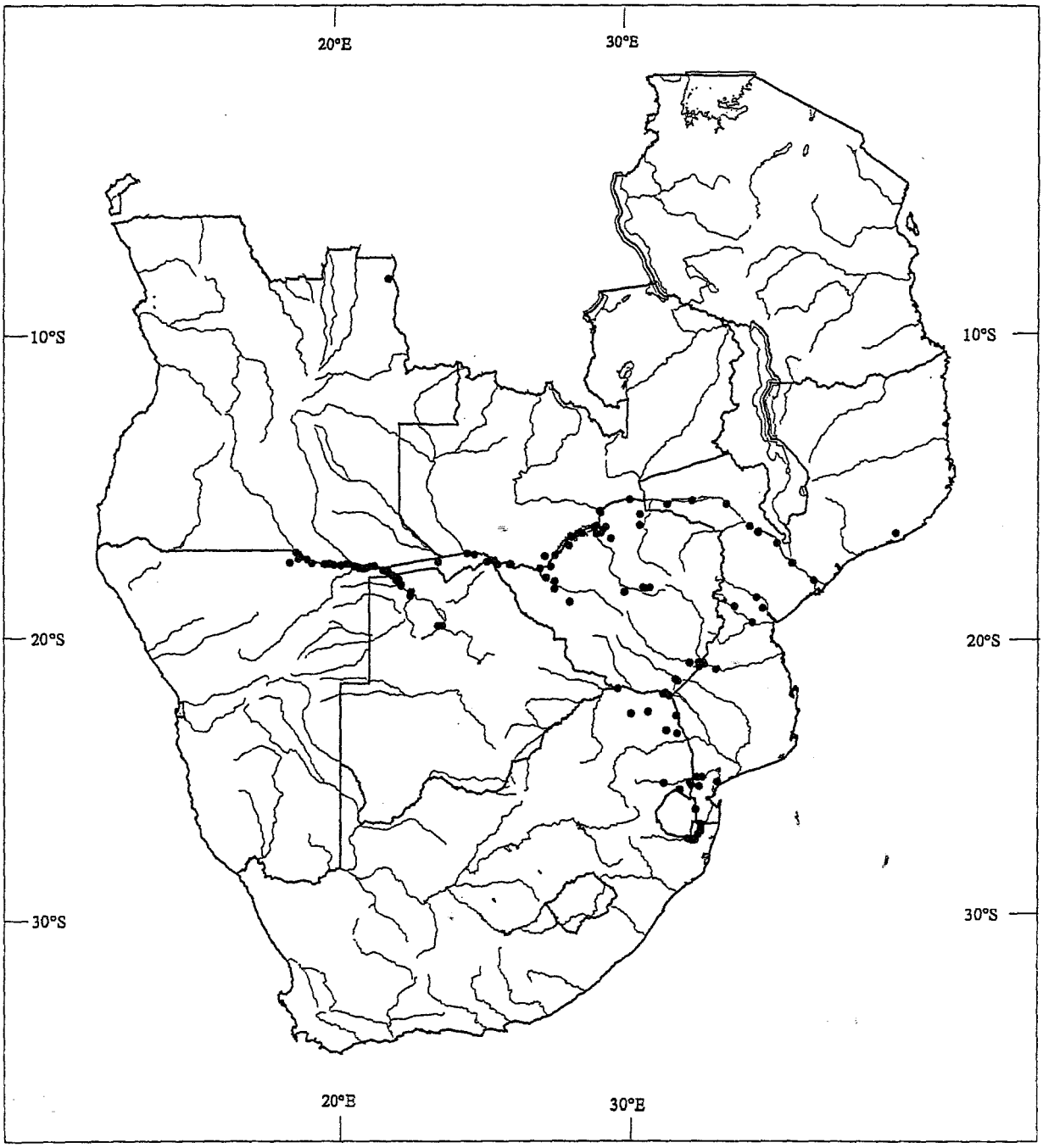


Figure F.324. Point distribution of *Hydrocynus vittatus*. Scale approximately 1:25 000 000

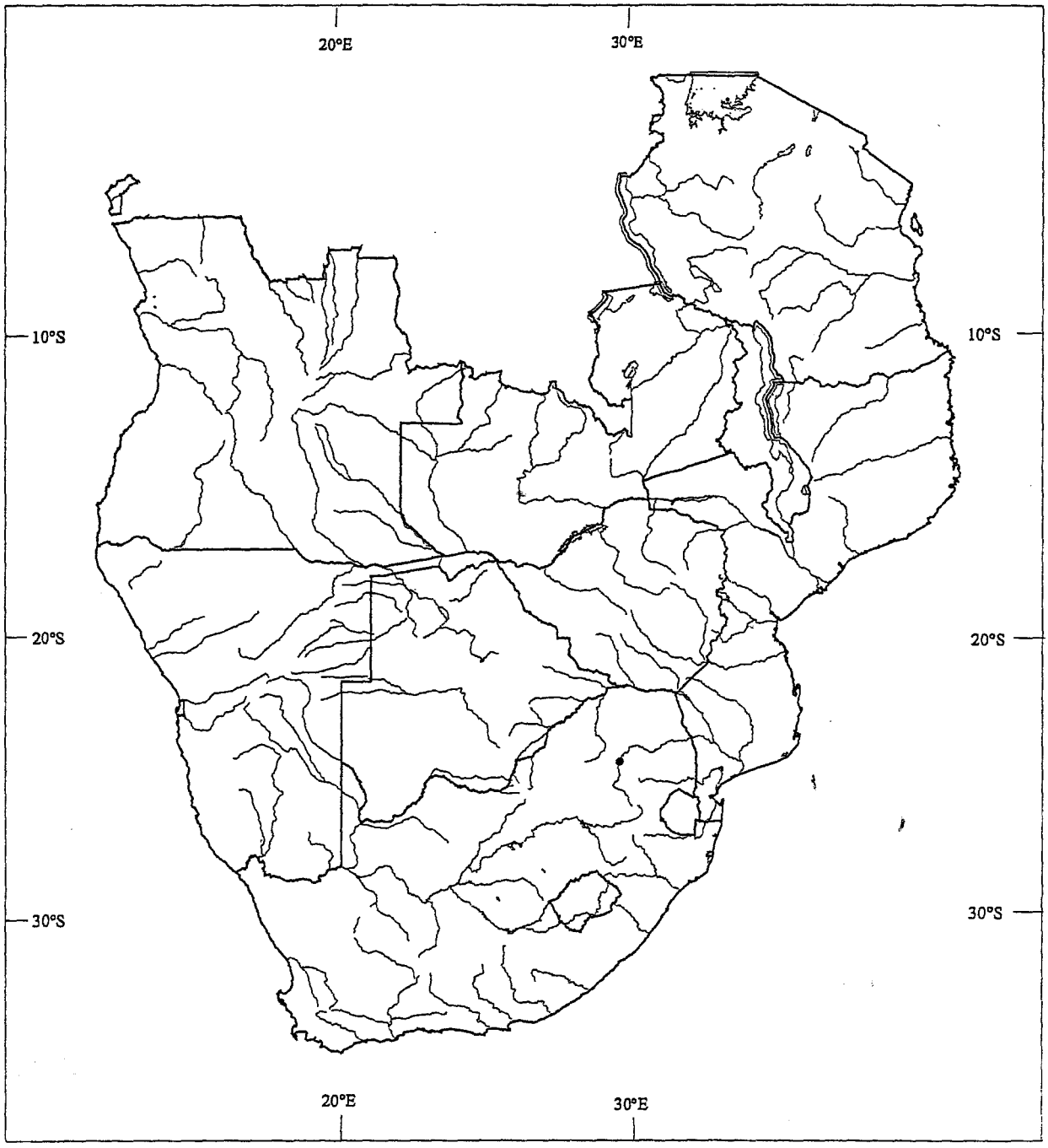


Figure F.325. Point distribution of *Hypophthalmichthys molitrix*. Scale approximately 1:25 000 000

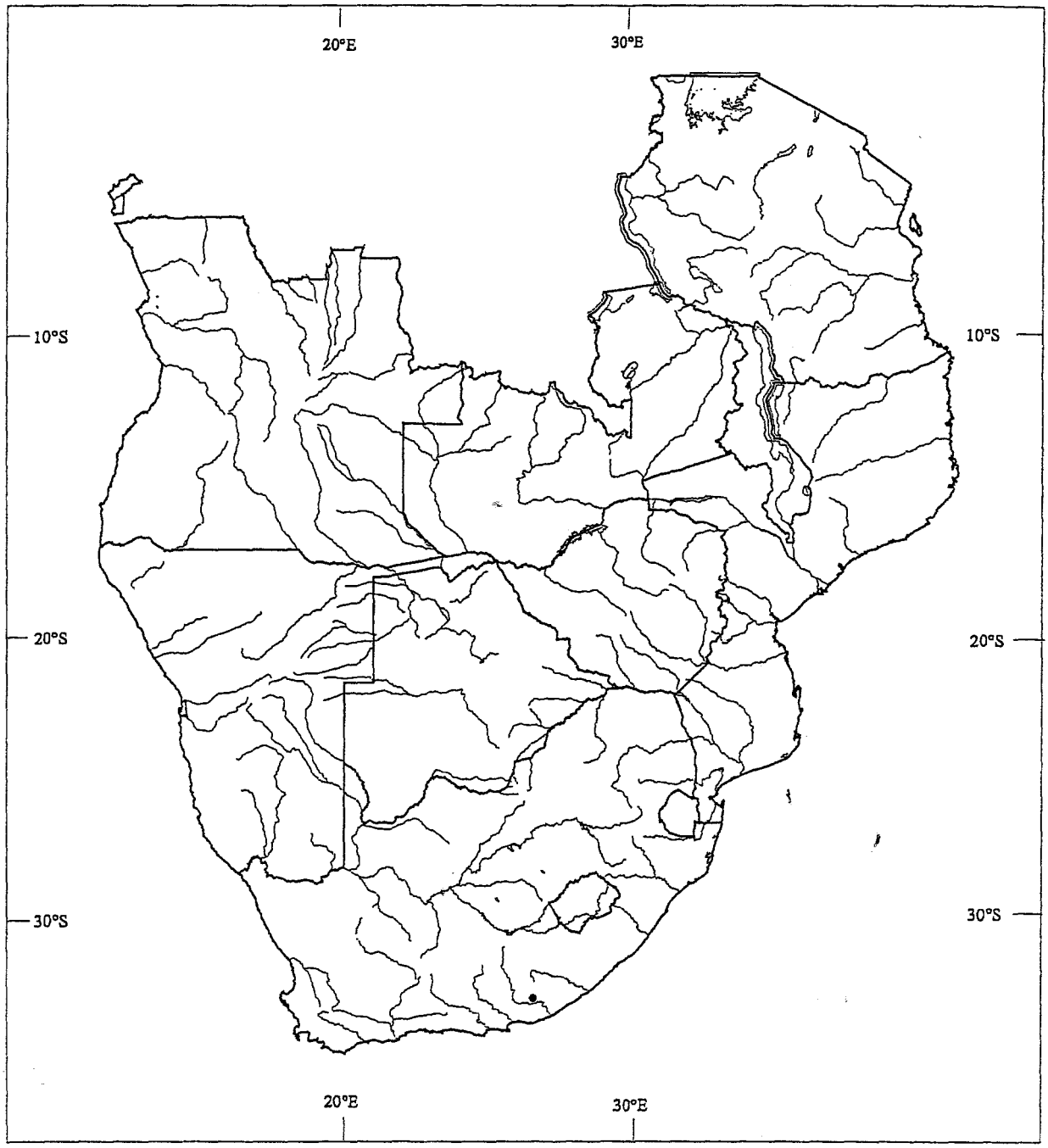


Figure F.326. Point distribution of *Hyporhamphus capensis*. Scale approximately 1:25 000 000

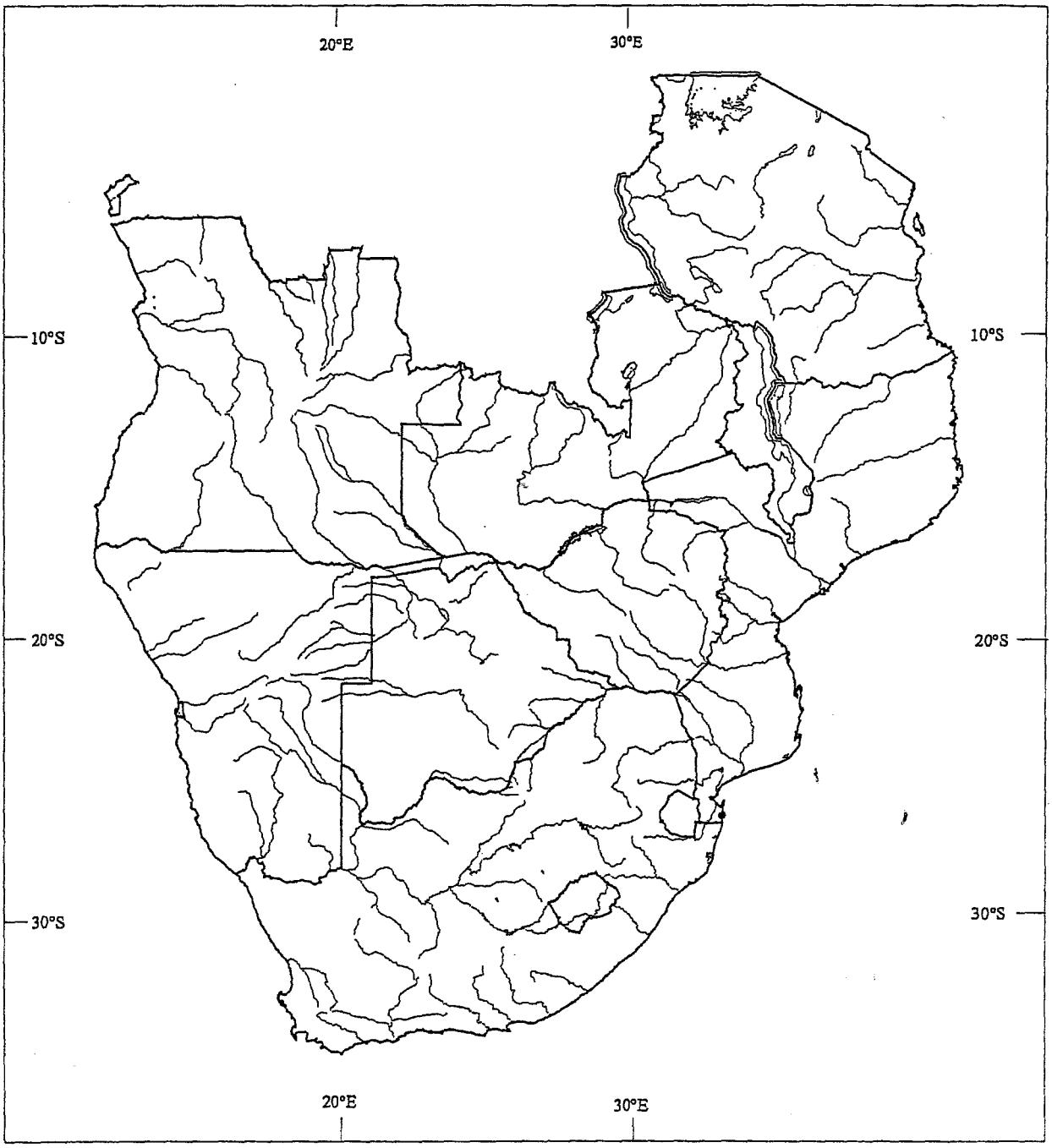


Figure F.327. Point distribution of *Hyporhamphus delagoae*. Scale approximately 1:25 000 000

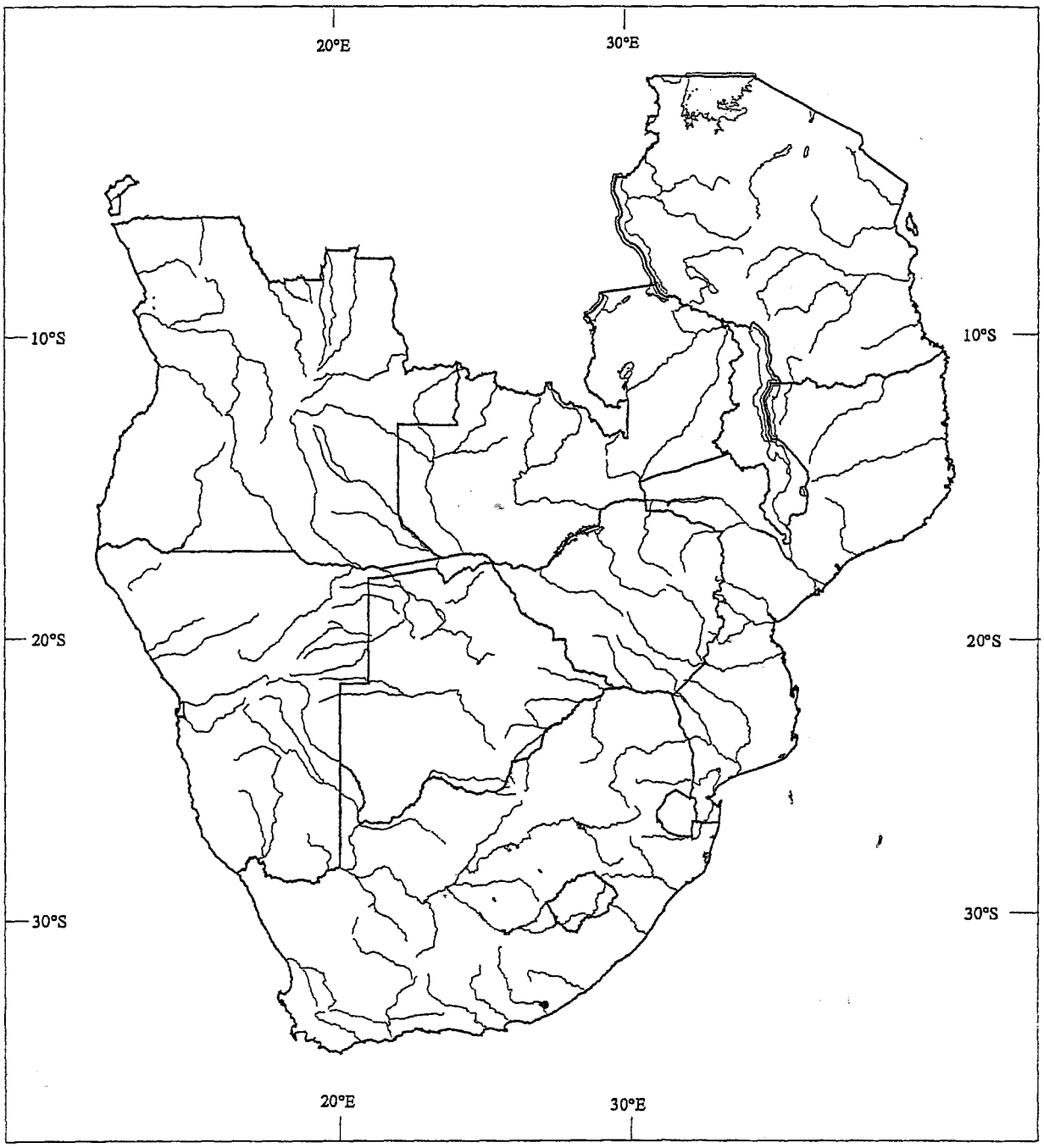


Figure F.328. Point distribution of *Hyporhamphus knysnaensis*. Scale approximately 1:25 000 000

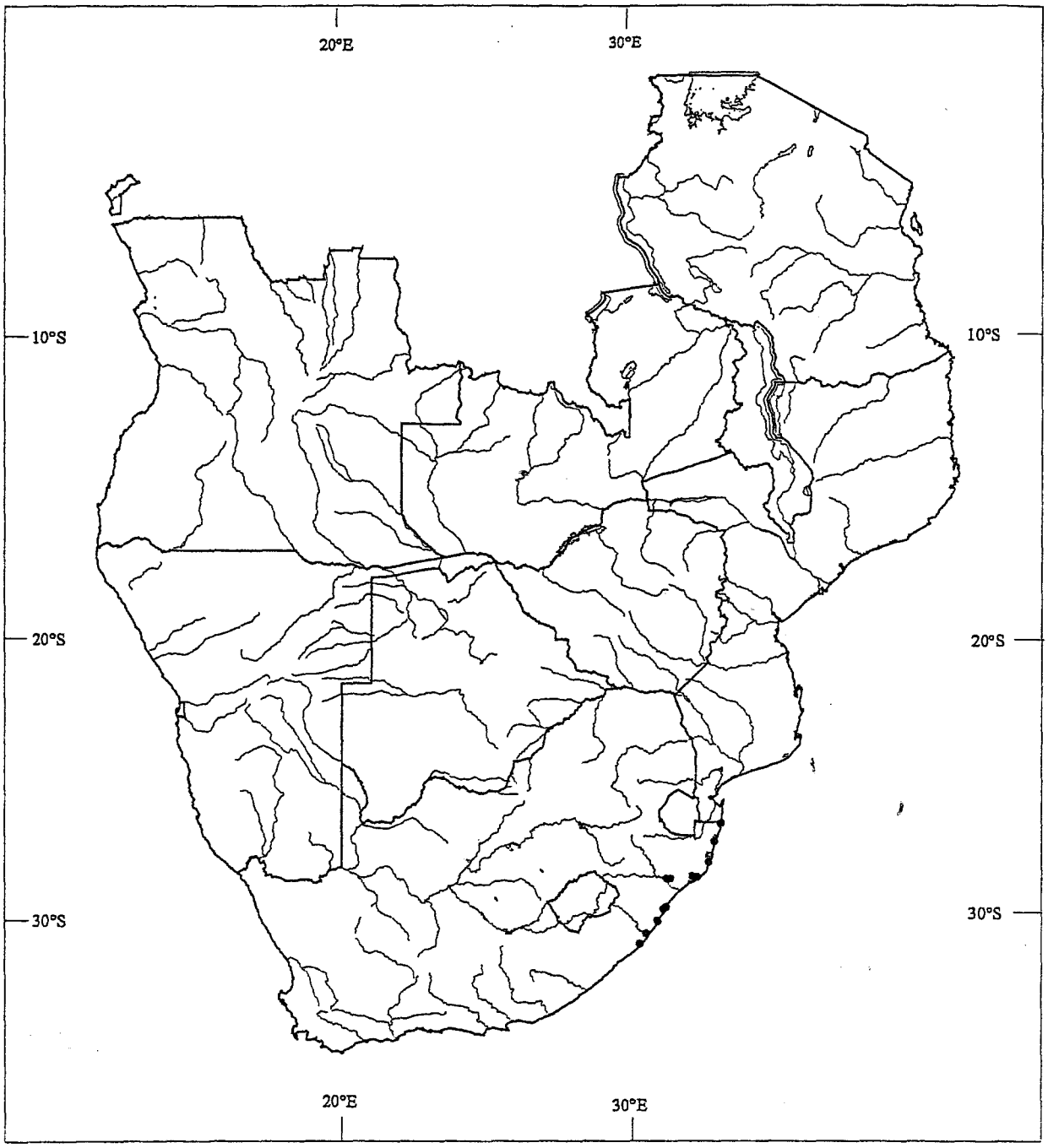


Figure F.329. Point distribution of *Hypseleotris dayi*. Scale approximately 1:25 000 000

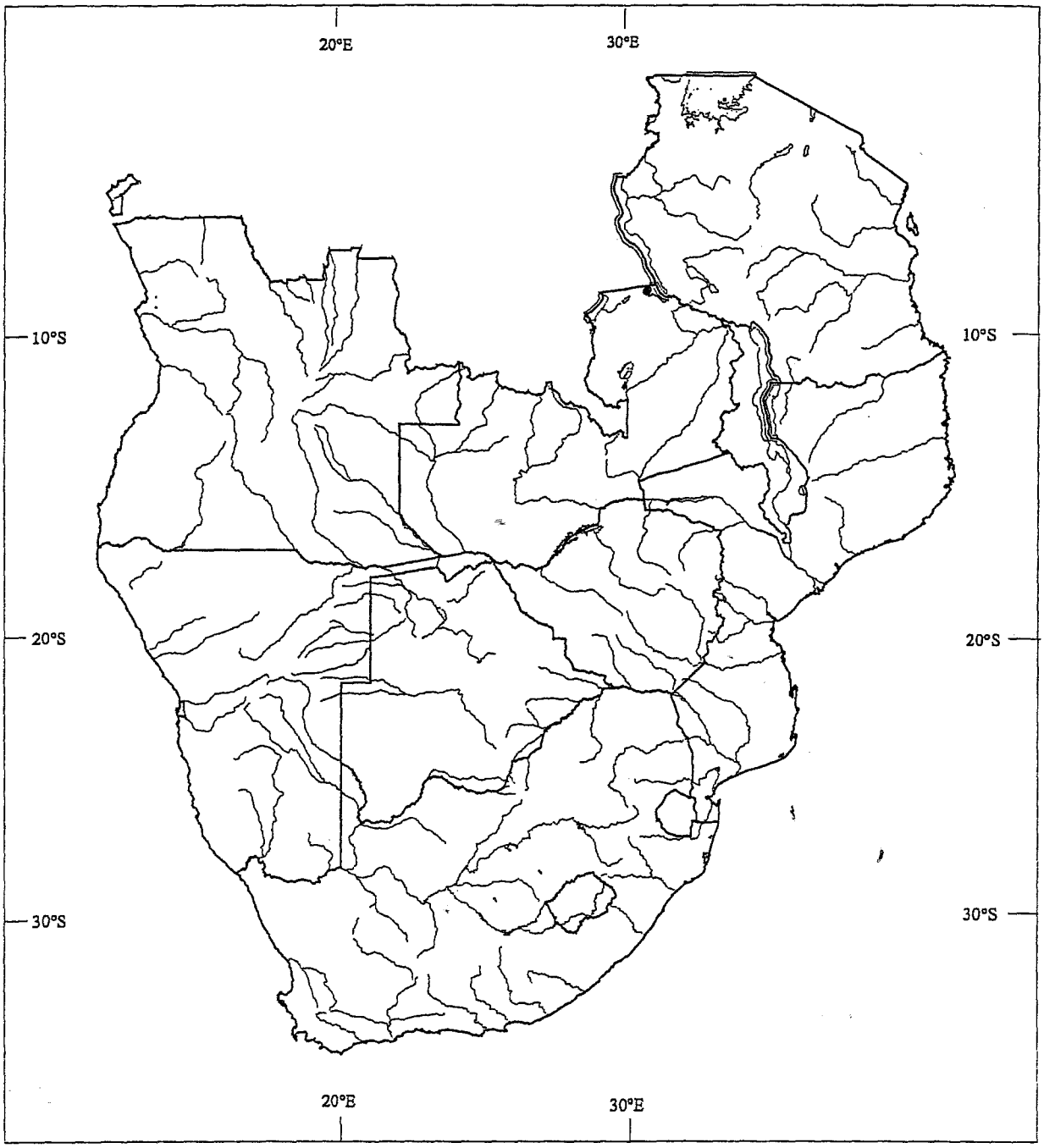


Figure F.330. Point distribution of *Julidochromis dickfeldi*. Scale approximately 1:25 000 000

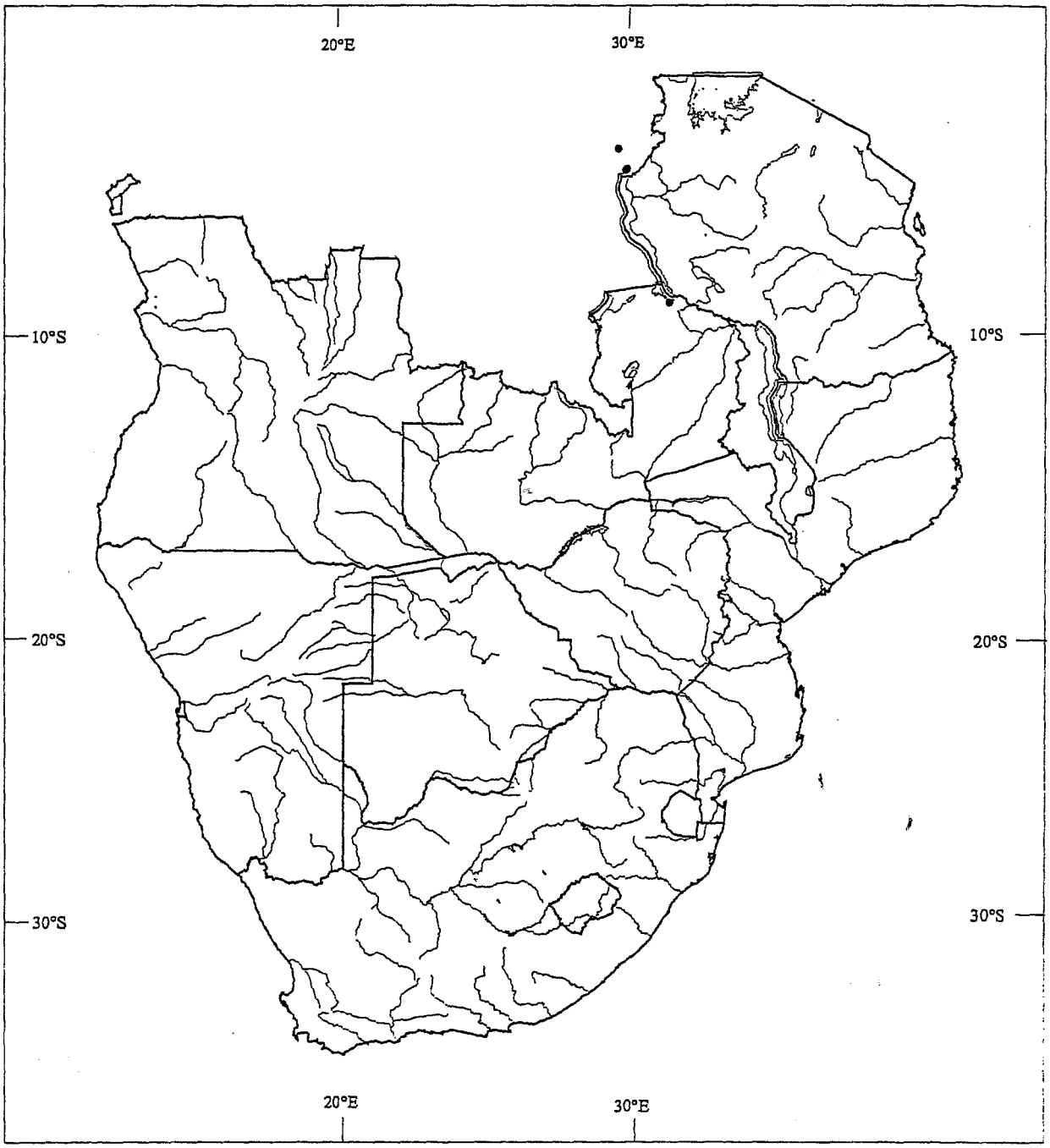


Figure F.331. Point distribution of *Julidochromis marlieri*. Scale approximately 1:25 000 000

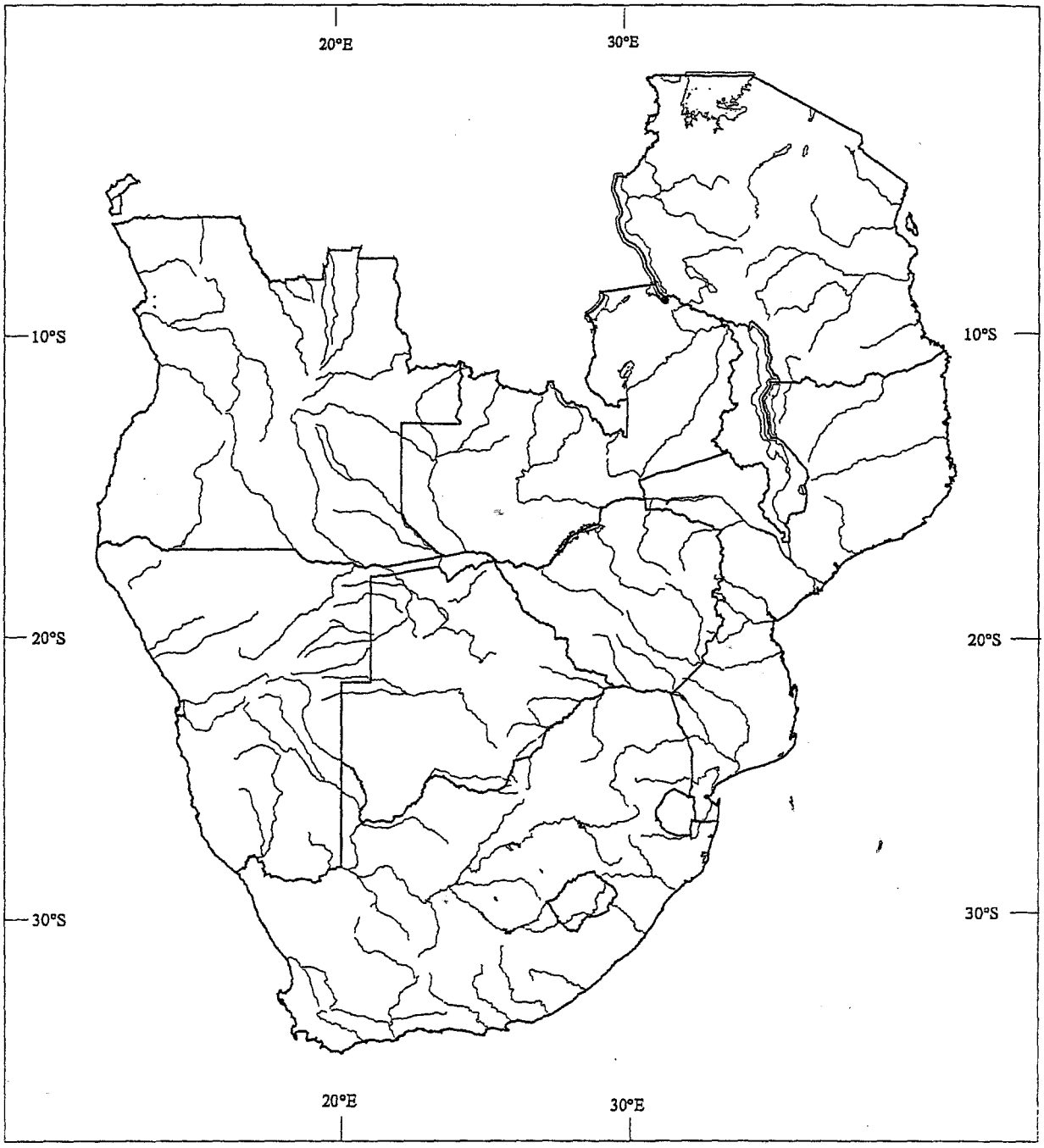


Figure F.332. Point distribution of *Julidochromis ornatus*. Scale approximately 1:25 000 000

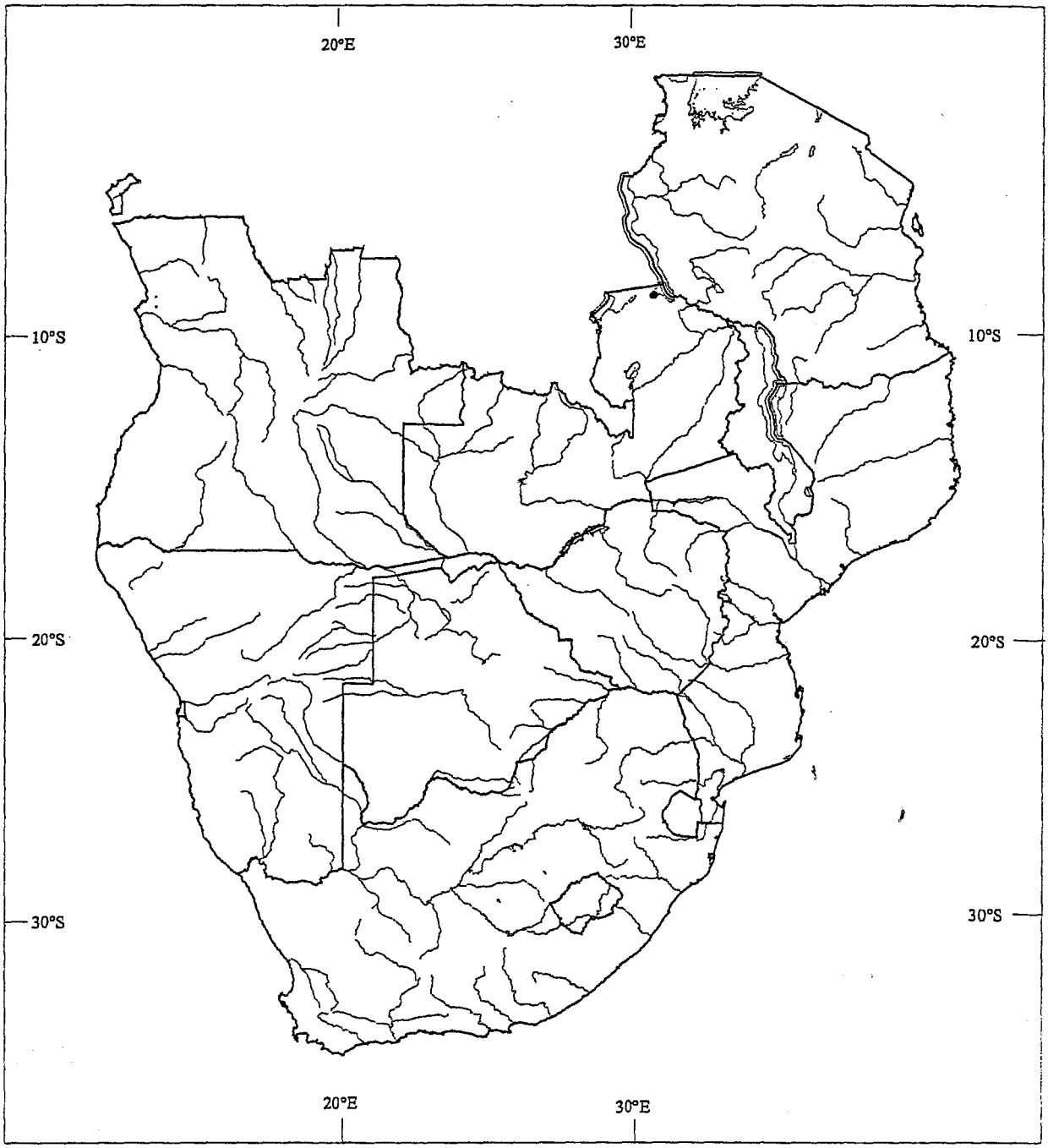


Figure F.333. Point distribution of *Julidochromis regani*. Scale approximately 1:25 000 000

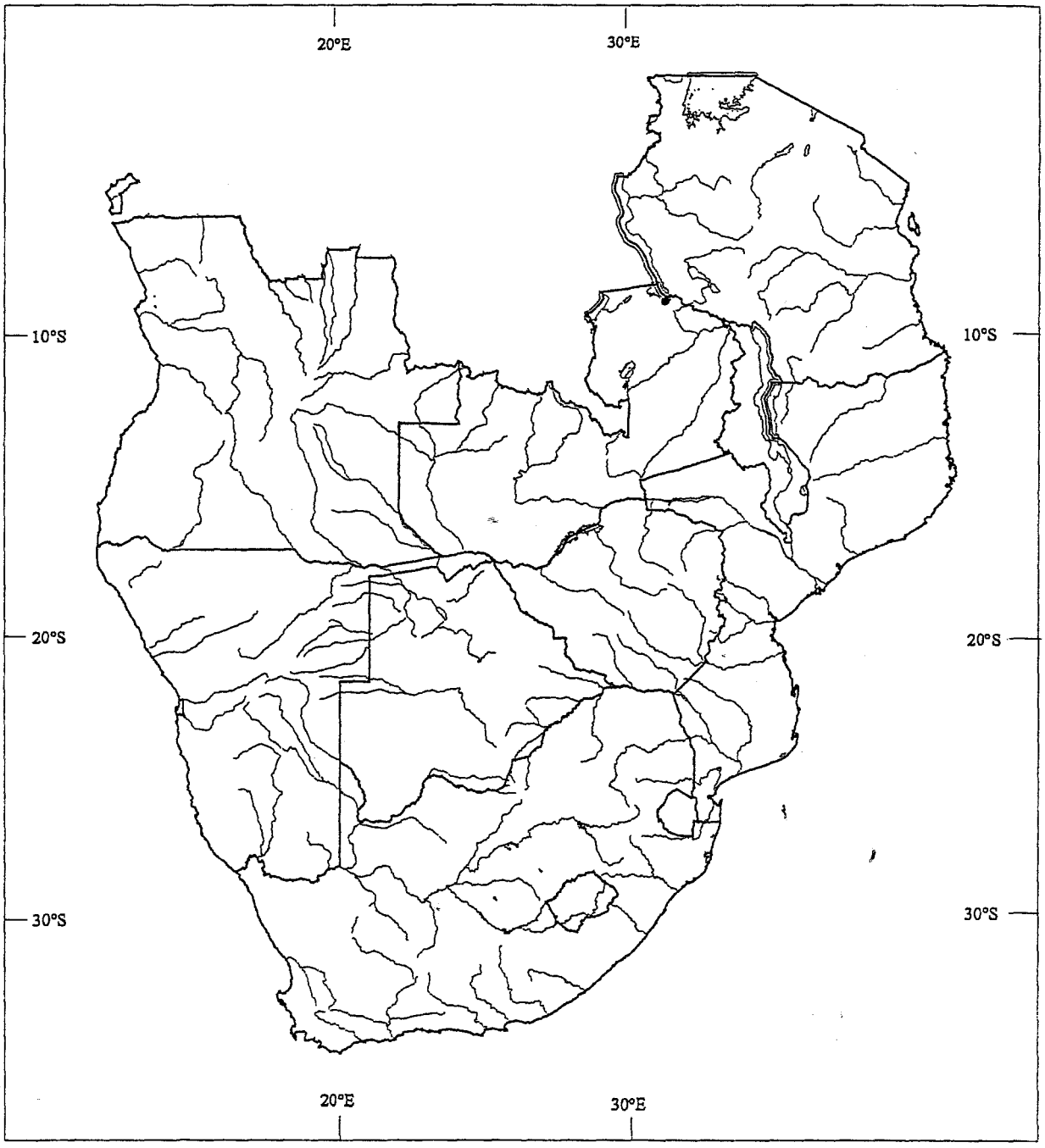


Figure F.334. Point distribution of *Julidochromis transcriptus*. Scale approximately 1:25 000 000

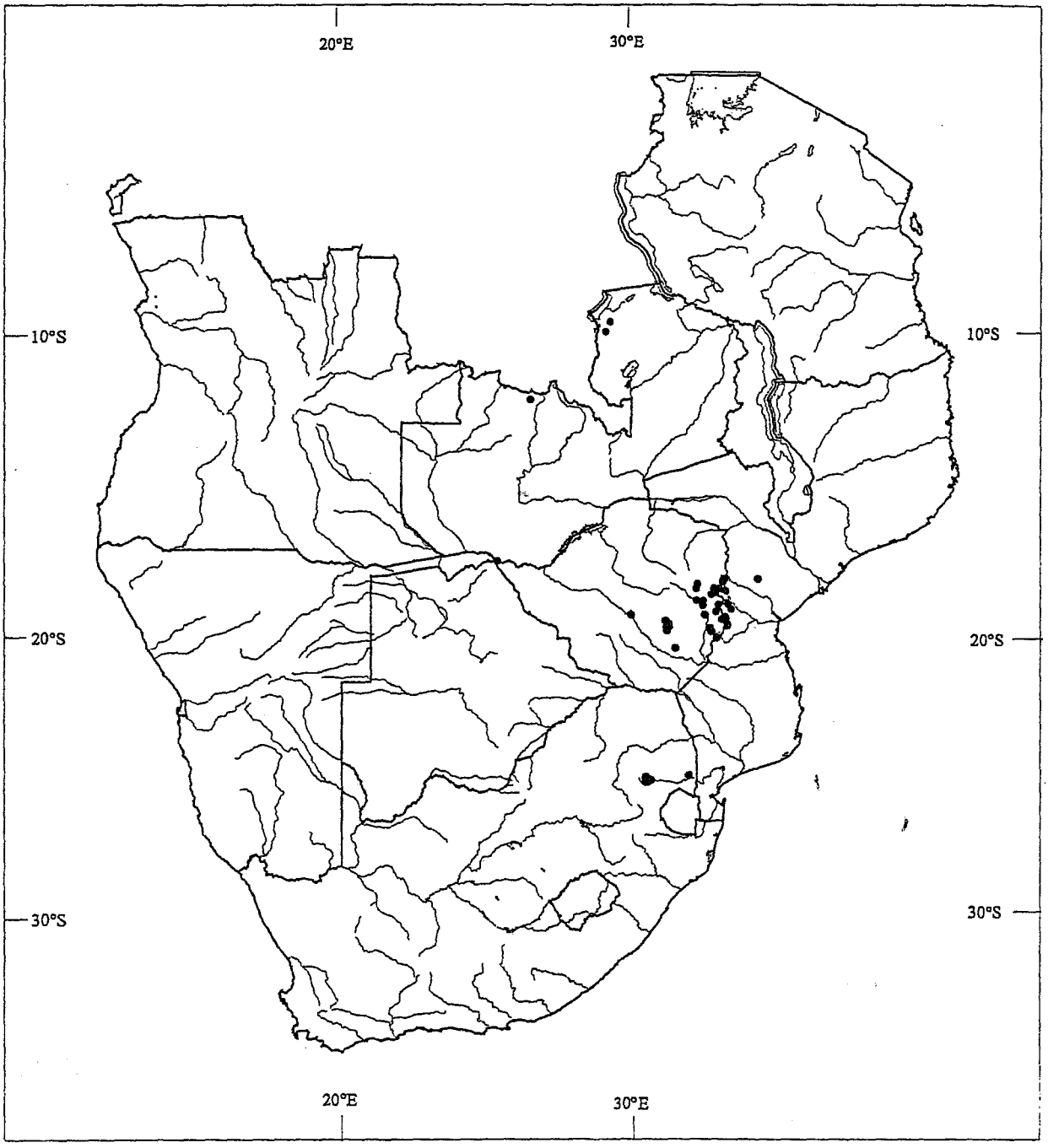


Figure F.335. Point distribution of *Kneria auriculata*. Scale approximately 1:25 000 000

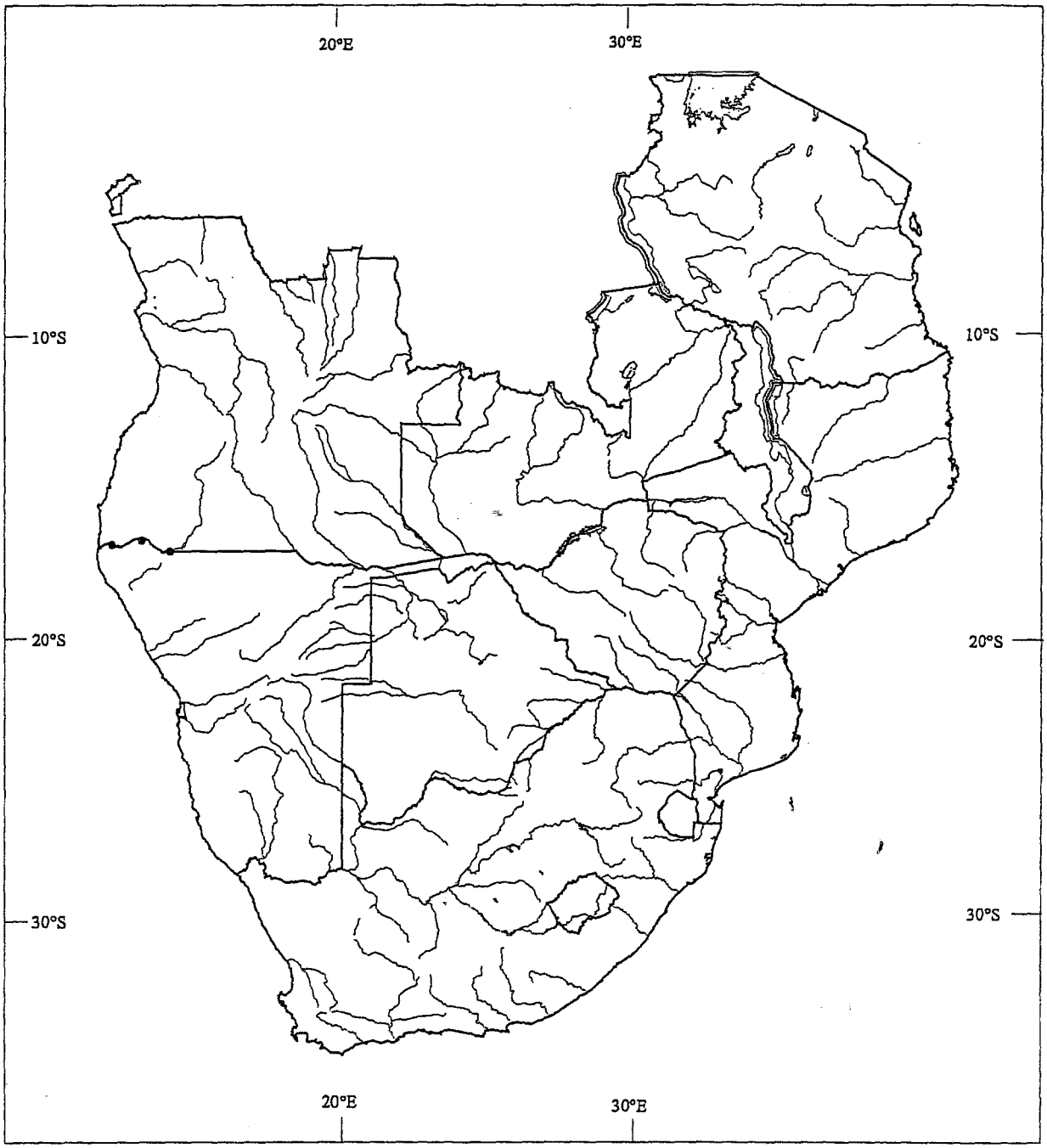


Figure F.336. Point distribution of *Kneria maydelli*. Scale approximately 1:25 000 000

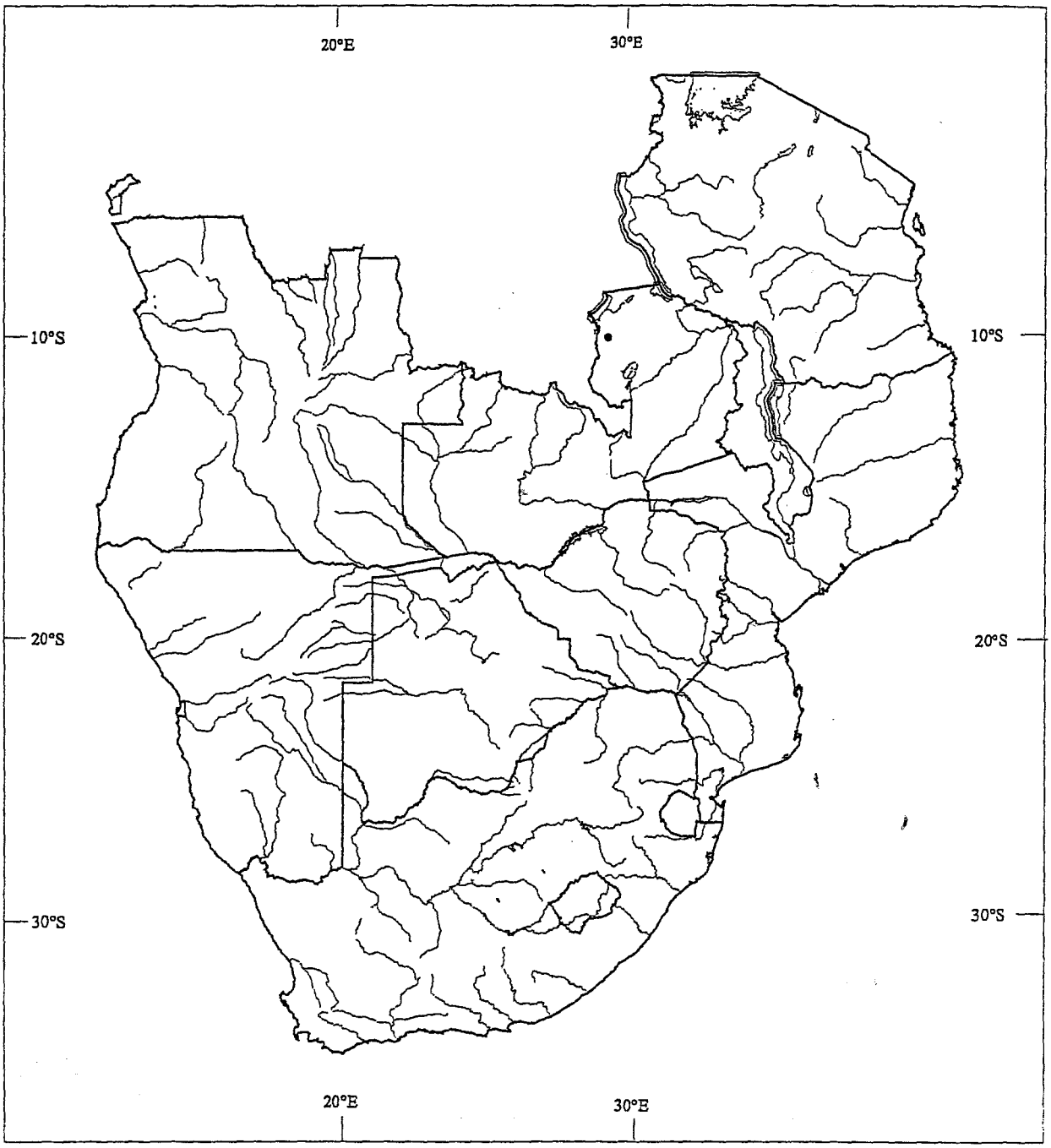


Figure F.337. Point distribution of *Kneria paucisquamata*. Scale approximately 1:25 000 000

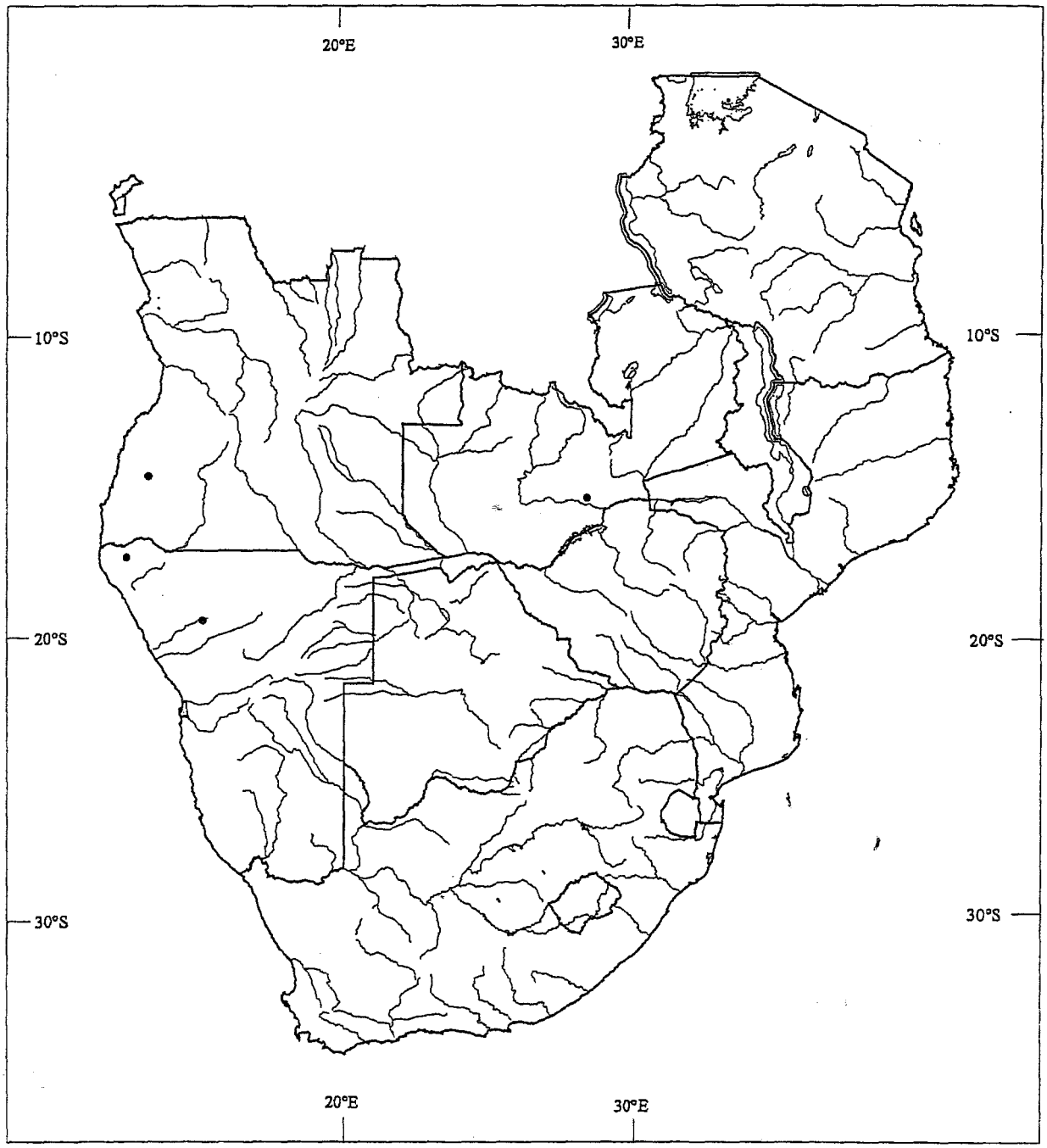


Figure F.338. Point distribution of *Kneria polli*. Scale approximately 1:25 000 000

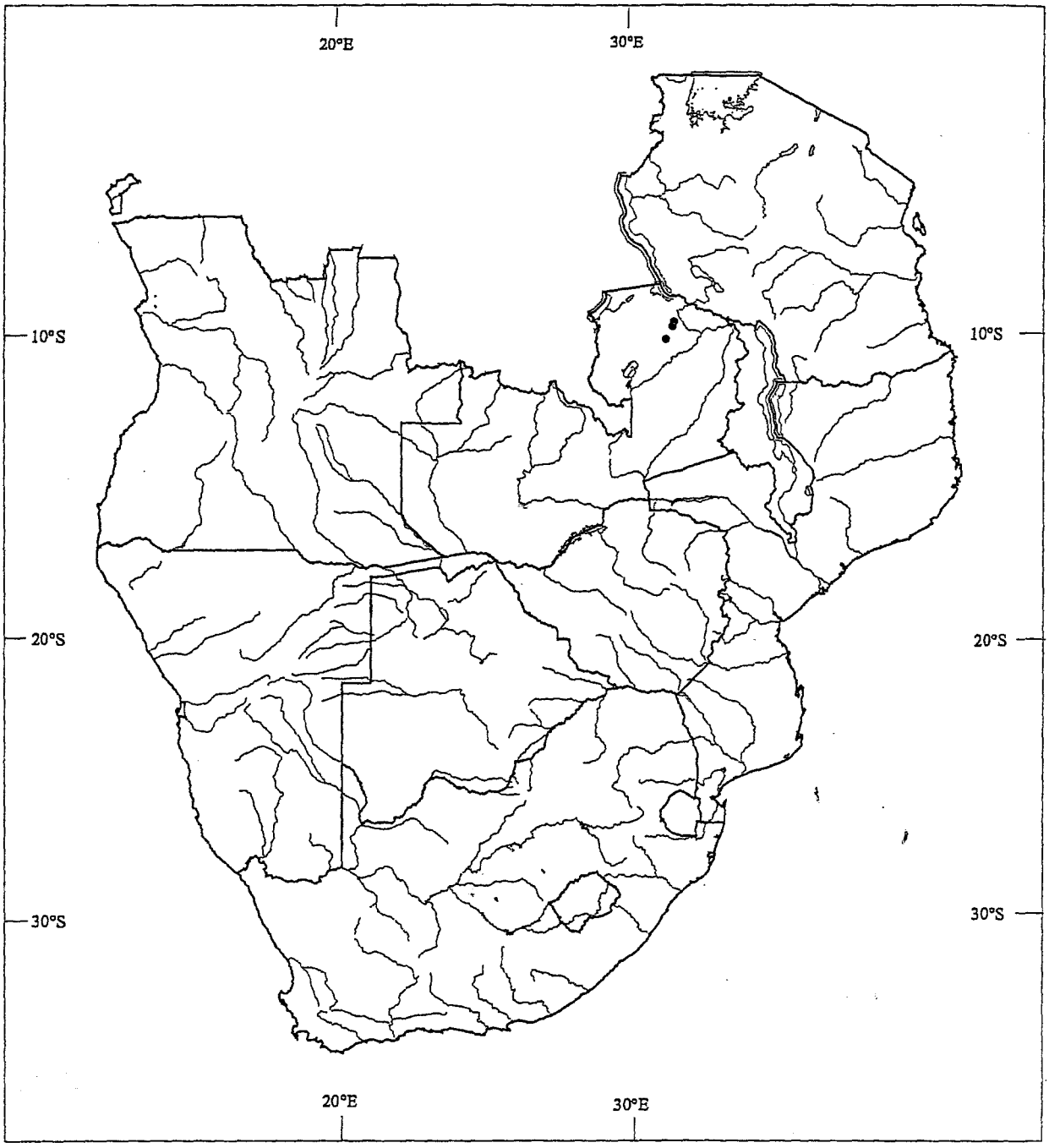


Figure F.339. Point distribution of *Kneria wittei*. Scale approximately 1:25 000 000

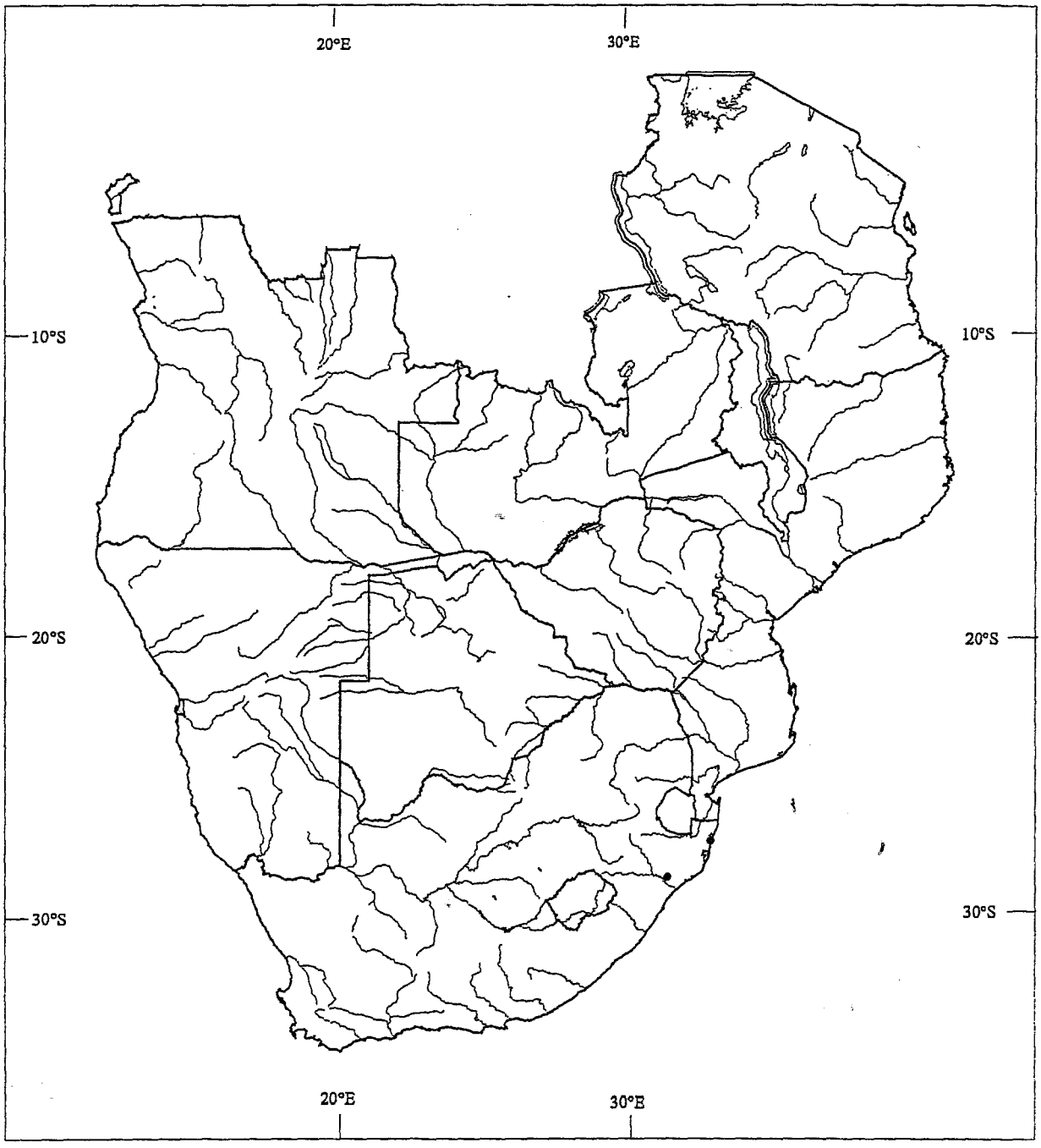


Figure F.340. Point distribution of *Kuhlia rupestris*. Scale approximately 1:25 000 000

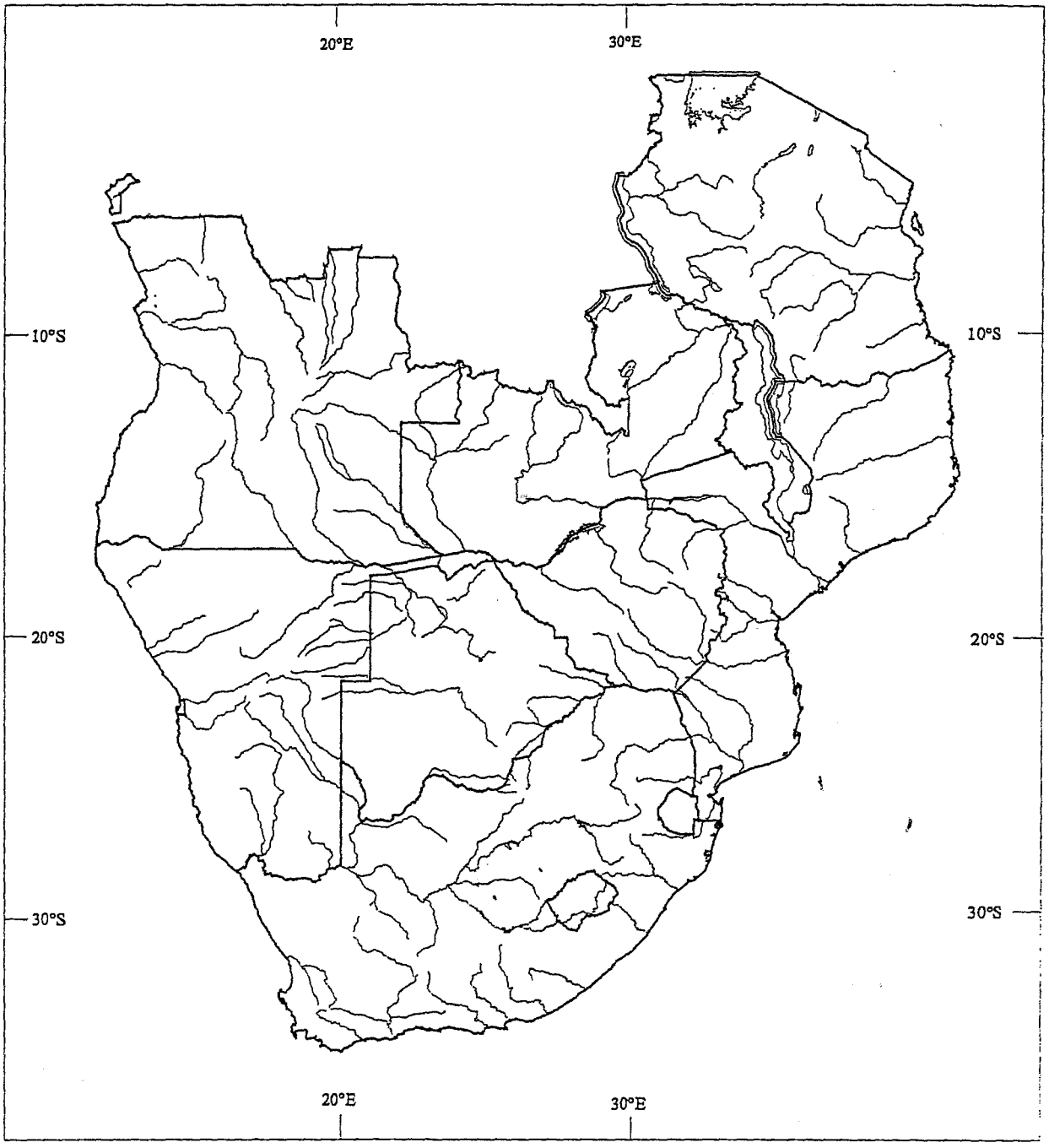


Figure F.341. Point distribution of *Kyphosus cinerascens*. Scale approximately 1:25 000 000

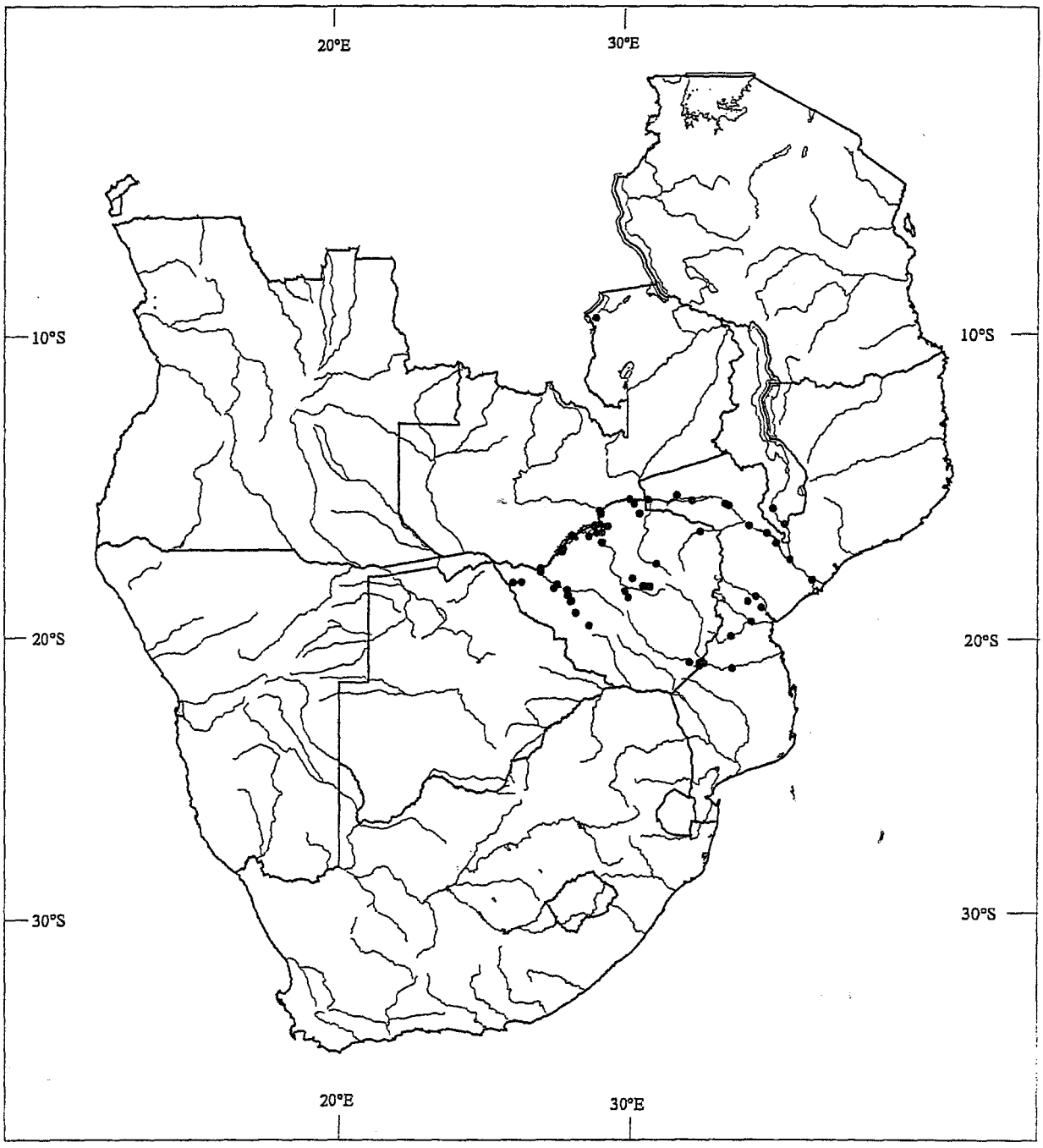


Figure F.342. Point distribution of *Labeo altivelis*. Scale approximately 1:25 000 000

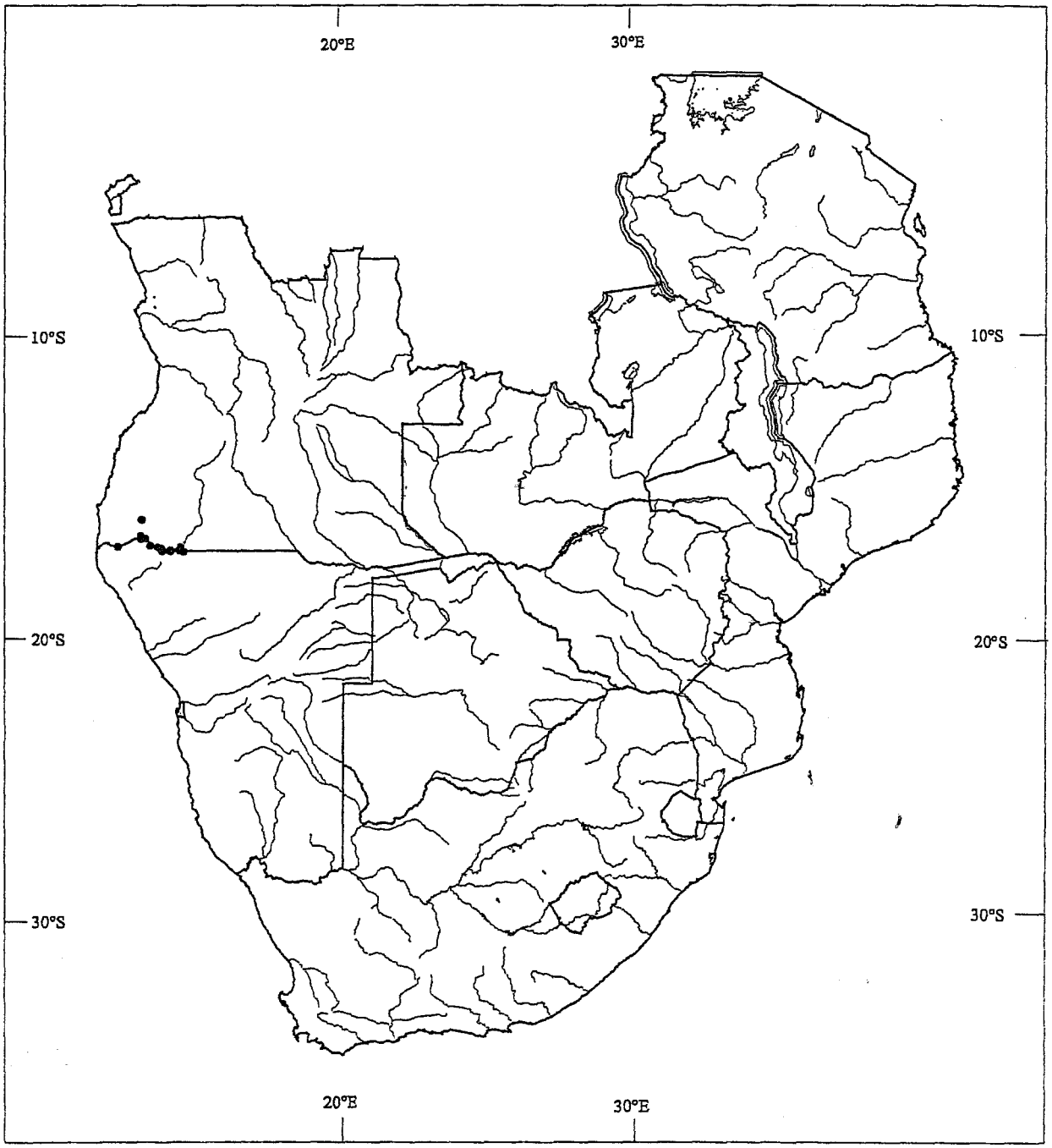


Figure F.343. Point distribution of *Labeo ansorgii*. Scale approximately 1:25 000 000

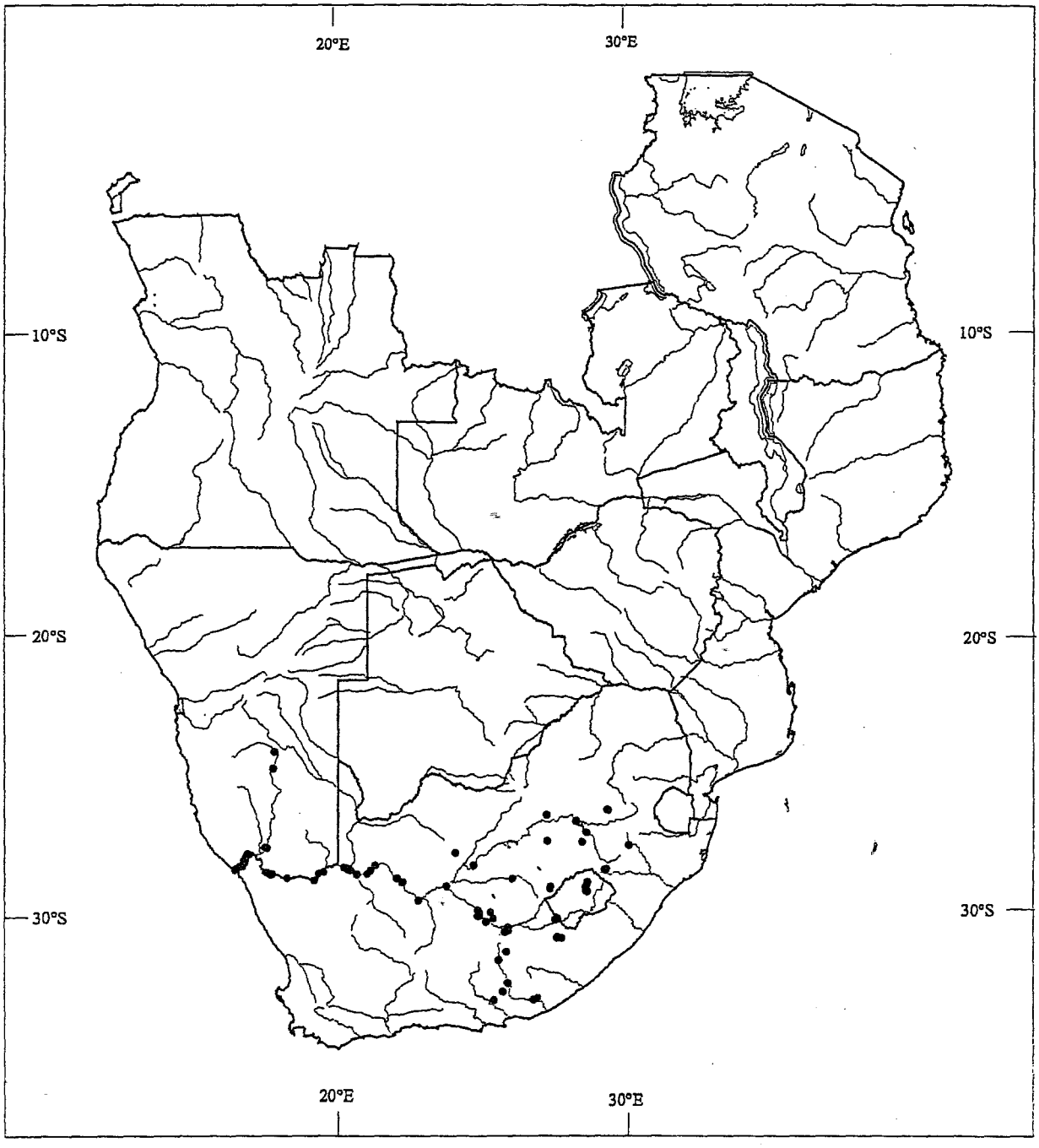


Figure F.344. Point distribution of *Labeo capensis*. Scale approximately 1:25 000 000

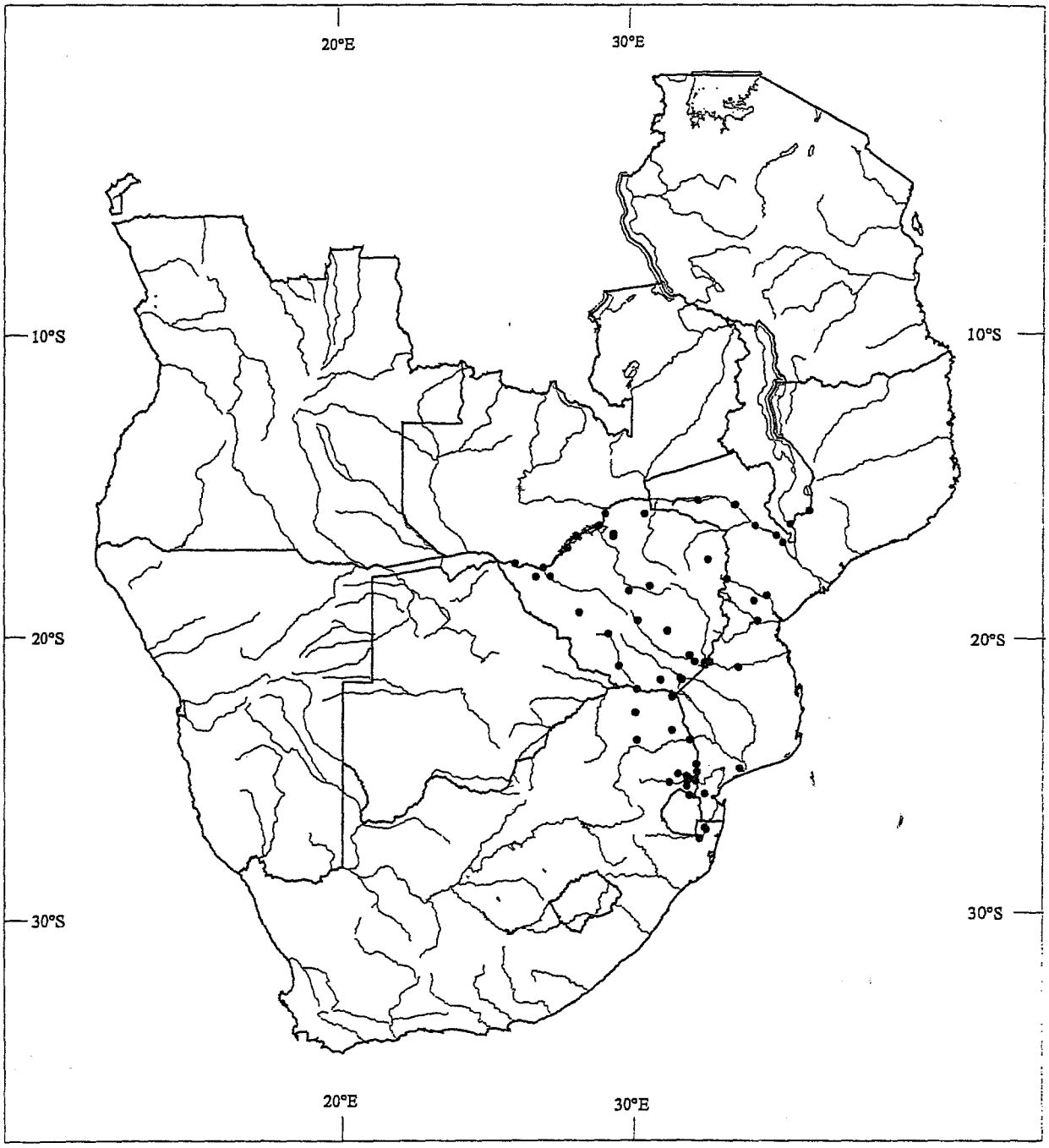


Figure F.345. Point distribution of *Labeo congoro*. Scale approximately 1:25 000 000

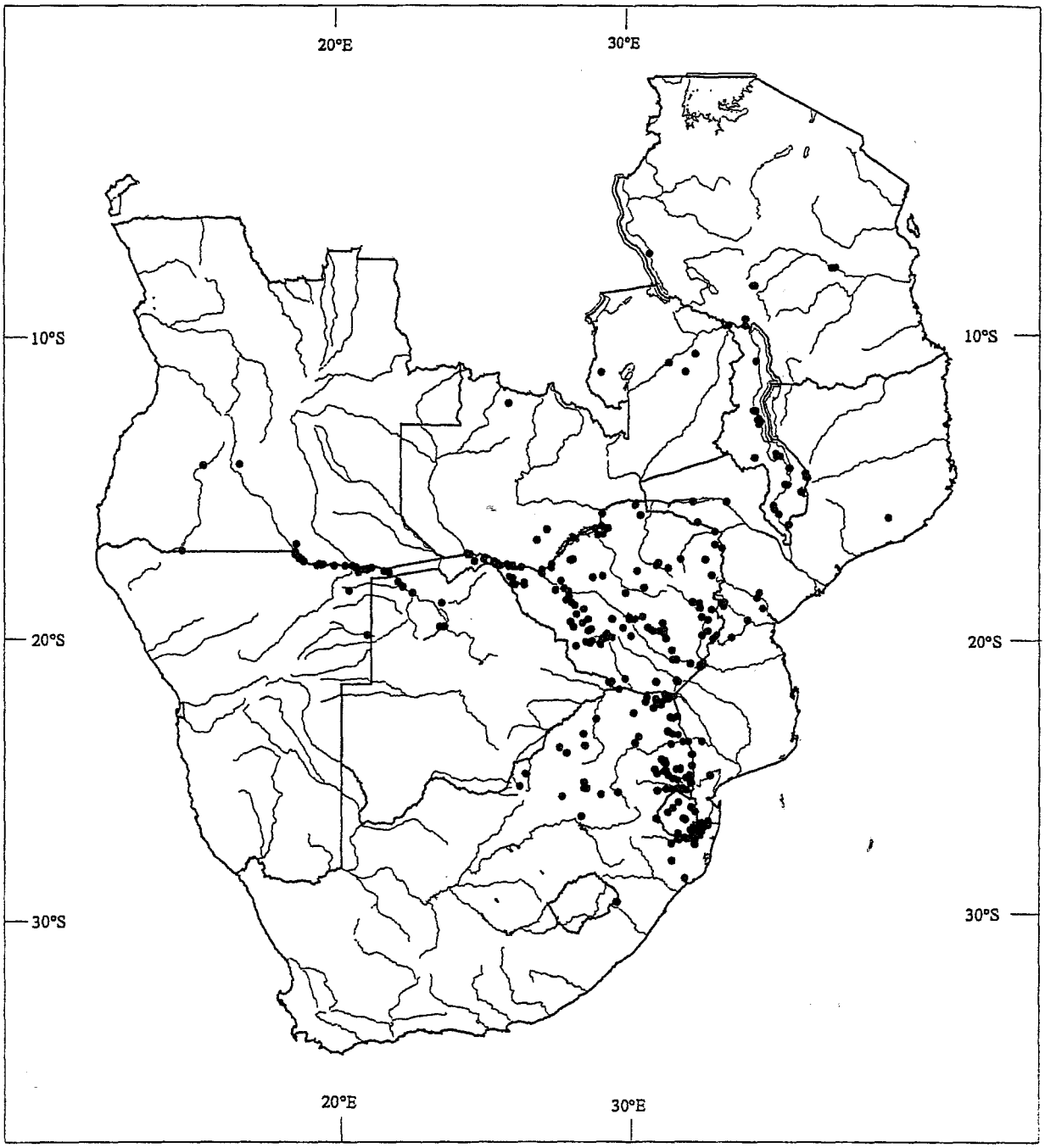


Figure F.346. Point distribution of *Labeo cylindricus*. Scale approximately 1:25 000 000

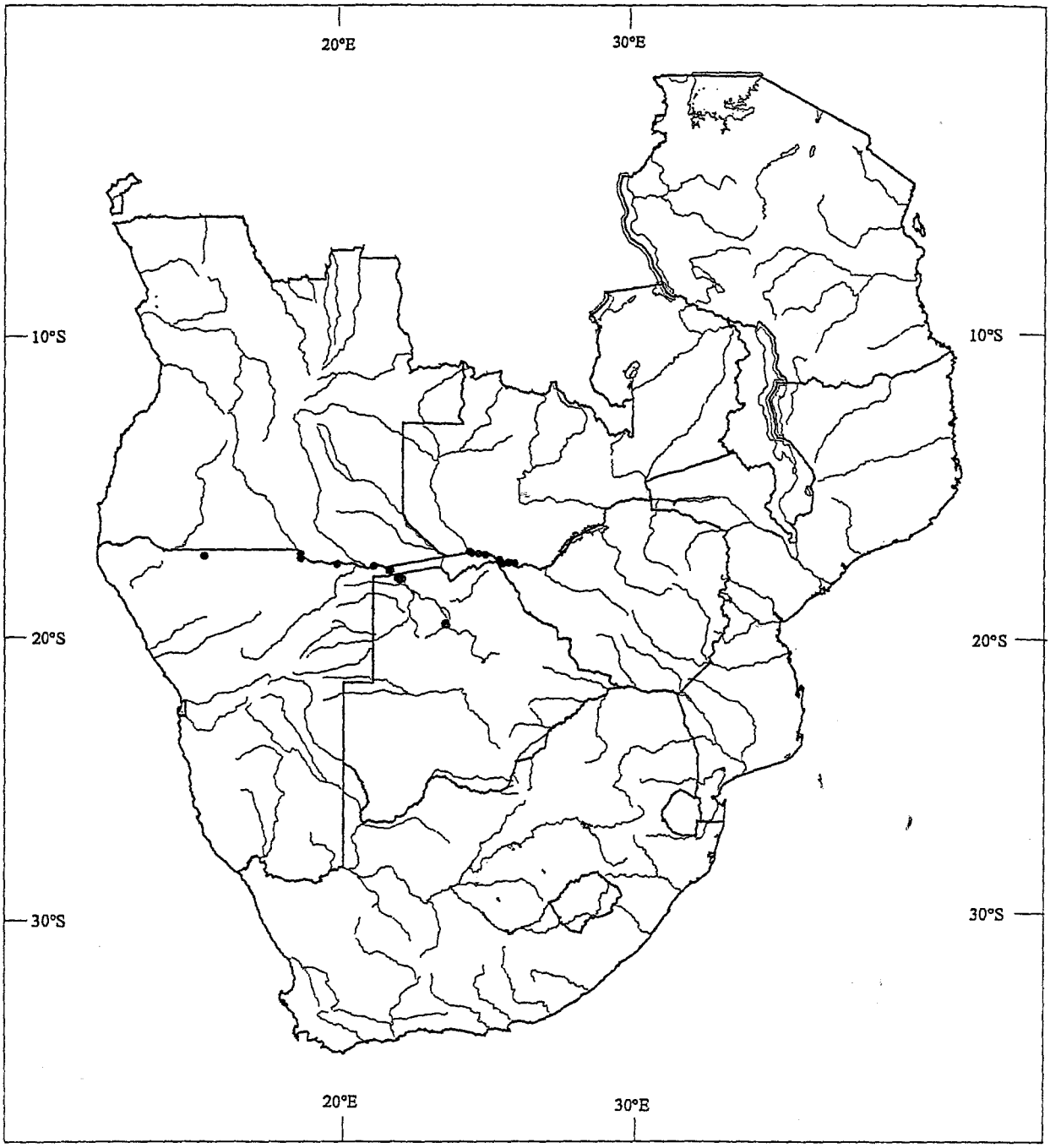


Figure F.347. Point distribution of *Labeo lunatus*. Scale approximately 1:25 000 000

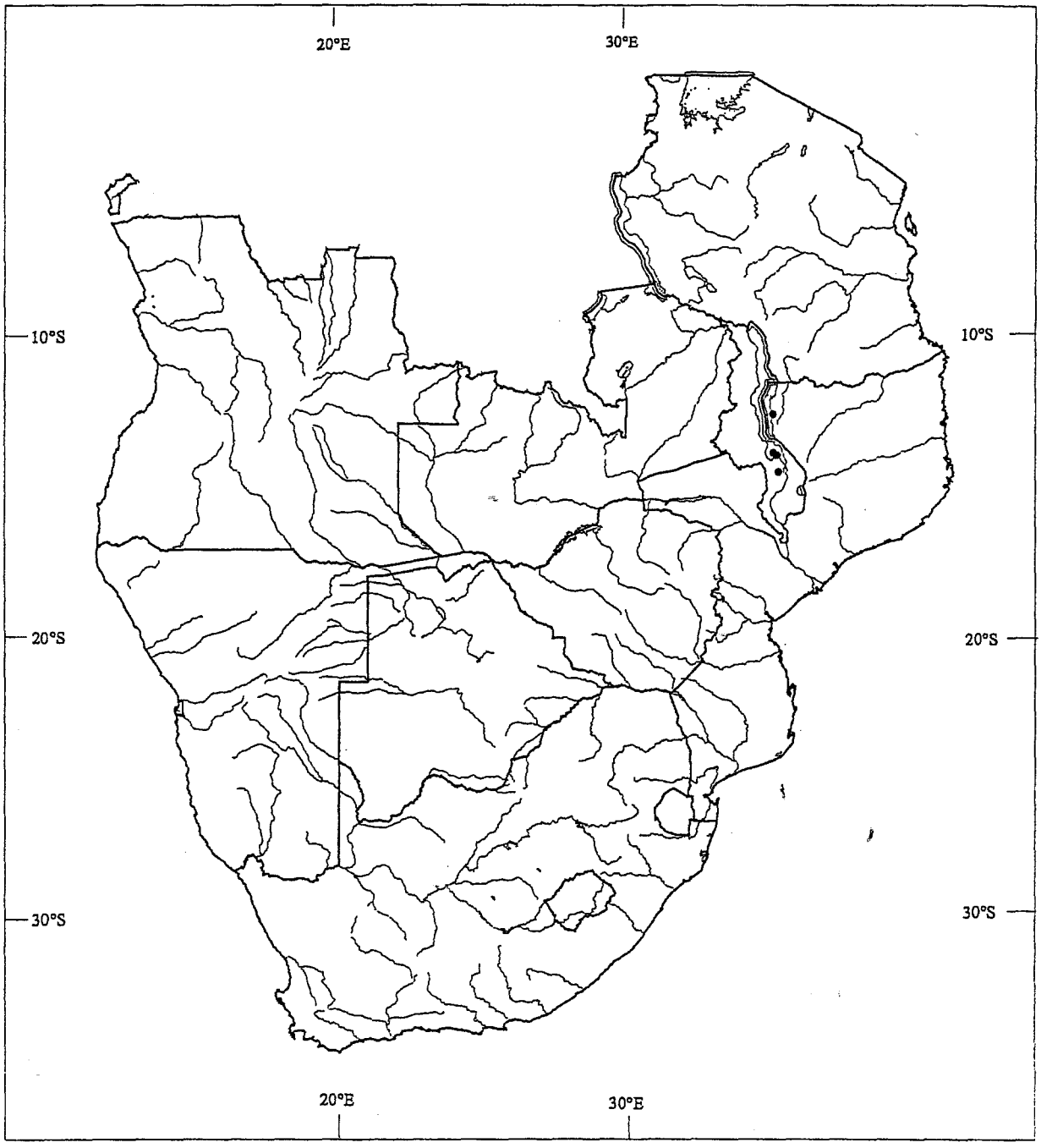


Figure F.348. Point distribution of *Labeo mesops*. Scale approximately 1:25 000 000

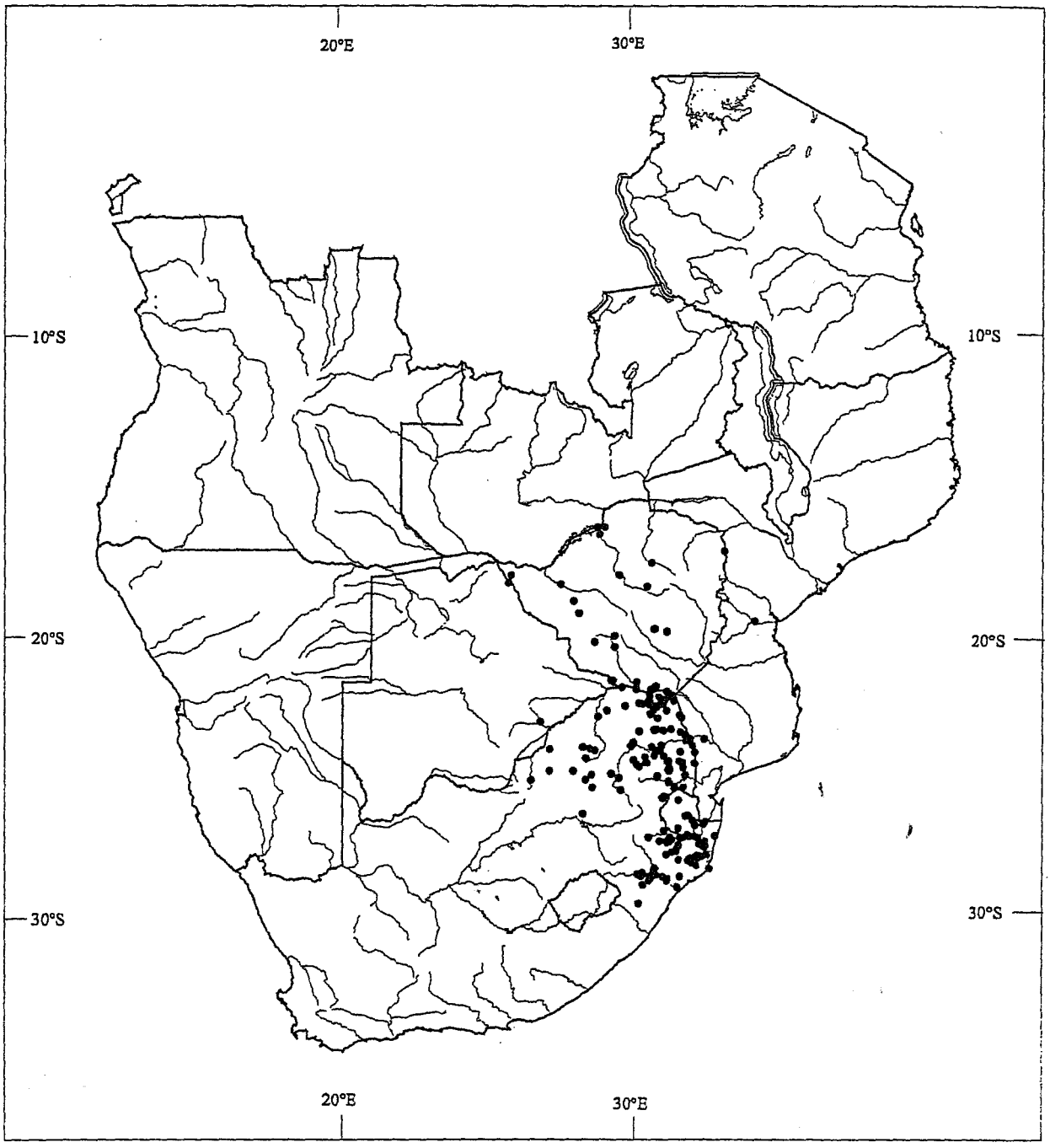


Figure F.349. Point distribution of *Labeo molybdinus*. Scale approximately 1:25 000 000

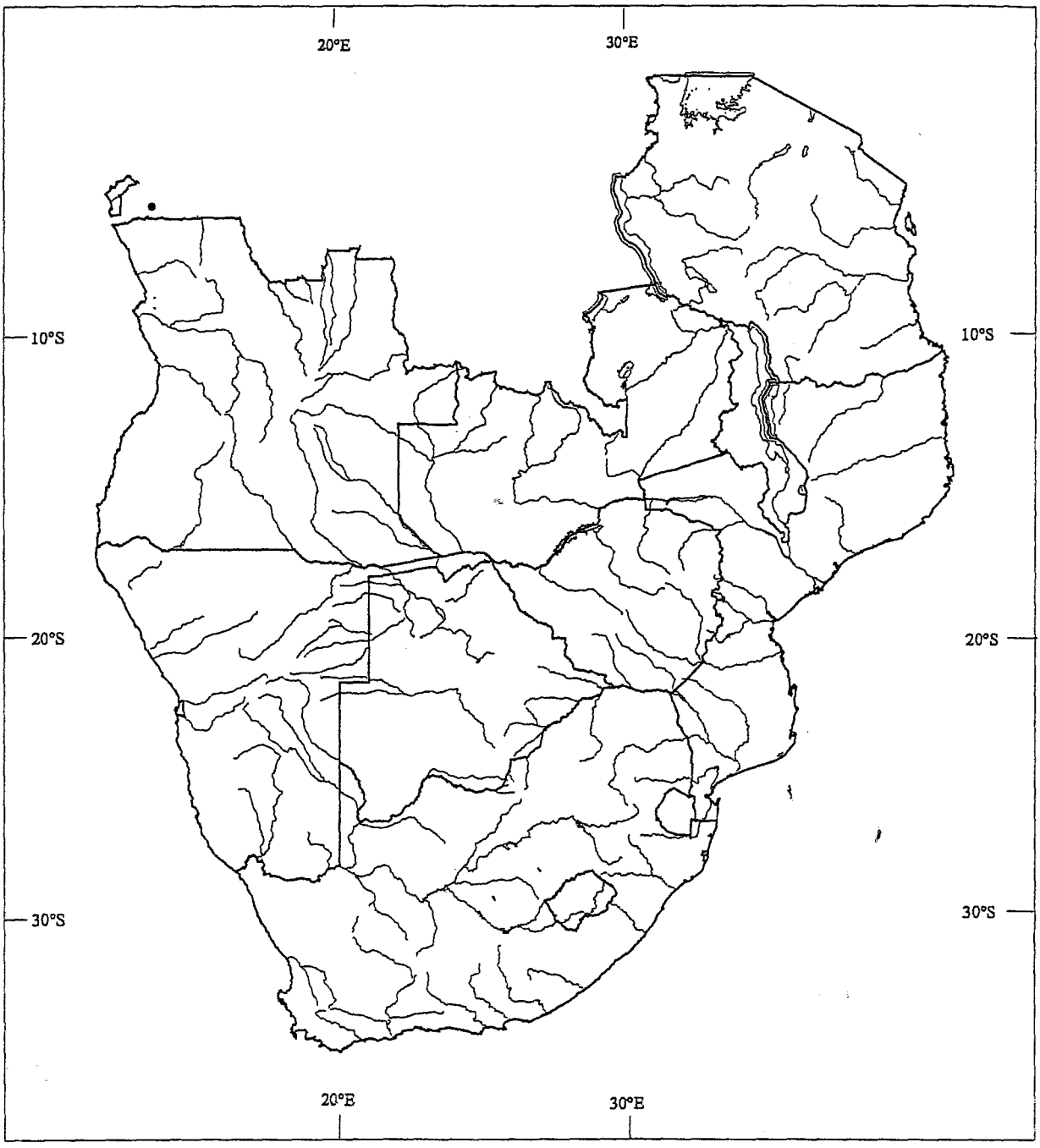


Figure F.350. Point distribution of *Labeo nasus*. Scale approximately 1:25 000 000

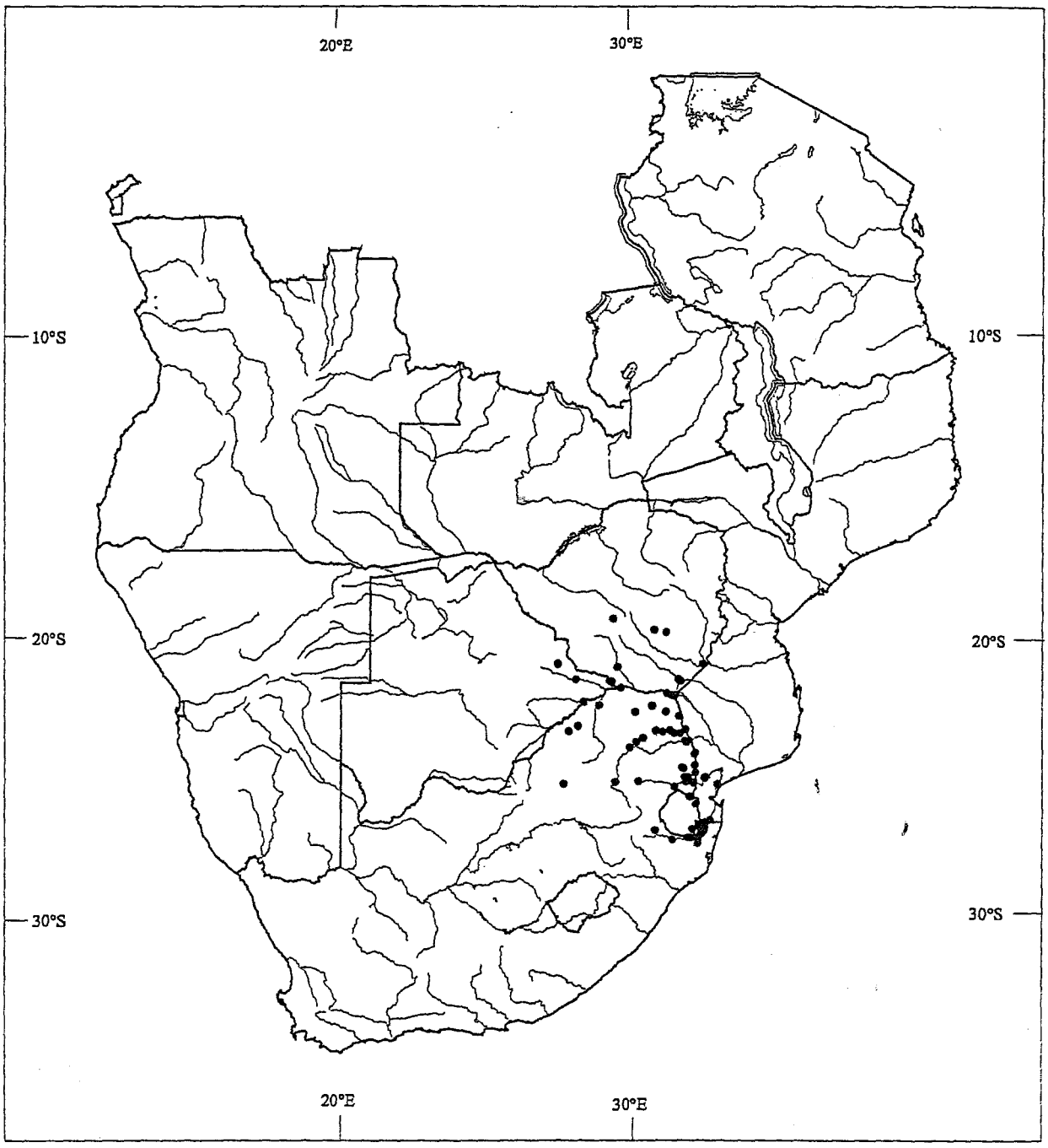


Figure F.351. Point distribution of *Labeo rosae*. Scale approximately 1:25 000 000

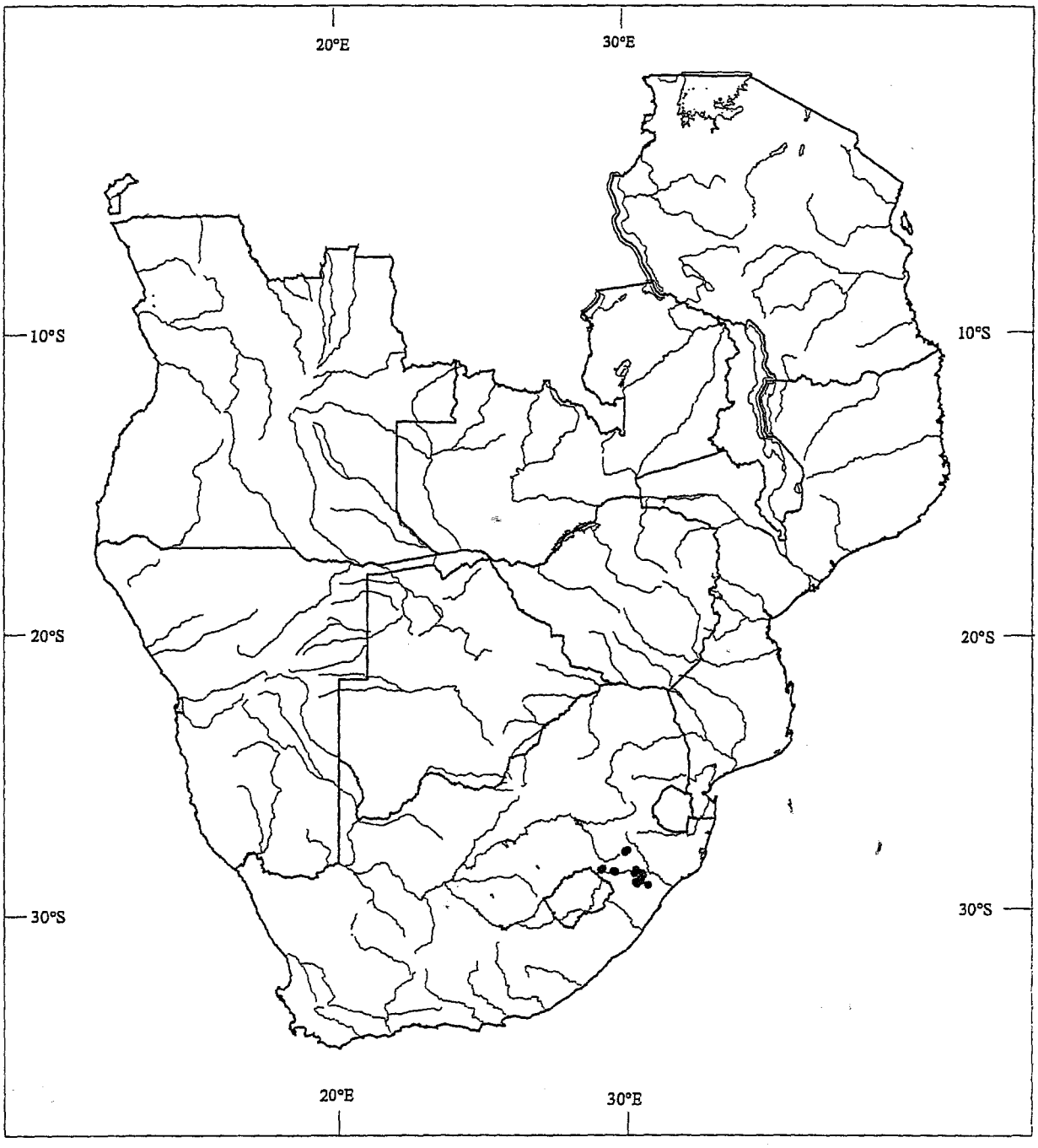


Figure F.352. Point distribution of *Labeo rubromaculatus*. Scale approximately 1:25 000 000

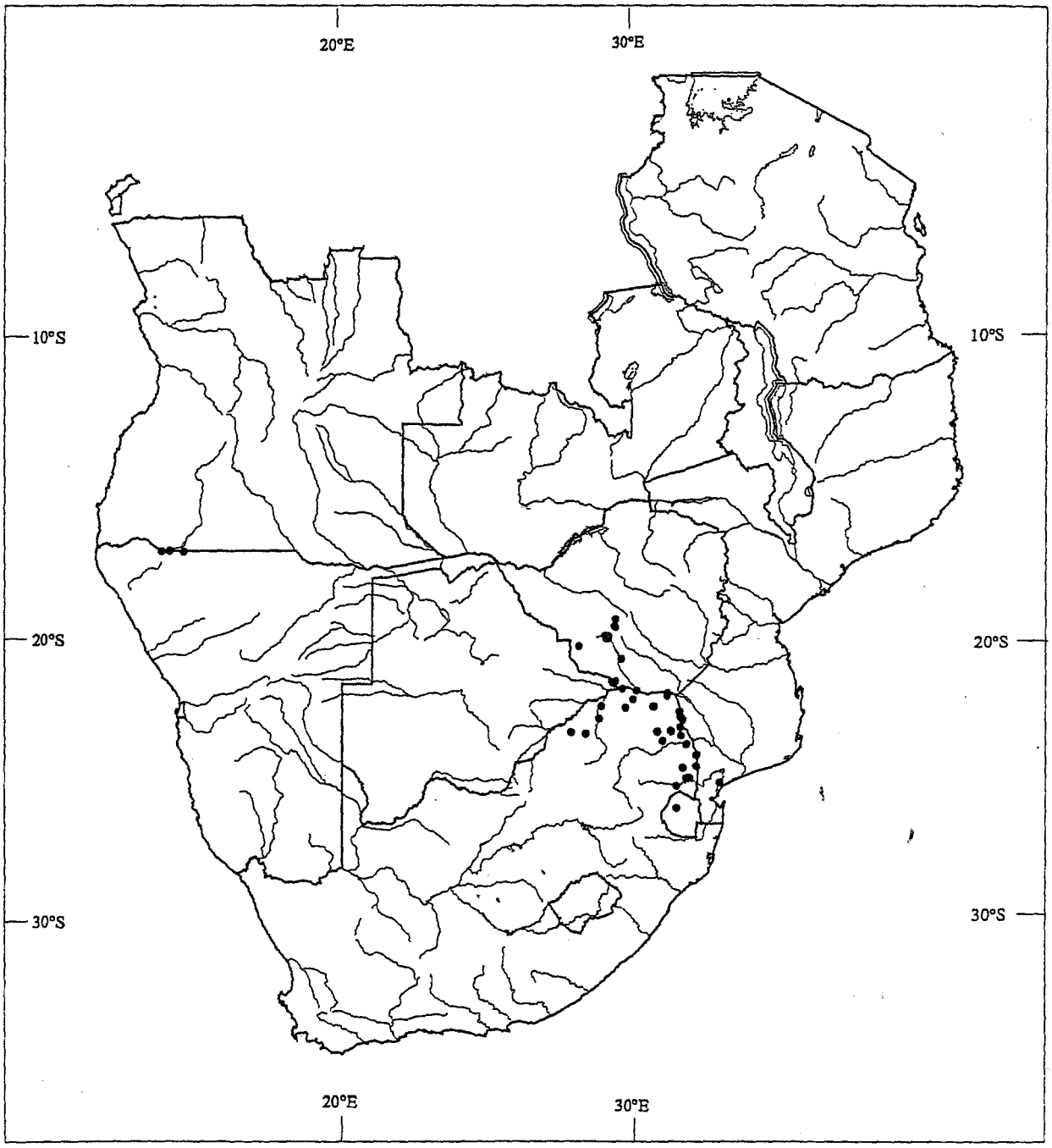


Figure F.353. Point distribution of *Labeo ruddi*. Scale approximately 1:25 000 000

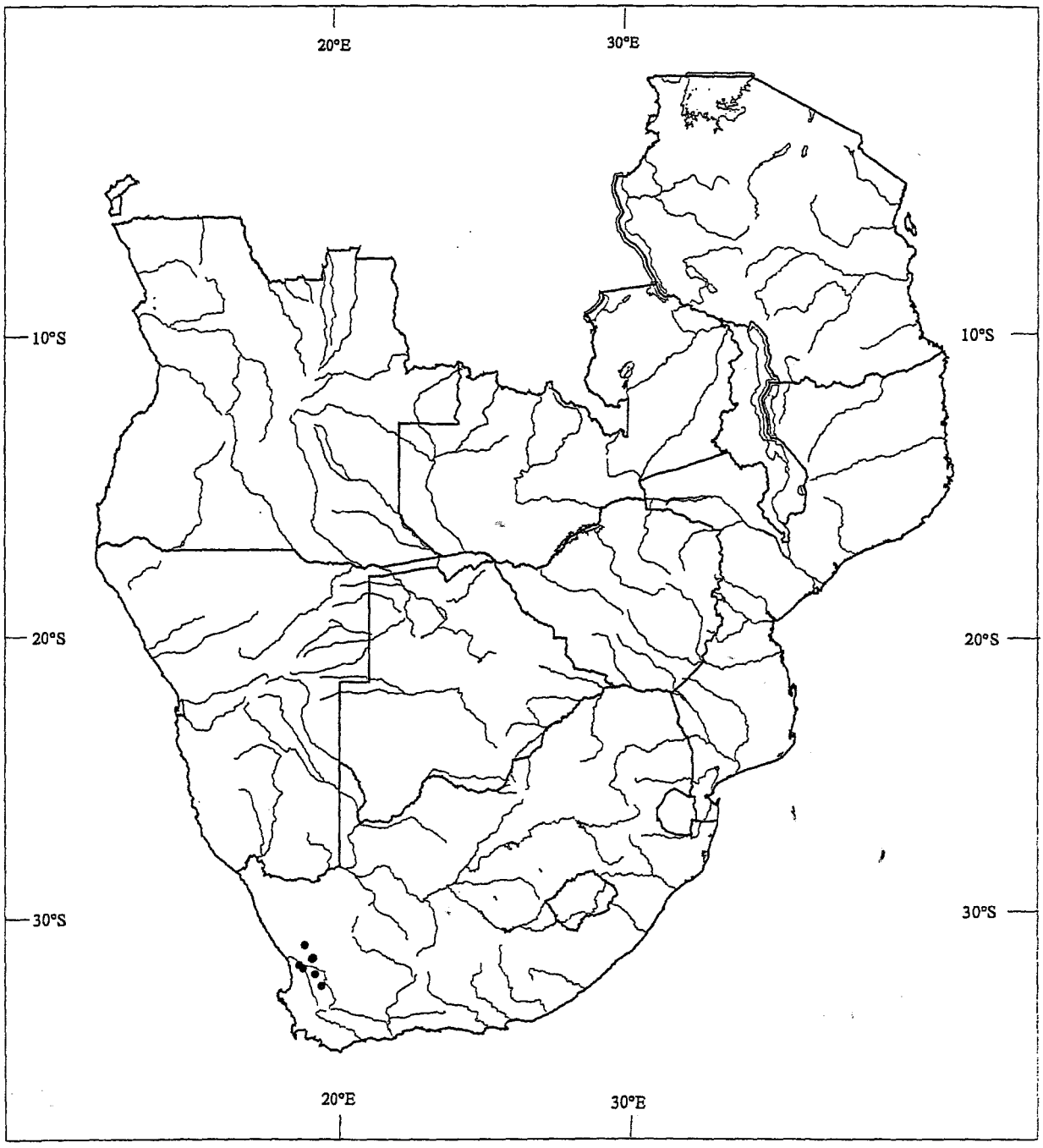


Figure F.354. Point distribution of *Labeo seeberi*. Scale approximately 1:25 000 000

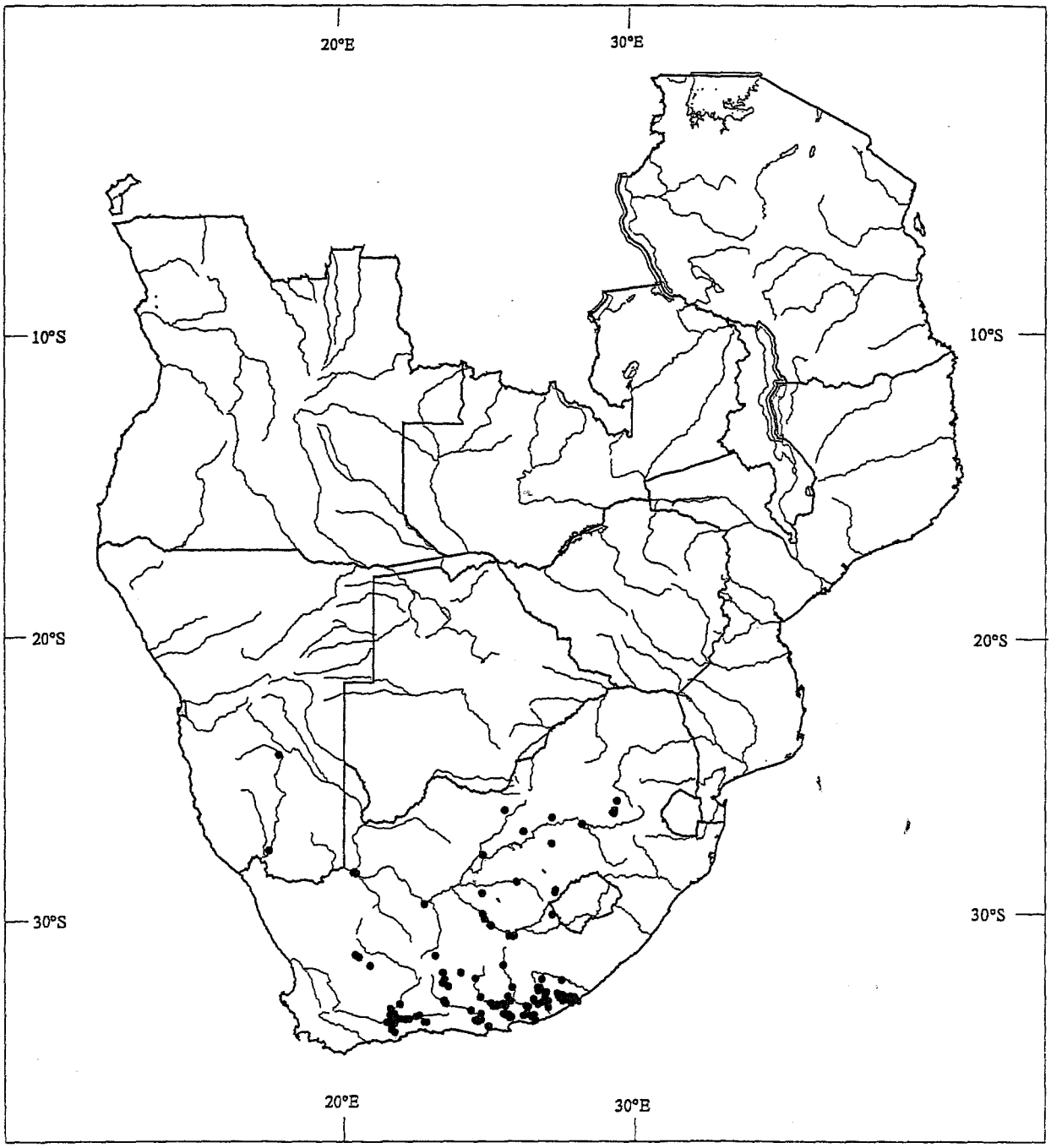


Figure F.355. Point distribution of *Labeo umbratus*. Scale approximately 1:25 000 000

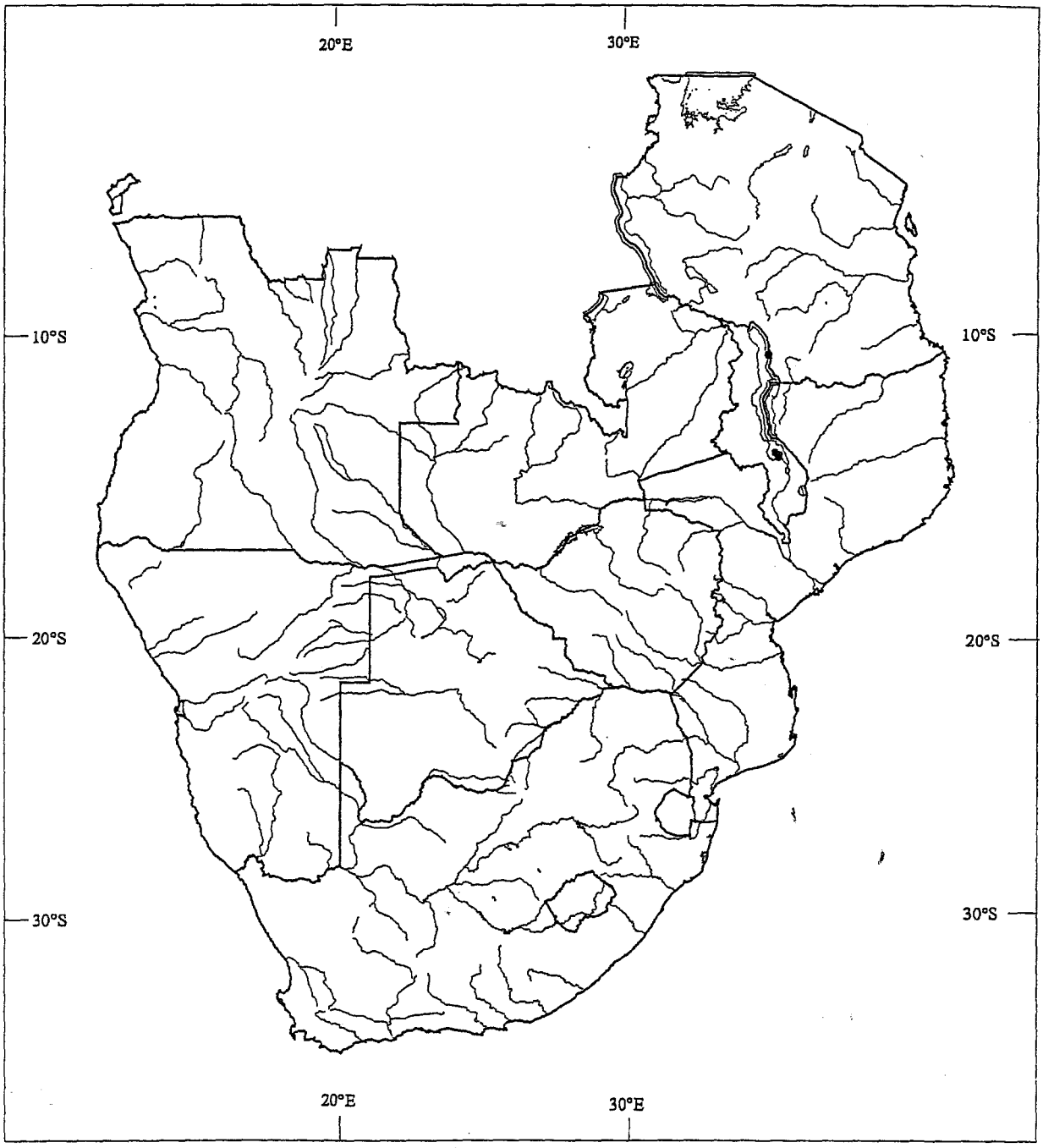


Figure F.356. Point distribution of *Labeotropheus fuelleborni*. Scale approximately 1:25 000 000

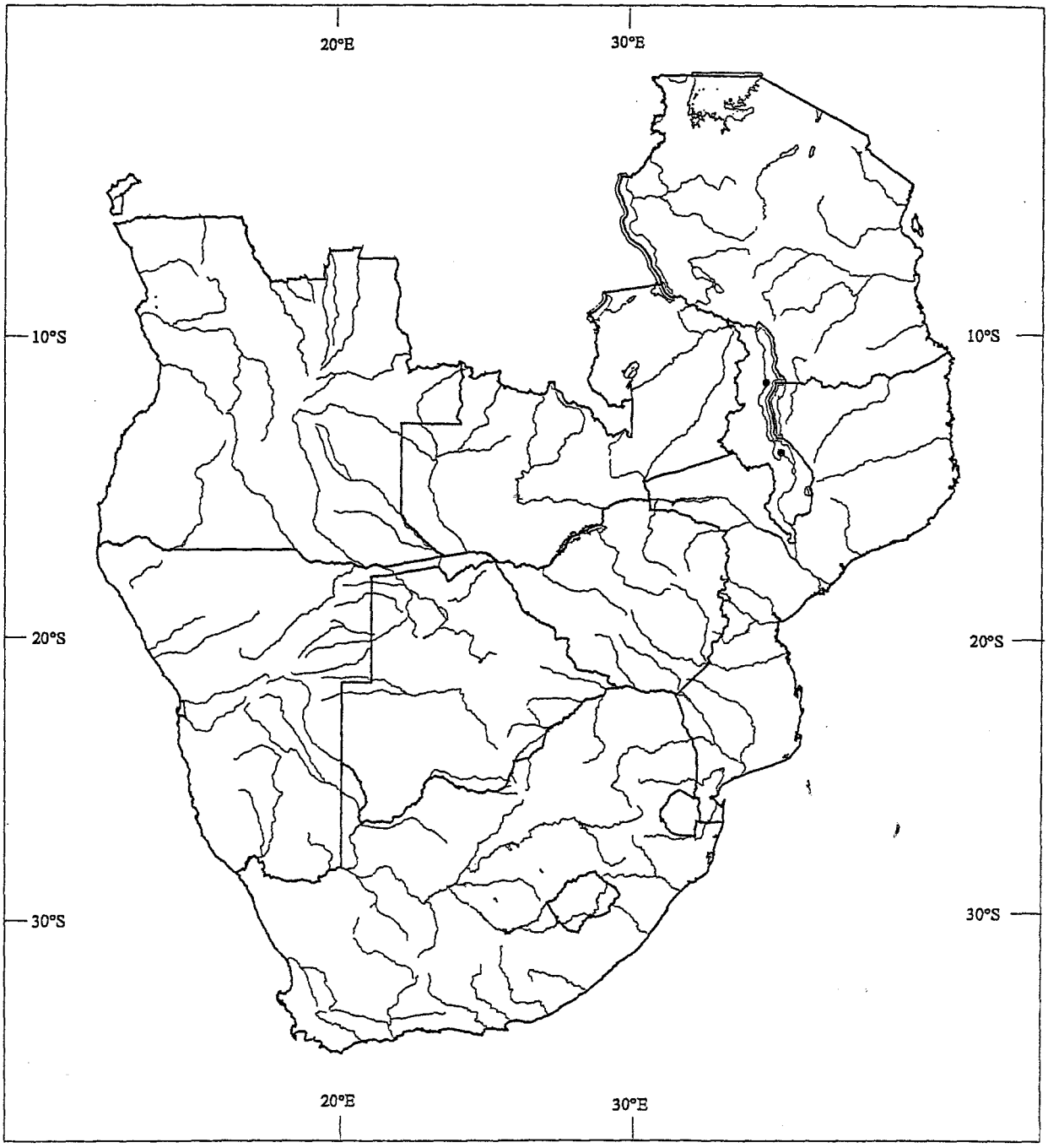


Figure F.357. Point distribution of *Labeotropheus trewavasre*. Scale approximately 1:25 000 000

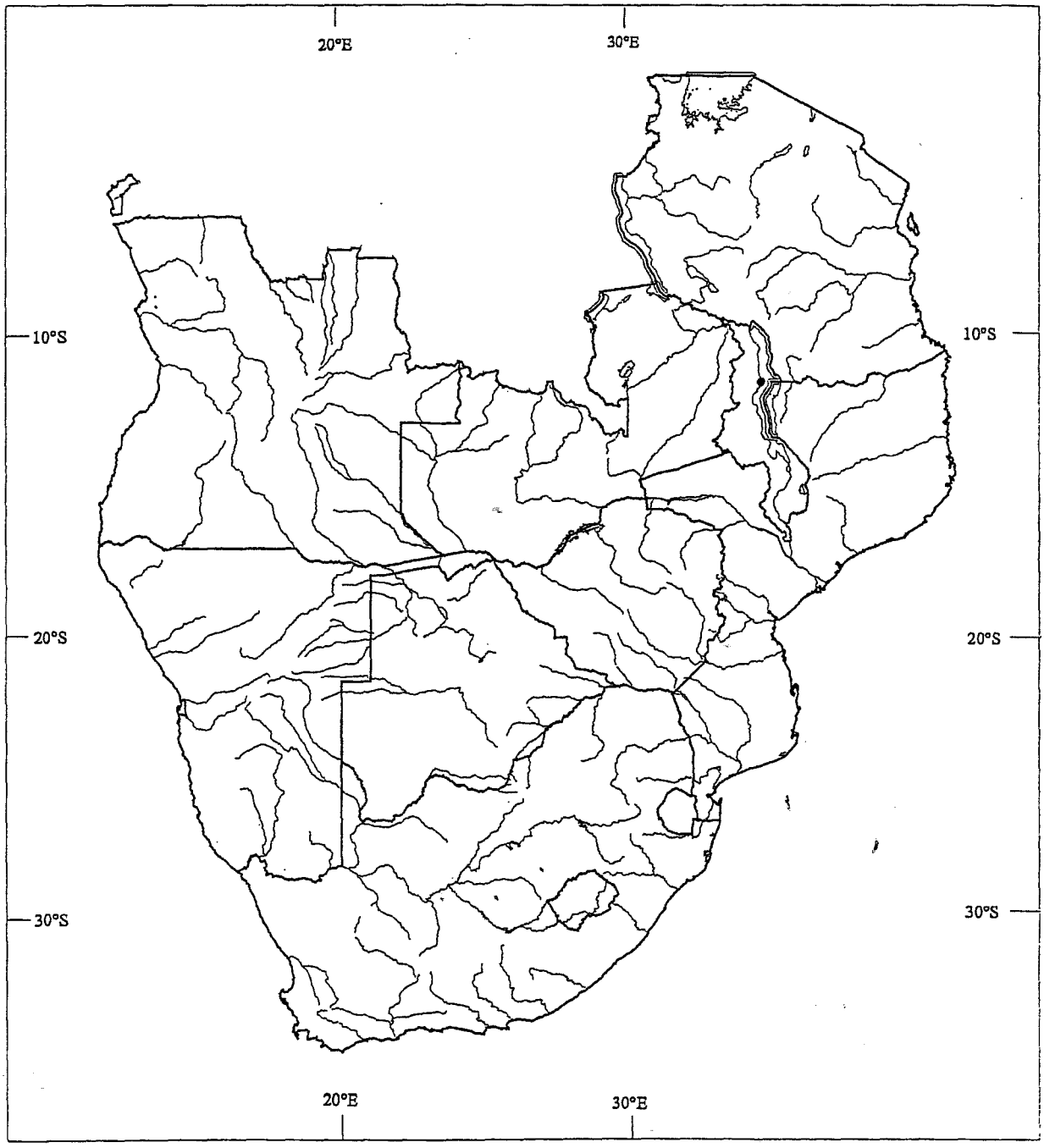


Figure F.358. Point distribution of *Labidochromis caeruleus*. Scale approximately 1:25 000 000

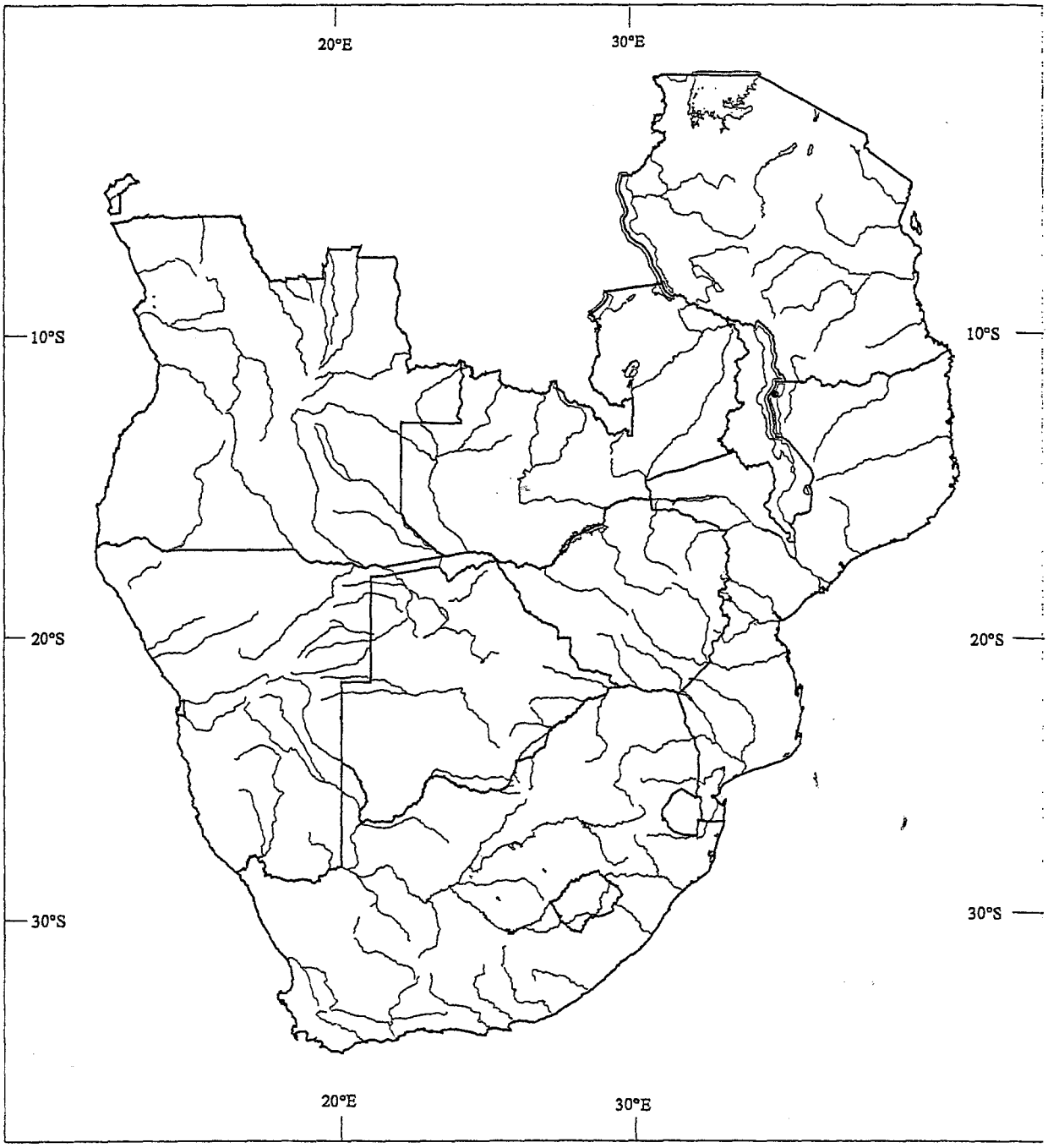


Figure F.359. Point distribution of *Labidochromis chisumulae*. Scale approximately 1:25 000 000

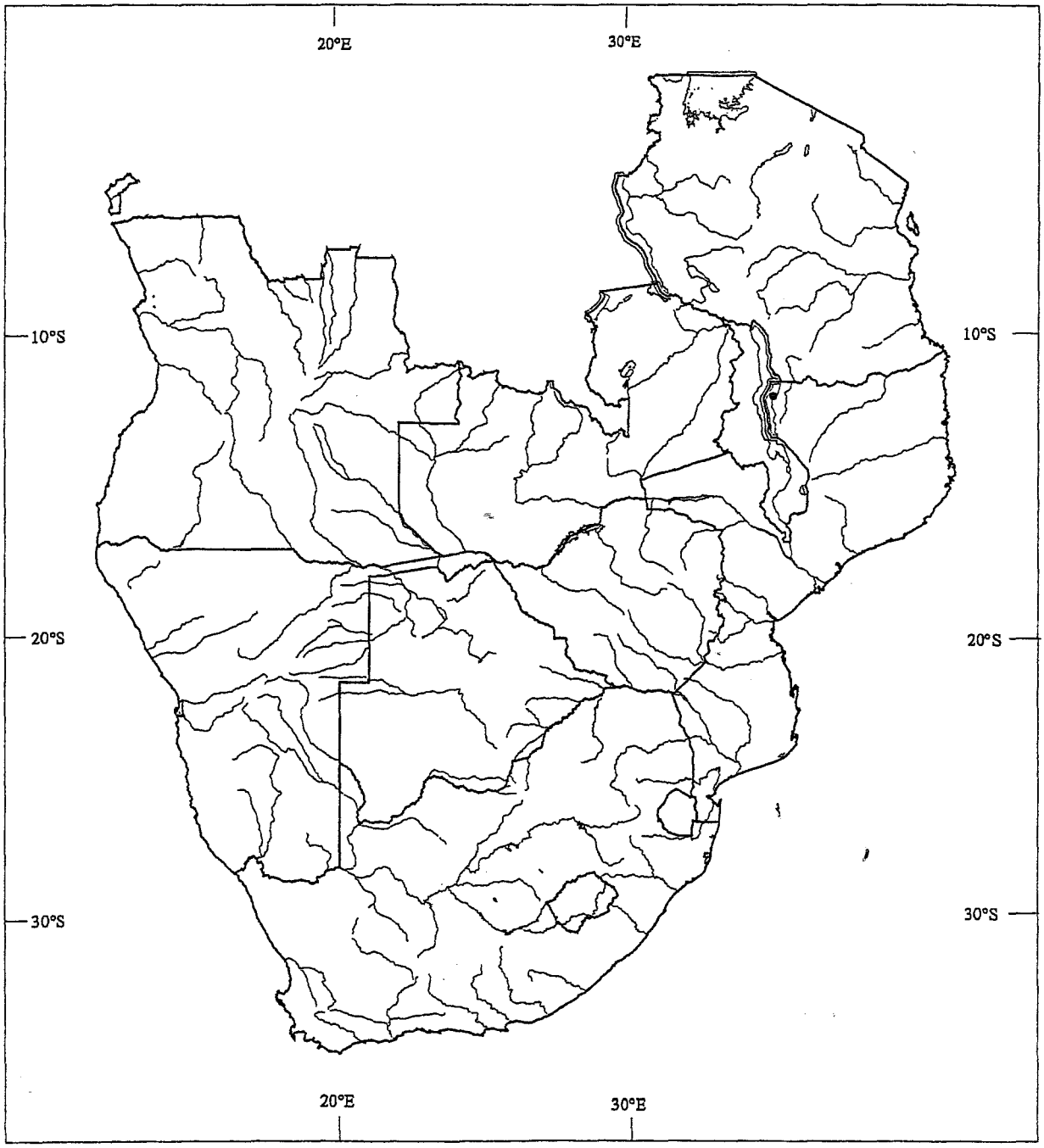


Figure F.360. Point distribution of *Labidochromis flavigulis*. Scale approximately 1:25 000 000

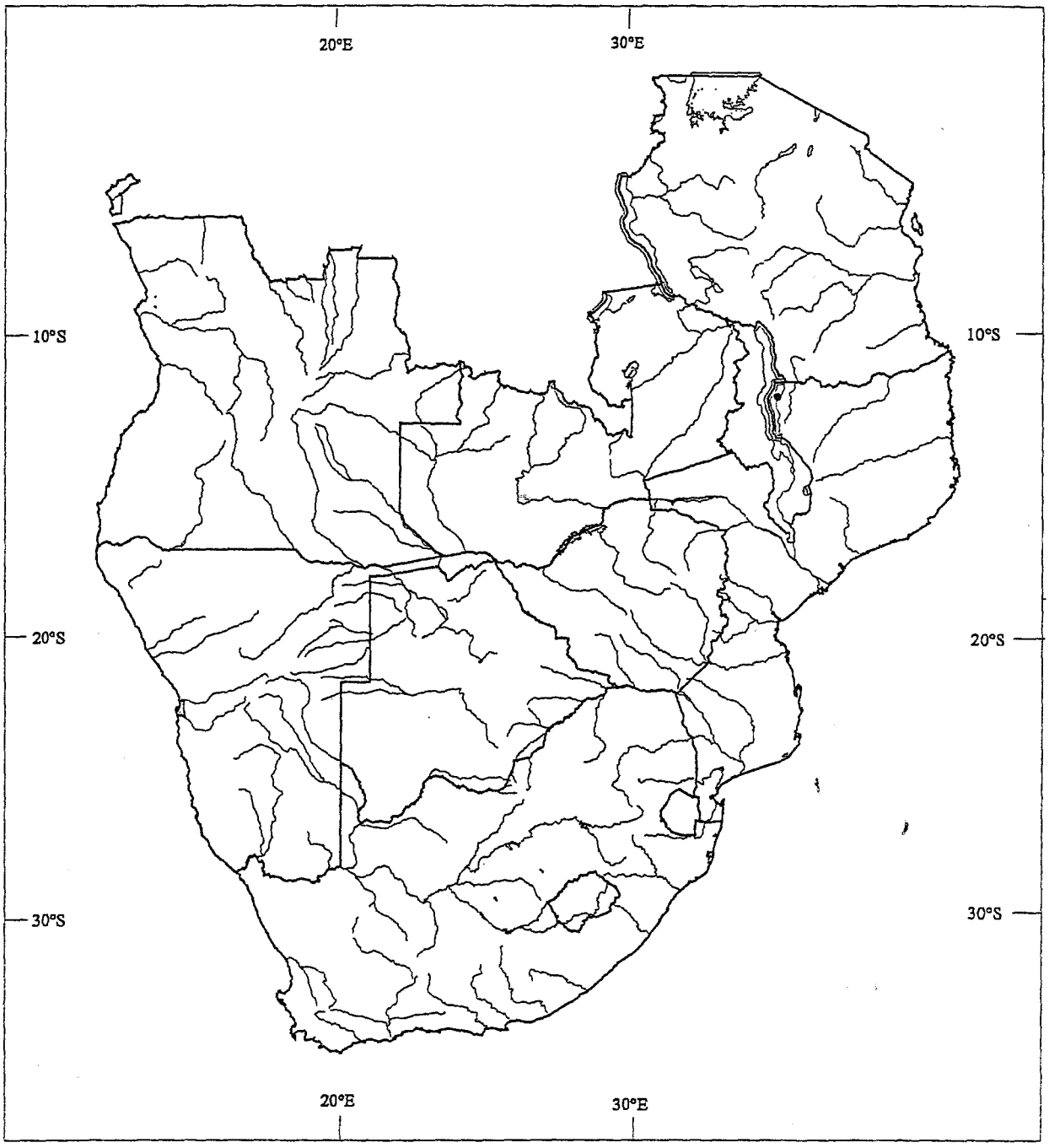


Figure F.361. Point distribution of *Labidochromis freibergi*. Scale approximately 1:25 000 000

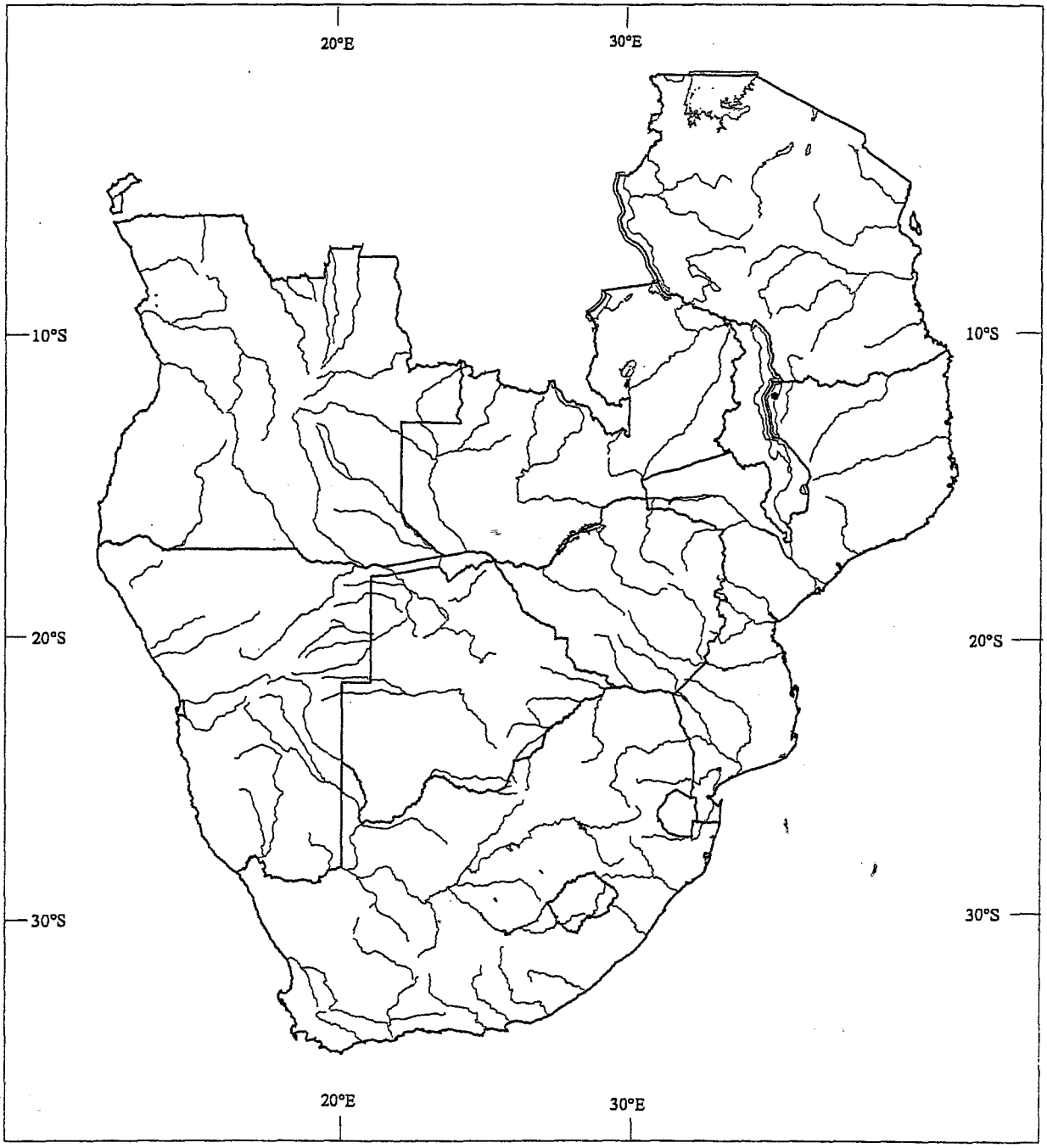


Figure F.362. Point distribution of *Labidochromis gigas*. Scale approximately 1:25 000 000

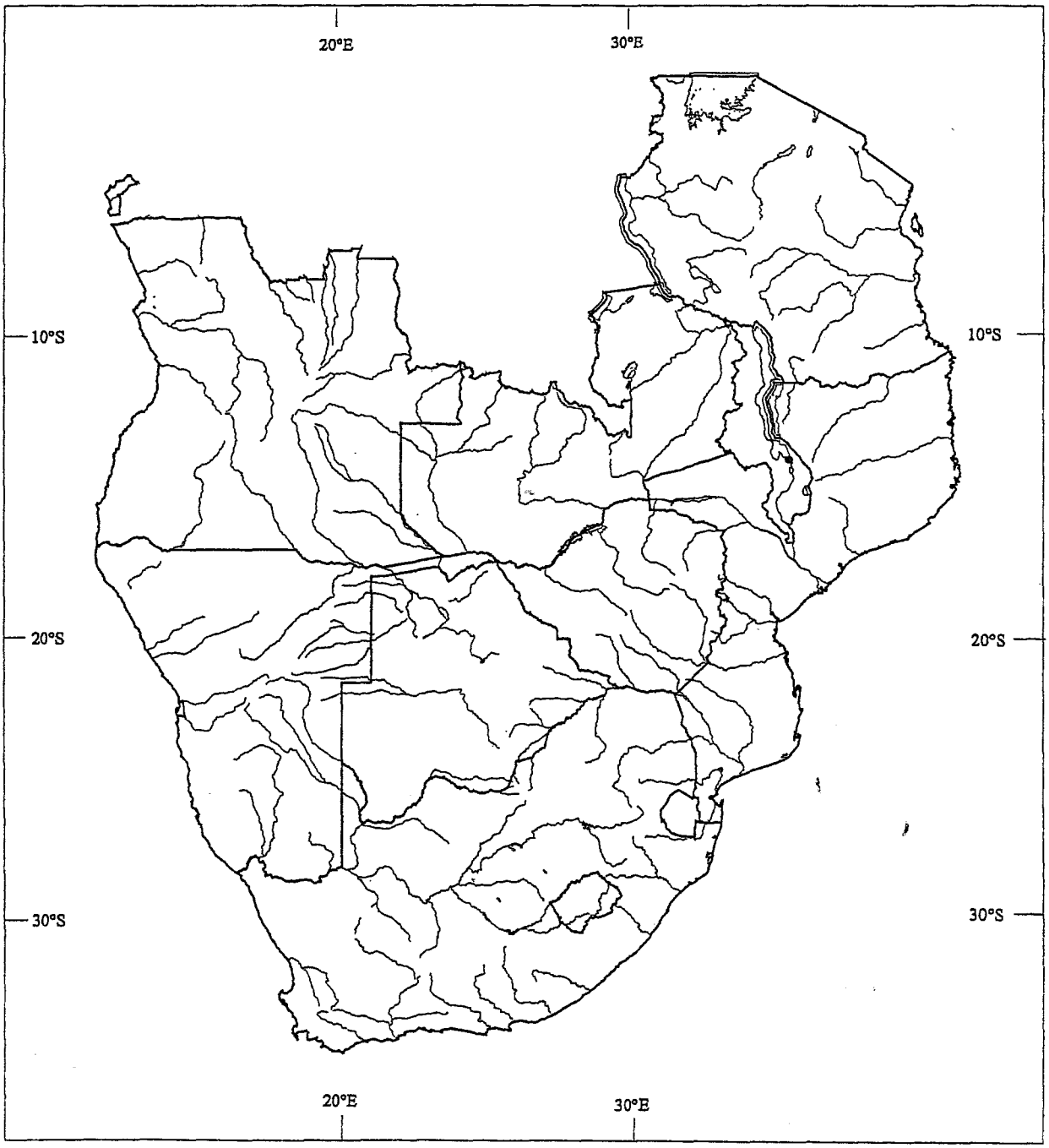


Figure F.363. Point distribution of *Labidochromis heterodon*. Scale approximately 1:25 000 000

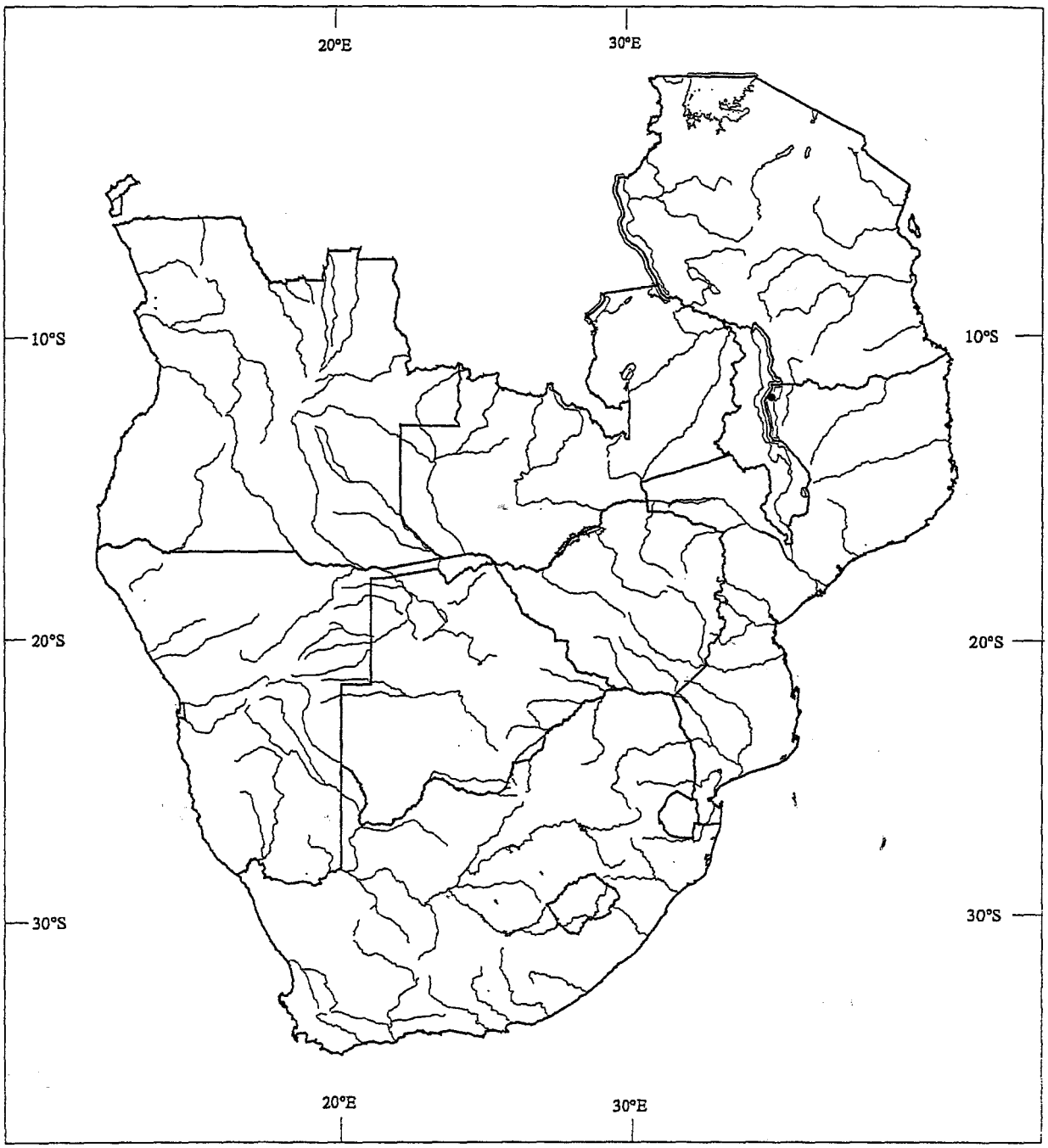


Figure F.364. Point distribution of *Labidochromis ianthinus*. Scale approximately 1:25 000 000

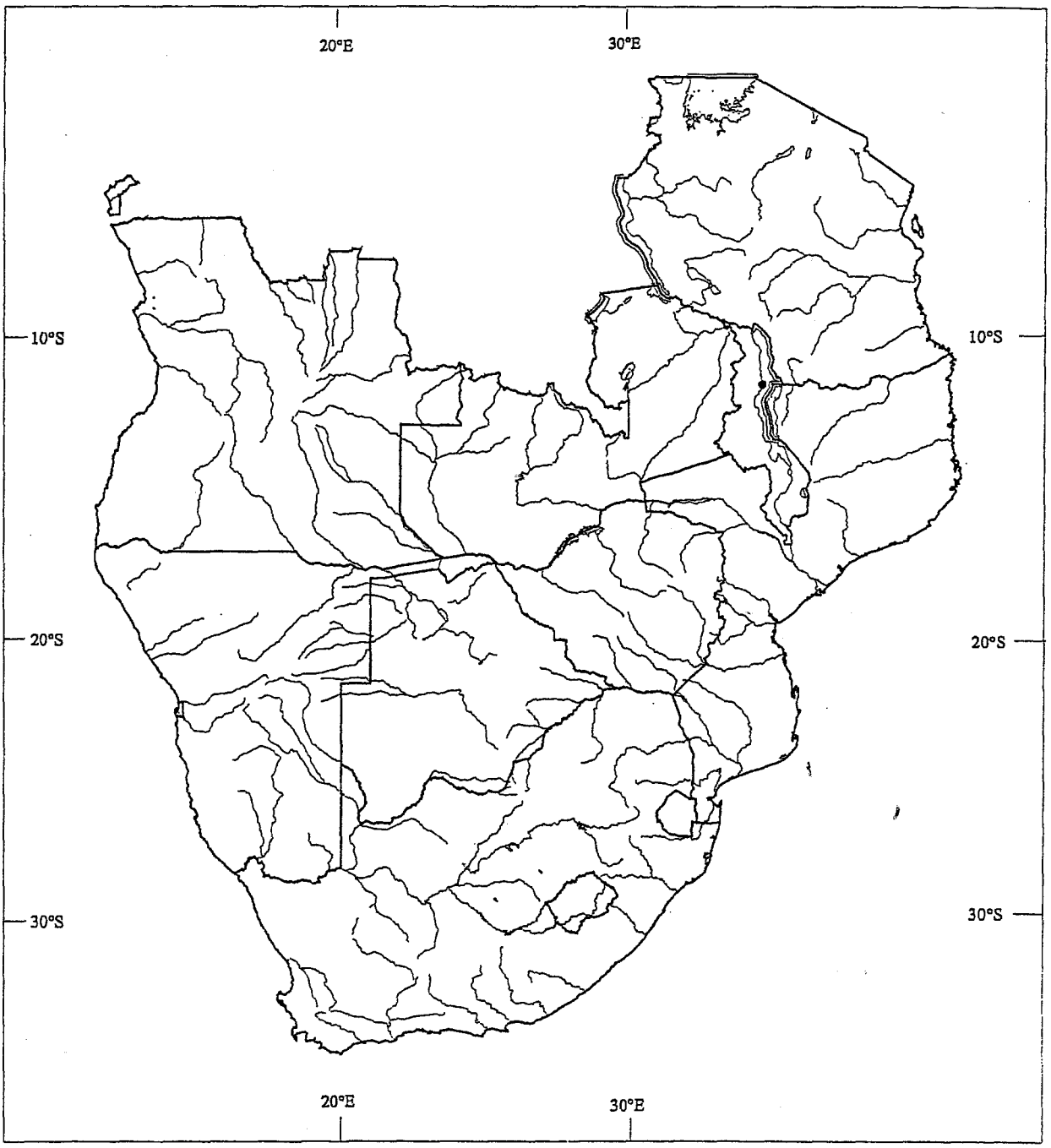


Figure F.365. Point distribution of *Labidochromis maculicauda*. Scale approximately 1:25 000 000

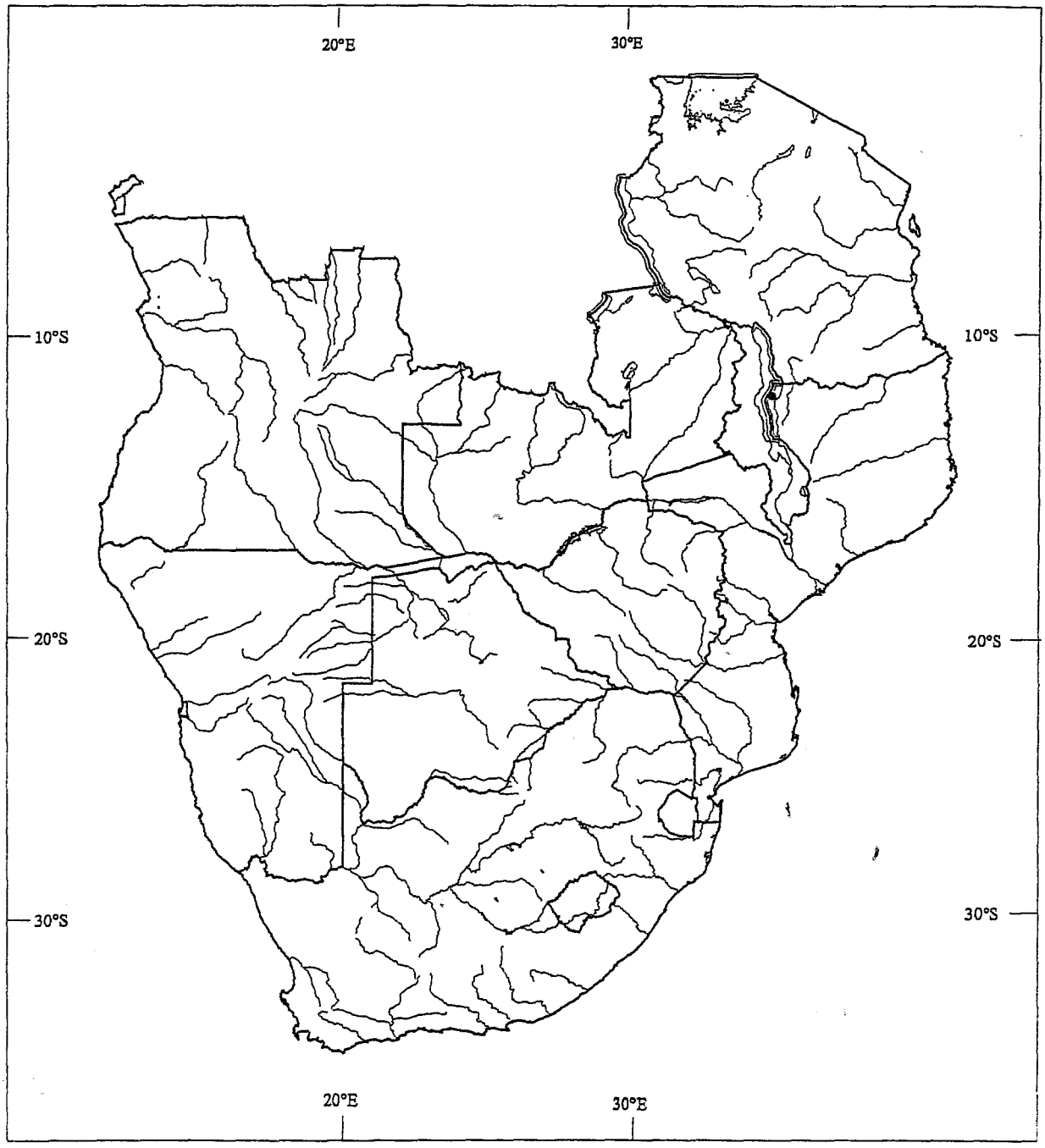


Figure F.366. Point distribution of *Labidochromis mbenjii*. Scale approximately 1:25 000 000

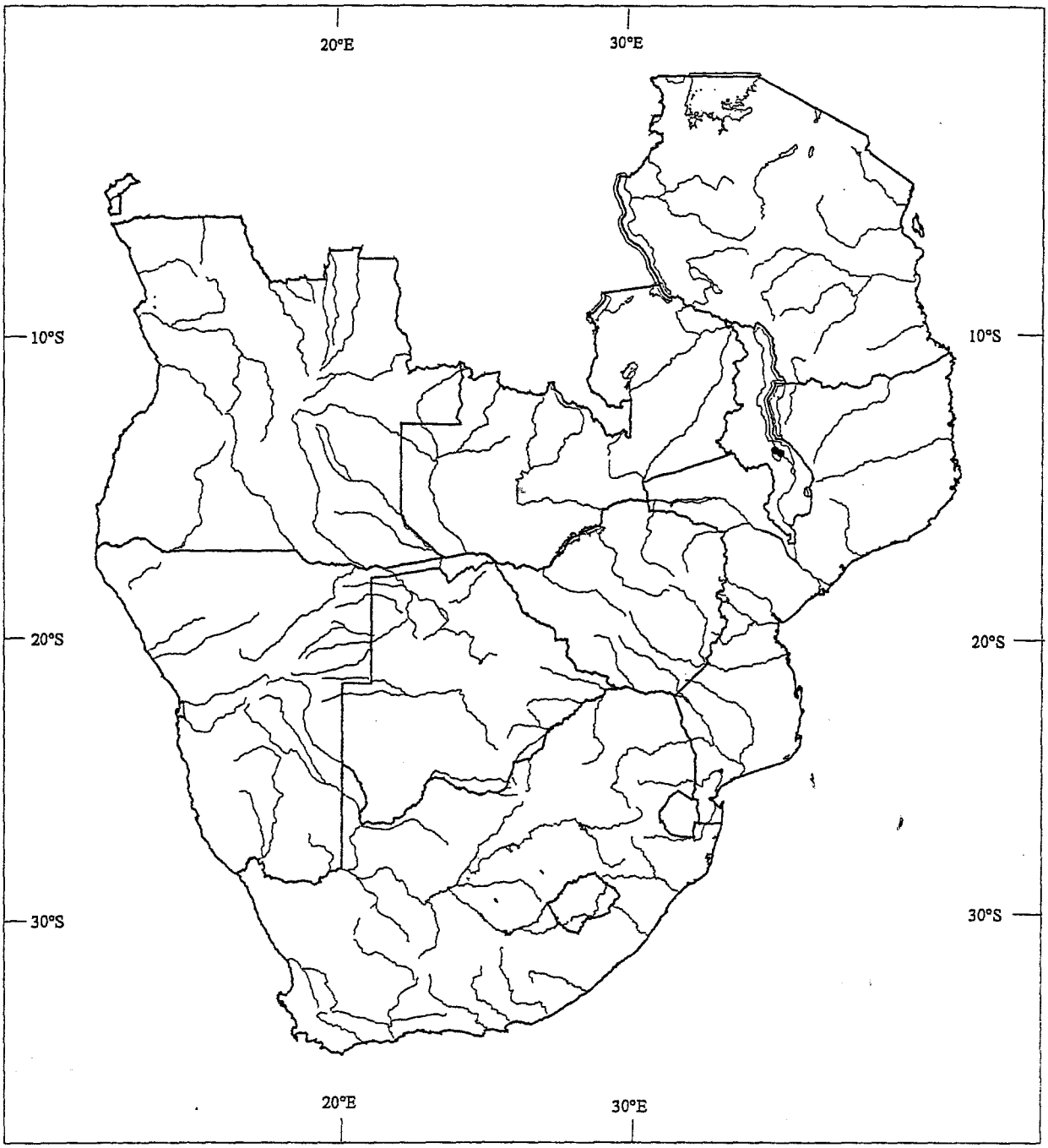


Figure F.367. Point distribution of *Labidochromis pallidus*. Scale approximately 1:25 000 000

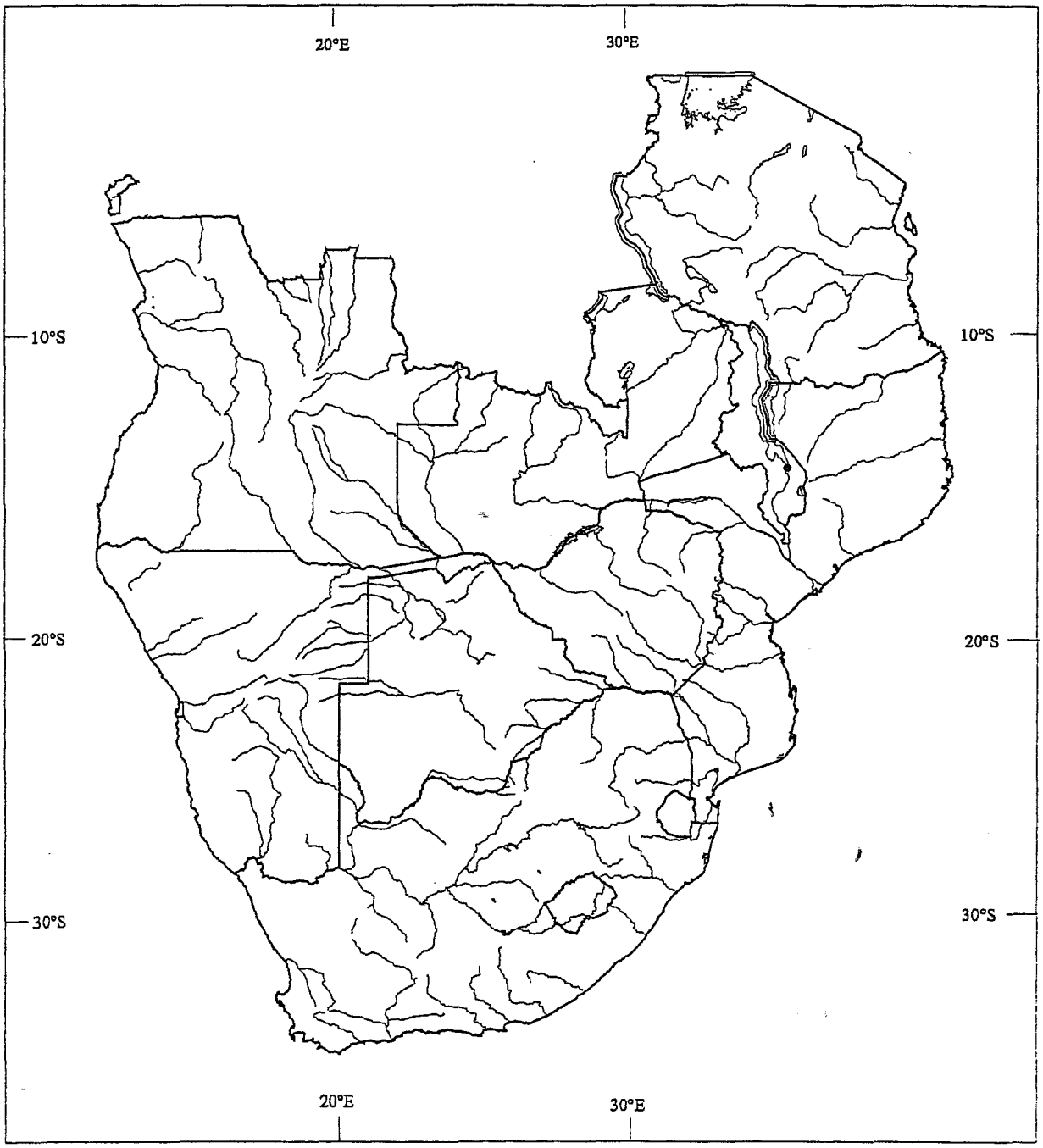


Figure F.368. Point distribution of *Labidochromis shiranus*. Scale approximately 1:25 000 000

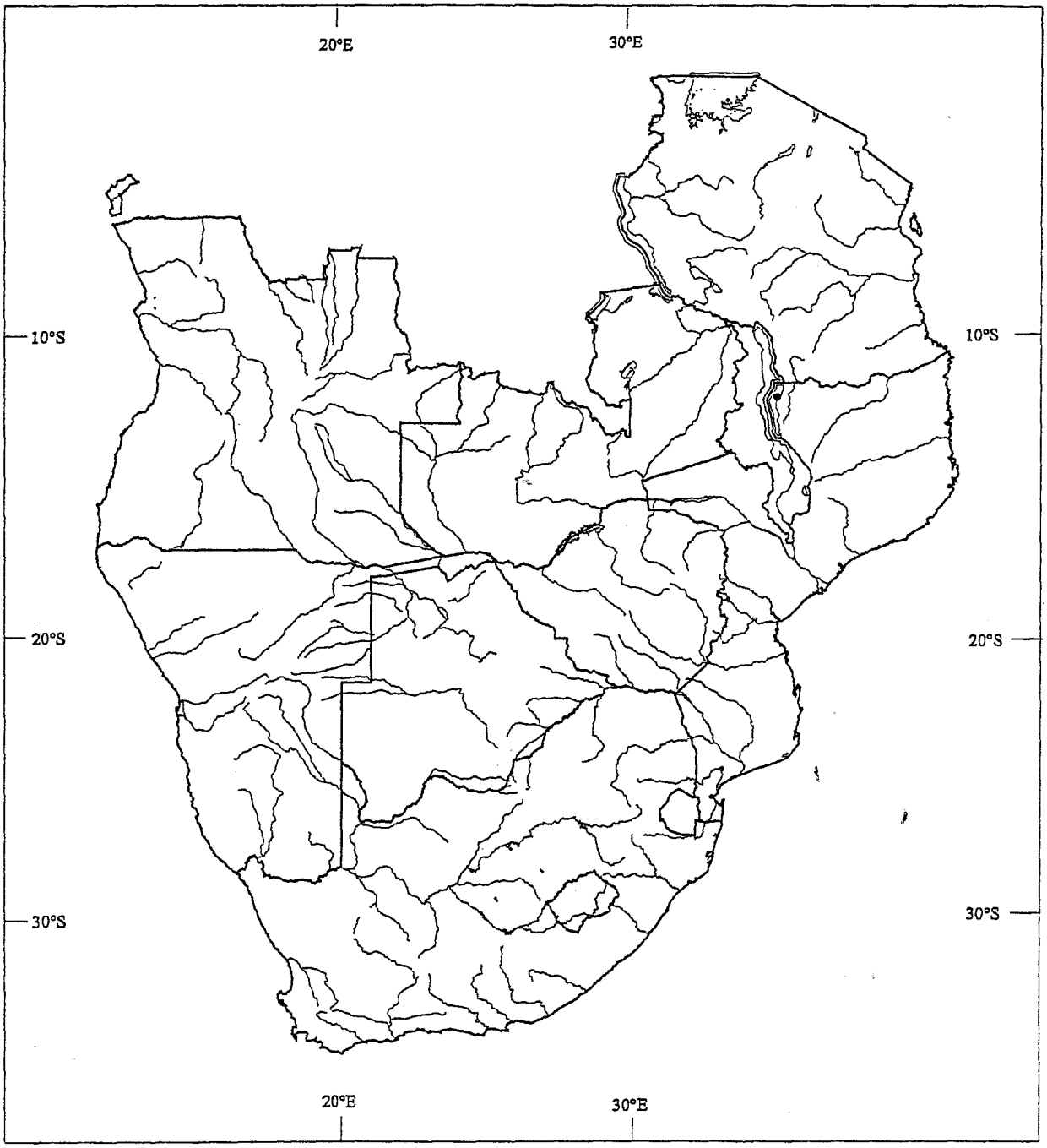


Figure F.369. Point distribution of *Labidochromis strigatus*. Scale approximately 1:25 000 000

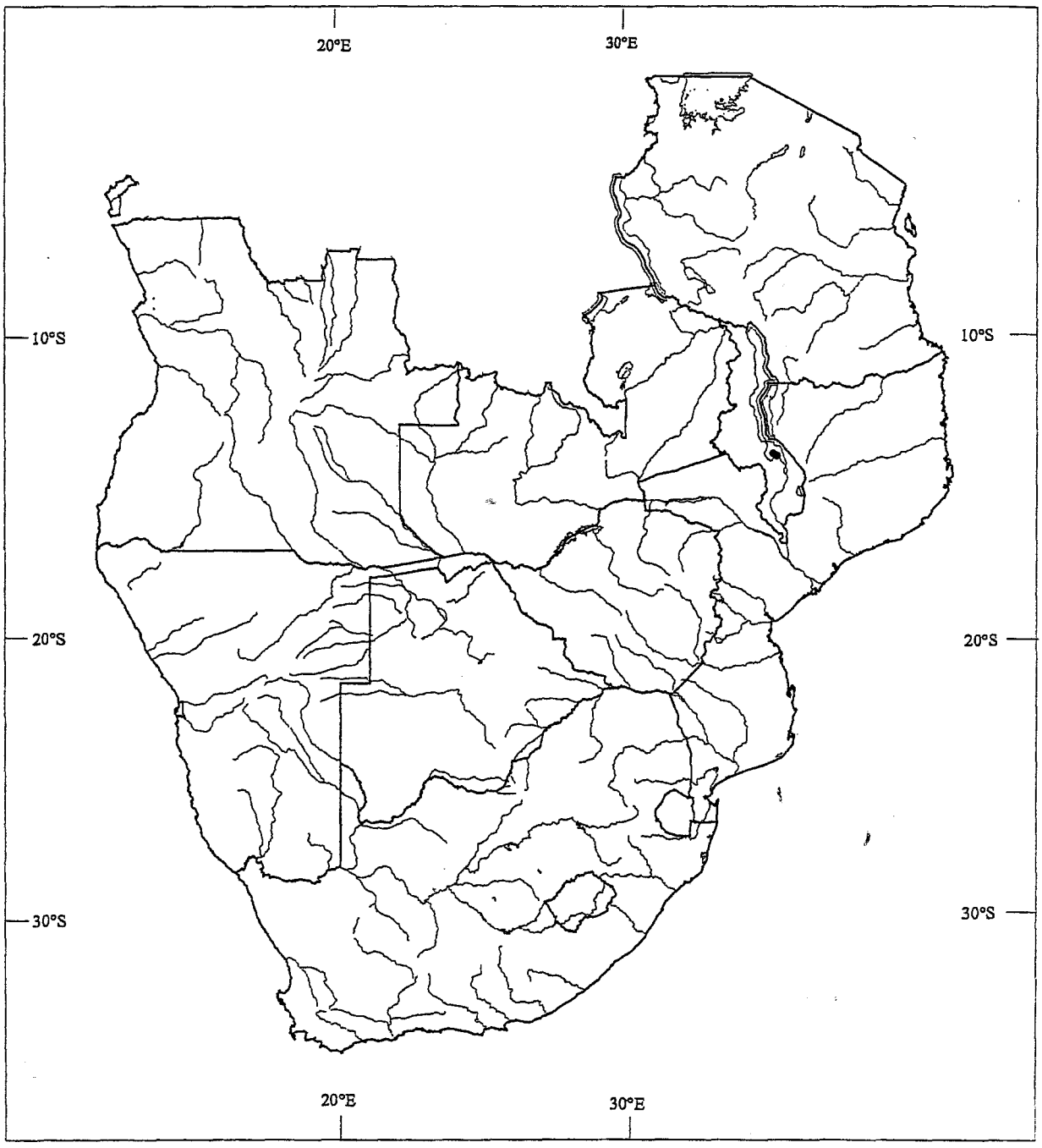


Figure F.370. Point distribution of *Labidochromis vellicans*. Scale approximately 1:25 000 000

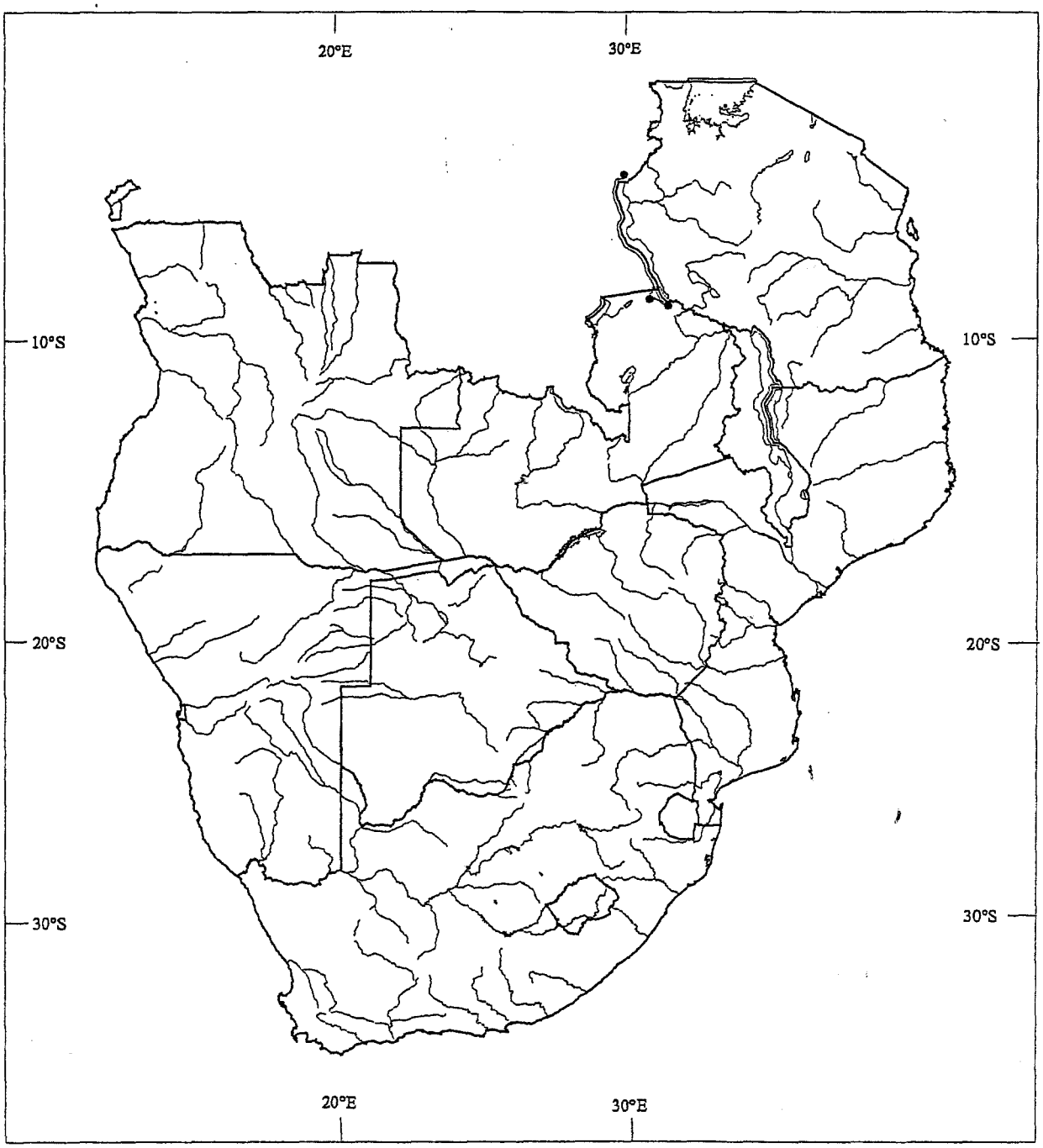


Figure F.371. Point distribution of *Lamprichthys tanganicanus*. Scale approximately 1:25 000 000

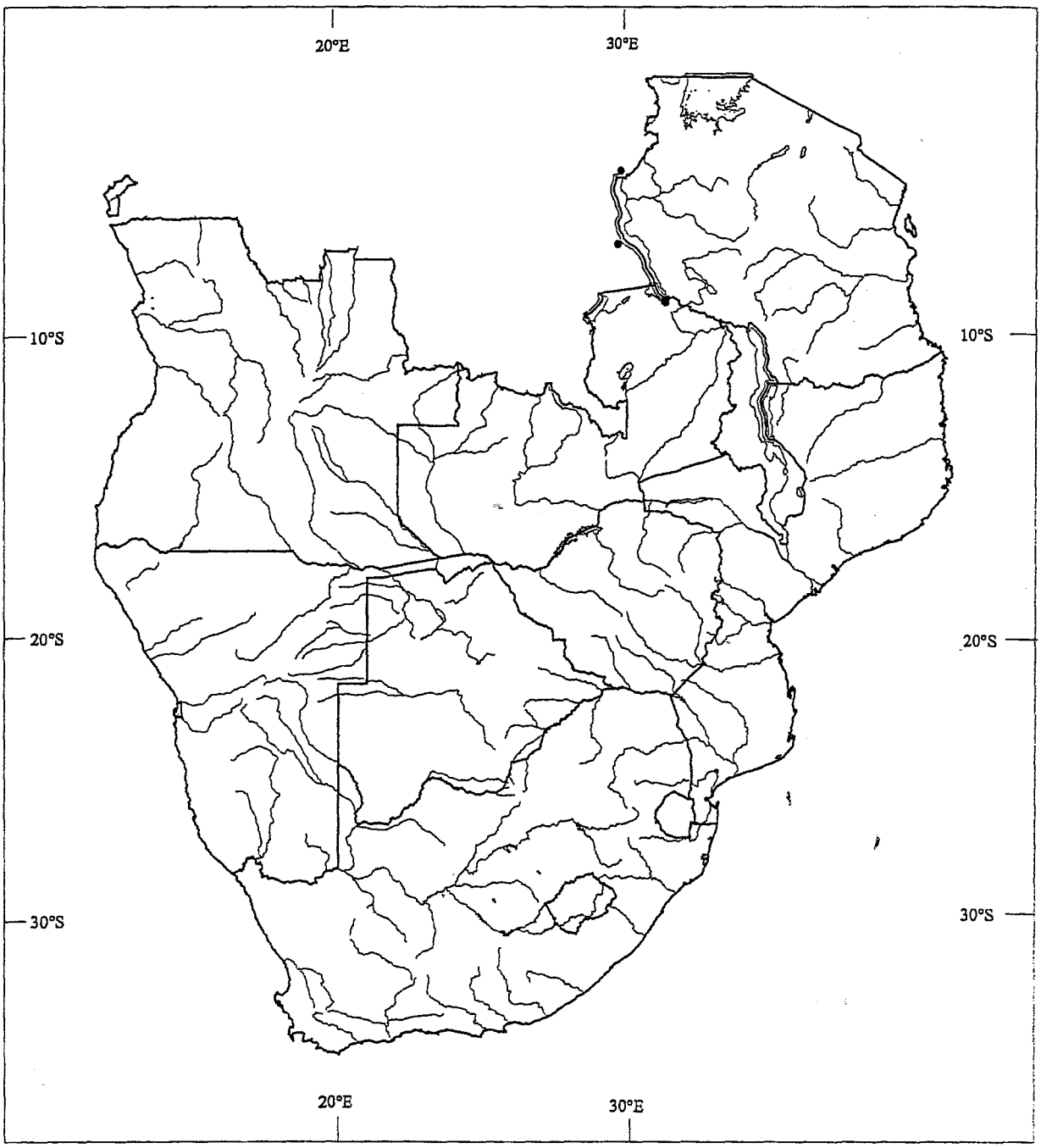


Figure F.372. Point distribution of *Lamprologus callipterus*. Scale approximately 1:25 000 000

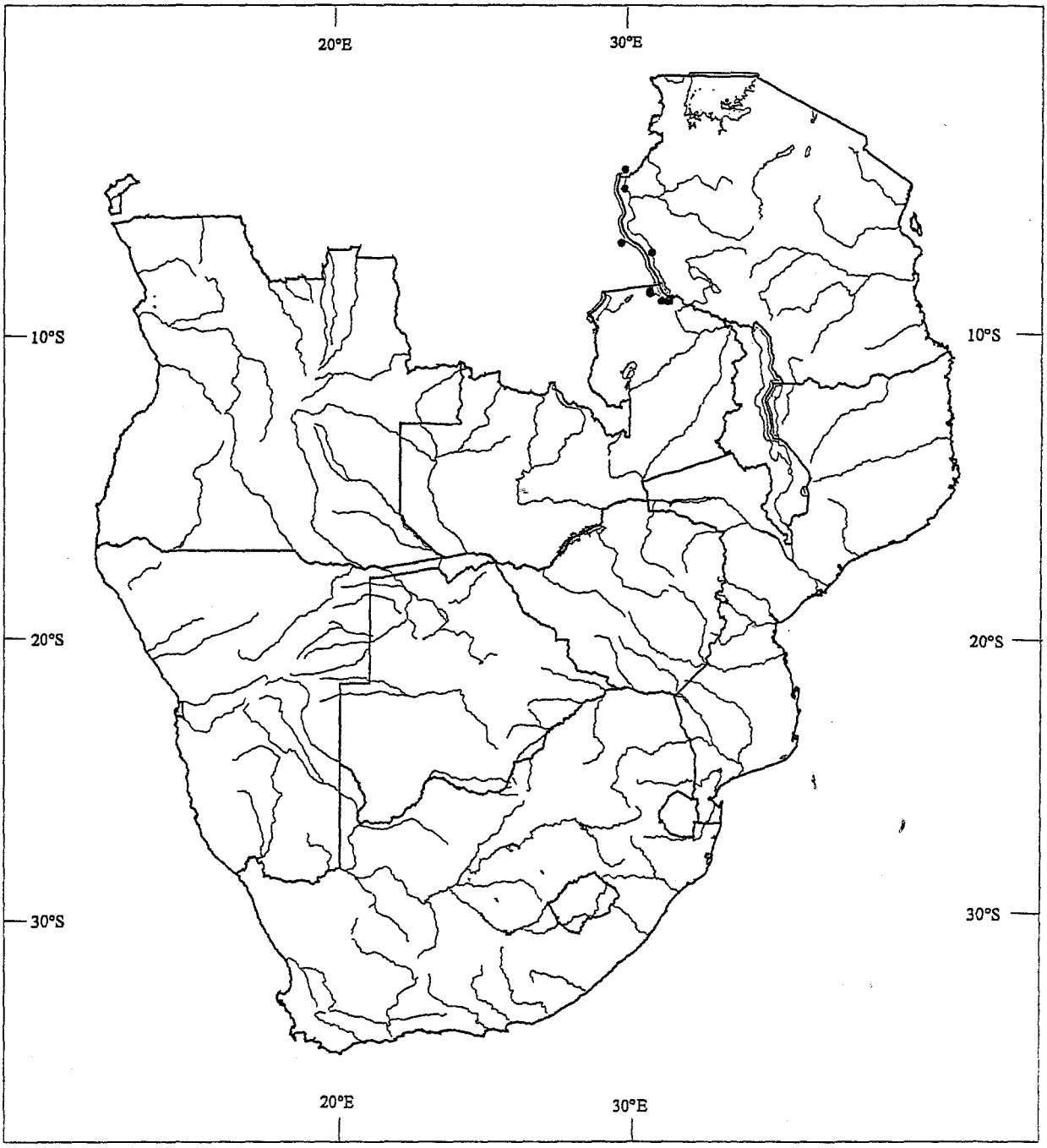


Figure F.373. Point distribution of *Lamprologus kungweensis*. Scale approximately 1:25 000 000

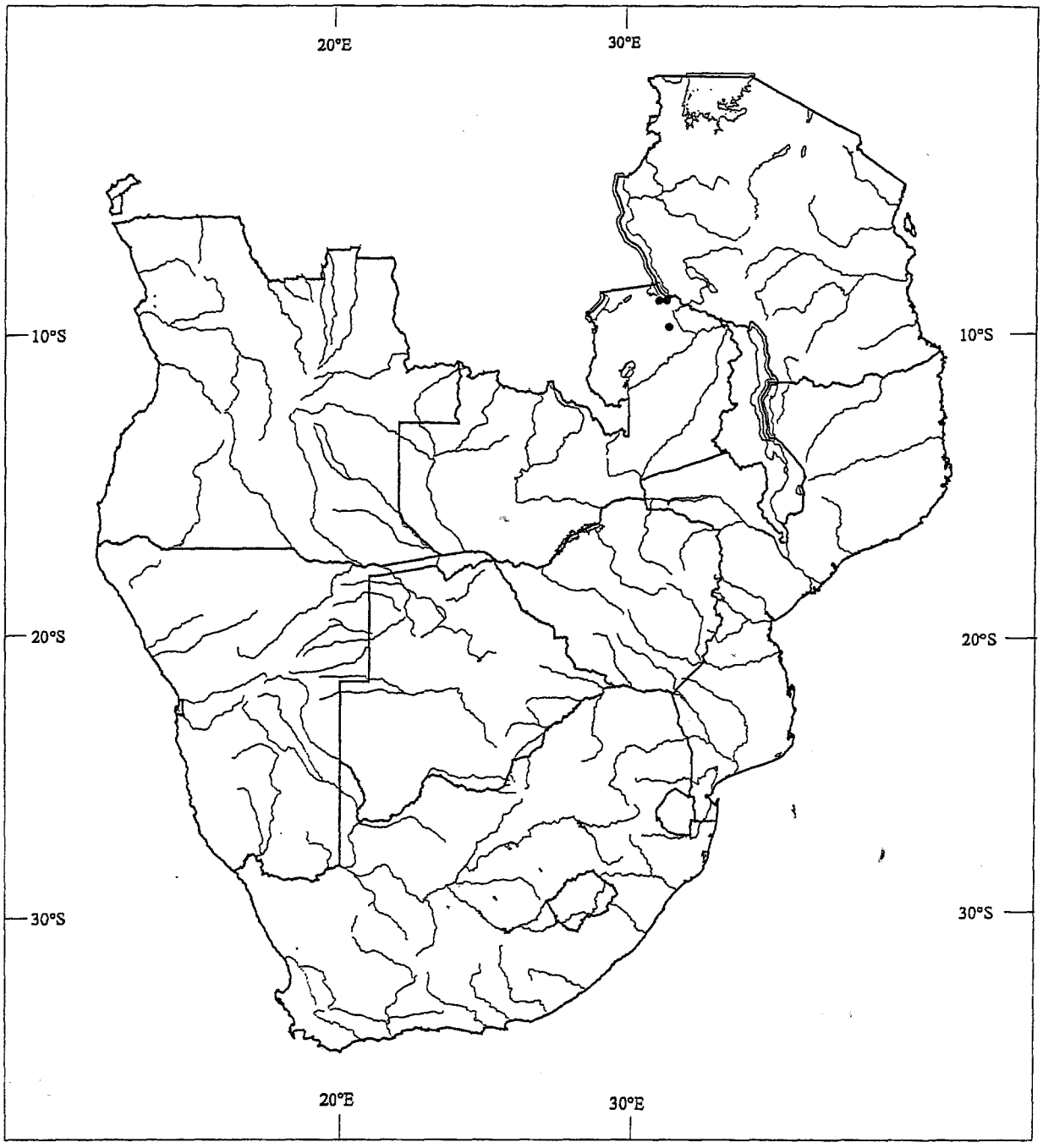


Figure F.374. Point distribution of *Lamprologus laparogramma*. Scale approximately 1:25 000 000

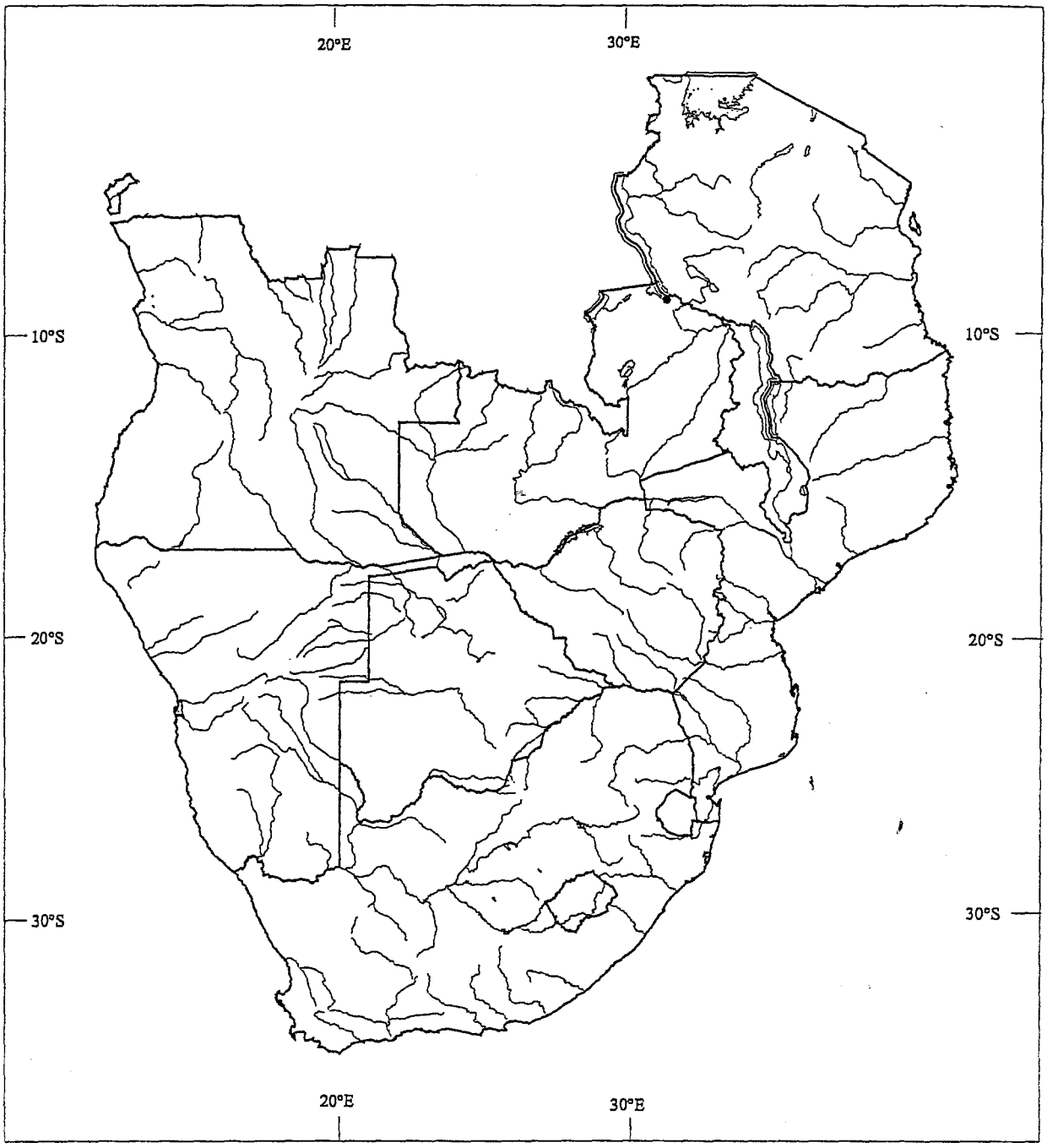


Figure F.375. Point distribution of *Lamprologus lemairei*. Scale approximately 1:25 000 000

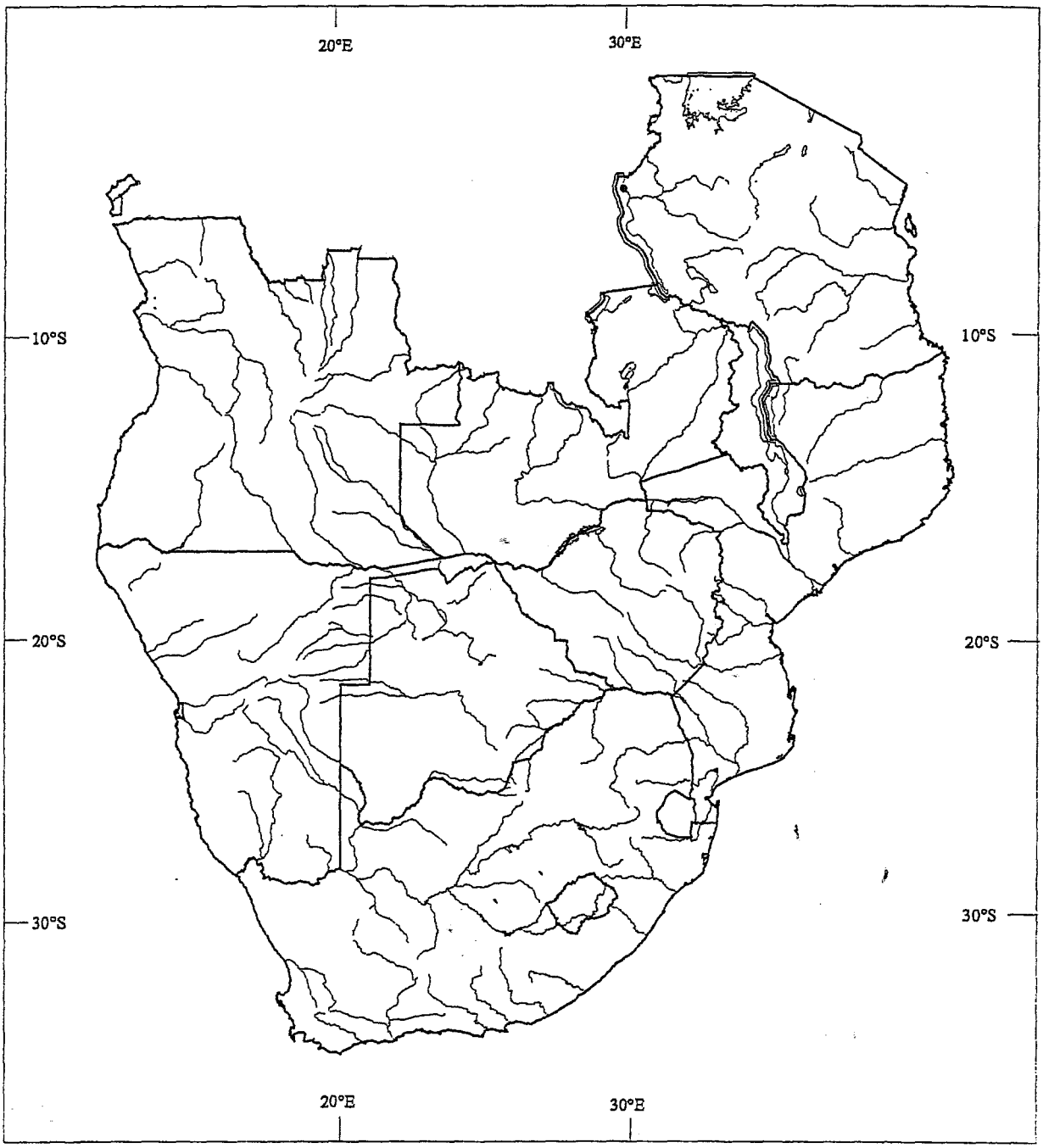


Figure F.376. Point distribution of *Lamprologus moorei*. Scale approximately 1:25 000 000

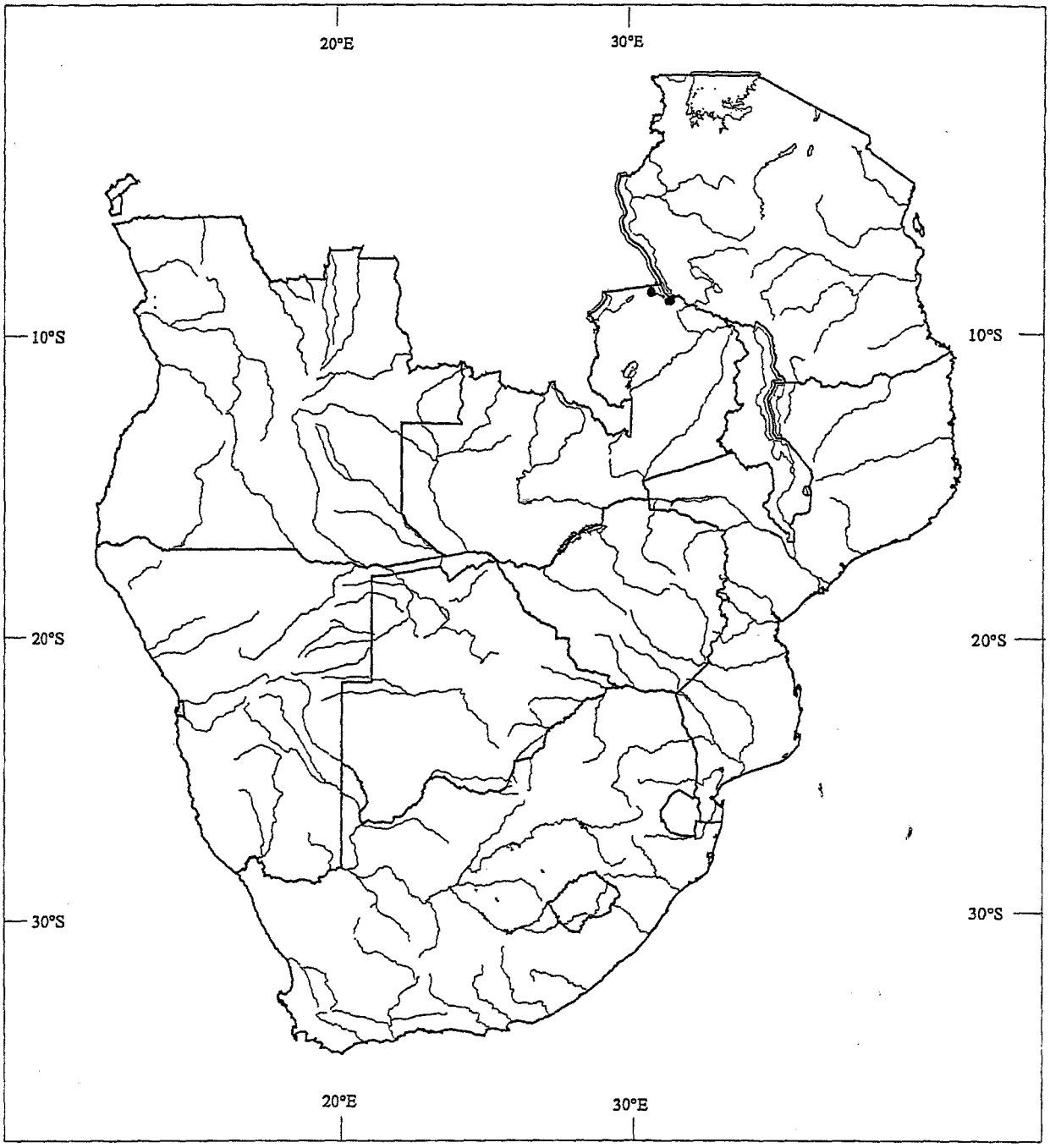


Figure F.377. Point distribution of *Lamprologus ornatipinnis*. Scale approximately 1:25 000 000

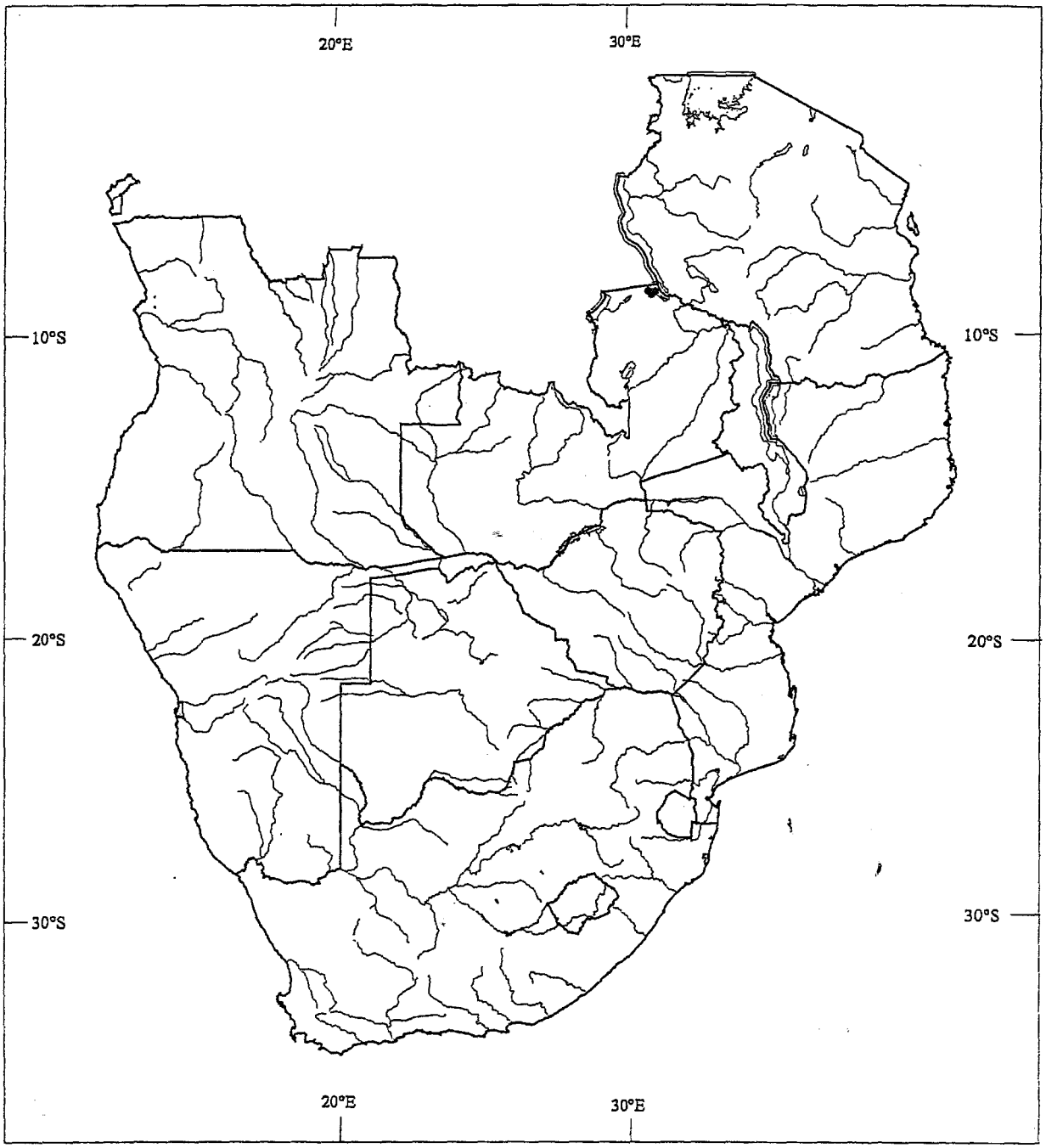


Figure F.378. Point distribution of *Lamprologus signatus*. Scale approximately 1:25 000 000

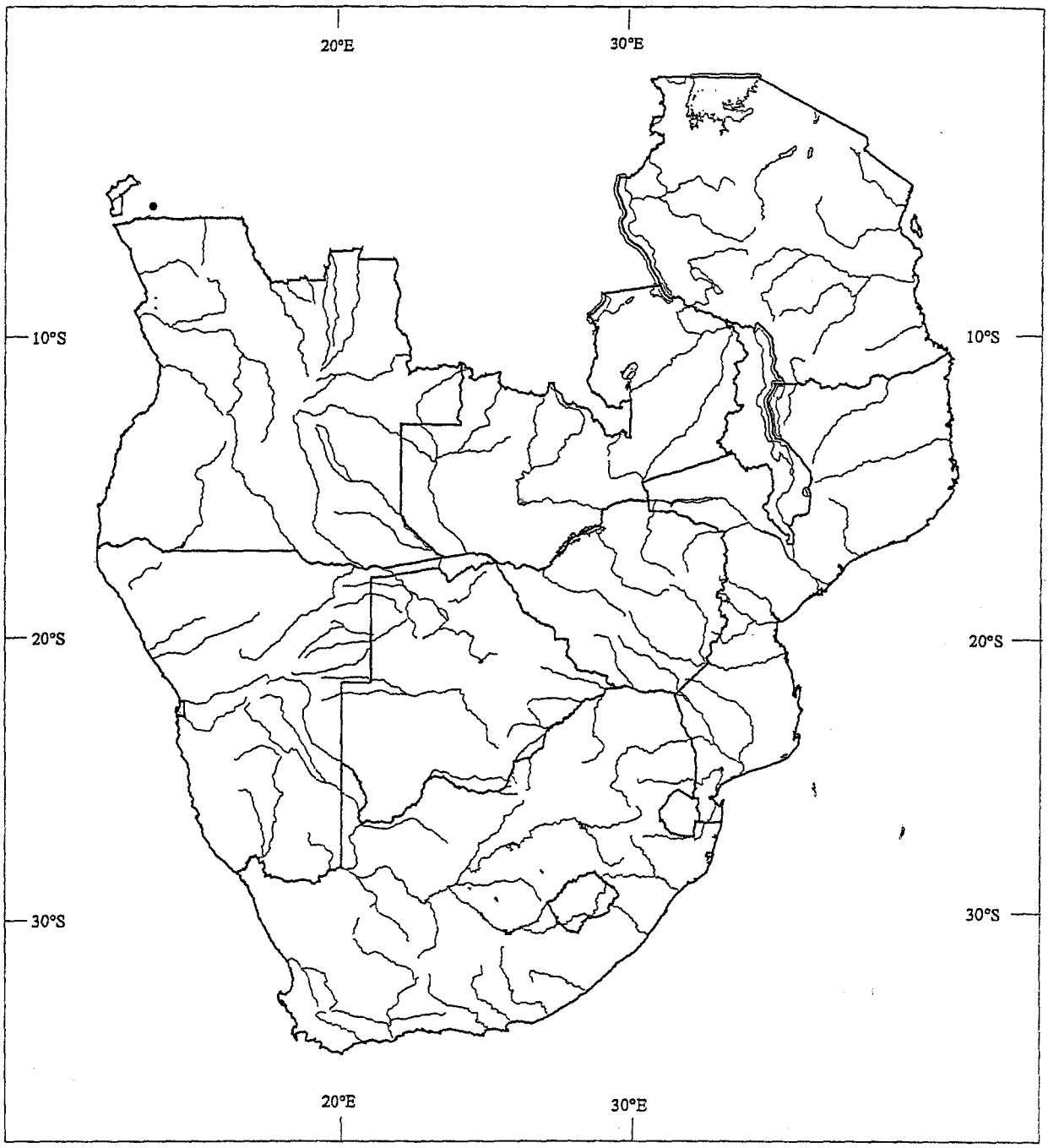


Figure F.379. Point distribution of *Lamprologus werneri*. Scale approximately 1:25 000 000

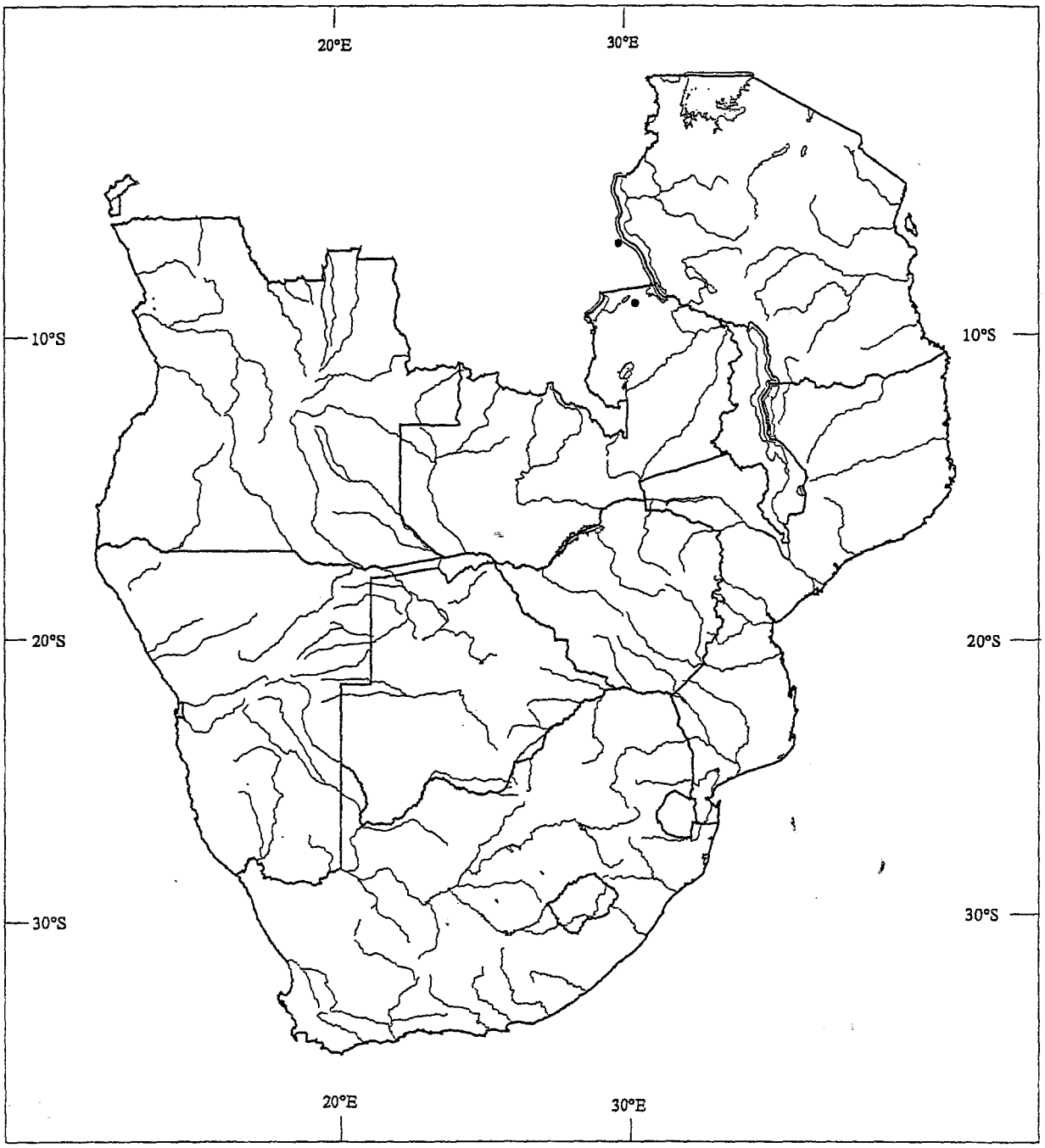


Figure F.380. Point distribution of *Lates augustifrons*. Scale approximately 1:25 000 000

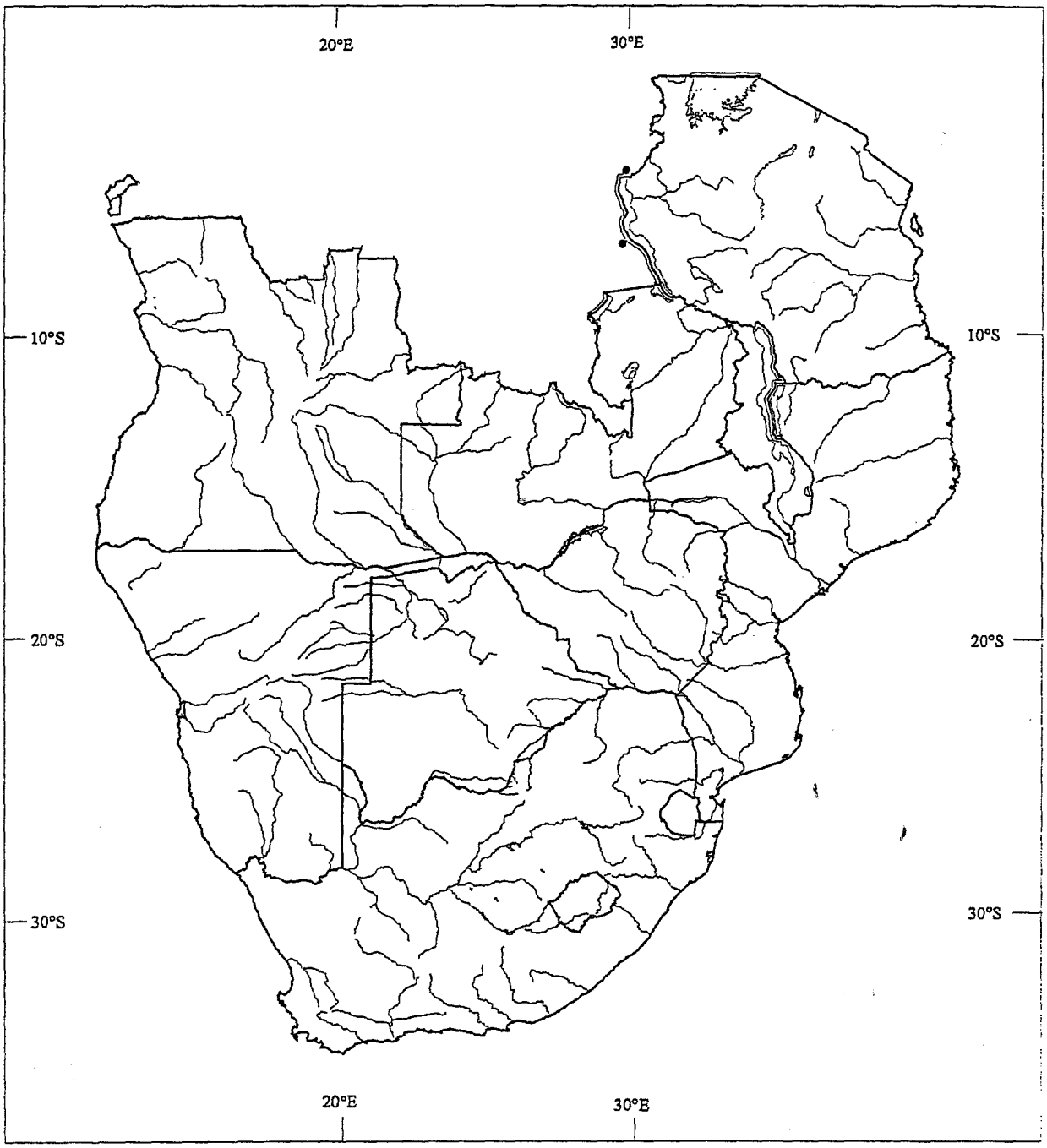


Figure F.381. Point distribution of *Lates mariae*. Scale approximately 1:25 000 000

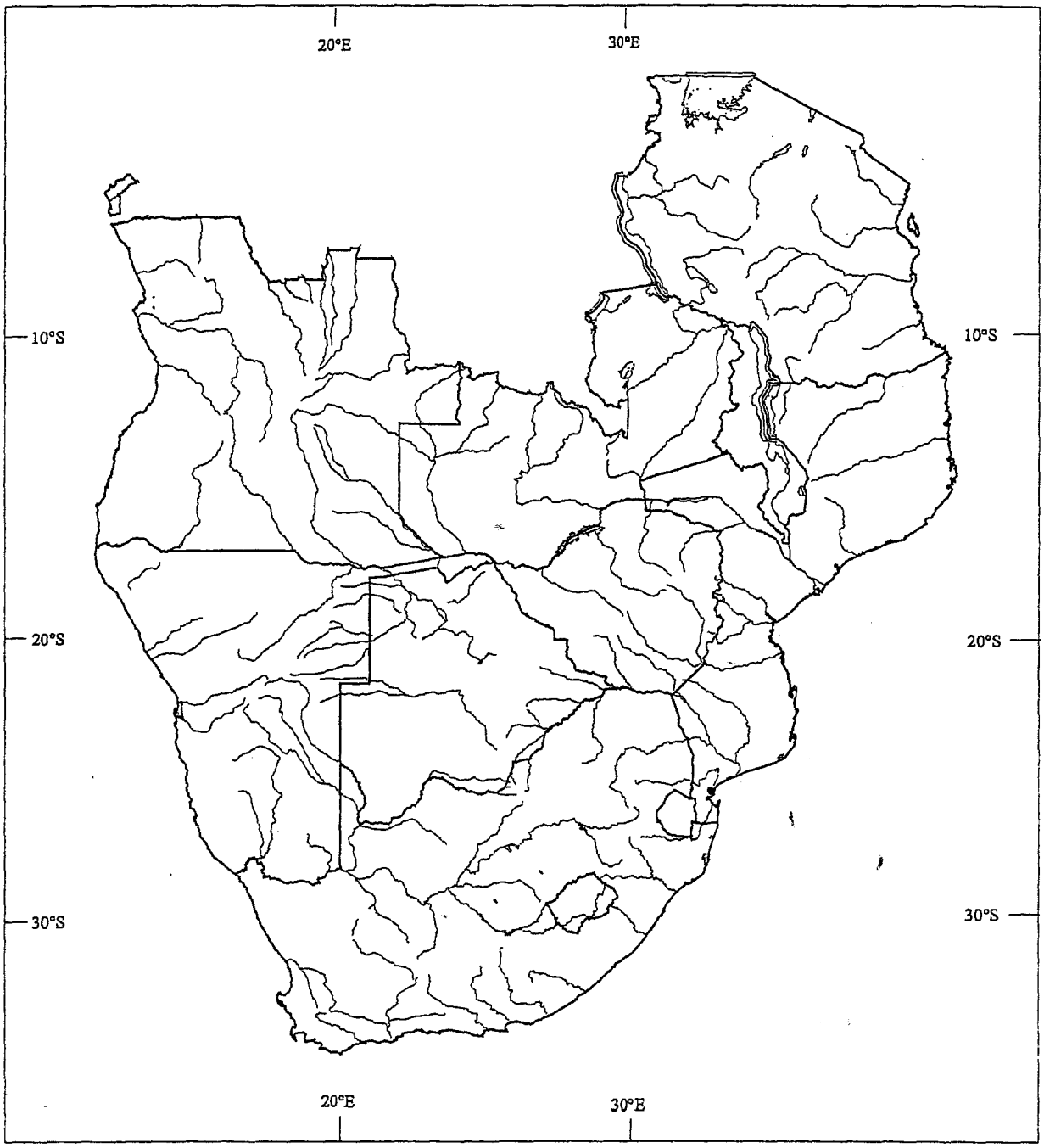


Figure F.382. Point distribution of *Leiognathus equula*. Scale approximately 1:25 000 000

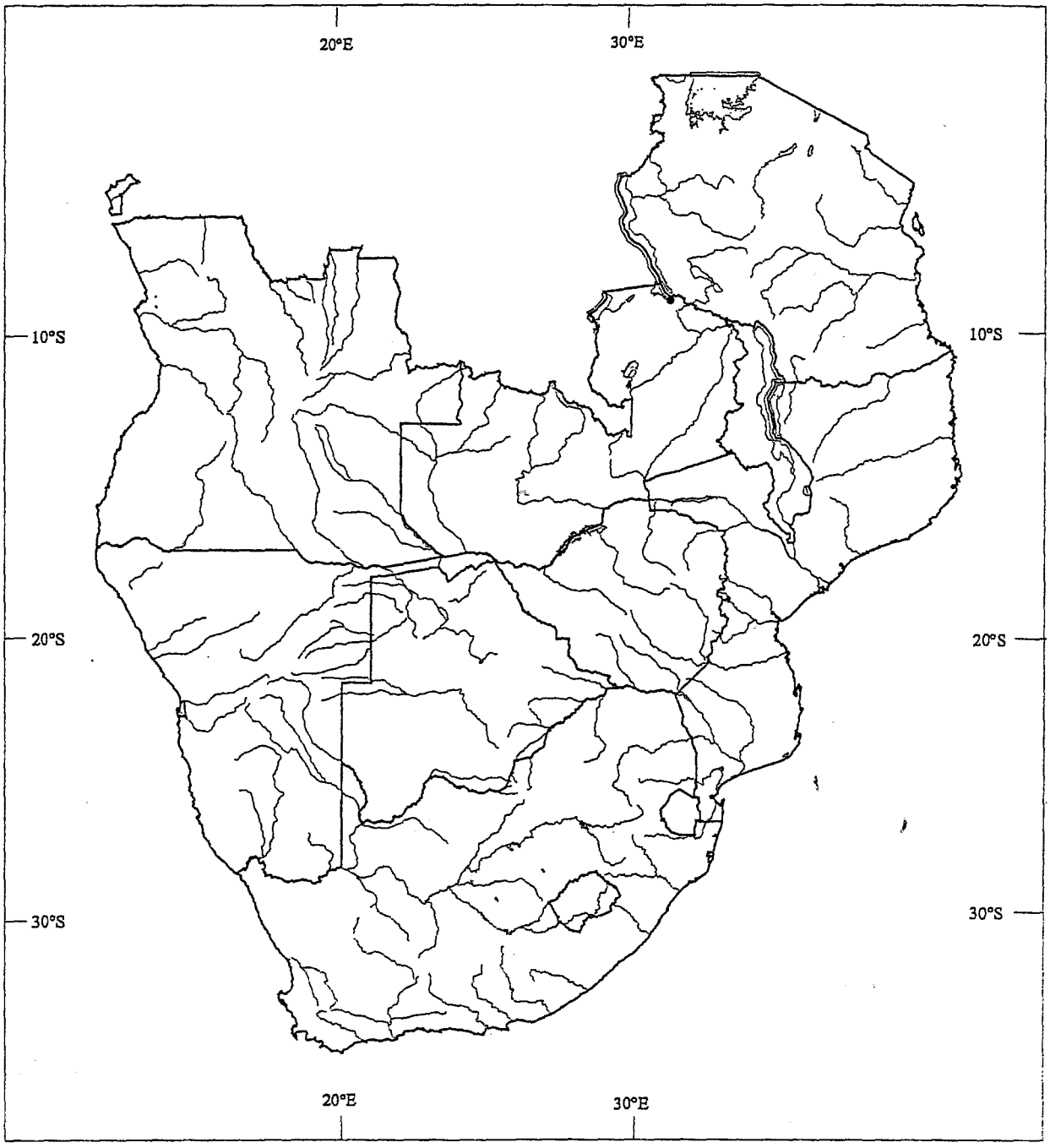


Figure F.383. Point distribution of *Lepidiolamprologus attenuatus*. Scale approximately 1:25 000 000

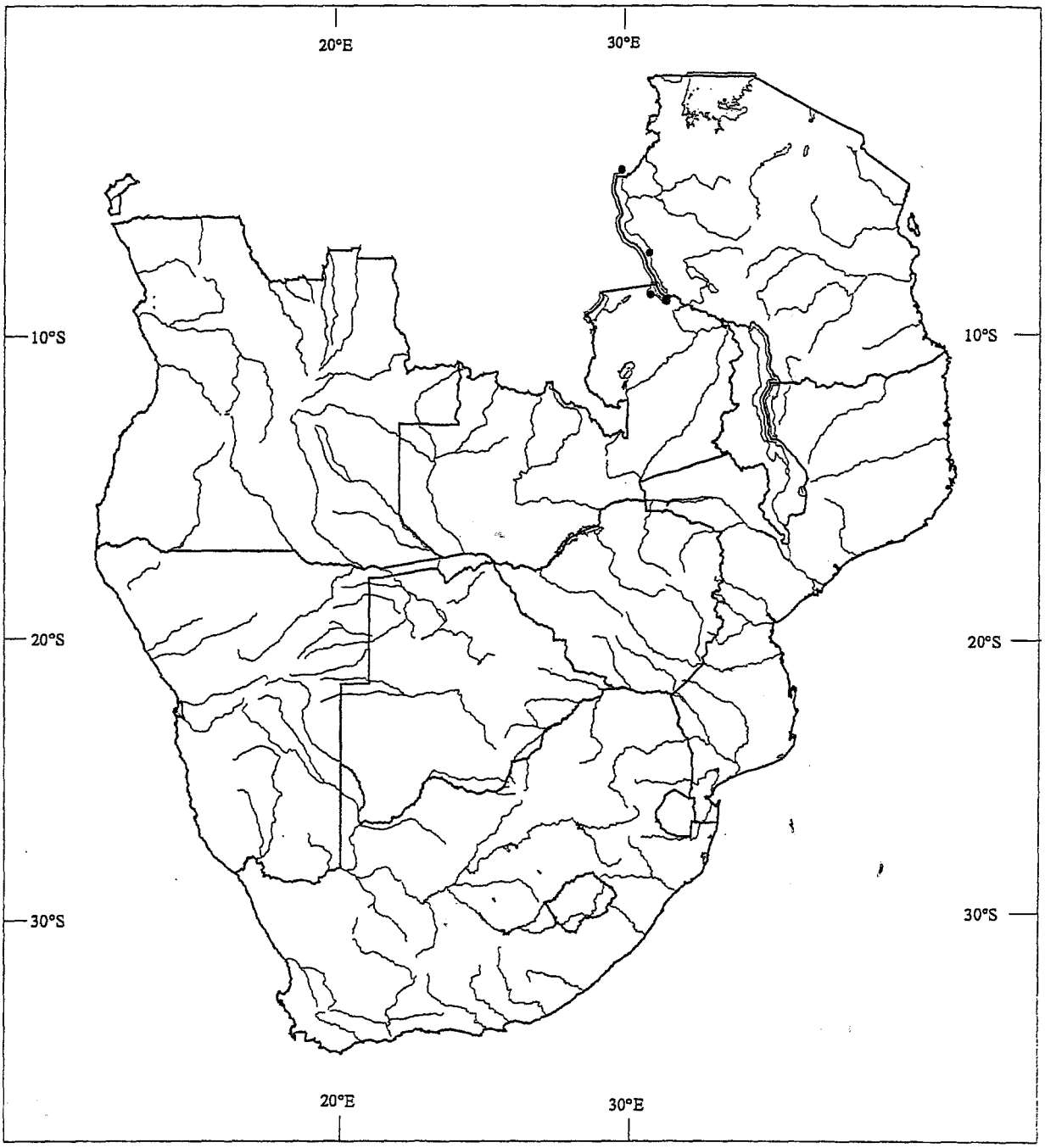


Figure F.384. Point distribution of *Lepidiolamprologus cunningtoni*. Scale approximately 1:25 000 000

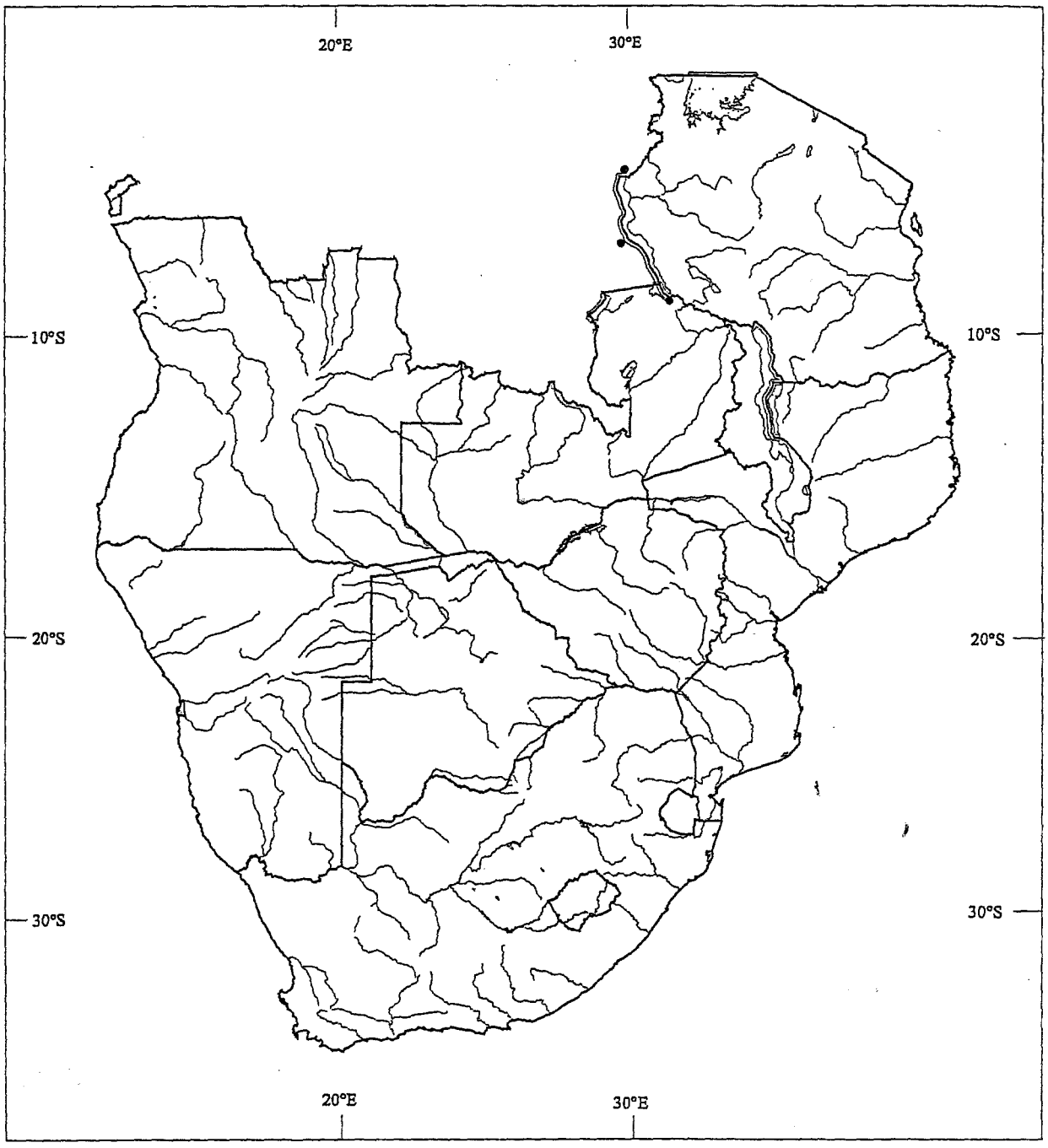


Figure F.385. Point distribution of *Lepidiolamprologus elongatus*. Scale approximately 1:25 000 000

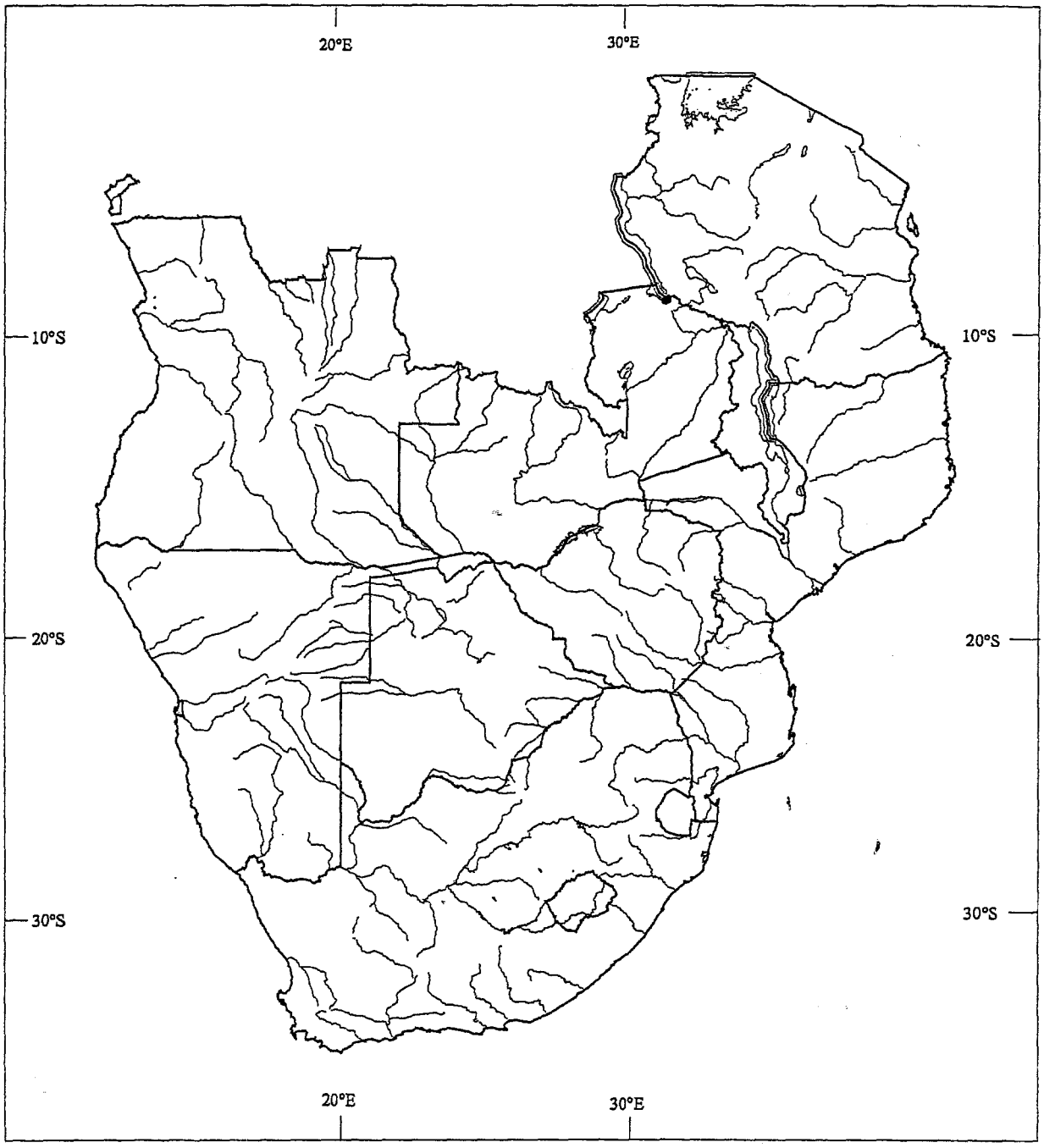


Figure F.386. Point distribution of *Lepidiolamprologus kendalli*. Scale approximately 1:25 000 000

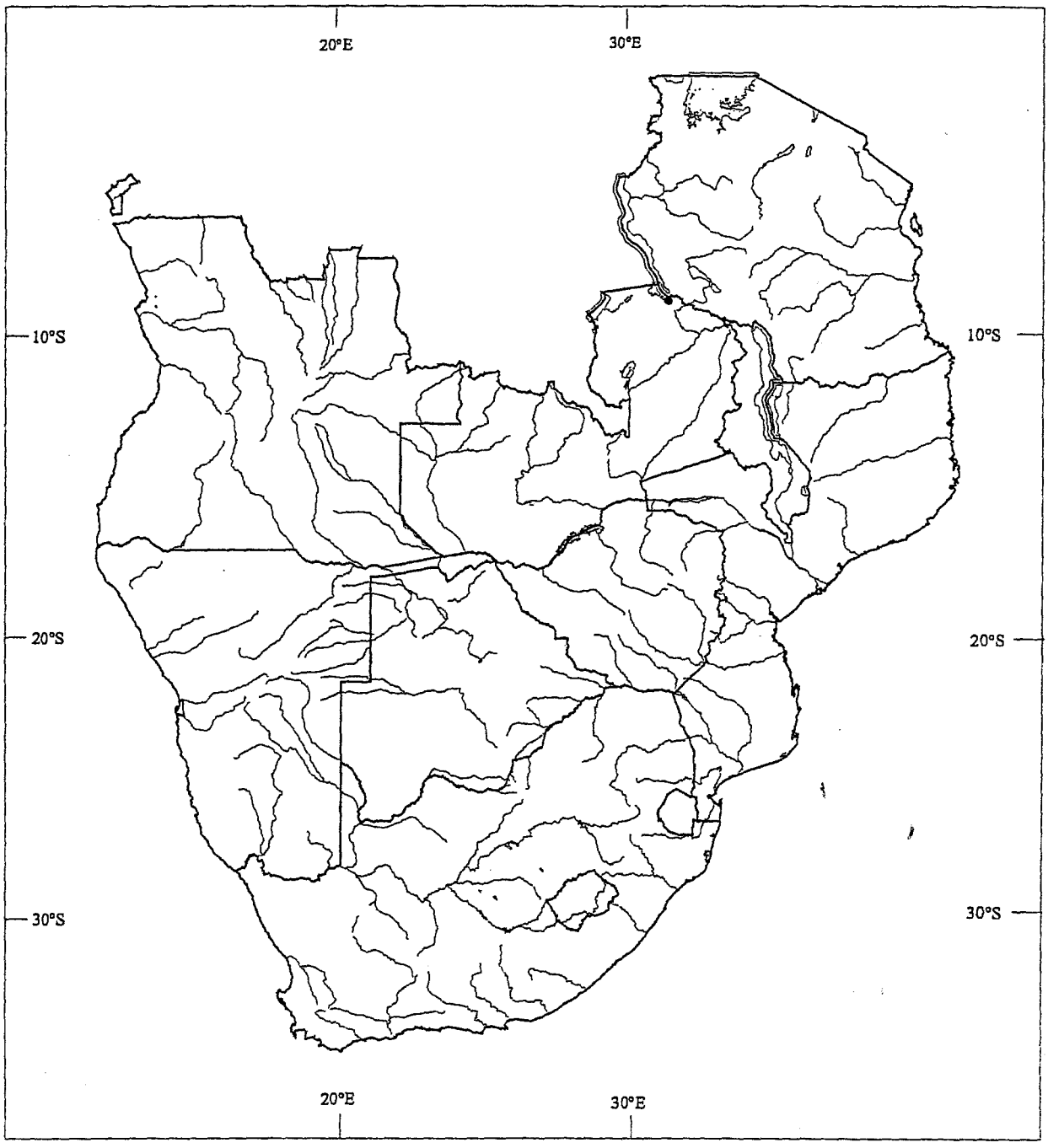


Figure F.387. Point distribution of *Lepidiolamprologus profundico*. Scale approximately 1:25 000 000

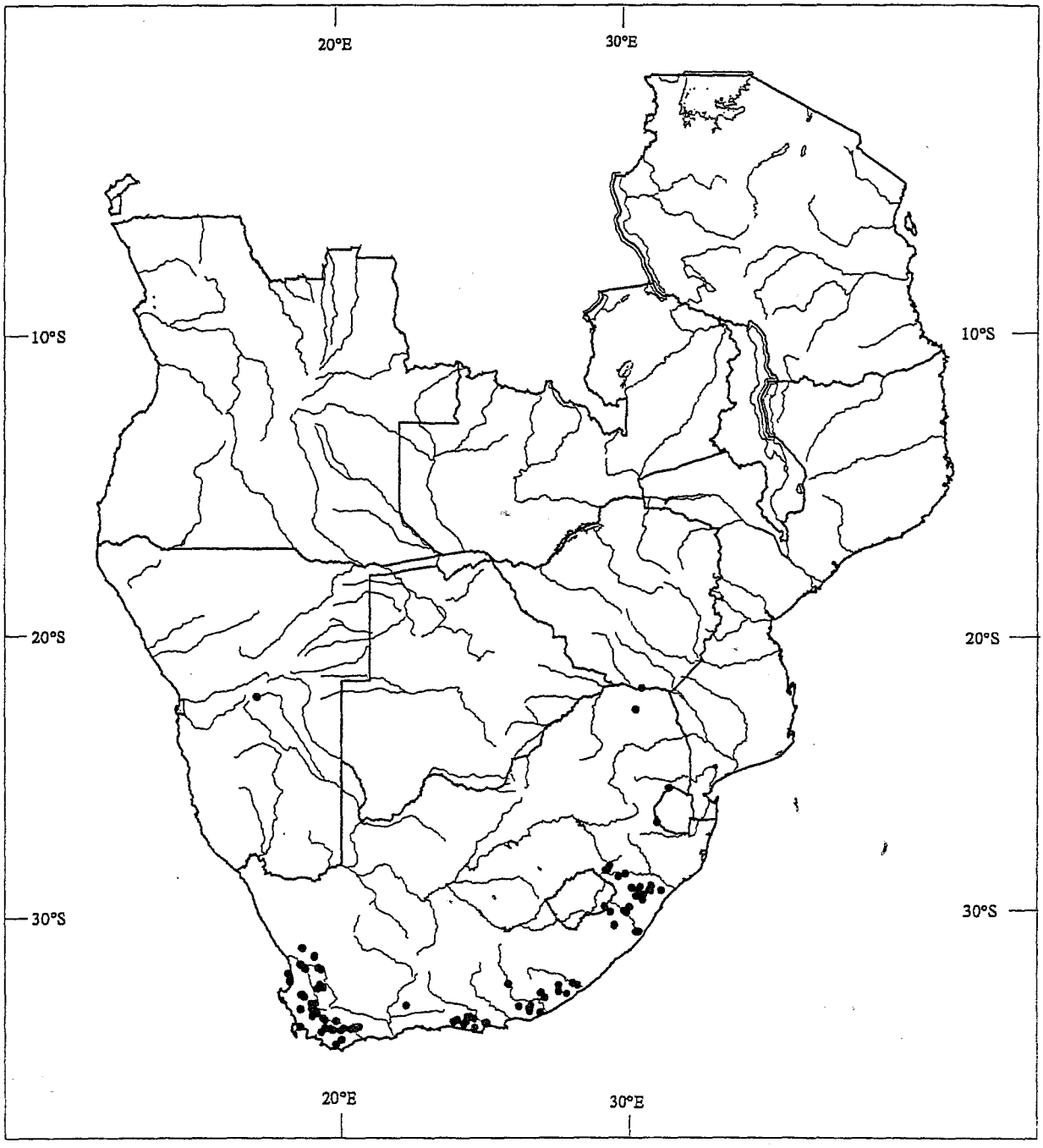


Figure F.388. Point distribution of *Lepomis macrochirus*. Scale approximately 1:25 000 000

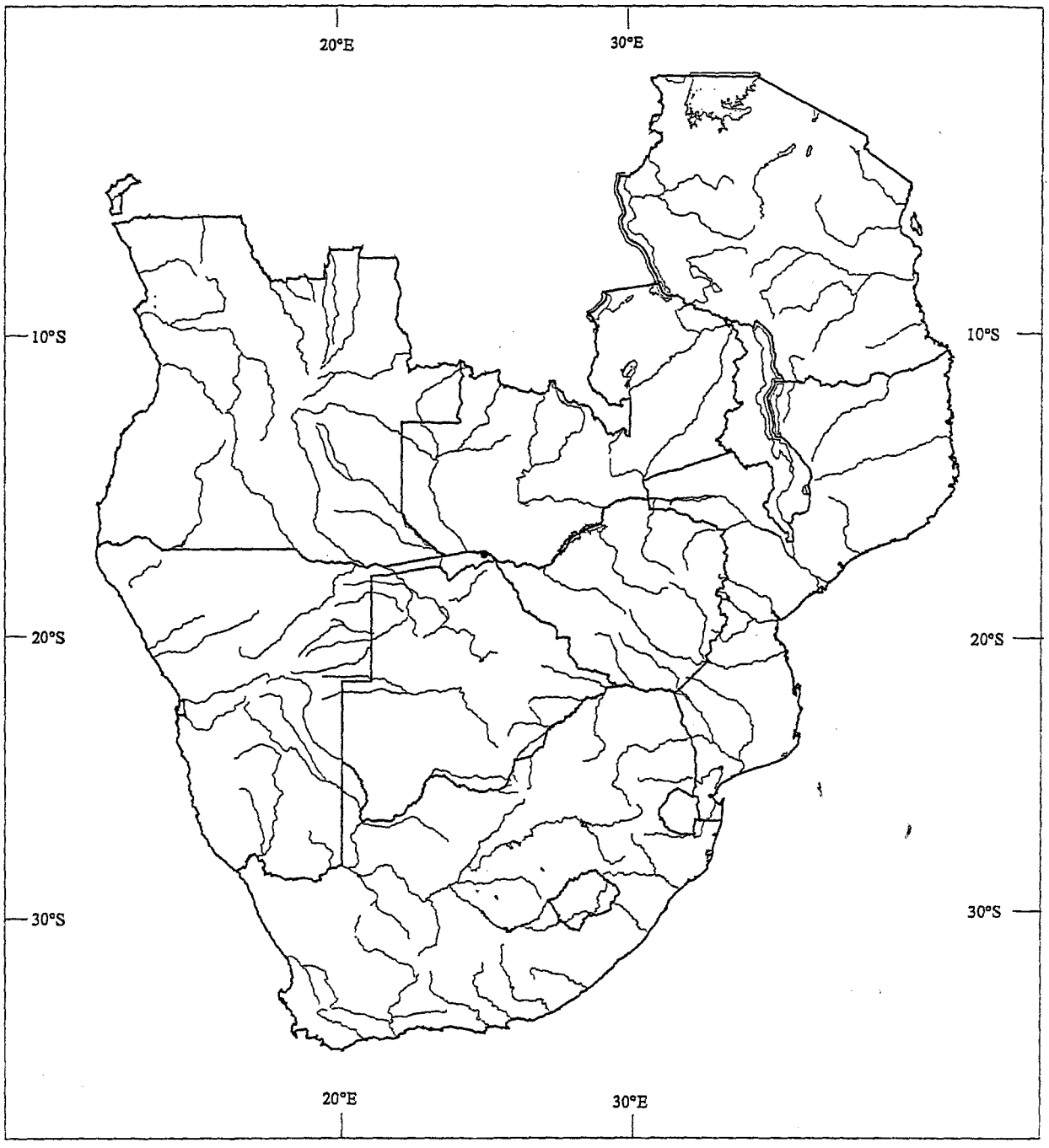


Figure F.389. Point distribution of *Leptoglanis cf. dorae*. Scale approximately 1:25 000 000

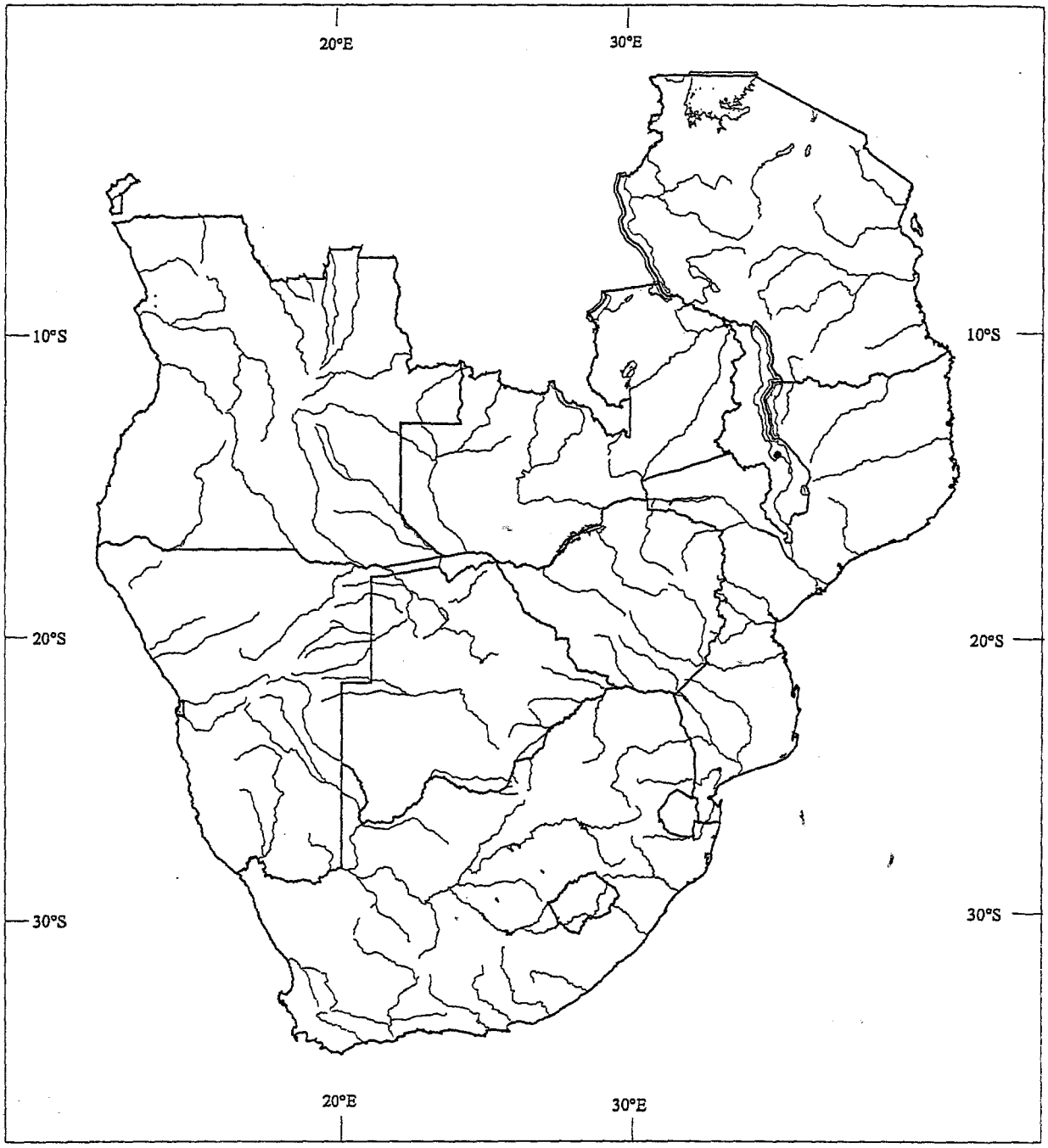


Figure F.390. Point distribution of *Leptoglanis lacustris*. Scale approximately 1:25 000 000

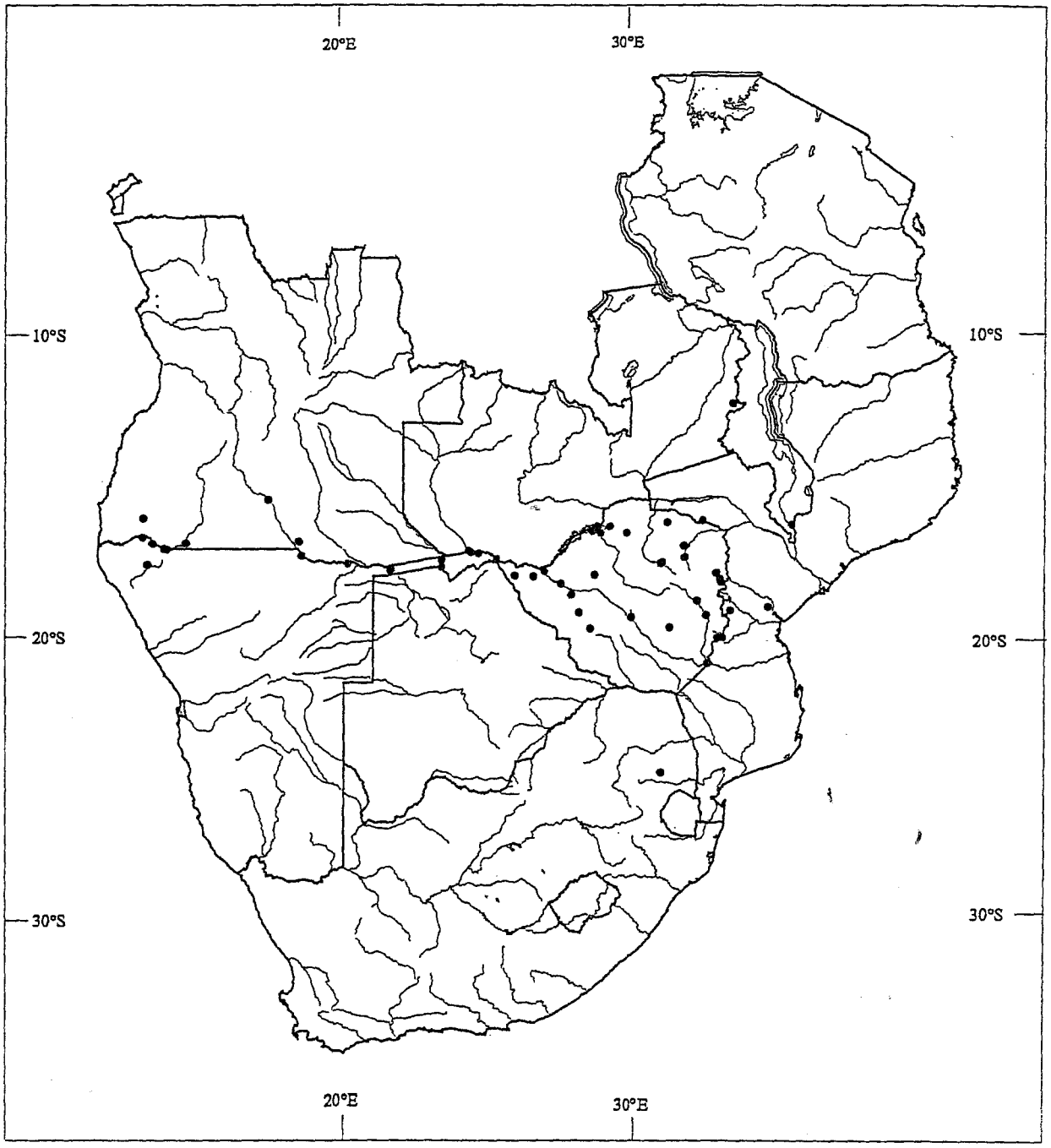


Figure F.391. Point distribution of *Leptoglanis rotundiceps*. Scale approximately 1:25 000 000

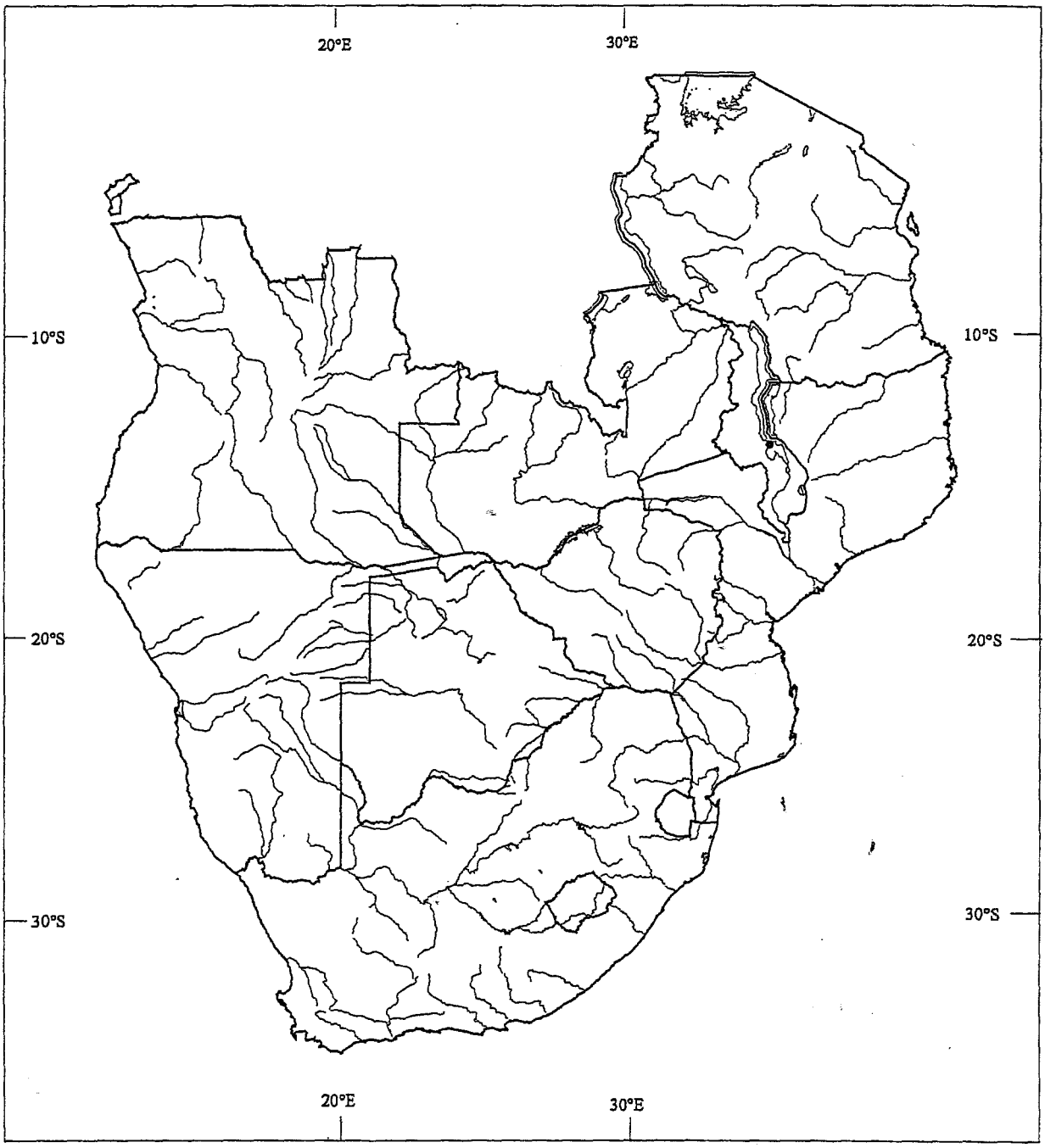


Figure F.392. Point distribution of *Lethrinops albus*. Scale approximately 1:25 000 000

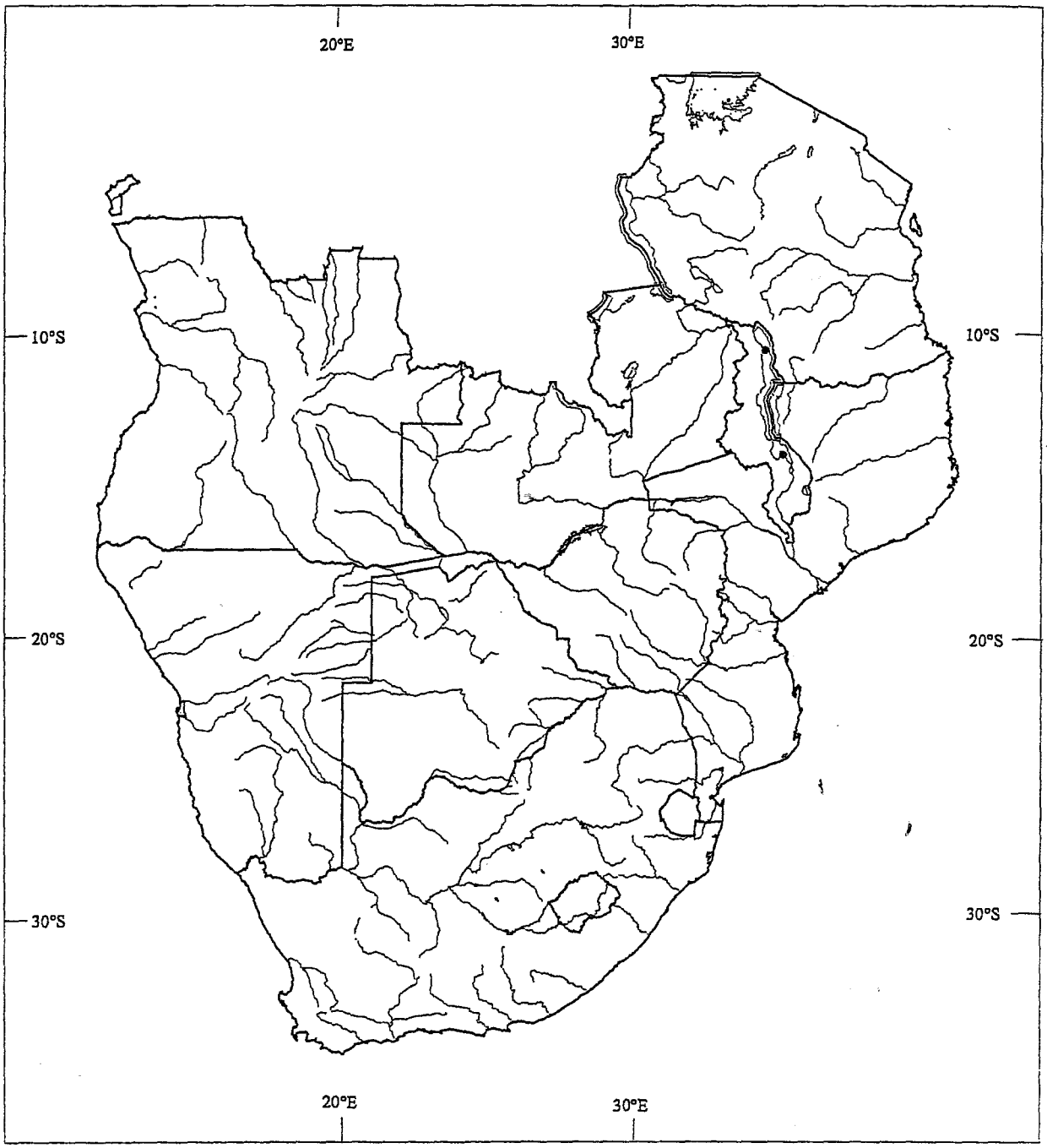


Figure F.393. Point distribution of *Lethrinops altus*. Scale approximately 1:25 000 000

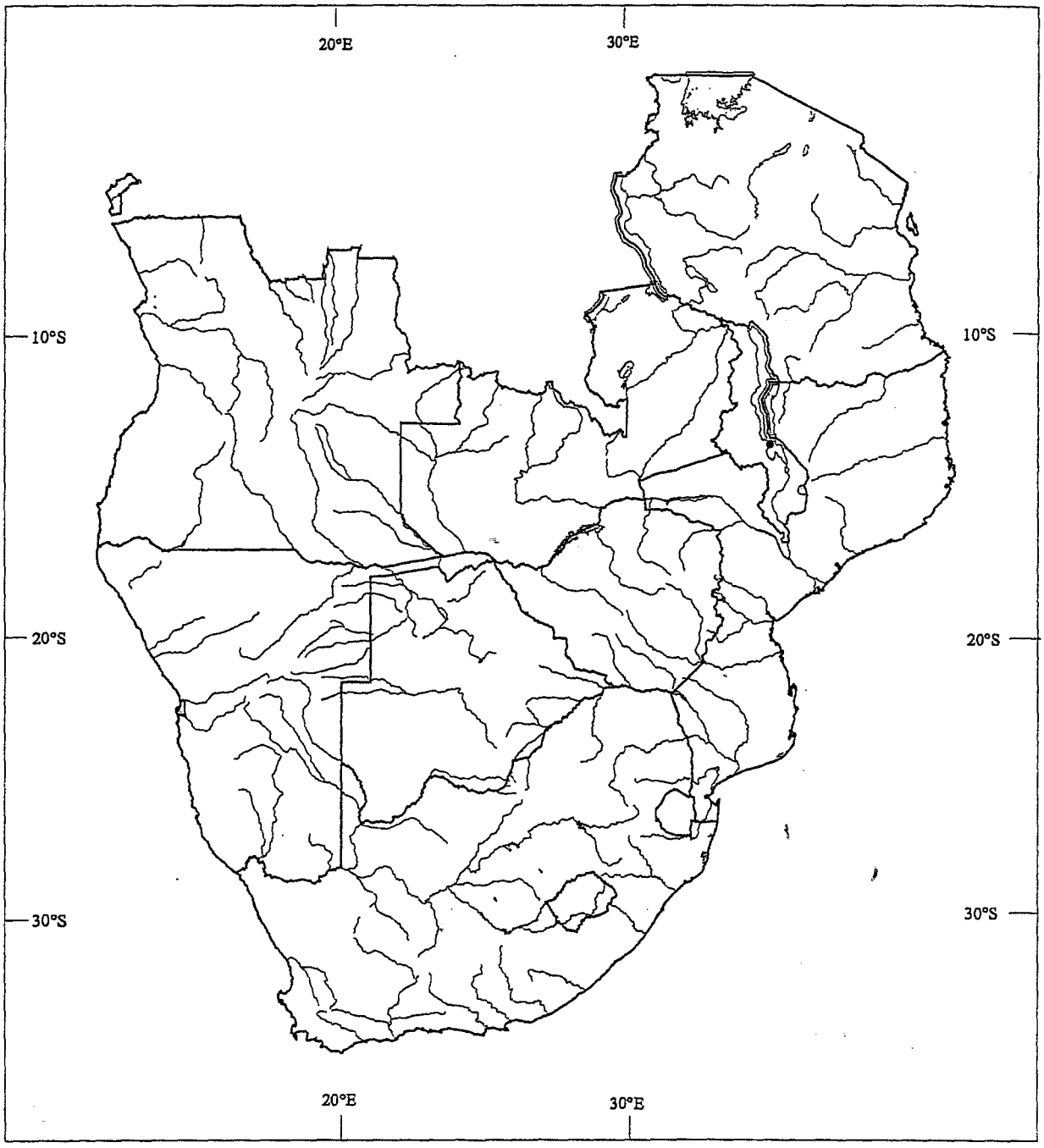


Figure F.394. Point distribution of *Lethrinops argentea*. Scale approximately 1:25 000 000

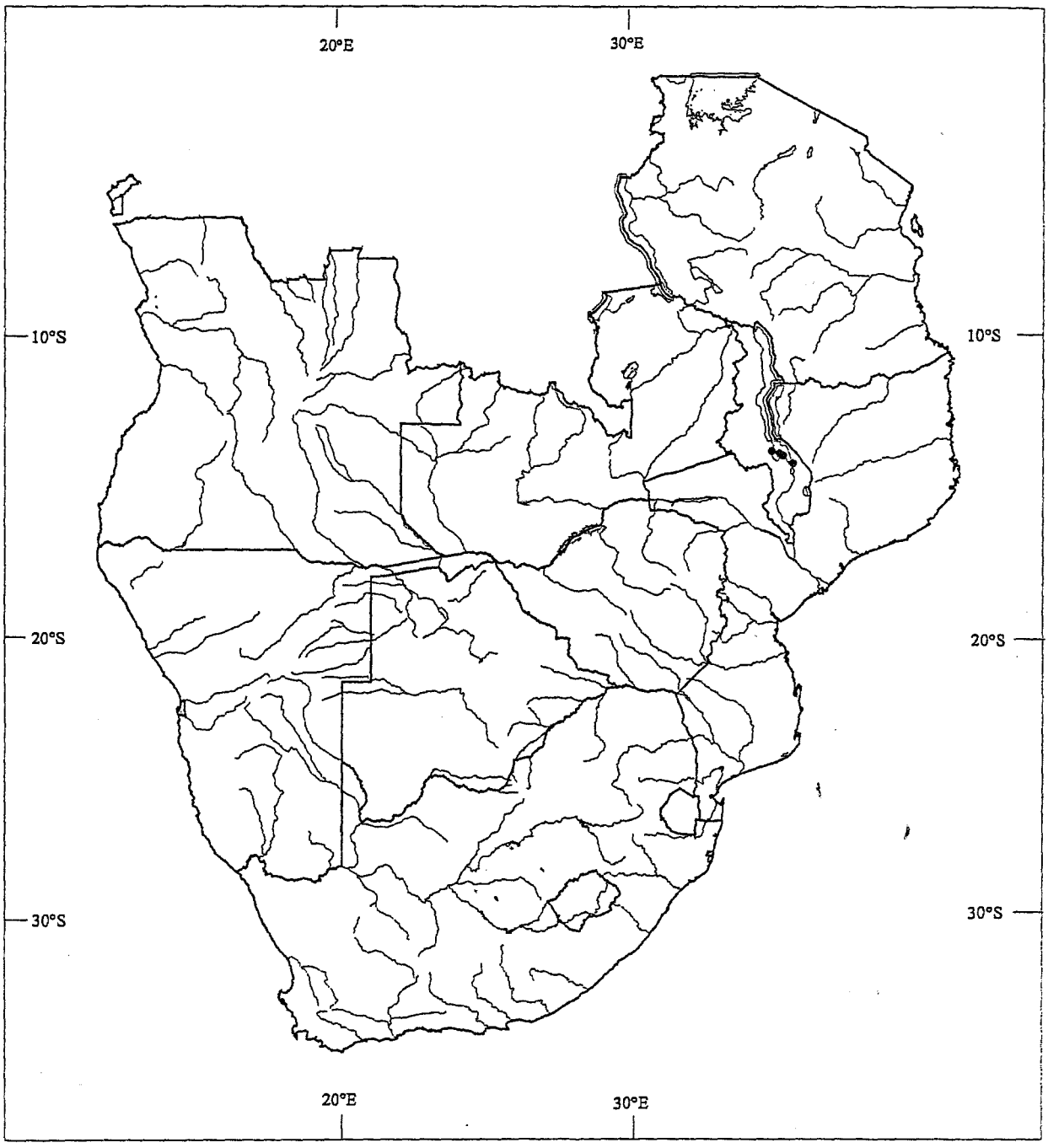


Figure F.395. Point distribution of *Lethrinops aurita*. Scale approximately 1:25 000 000

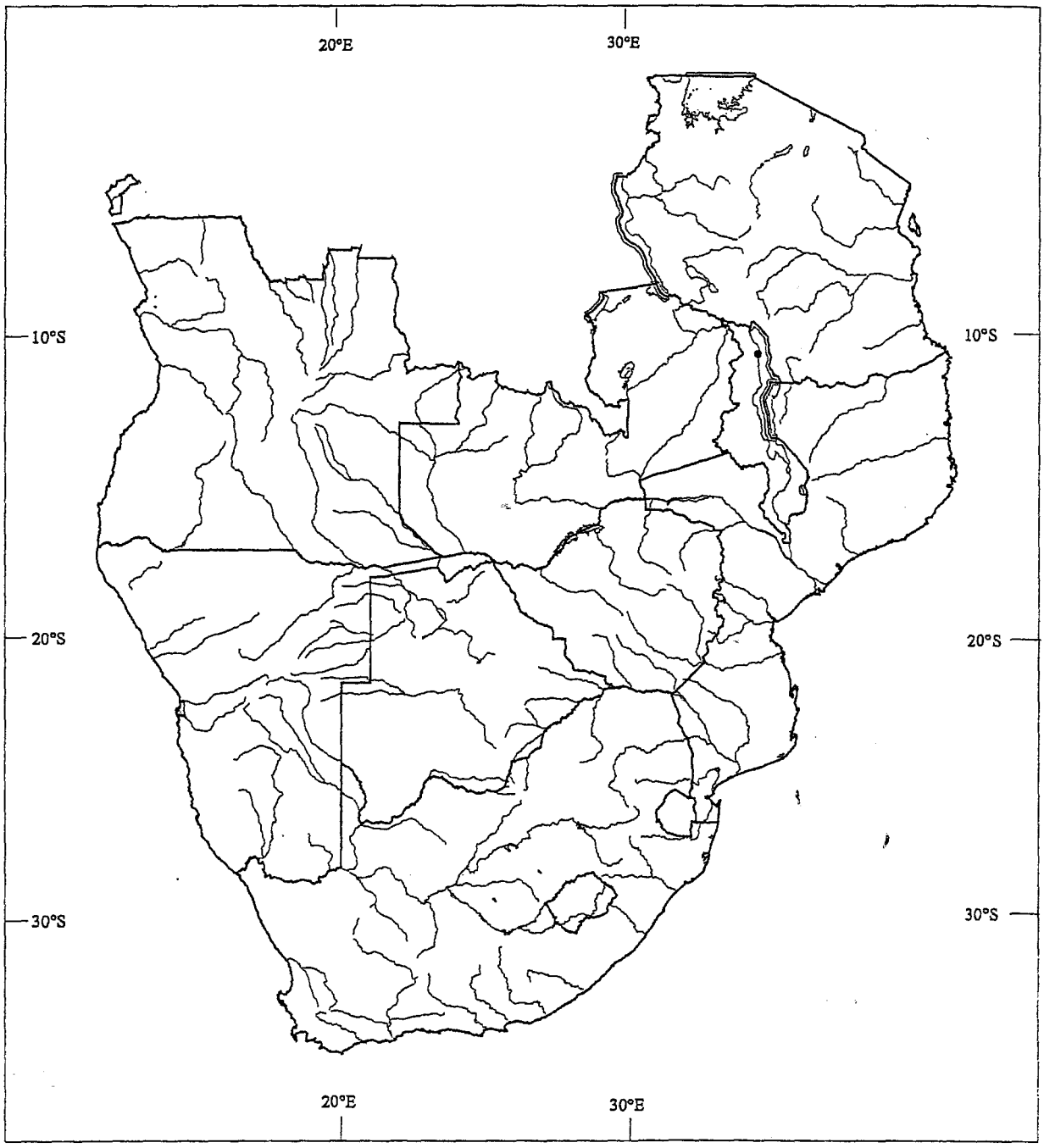


Figure F.396. Point distribution of *Lethrinops brevis*. Scale approximately 1:25 000 000

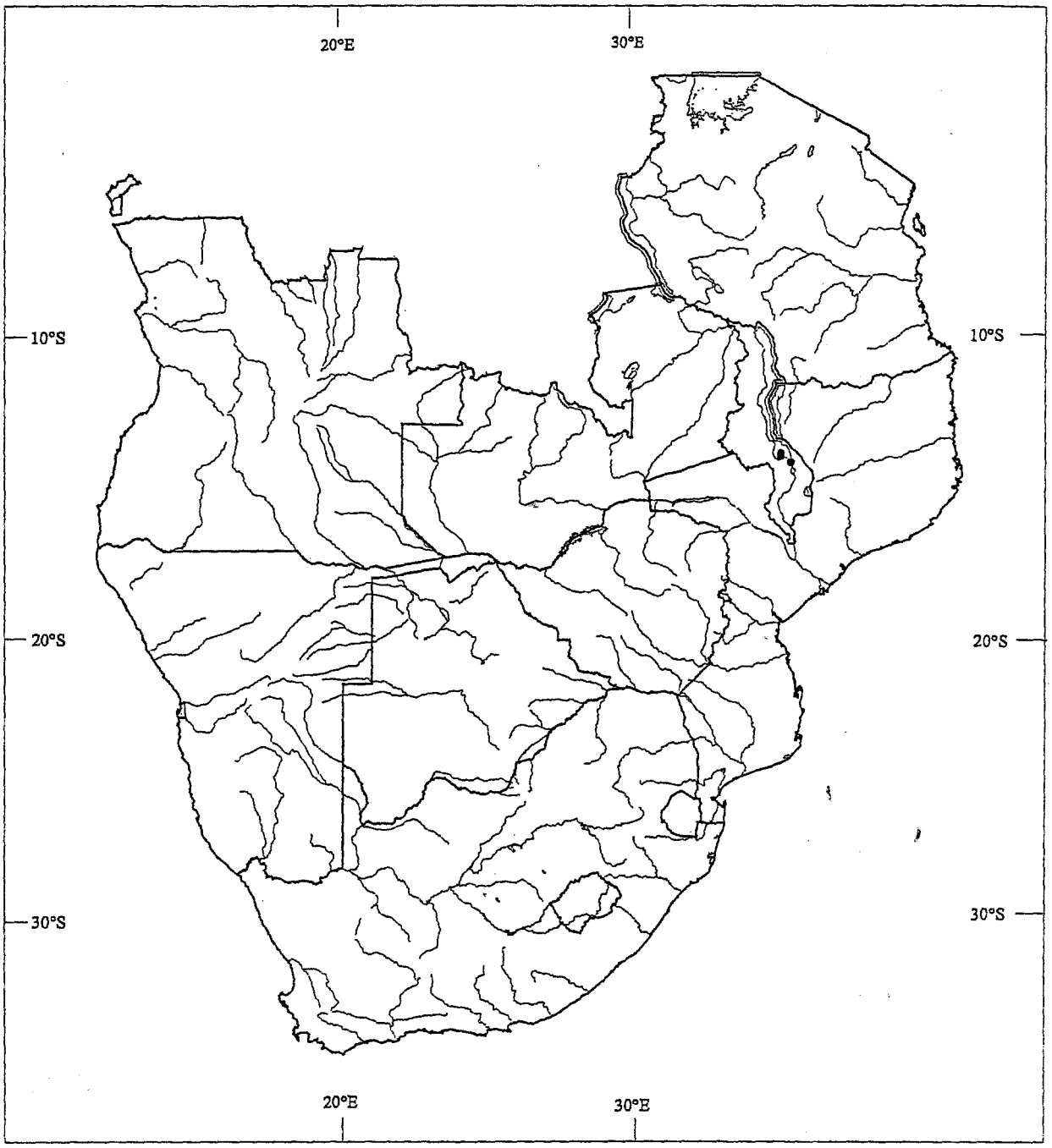


Figure F.397. Point distribution of *Lethrinops christyi*. Scale approximately 1:25 000 000

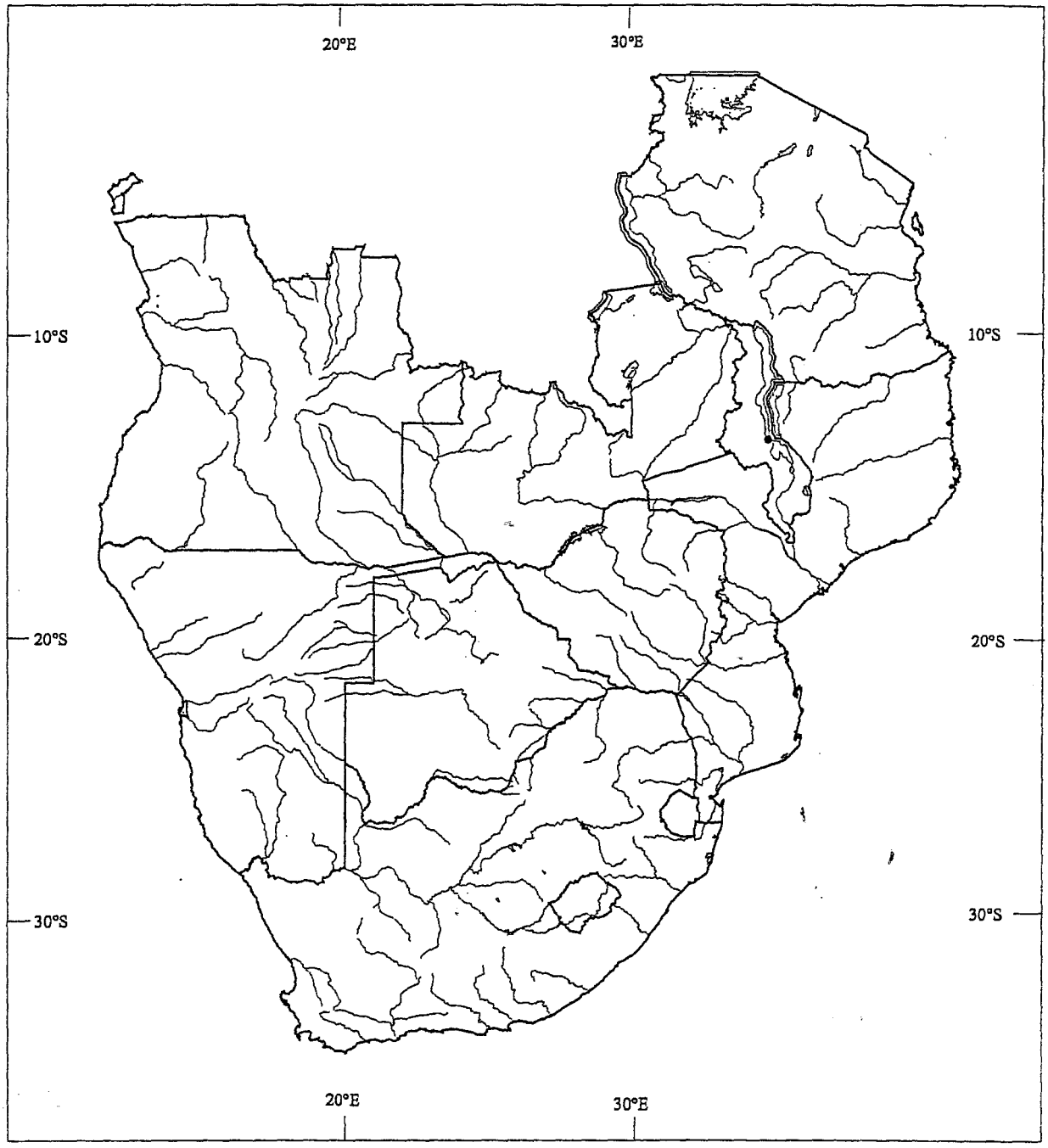


Figure F.398. Point distribution of *Lethrinops furcifer*. Scale approximately 1:25 000 000

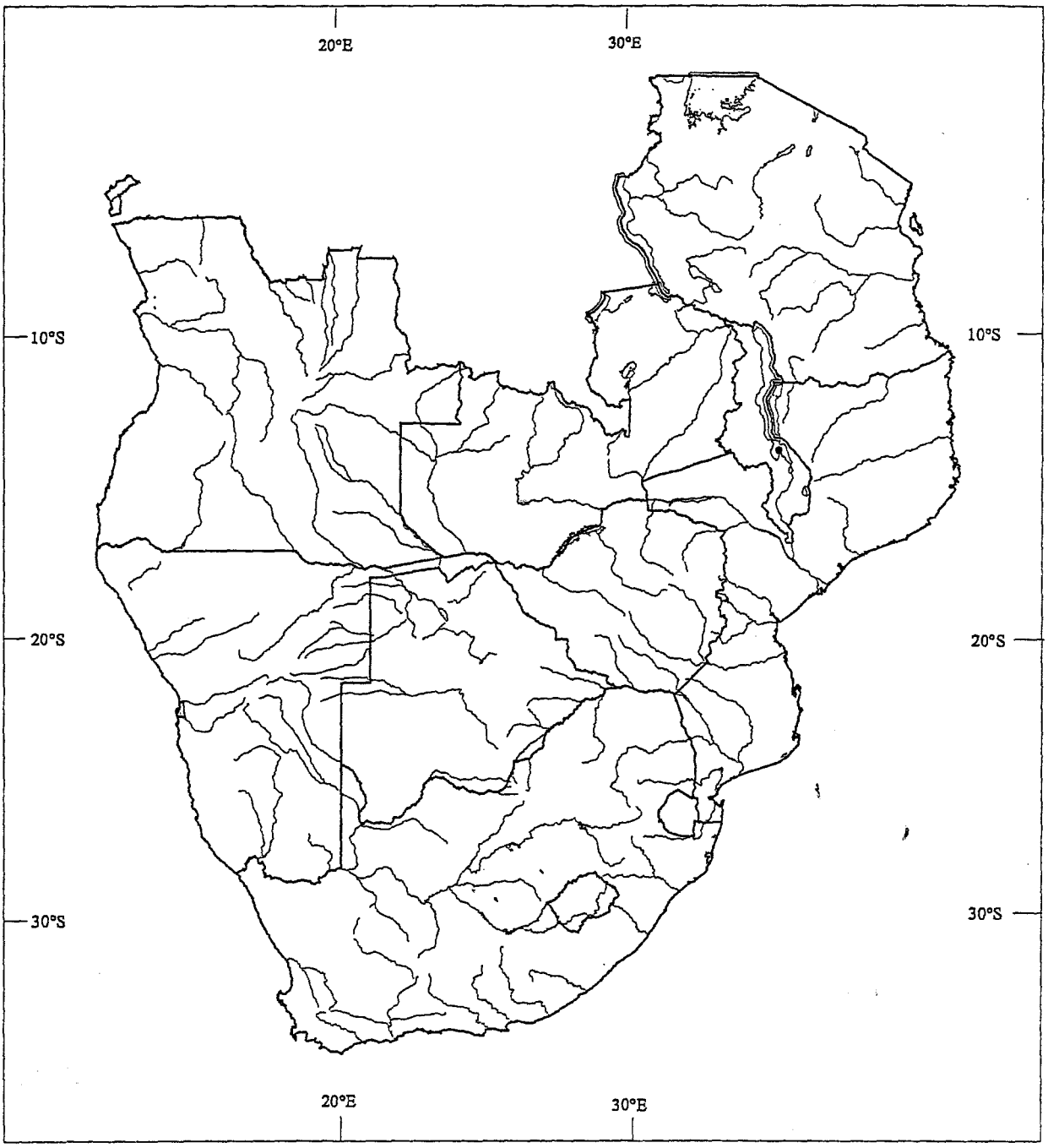


Figure F.399. Point distribution of *Lethrinops gossei*. Scale approximately 1:25 000 000

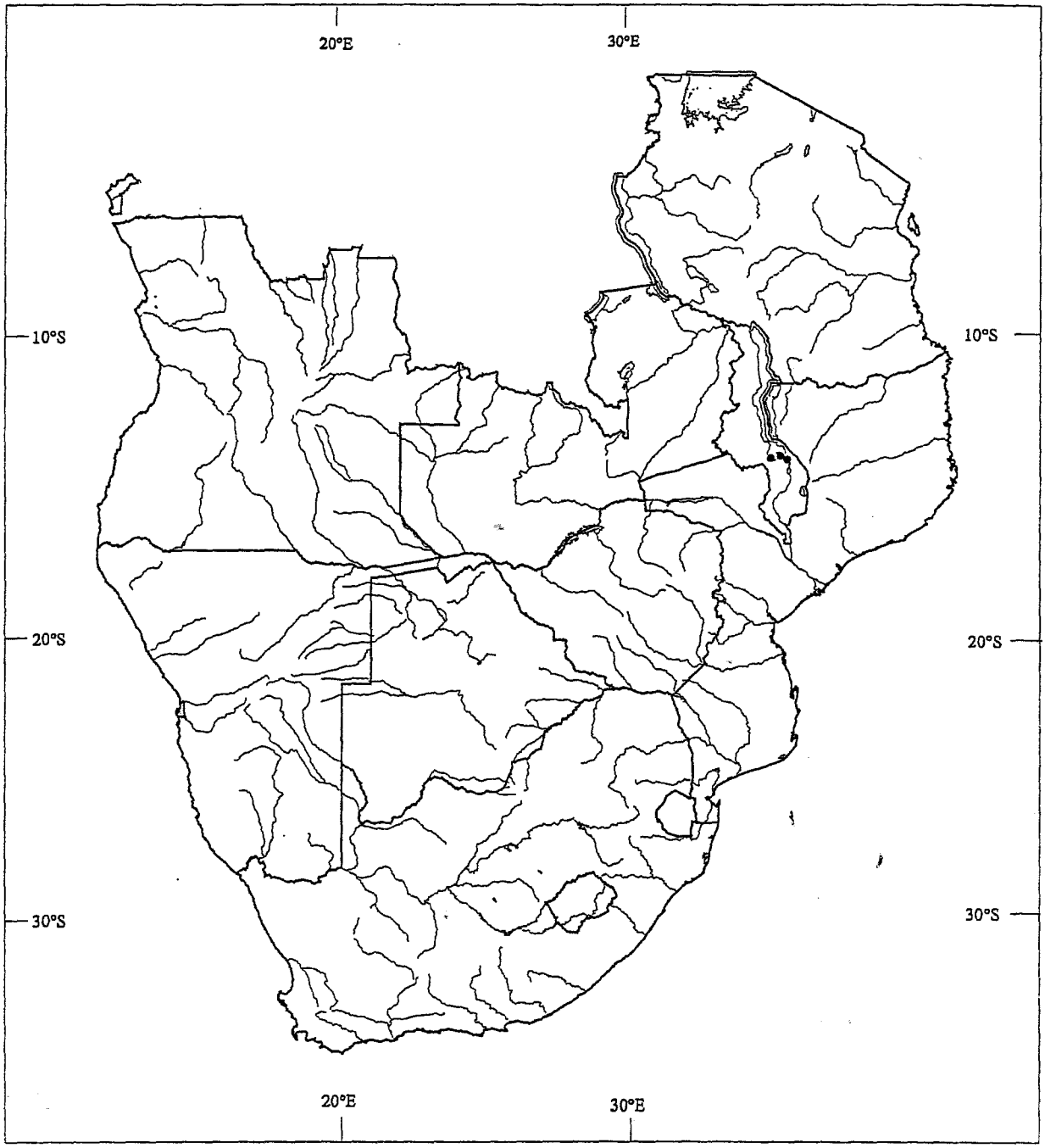


Figure F.400. Point distribution of *Lethrinops lethrinus*. Scale approximately 1:25 000 000

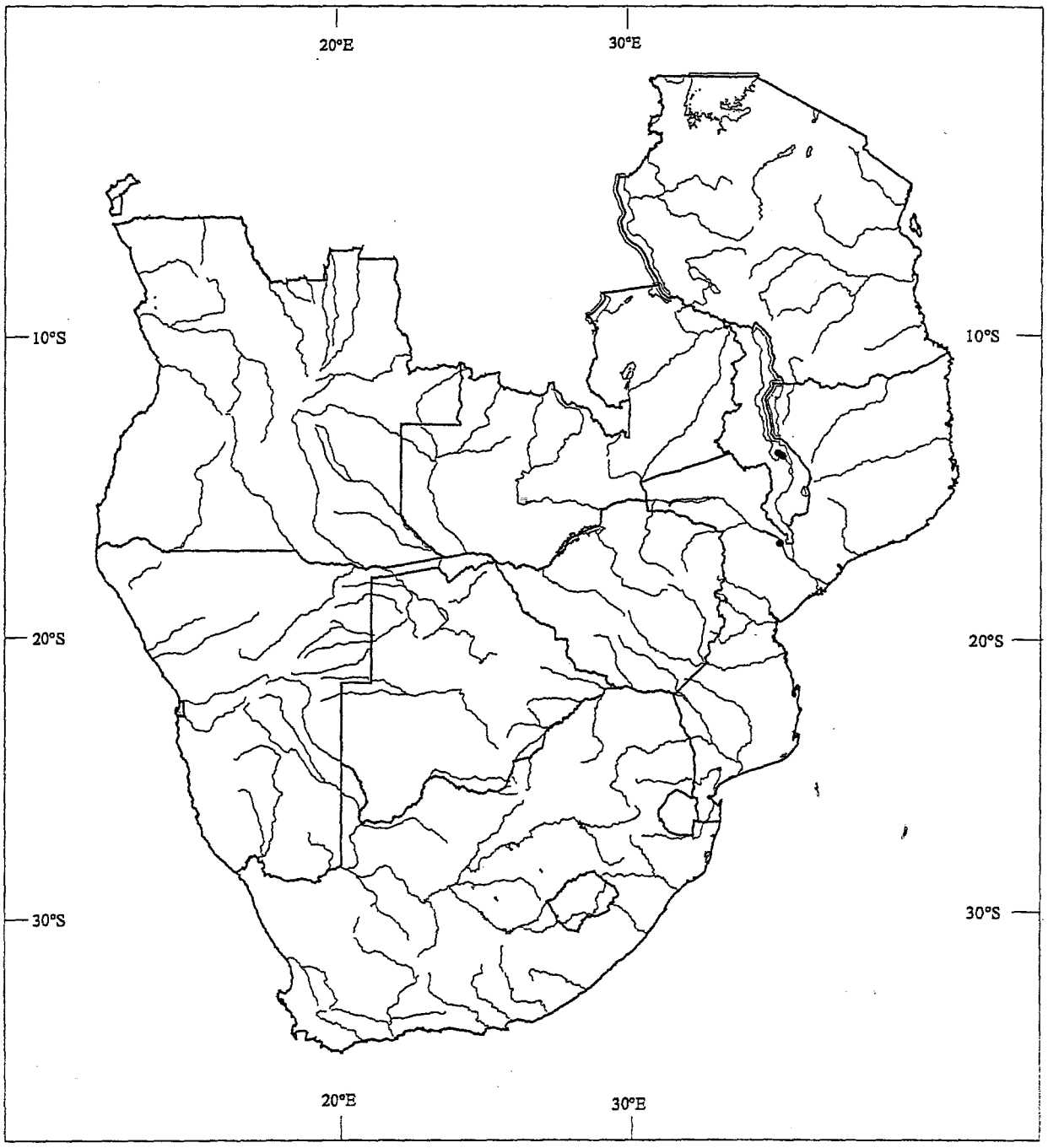


Figure F.401. Point distribution of *Lethrinops longimanus*. Scale approximately 1:25 000 000

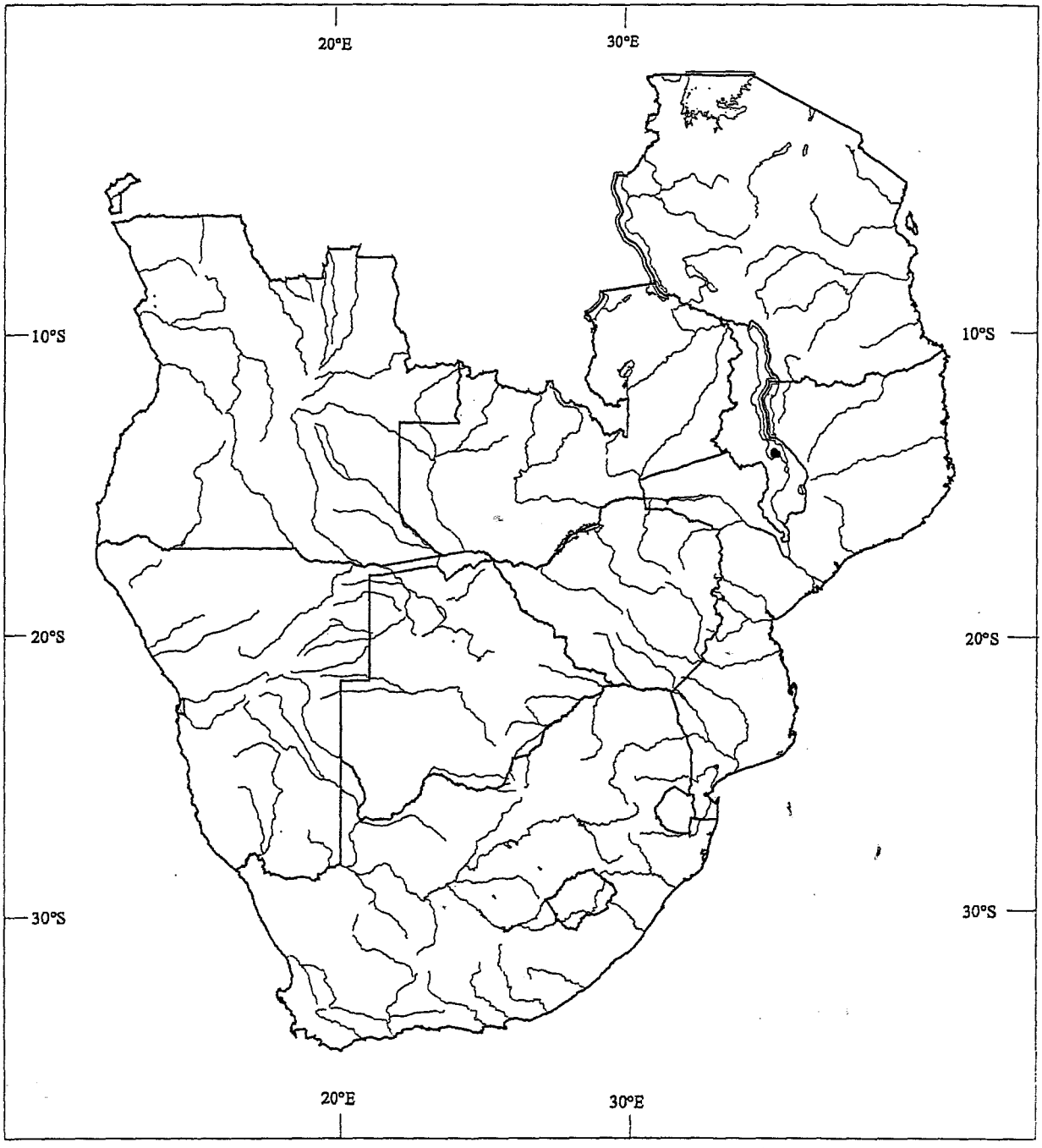


Figure F.402. Point distribution of *Lethrinops longipinnis*. Scale approximately 1:25 000 000

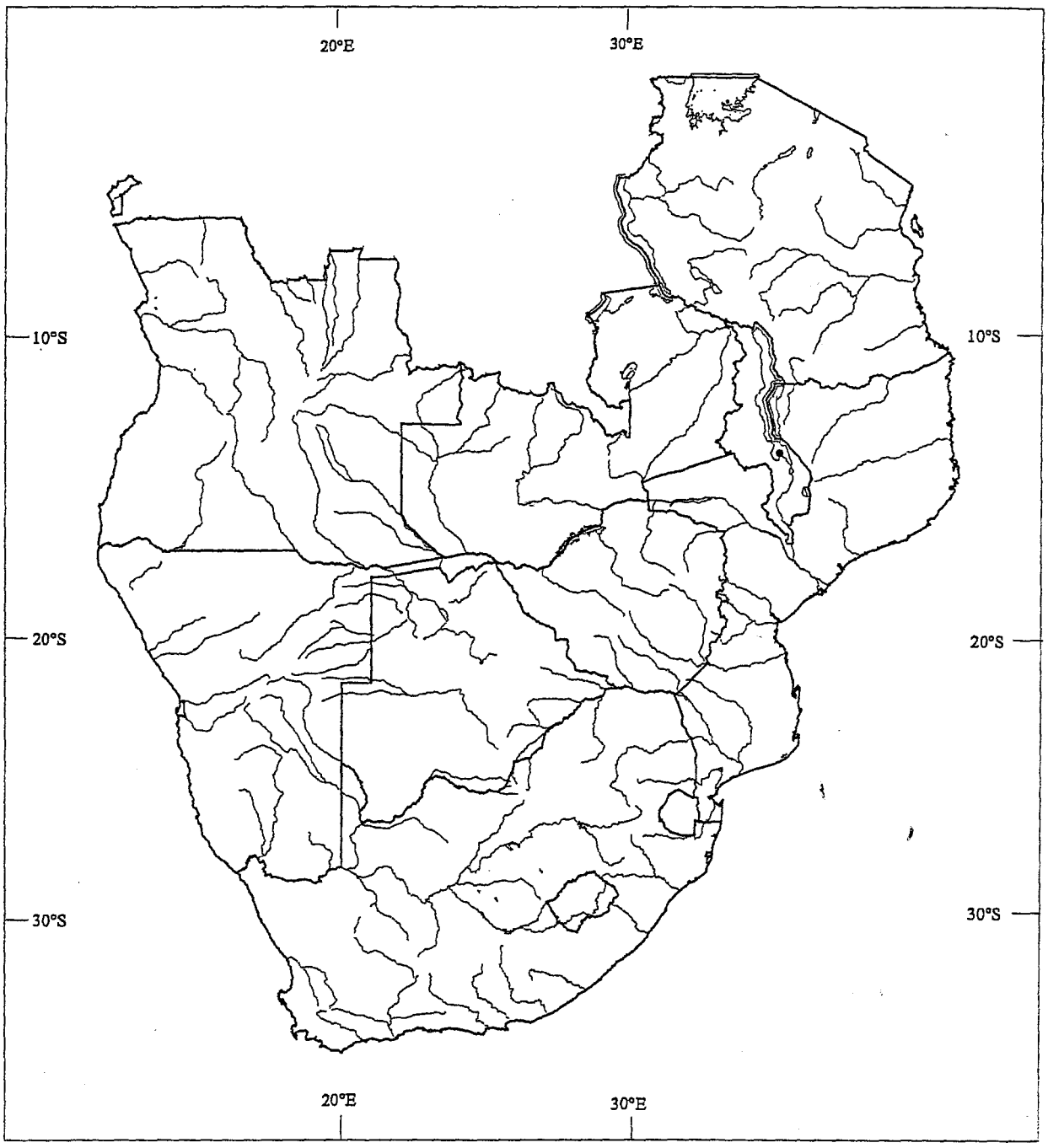


Figure F.403. Point distribution of *Lethrinops macracanthus*. Scale approximately 1:25 000 000

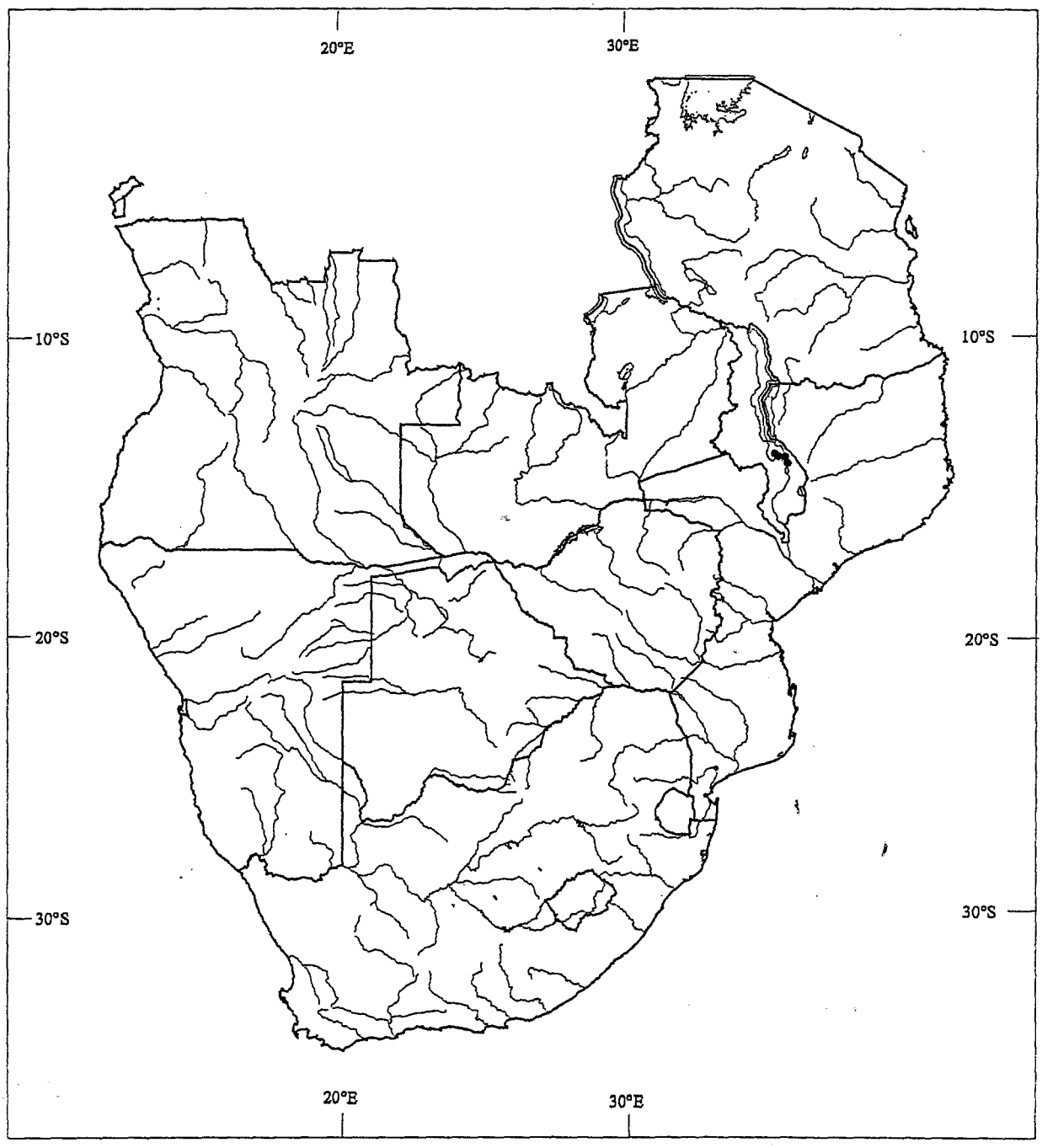


Figure F.404. Point distribution of *Lethrinops macrochir*. Scale approximately 1:25 000 000

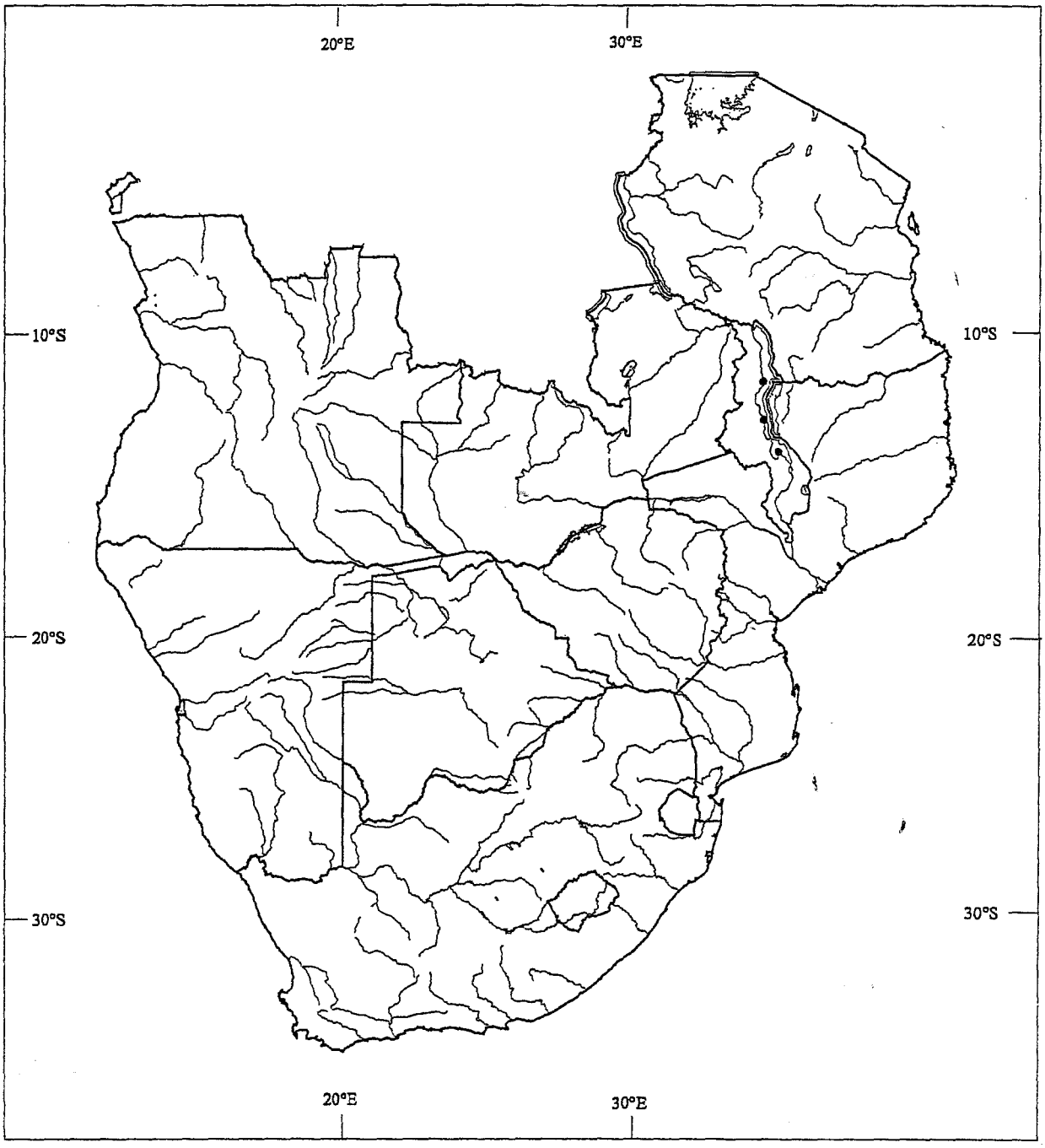


Figure F.405. Point distribution of *Lethrinops macropthalmus*. Scale approximately 1:25 000 000

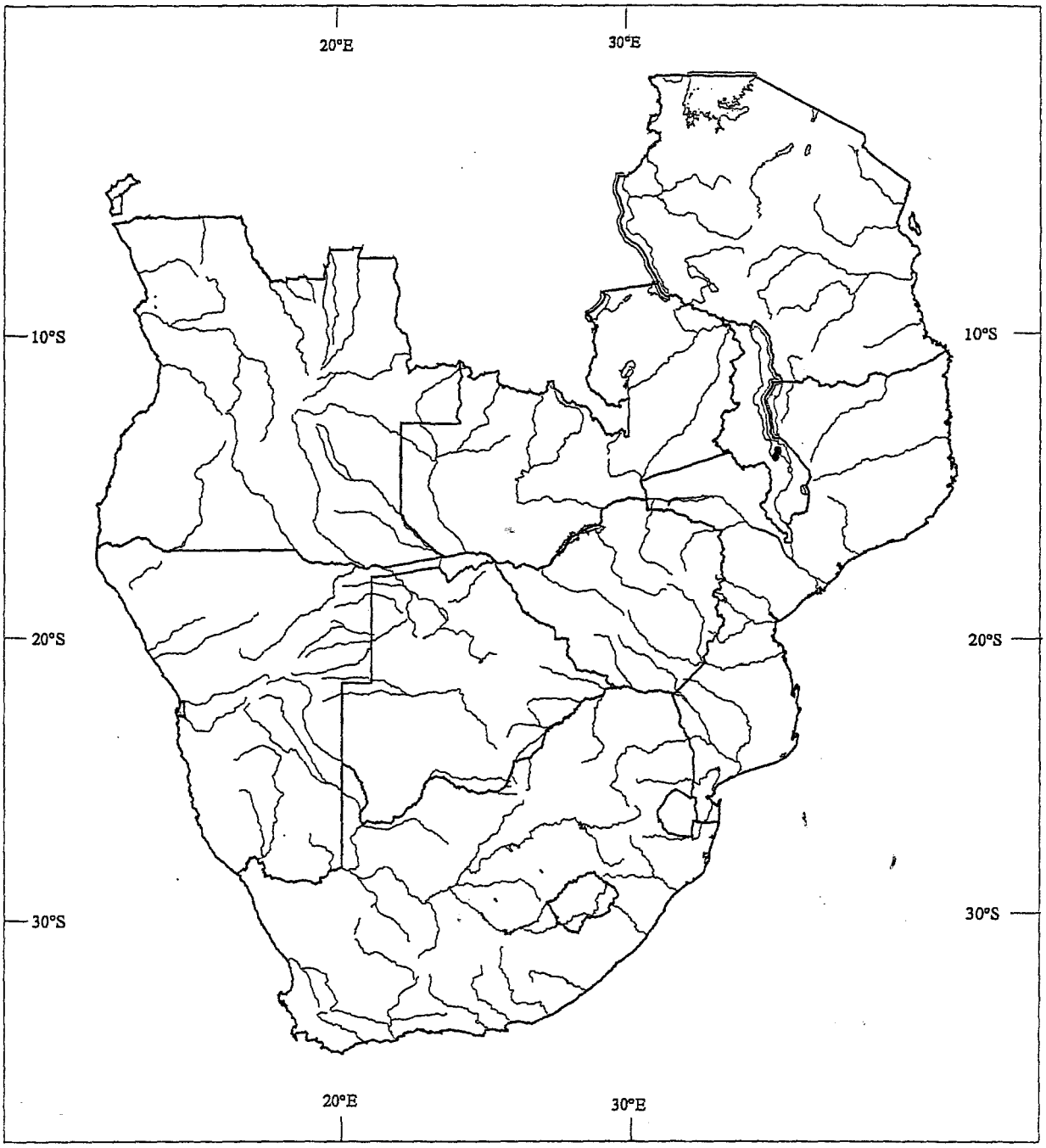


Figure F.406. Point distribution of *Lethrinops micrentodon*. Scale approximately 1:25 000 000

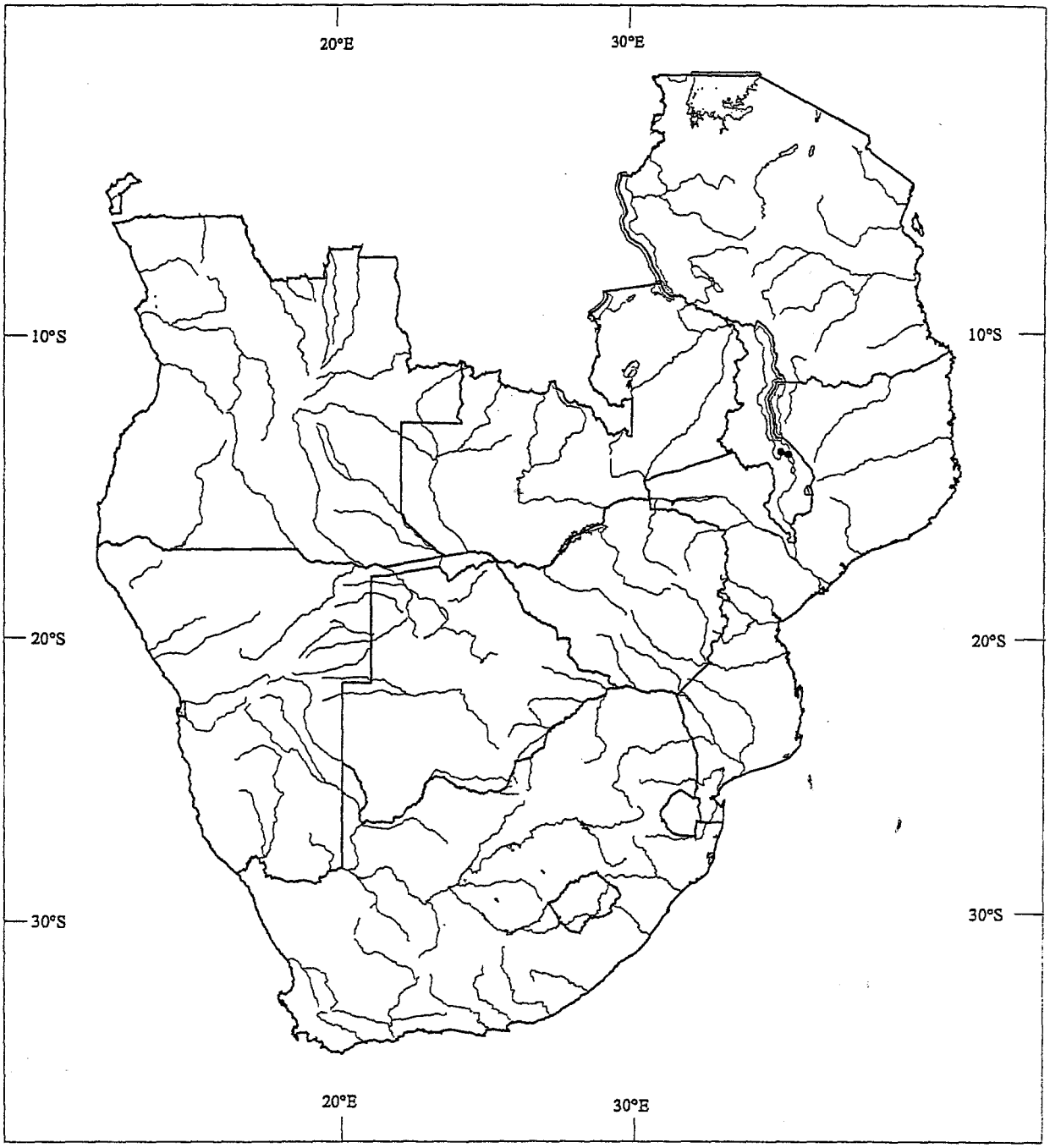


Figure F.407. Point distribution of *Lethrinops microdon*. Scale approximately 1:25 000 000

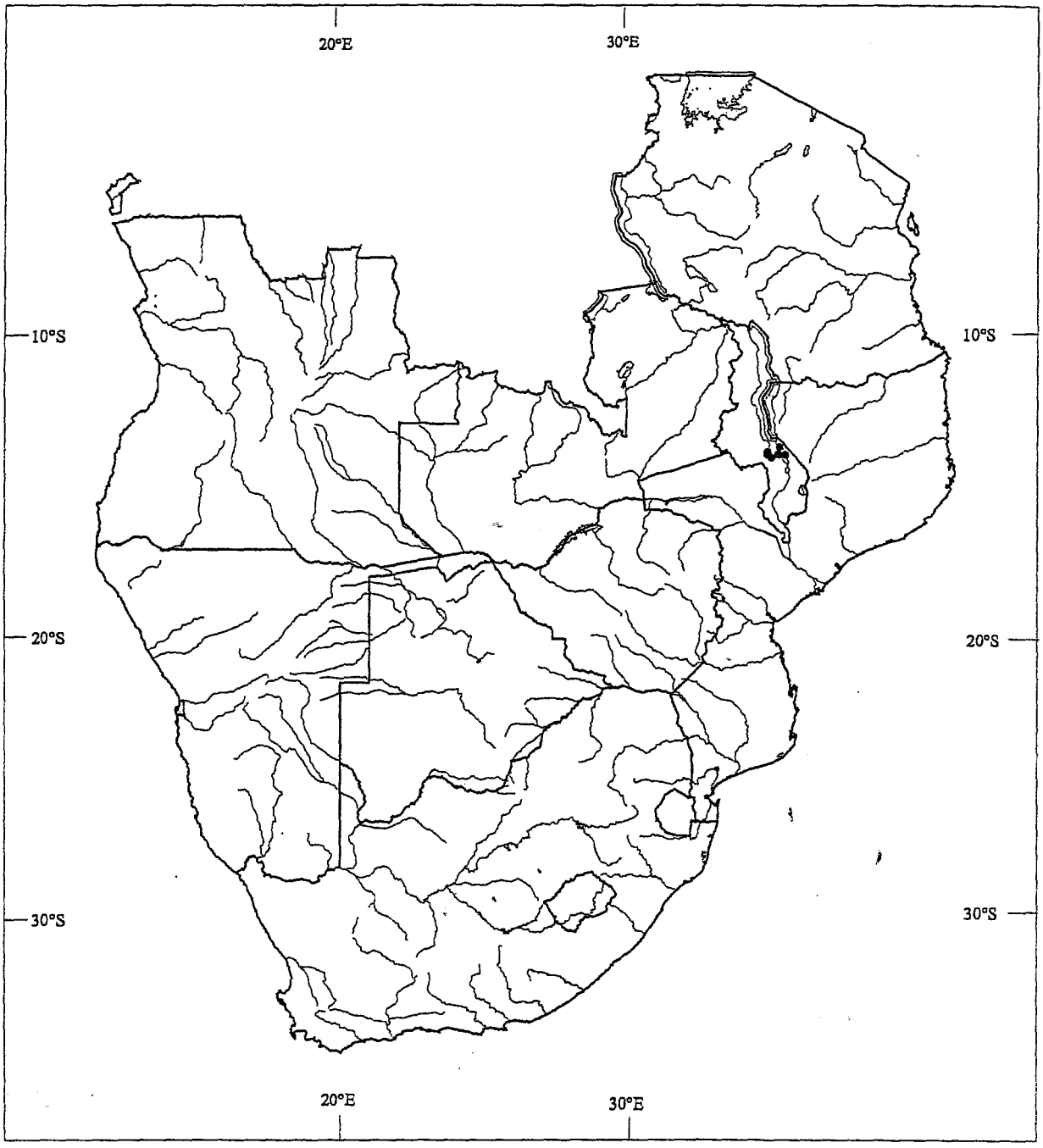


Figure F.408. Point distribution of *Lethrinops mylodon.* Scale approximately 1:25 000 000

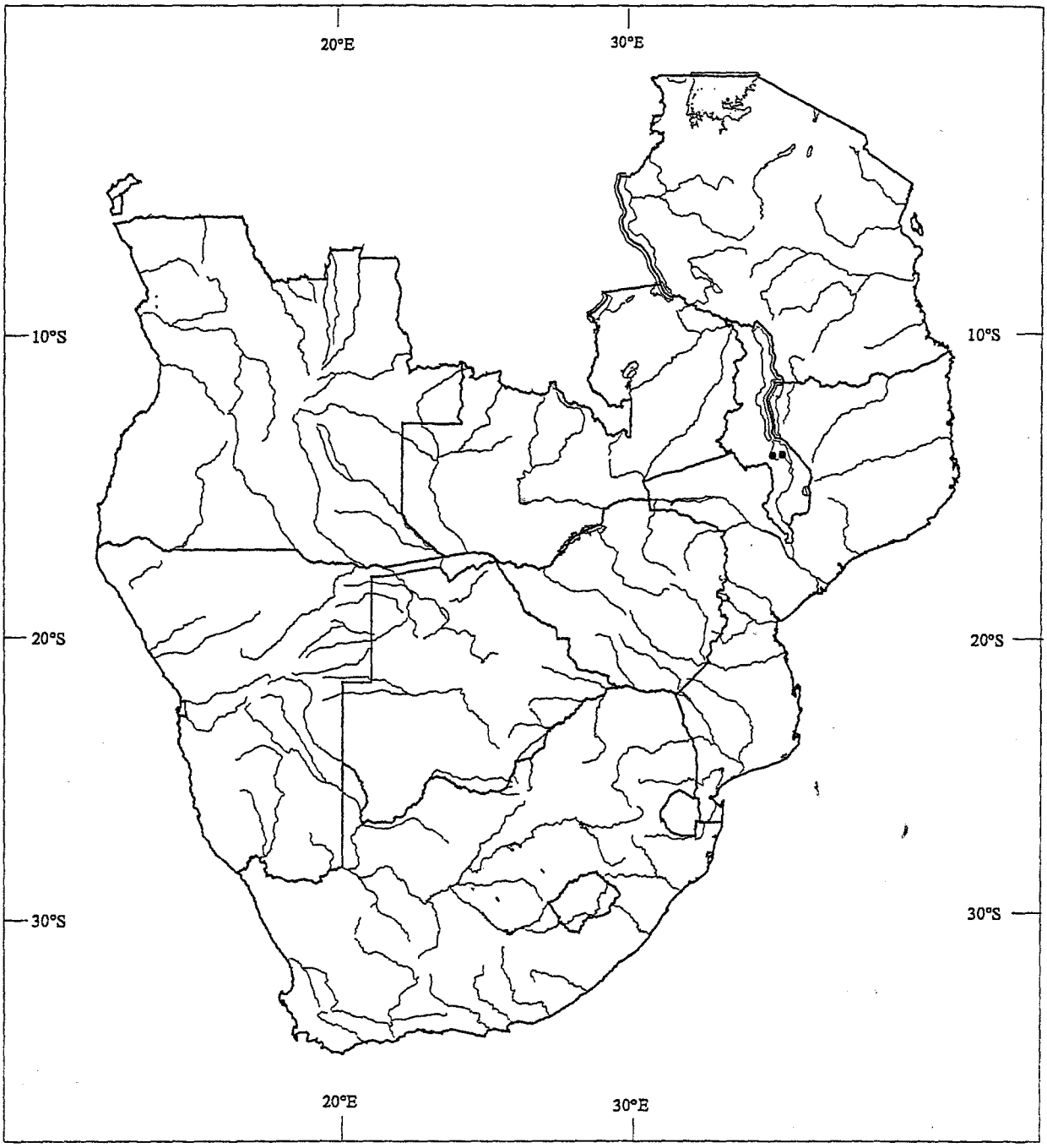


Figure F.409. Point distribution of *Lethrinops parvidens*. Scale approximately 1:25 000 000

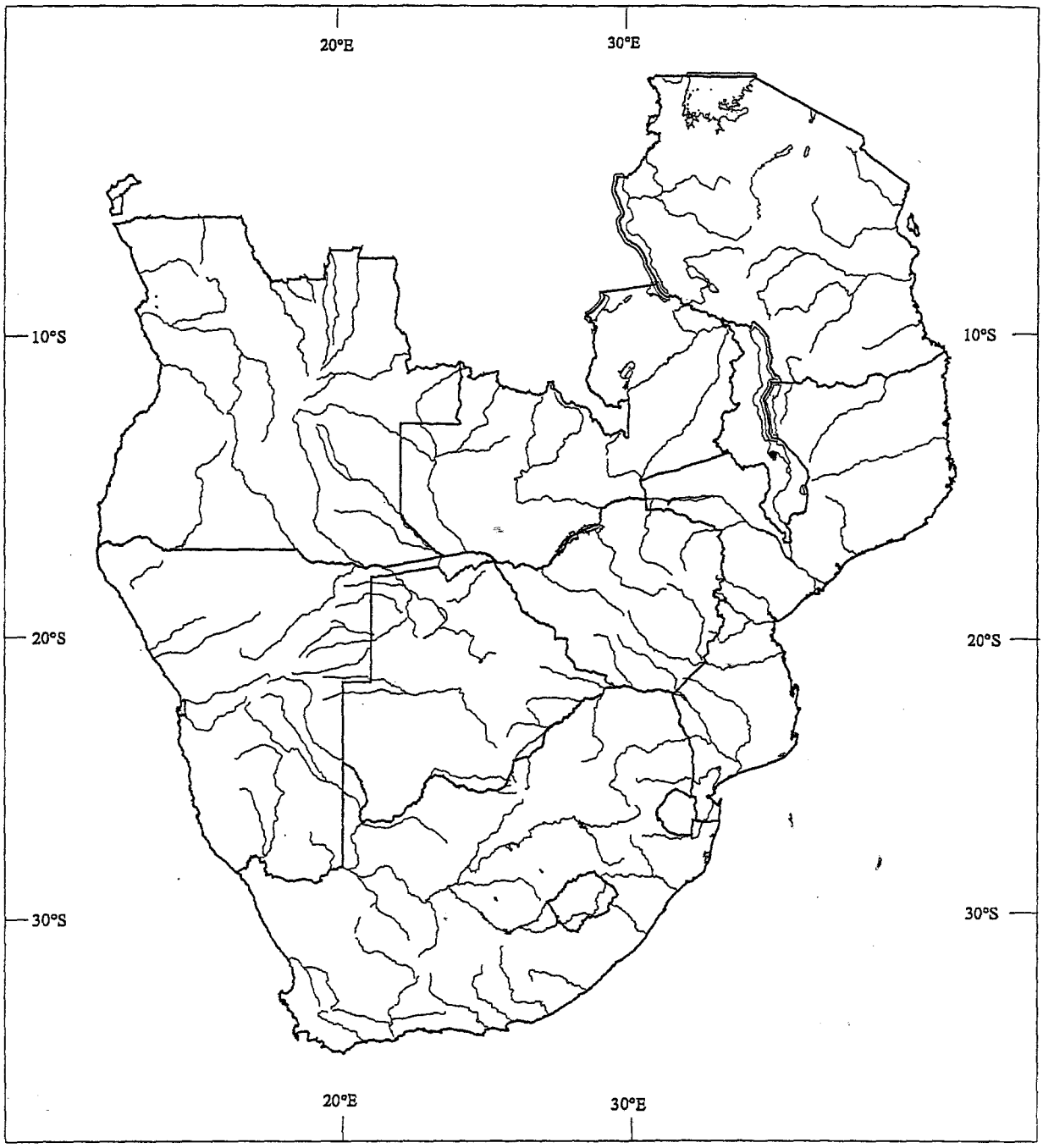


Figure F.410. Point distribution of *Lethrinops polli*. Scale approximately 1:25 000 000

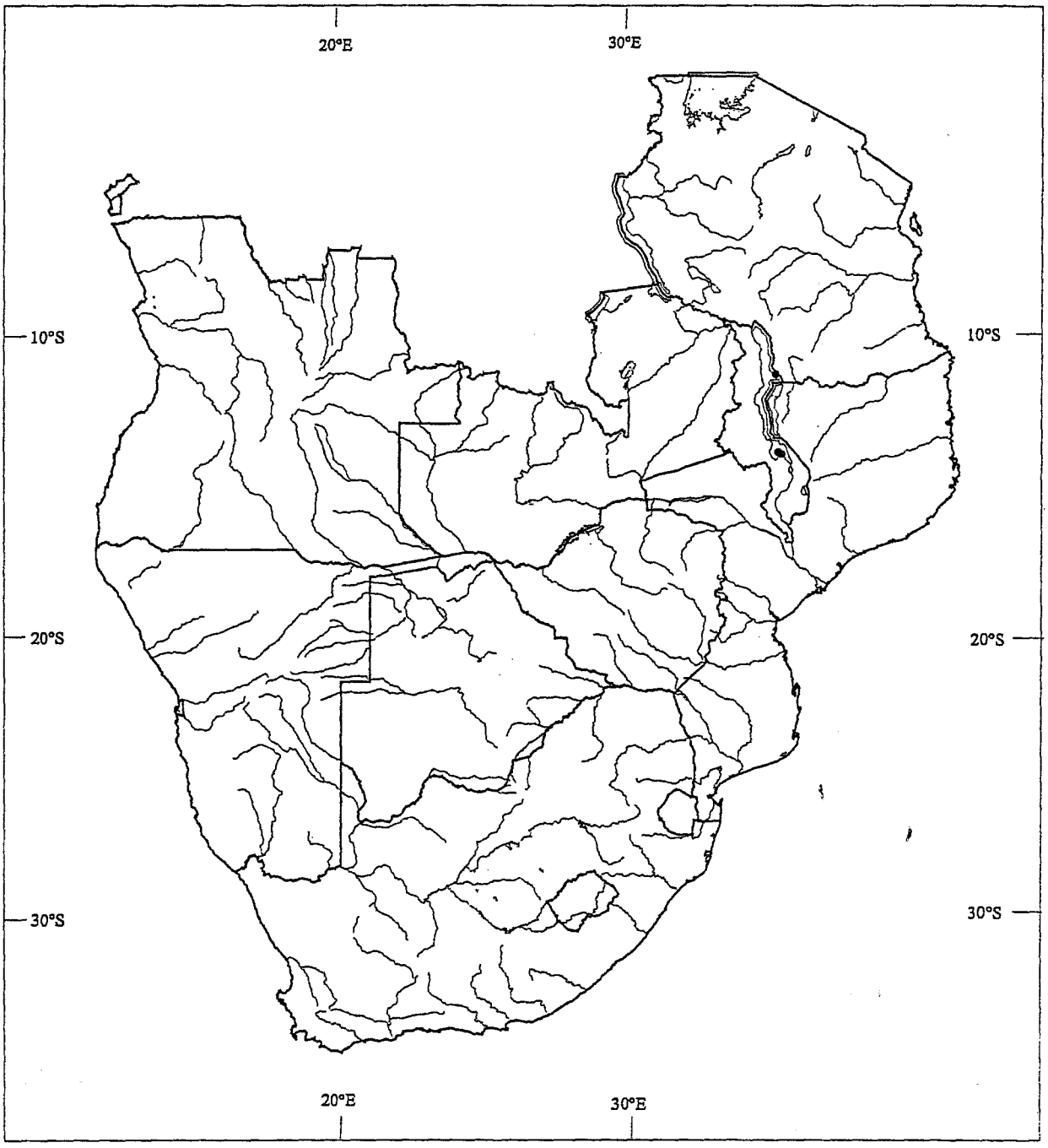


Figure F.411. Point distribution of *Lethrinops praeorbitalis*. Scale approximately 1:25 000 000

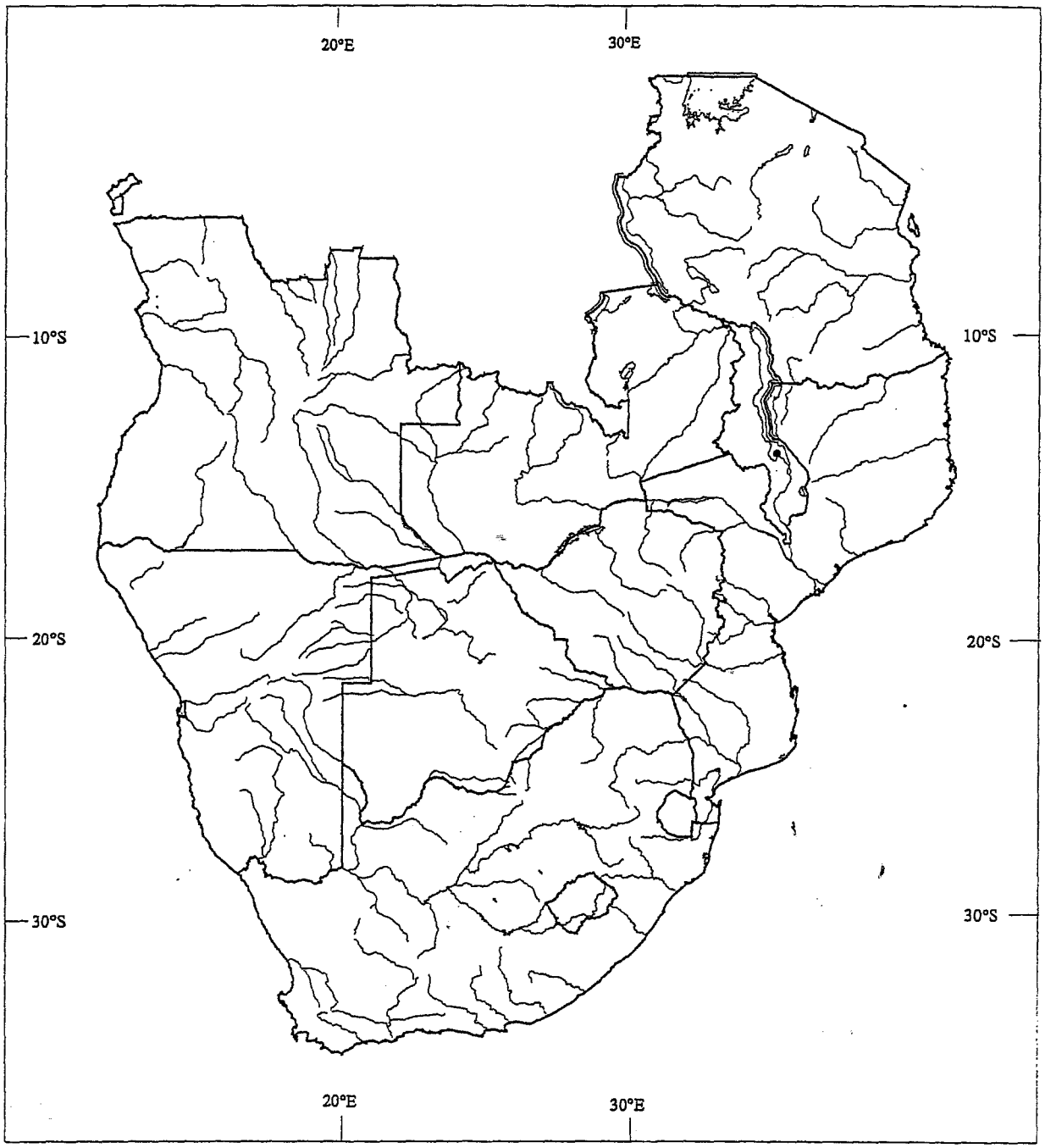


Figure F.412. Point distribution of *Lethrinops stridei*. Scale approximately 1:25 000 000

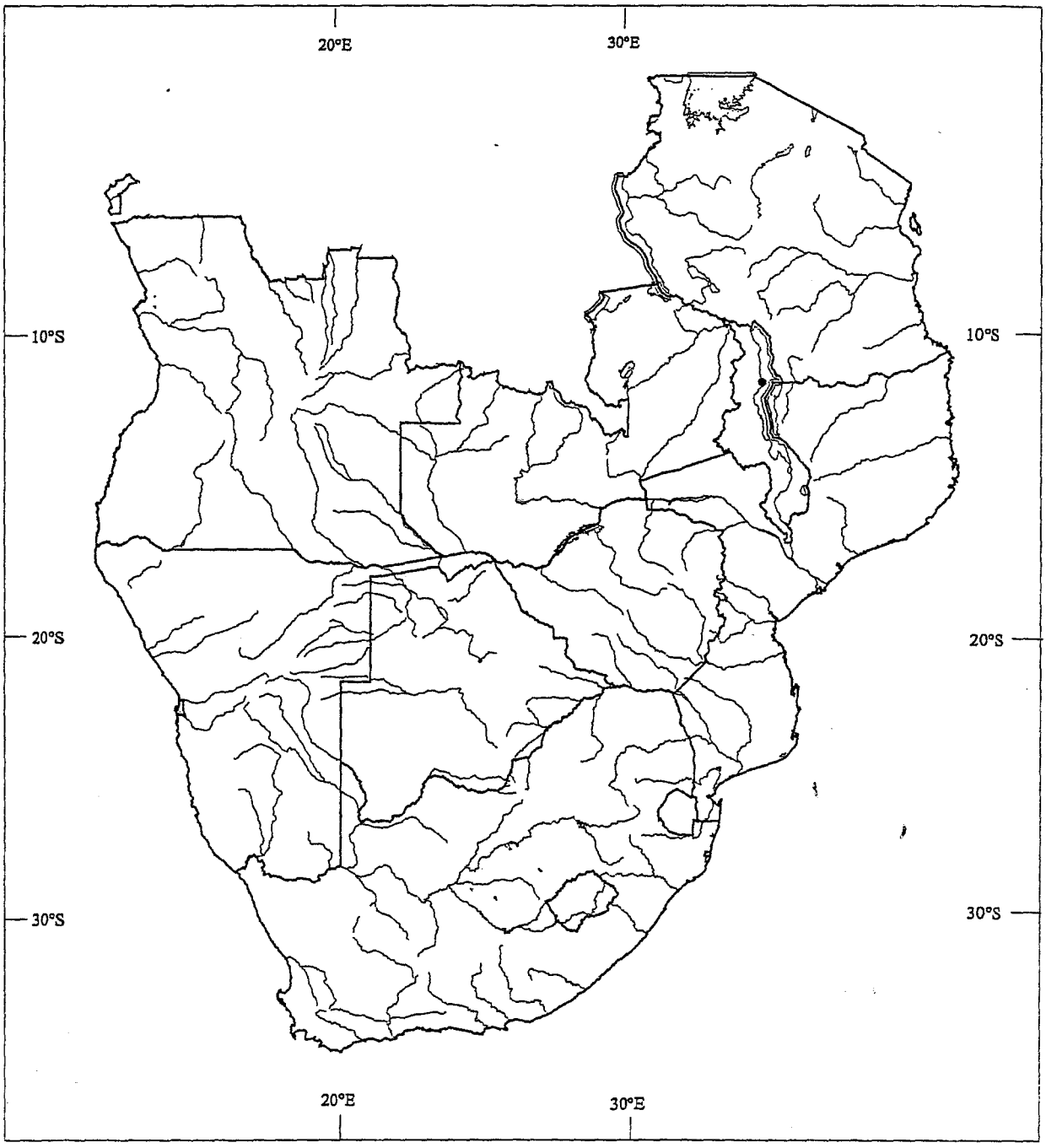


Figure F.413. Point distribution of *Lichnochromis acutileps*. Scale approximately 1:25 000 000

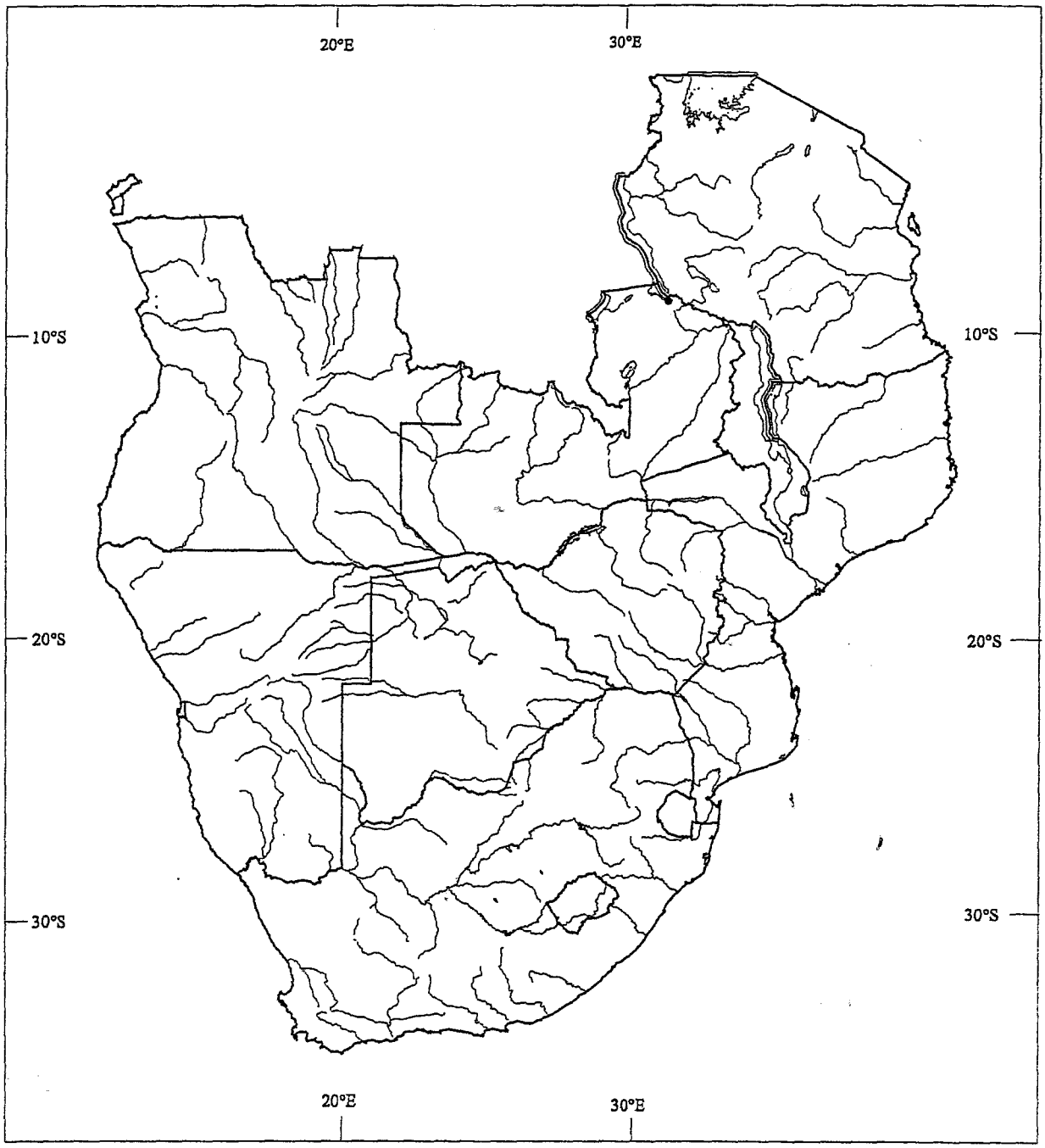


Figure F.414. Point distribution of *Limnochromis abeelei*. Scale approximately 1:25 000 000

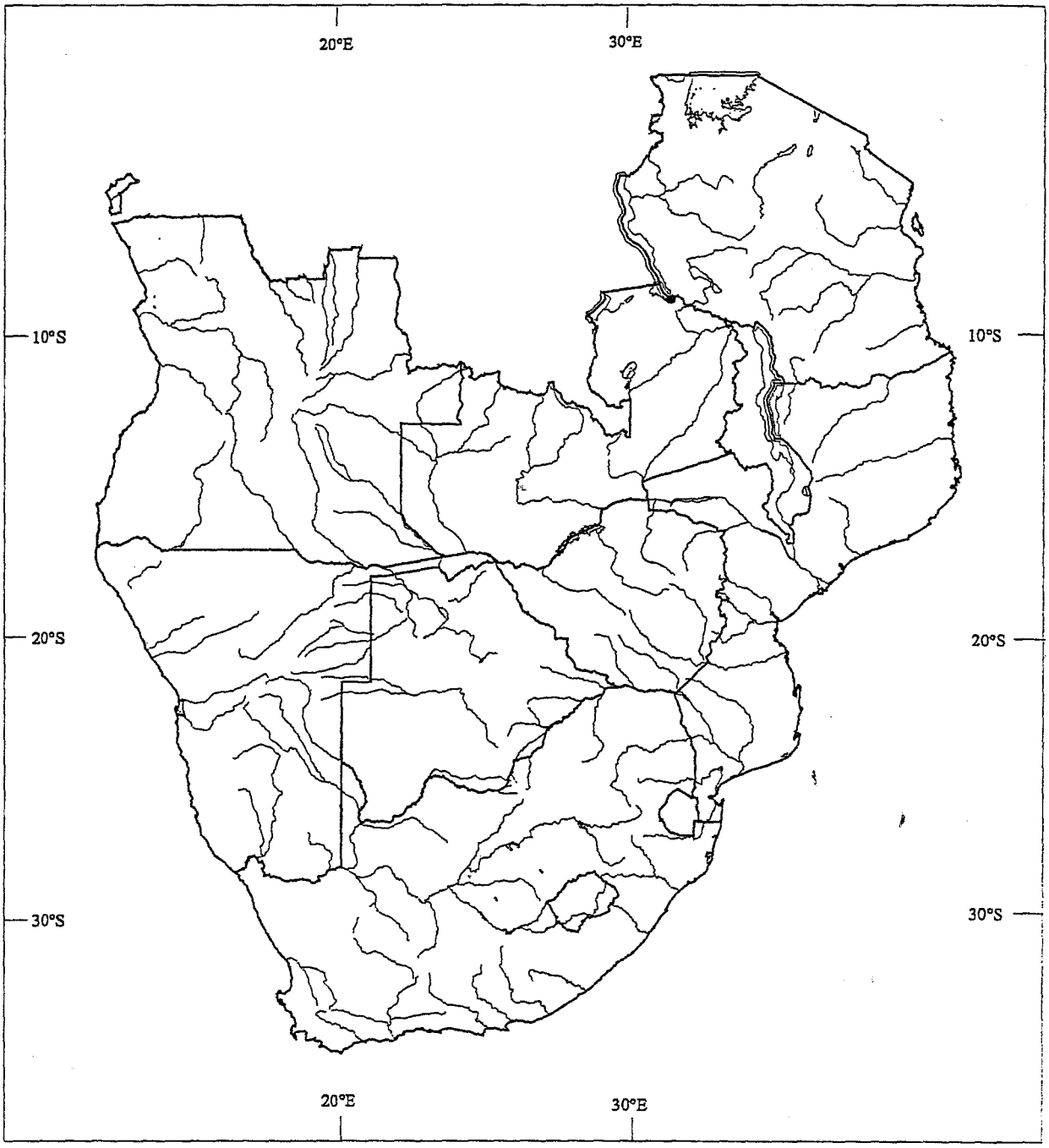


Figure F.415. Point distribution of *Limnochromis auritus*. Scale approximately 1:25 000 000

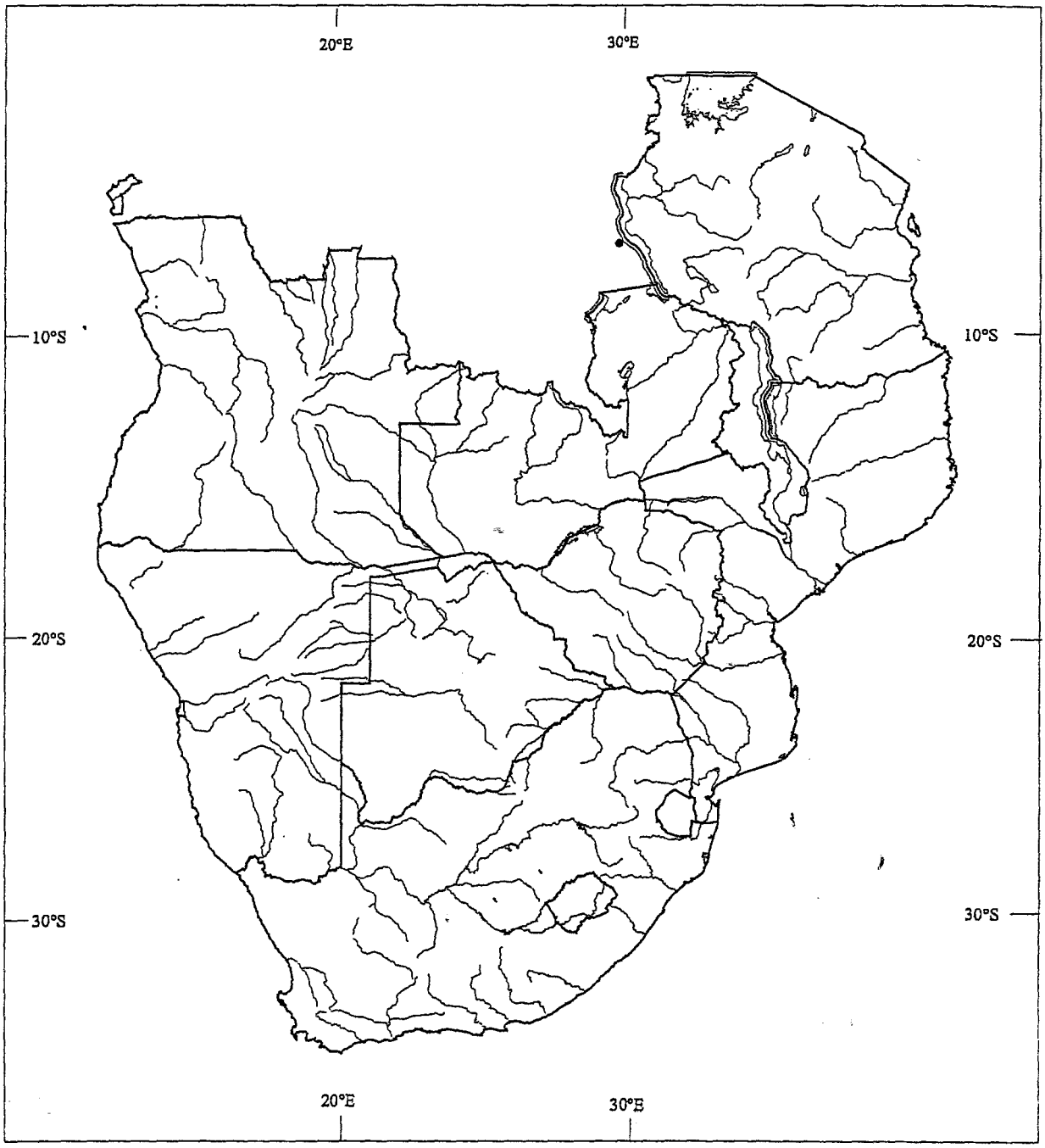


Figure F.416. Point distribution of *Limnochromis pfefferi*. Scale approximately 1:25 000 000

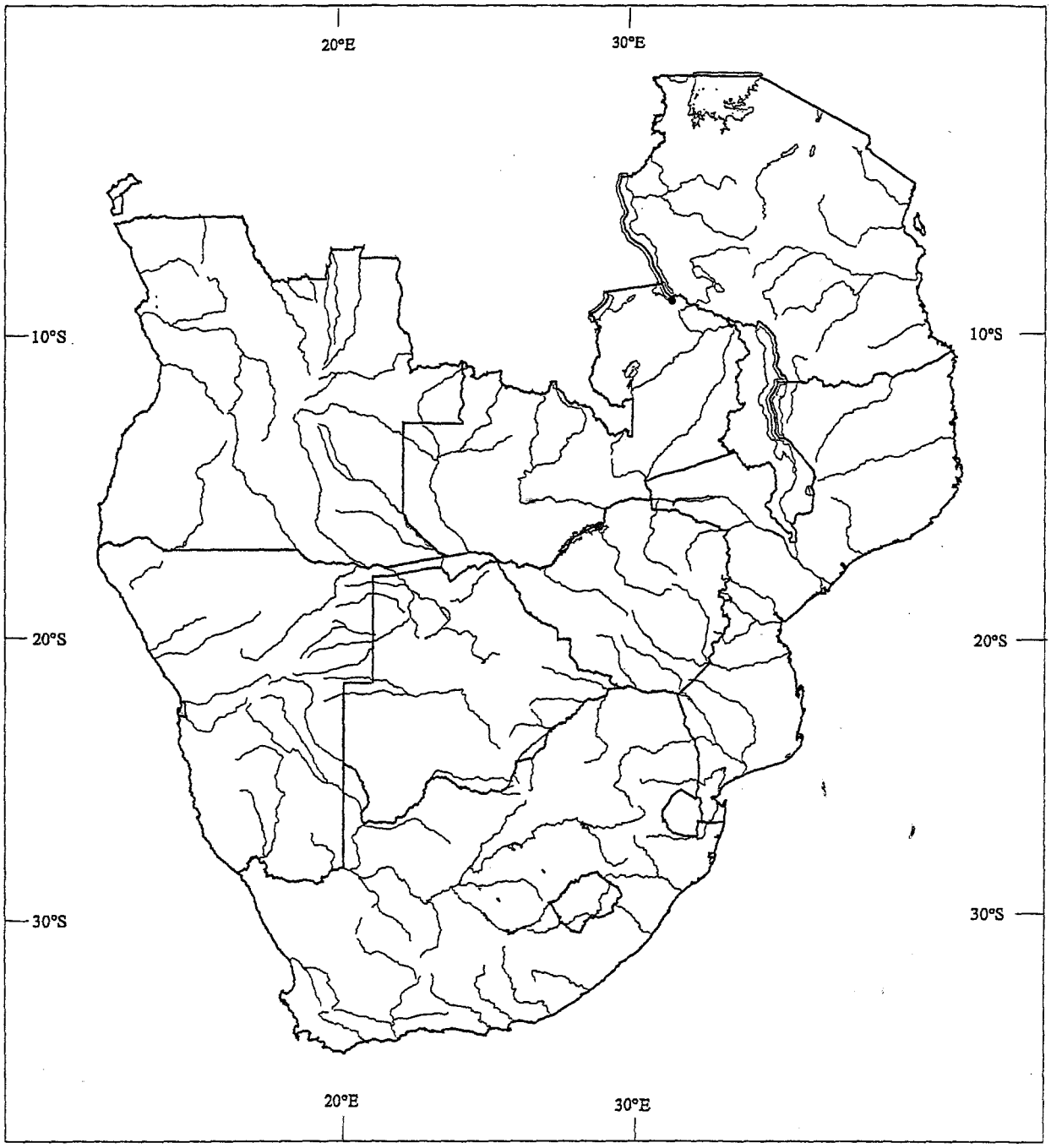


Figure F.417. Point distribution of *Limnothrissa miodon*. Scale approximately 1:25 000 000

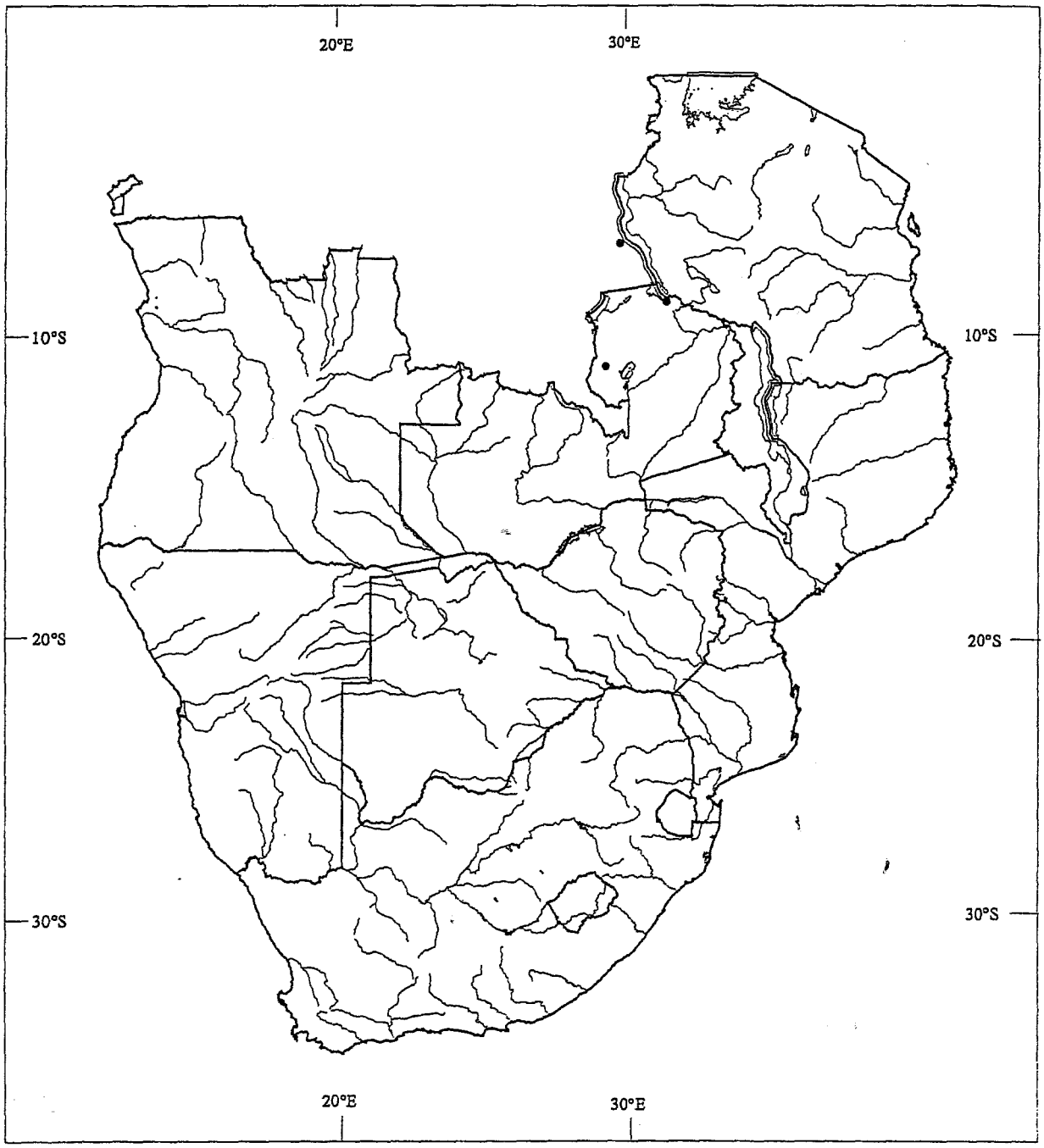


Figure F.418. Point distribution of *Limnotilapia dardeni*. Scale approximately 1:25 000 000

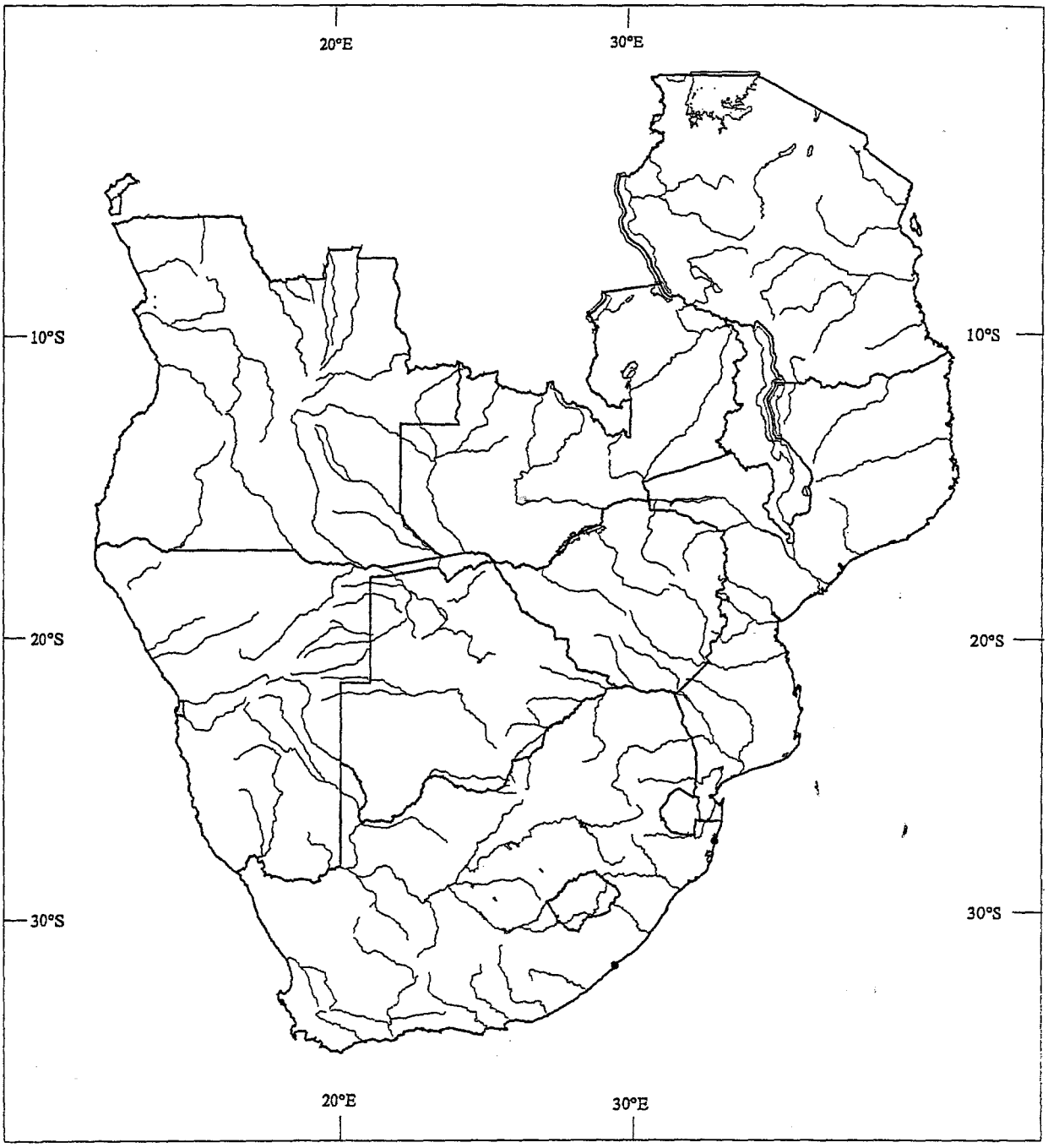


Figure F.419. Point distribution of *Liza macrolepis*. Scale approximately 1:25 000 000

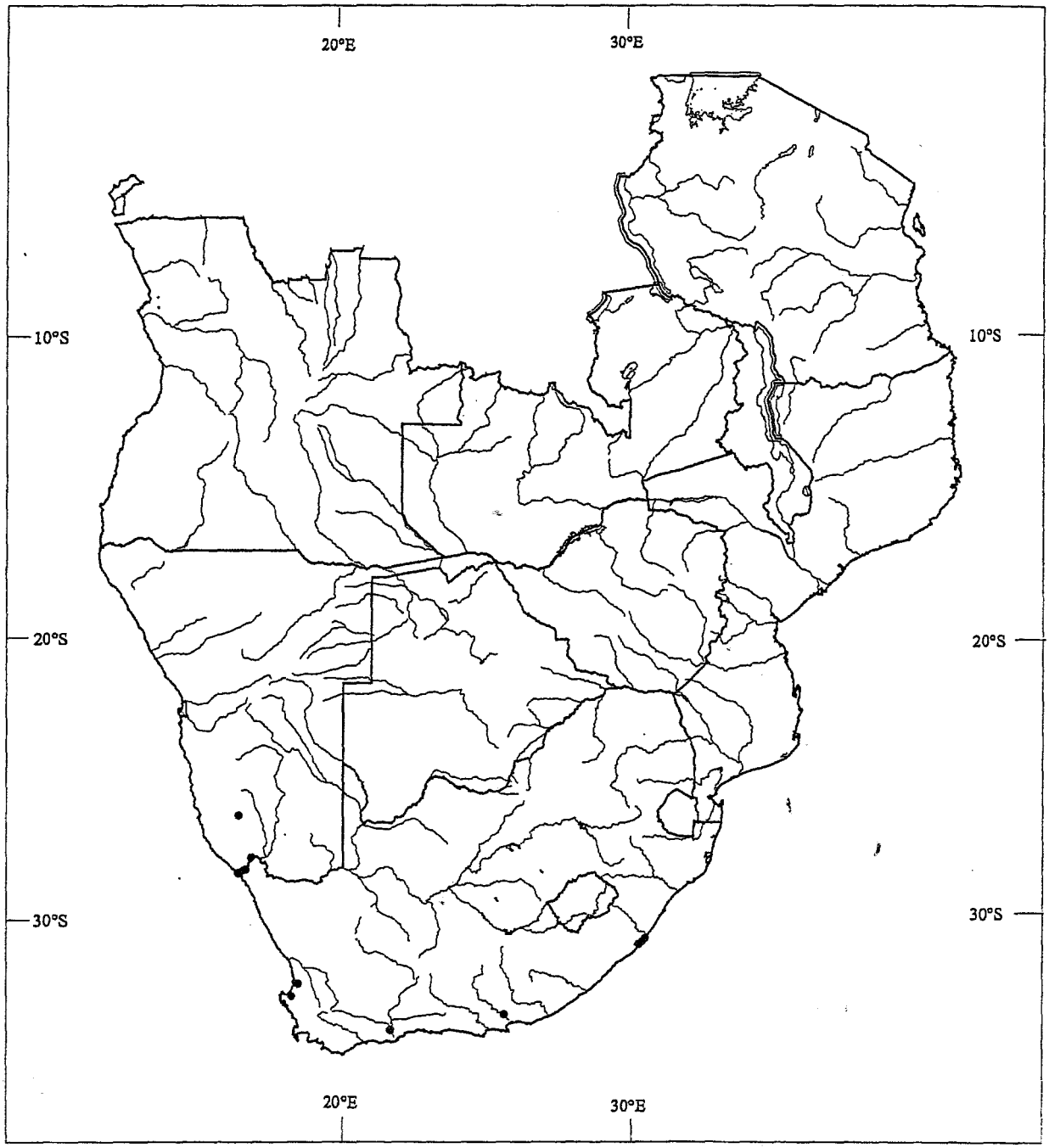


Figure F.420. Point distribution of *Liza richardsonii*. Scale approximately 1:25 000 000

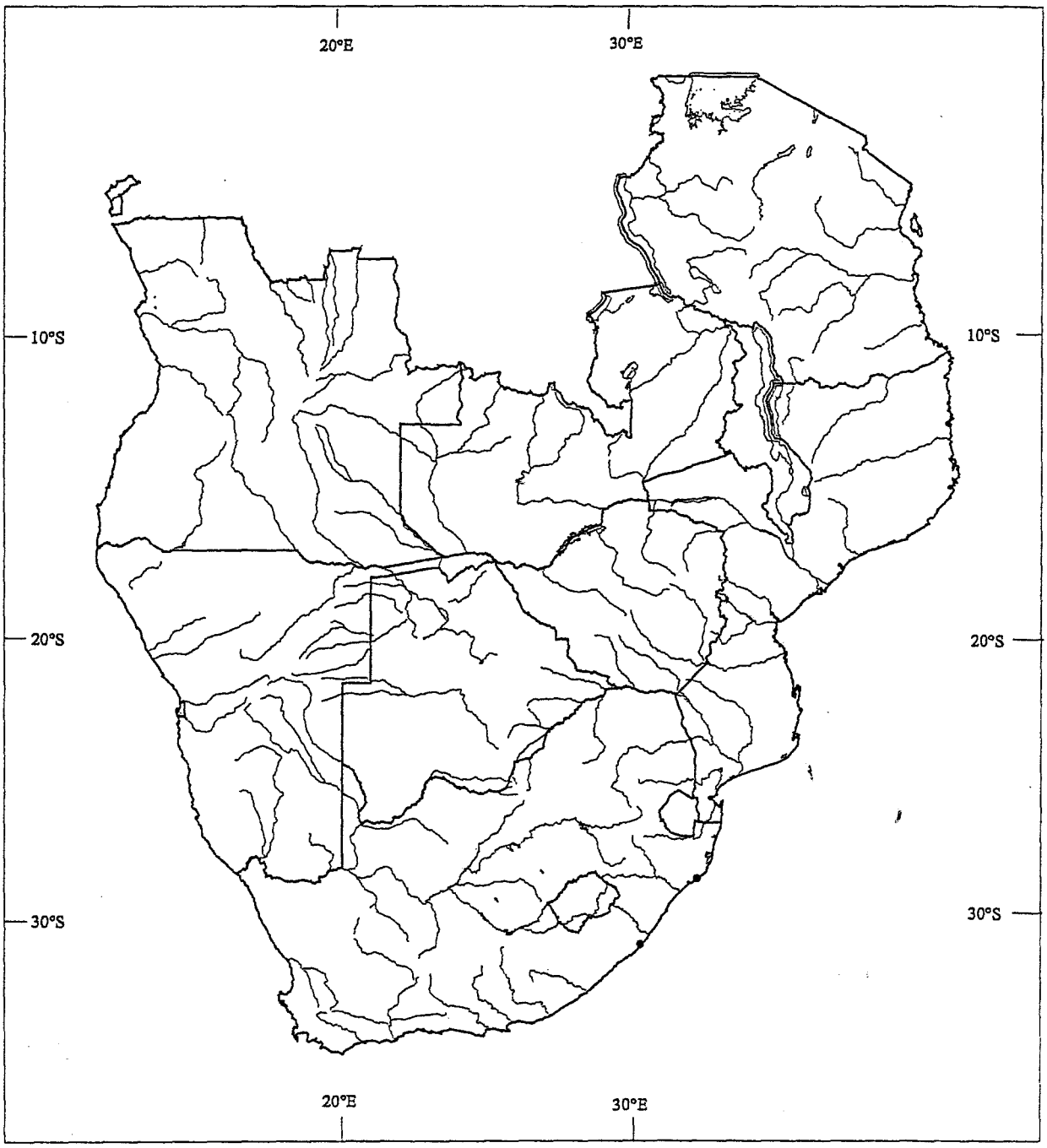


Figure F.421. Point distribution of *Liza tricuspidens*. Scale approximately 1:25 000 000

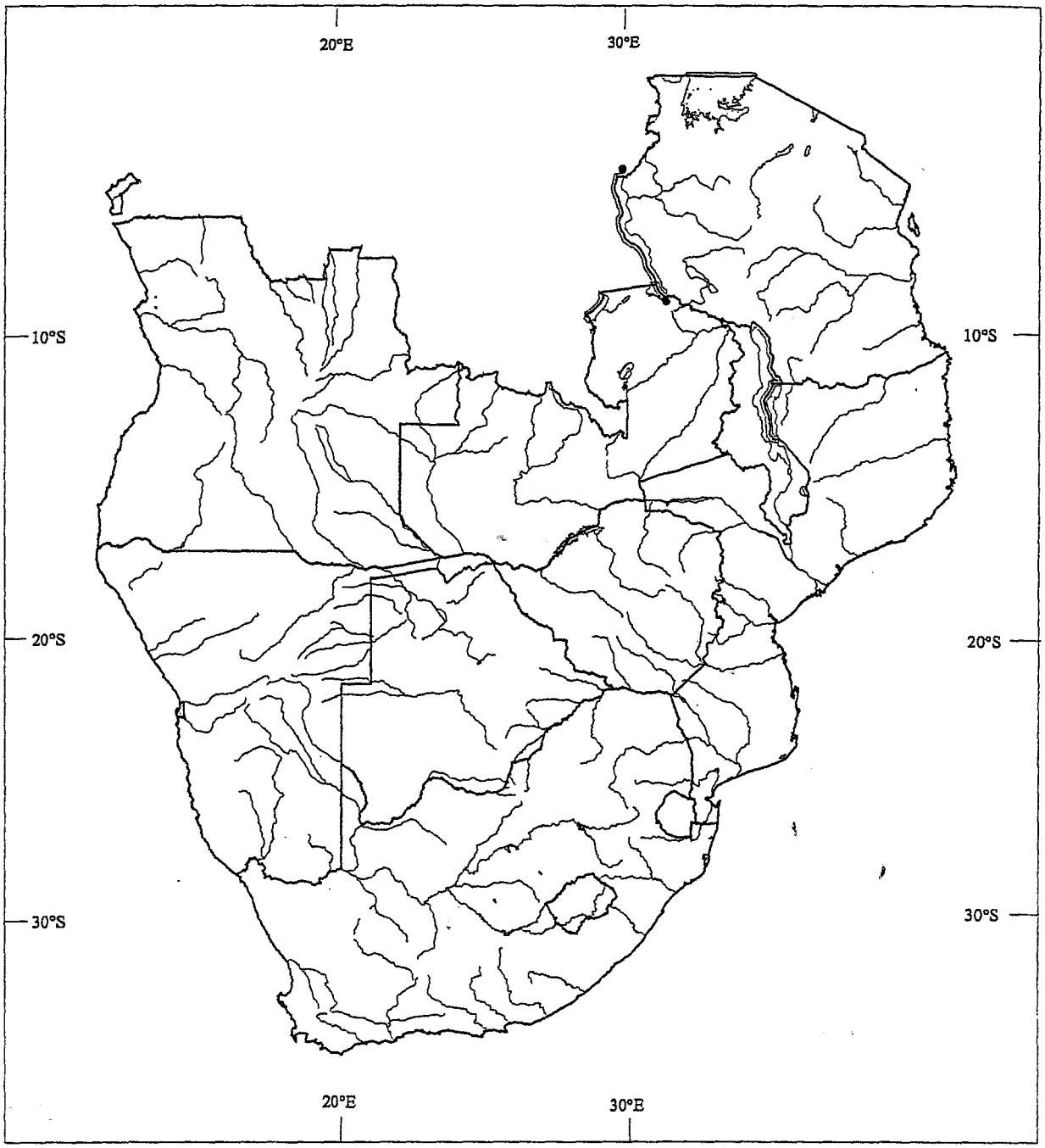


Figure F.422. Point distribution of *Lobochilotes labiatus*. Scale approximately 1:25 000 000

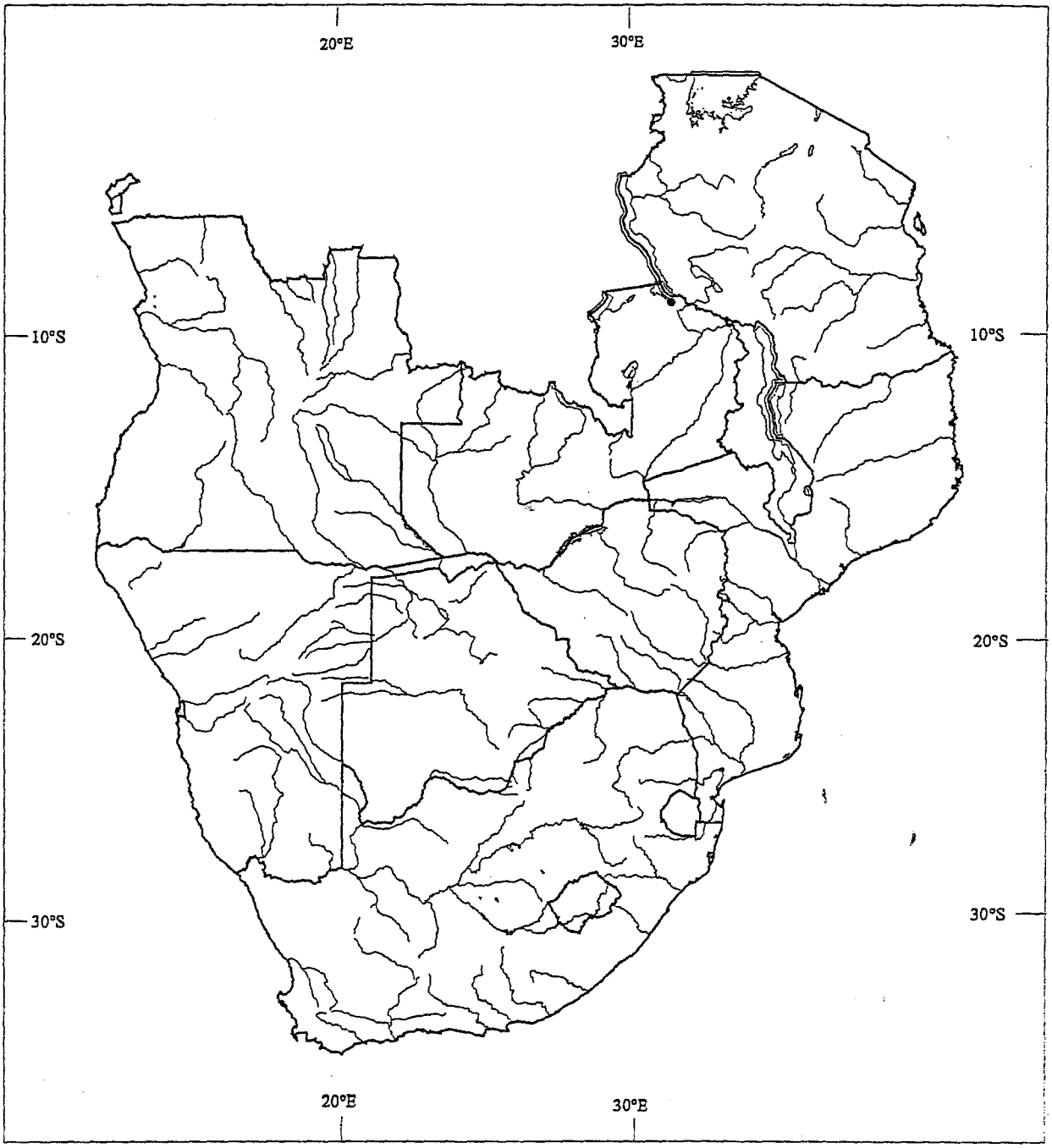


Figure F.423. Point distribution of *Lophiobagrus brevispinnis*. Scale approximately 1:25 000 000

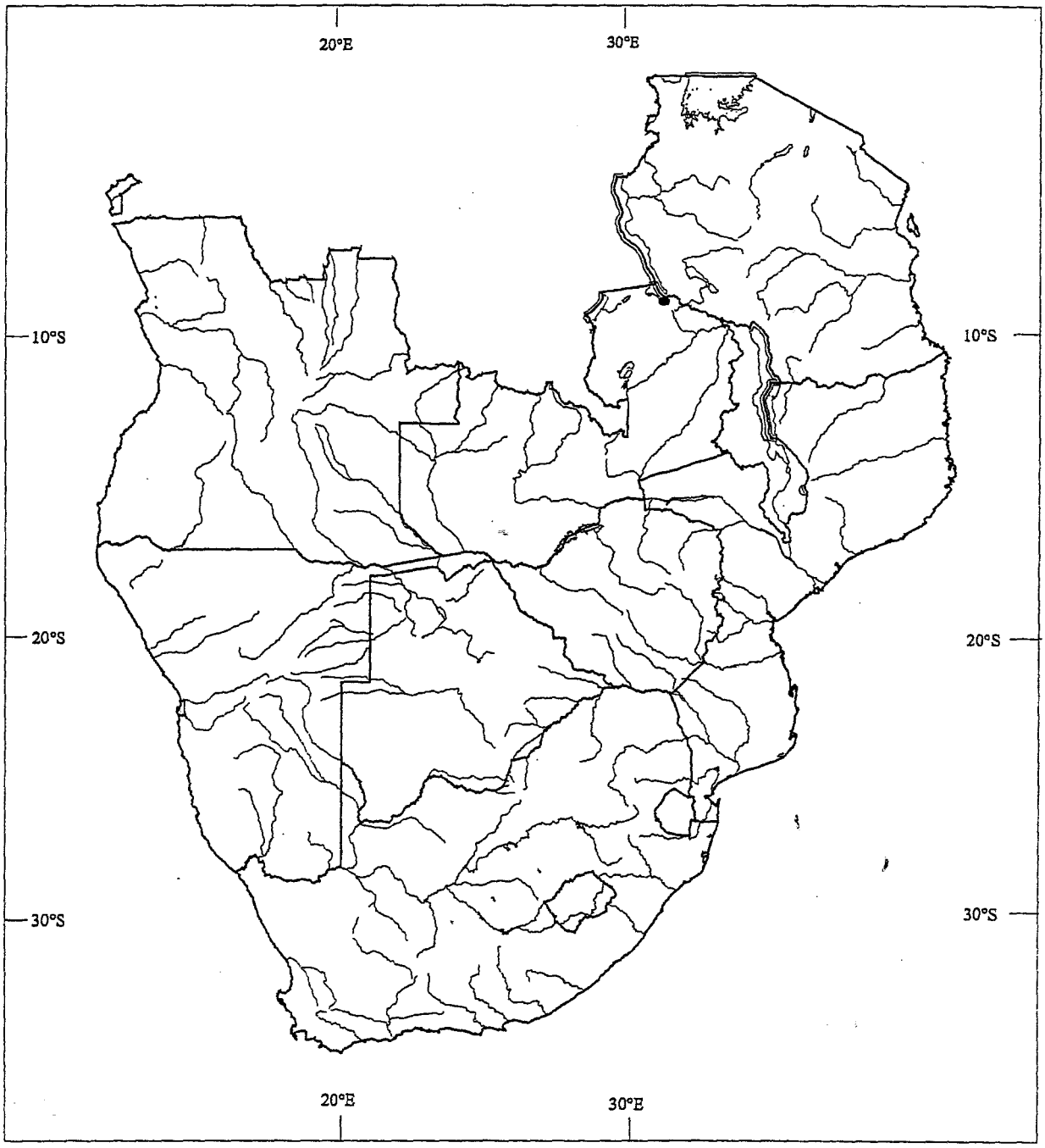


Figure F.424. Point distribution of *Lophiobagrus cyclurus*. Scale approximately 1:25 000 000

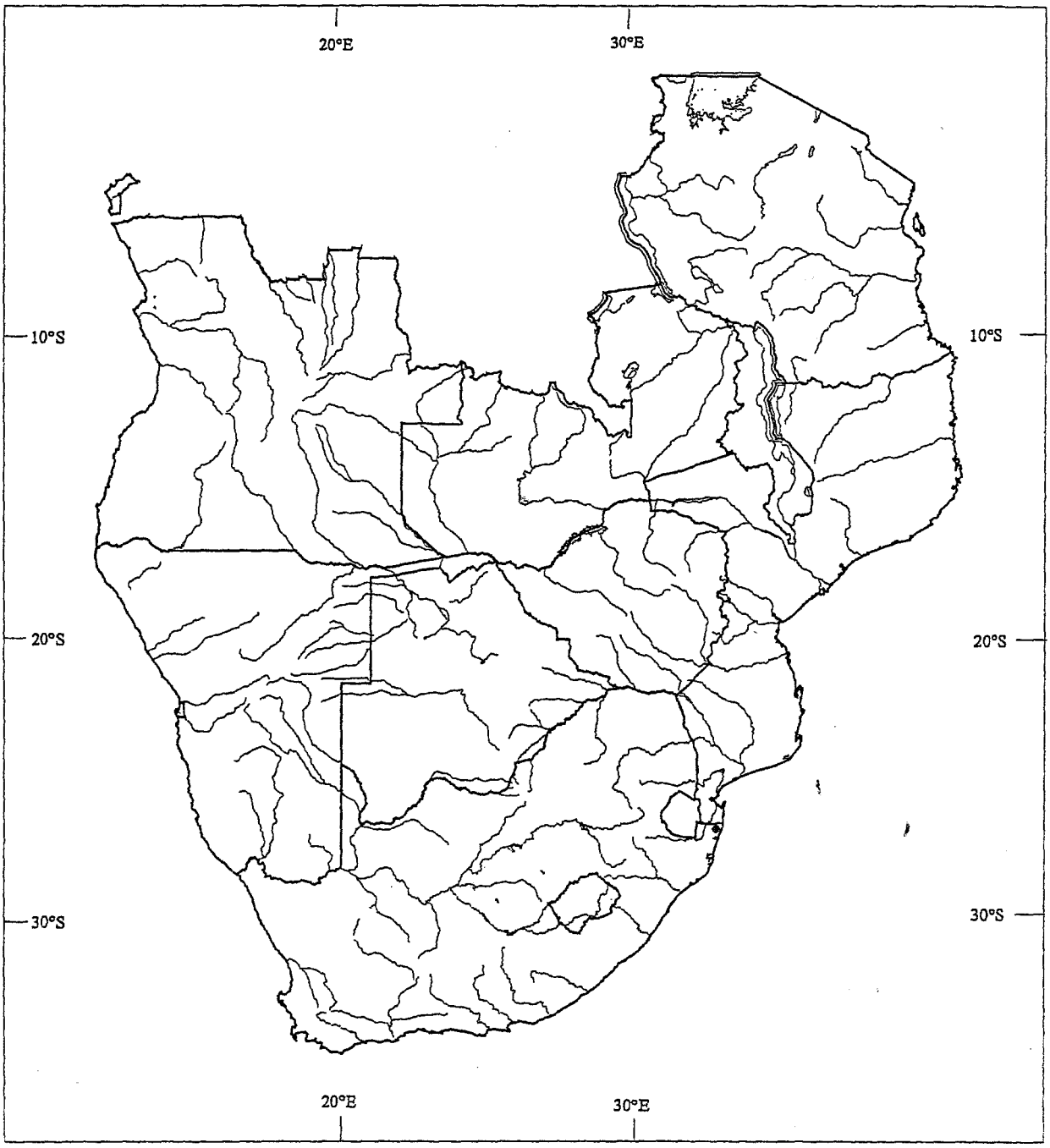


Figure F.425. Point distribution of *Lutjanus argentimaculatus*. Scale approximately 1:25 000 000

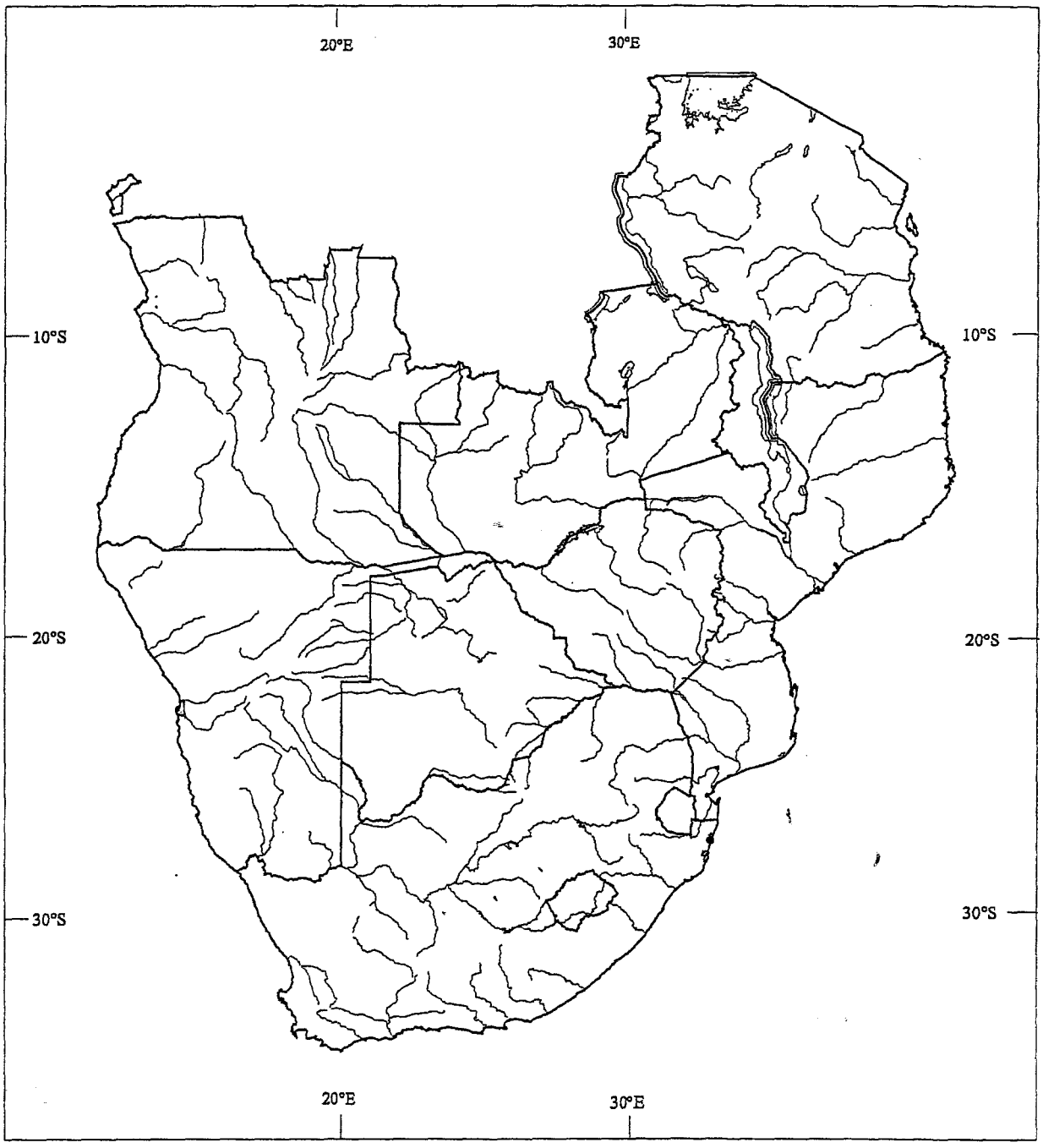


Figure F.426. Point distribution of *Lycodontis punctatus*. Scale approximately 1:25 000 000

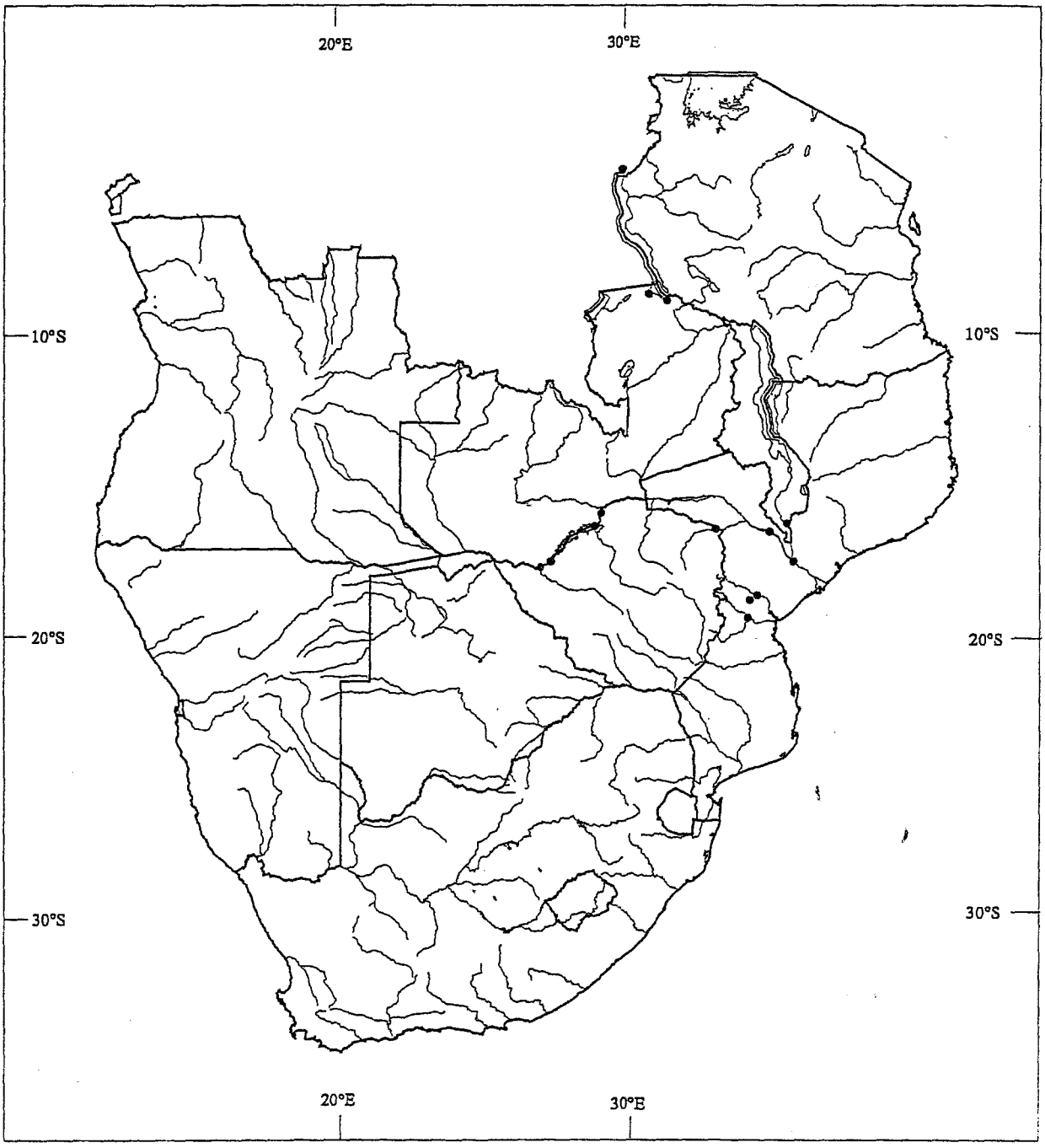


Figure F.427. Point distribution of *Malapterurus electricus*. Scale approximately 1:25 000 000

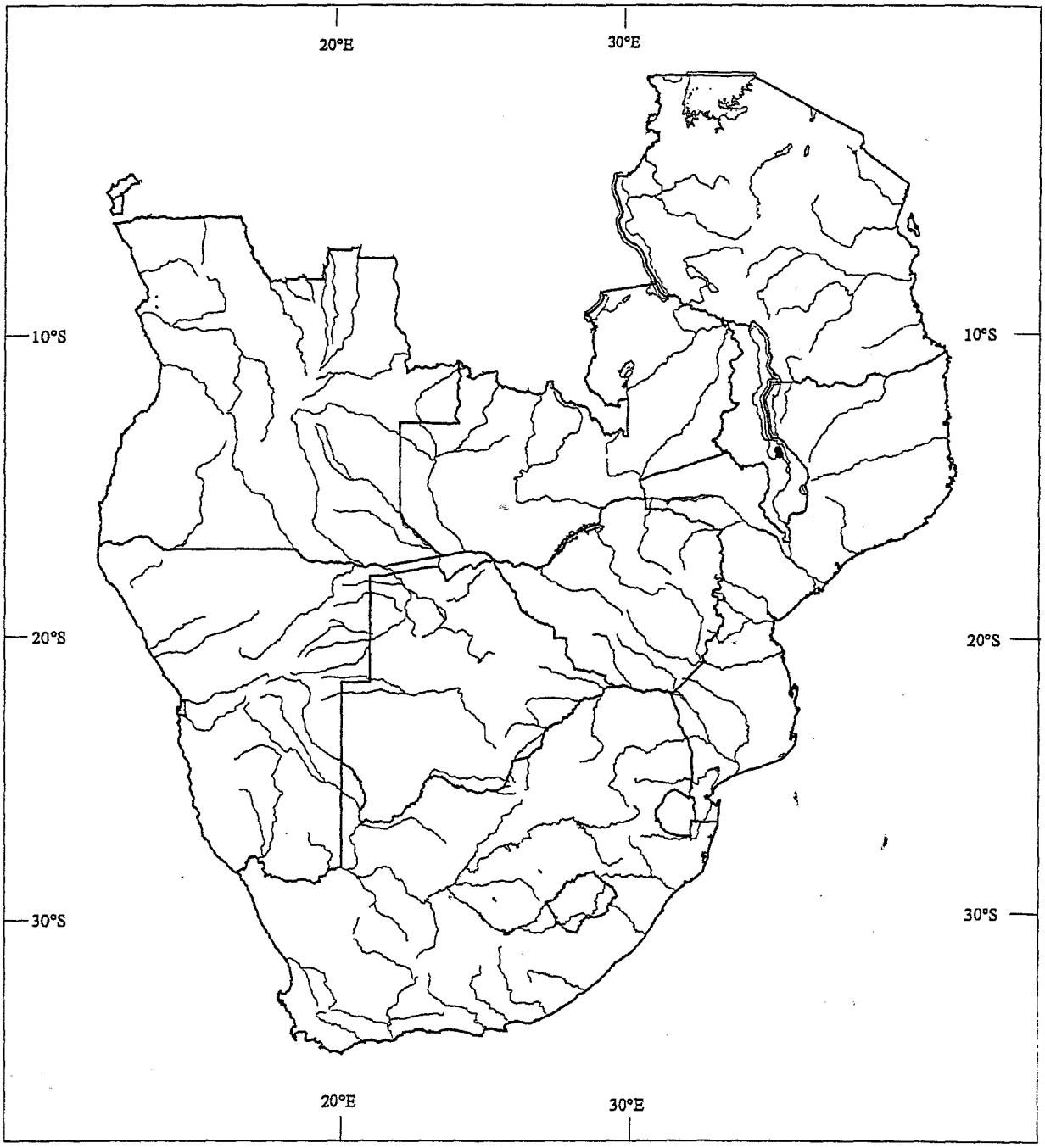


Figure F.428. Point distribution of *Maravichromis anaphyrus*. Scale approximately 1:25 000 000

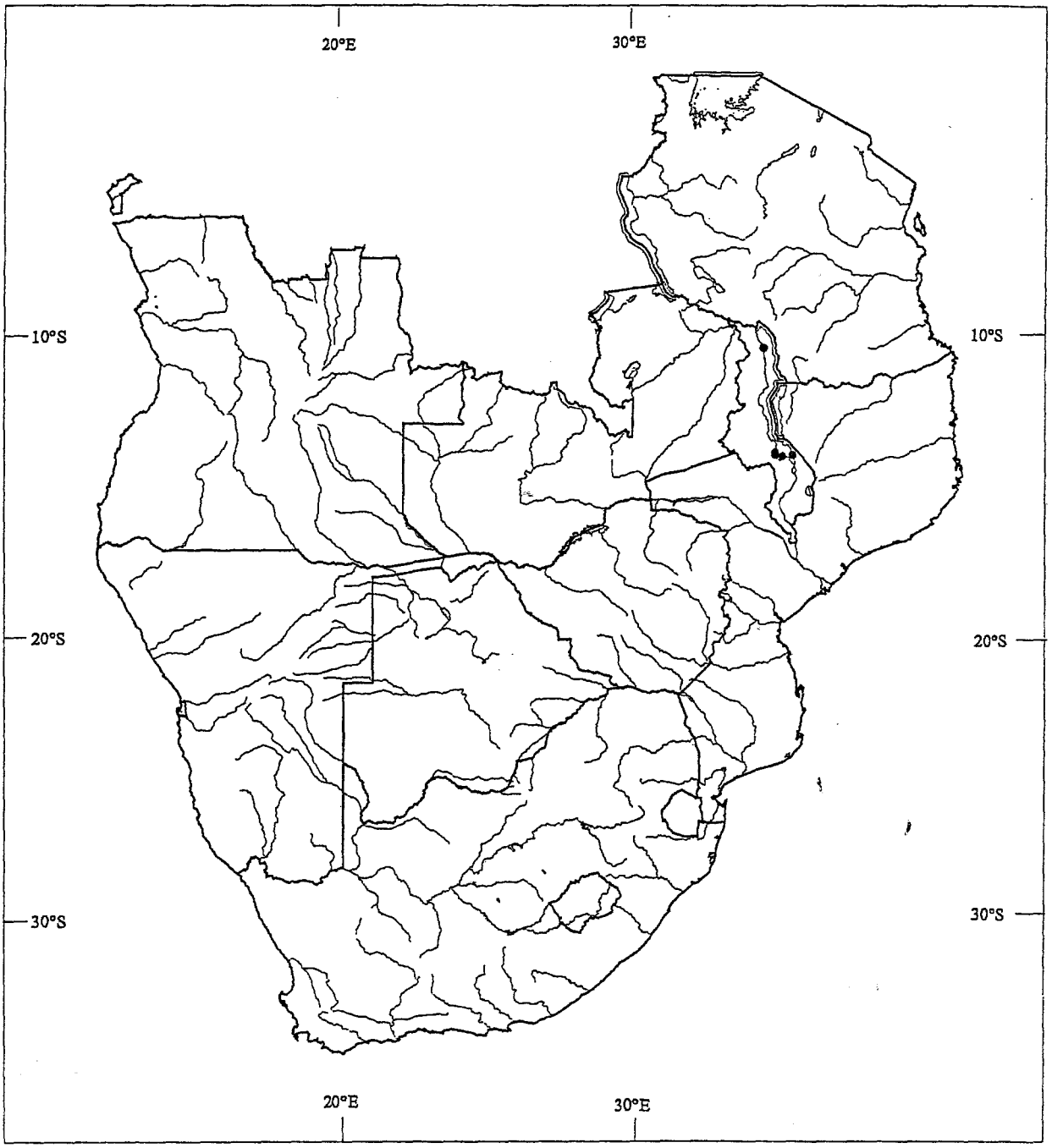


Figure F.429. Point distribution of *Maravichromis formosus*. Scale approximately 1:25 000 000

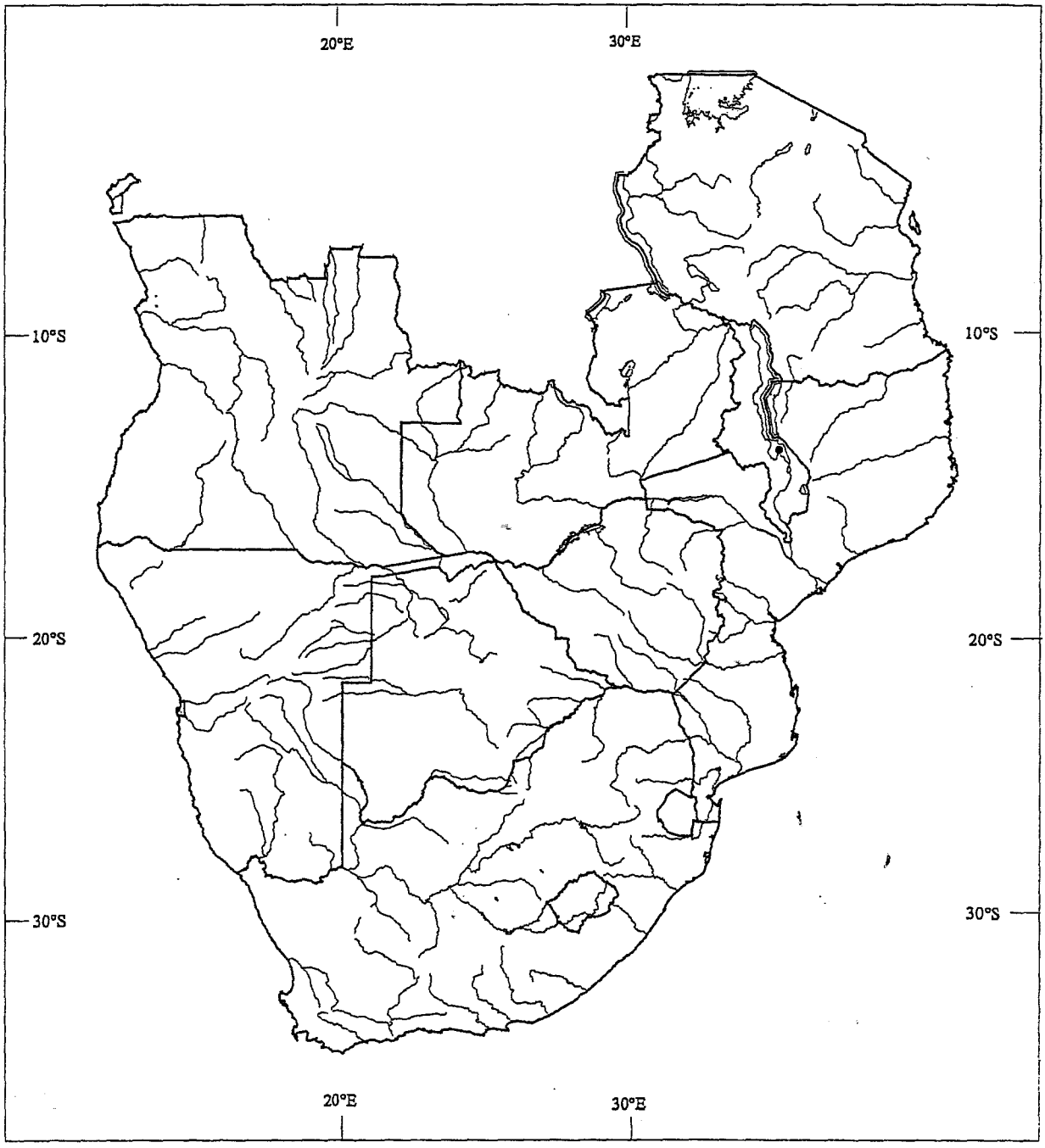


Figure F.430. Point distribution of *Maravichromis guentheri*. Scale approximately 1:25 000 000

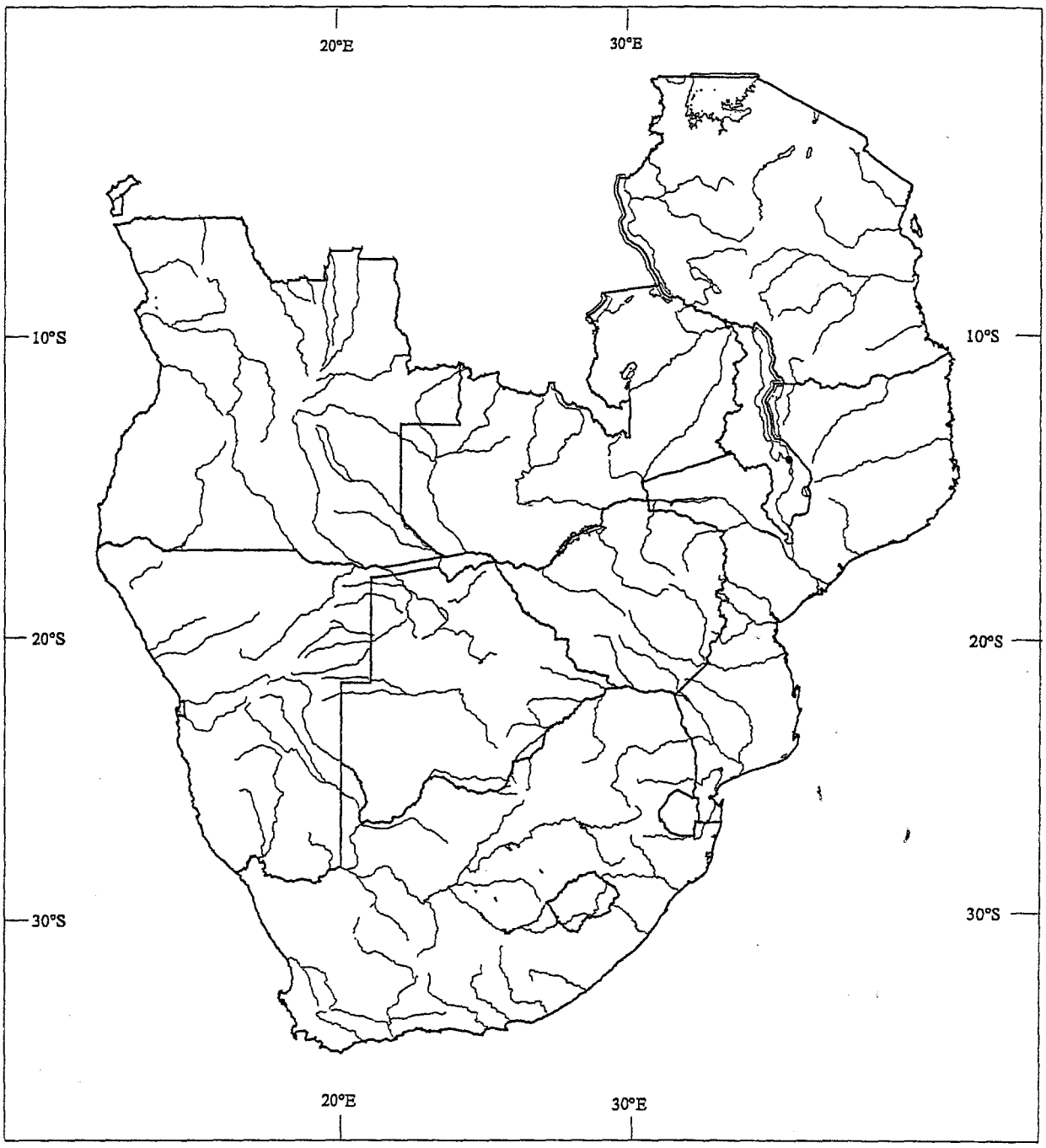


Figure F.431. Point distribution of *Maravichromis incola*. Scale approximately 1:25 000 000

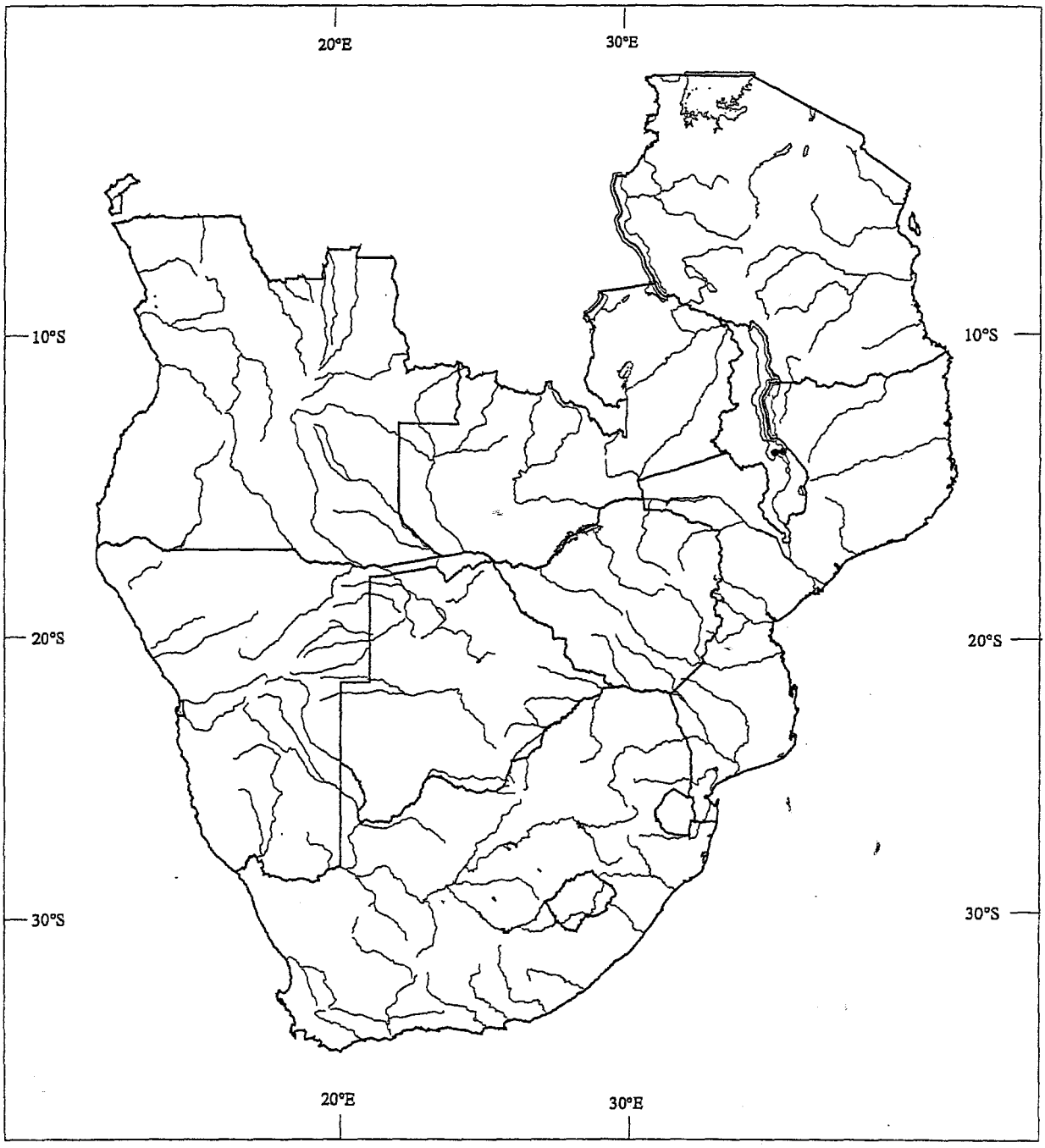


Figure F.432. Point distribution of *Maravichromis labidon*. Scale approximately 1:25 000 000

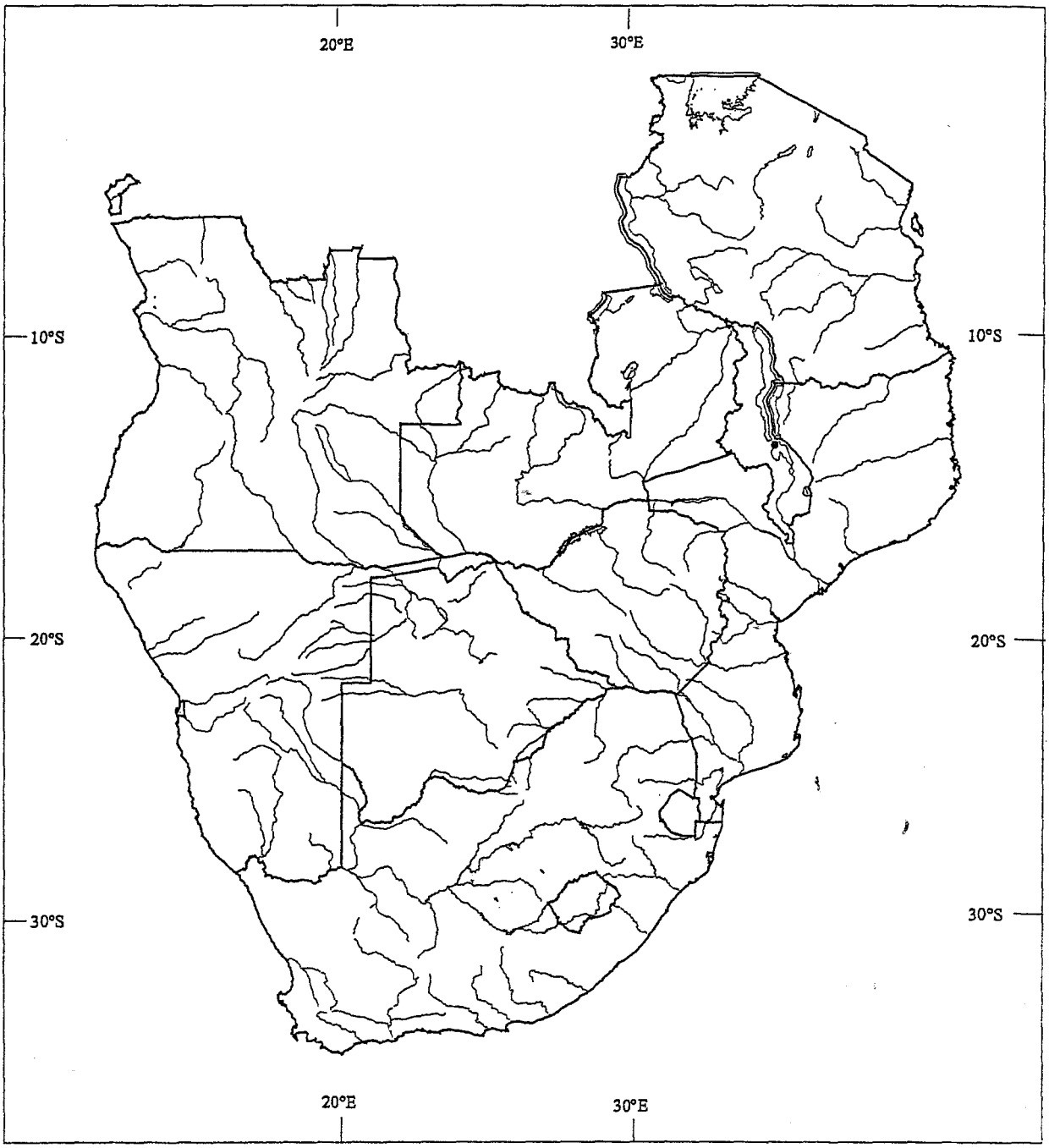


Figure F.433. Point distribution of *Maravichromis mollis*. Scale approximately 1:25 000 000

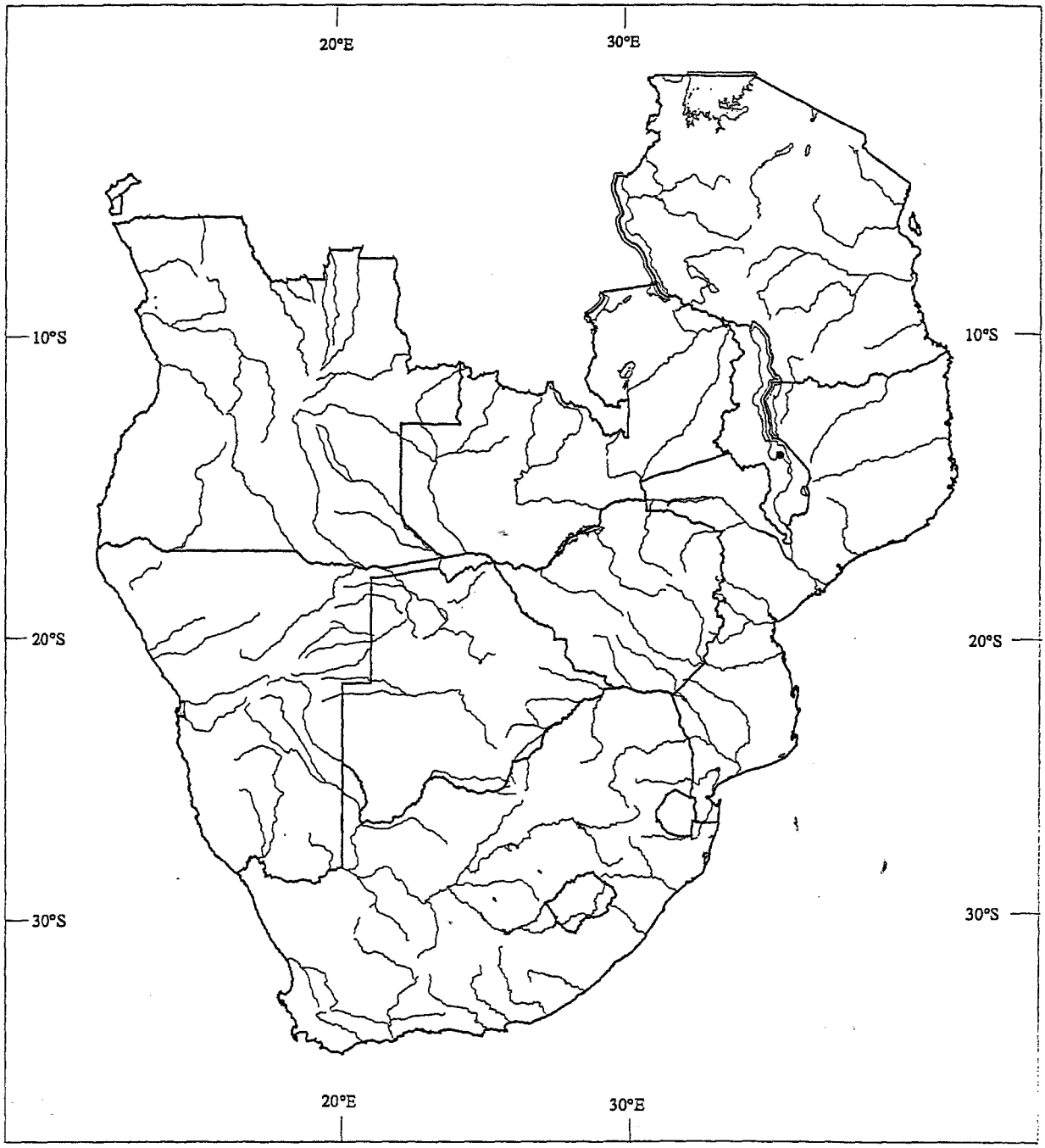


Figure F.434. Point distribution of *Maravichromis semipalatus*. Scale approximately 1:25 000 000

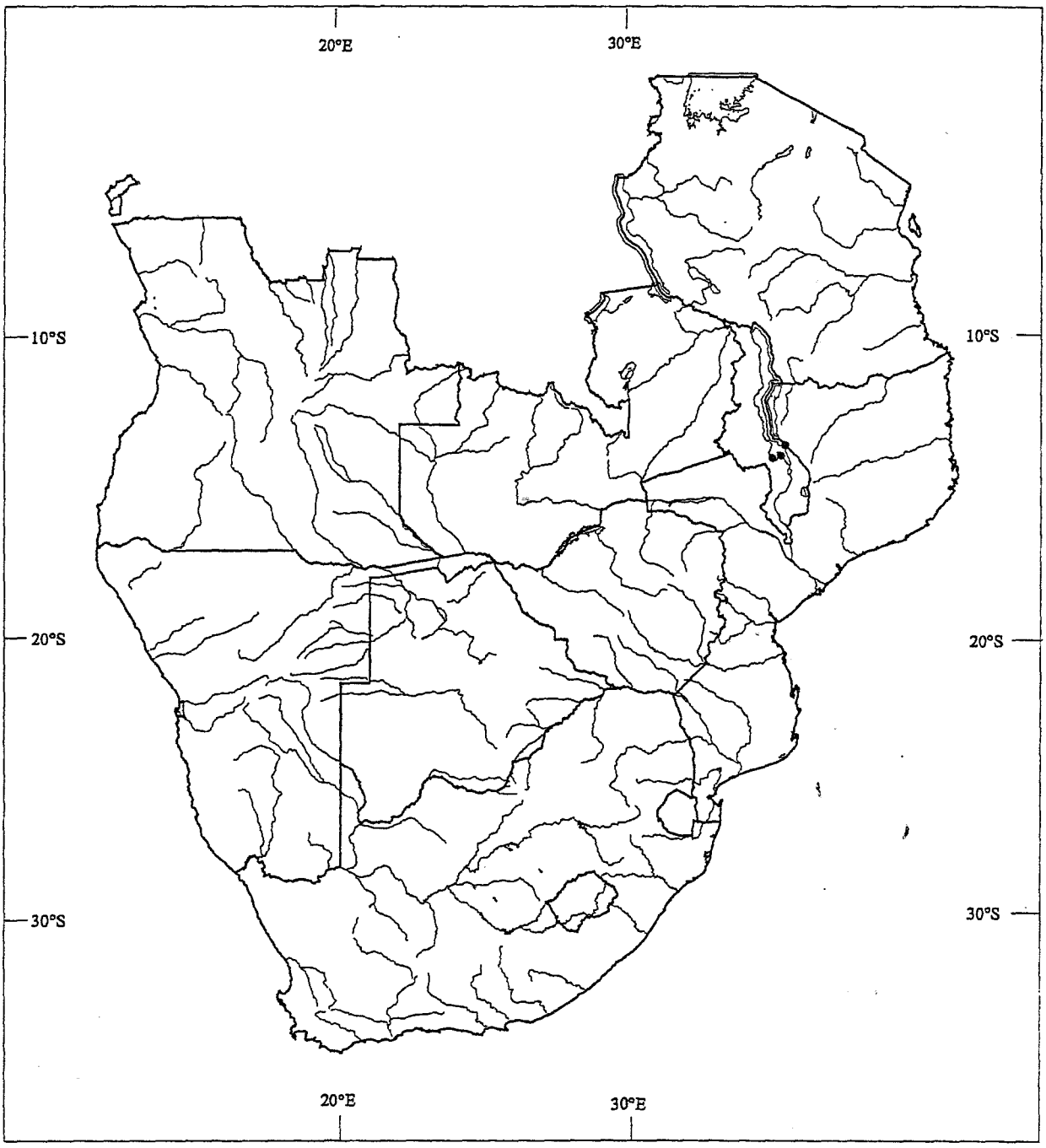


Figure F.435. Point distribution of *Maravichromis sphaerodon*. Scale approximately 1:25 000 000

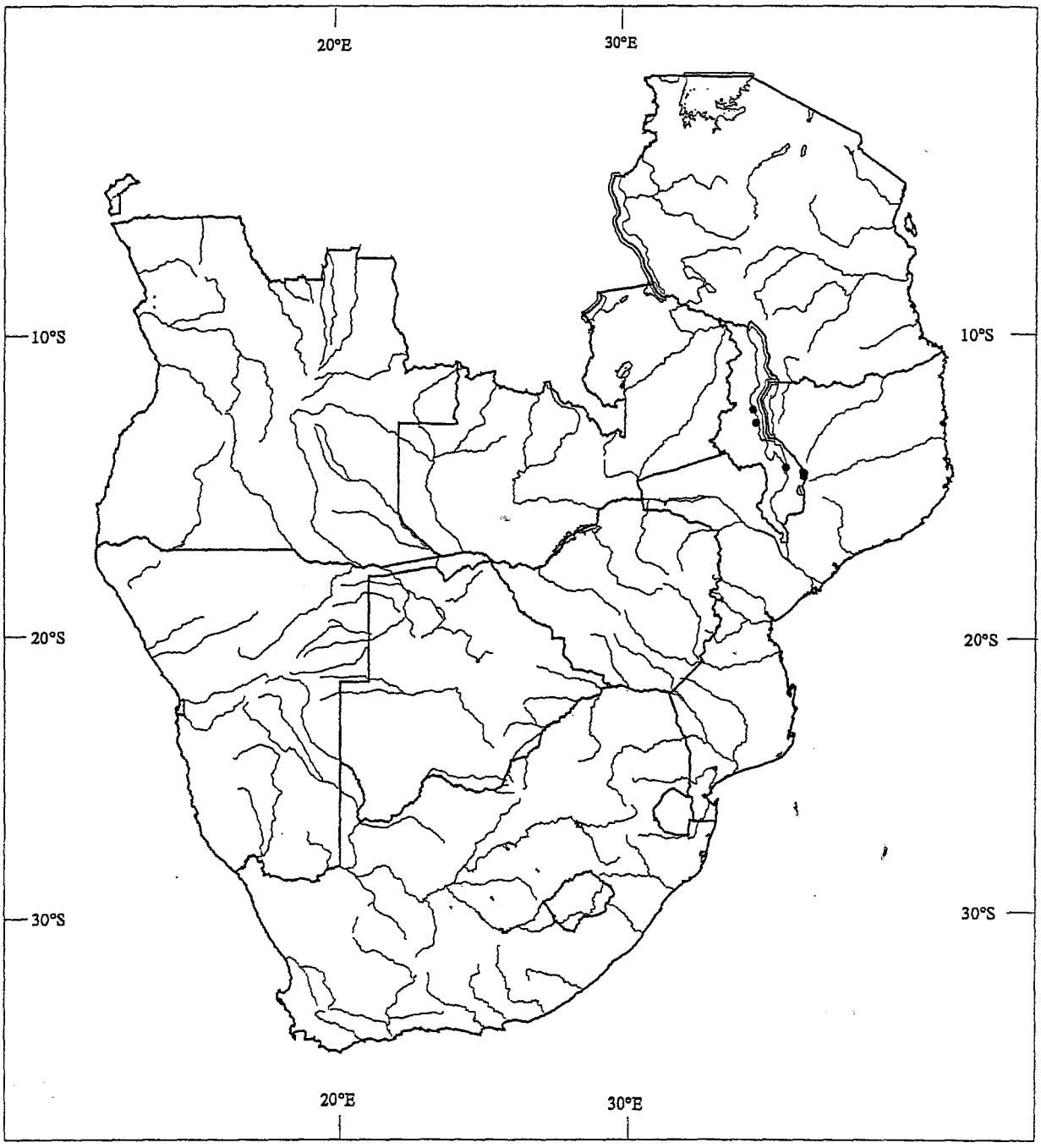


Figure F.436. Point distribution of *Marcusenius livingstonii*. Scale approximately 1:25 000 000

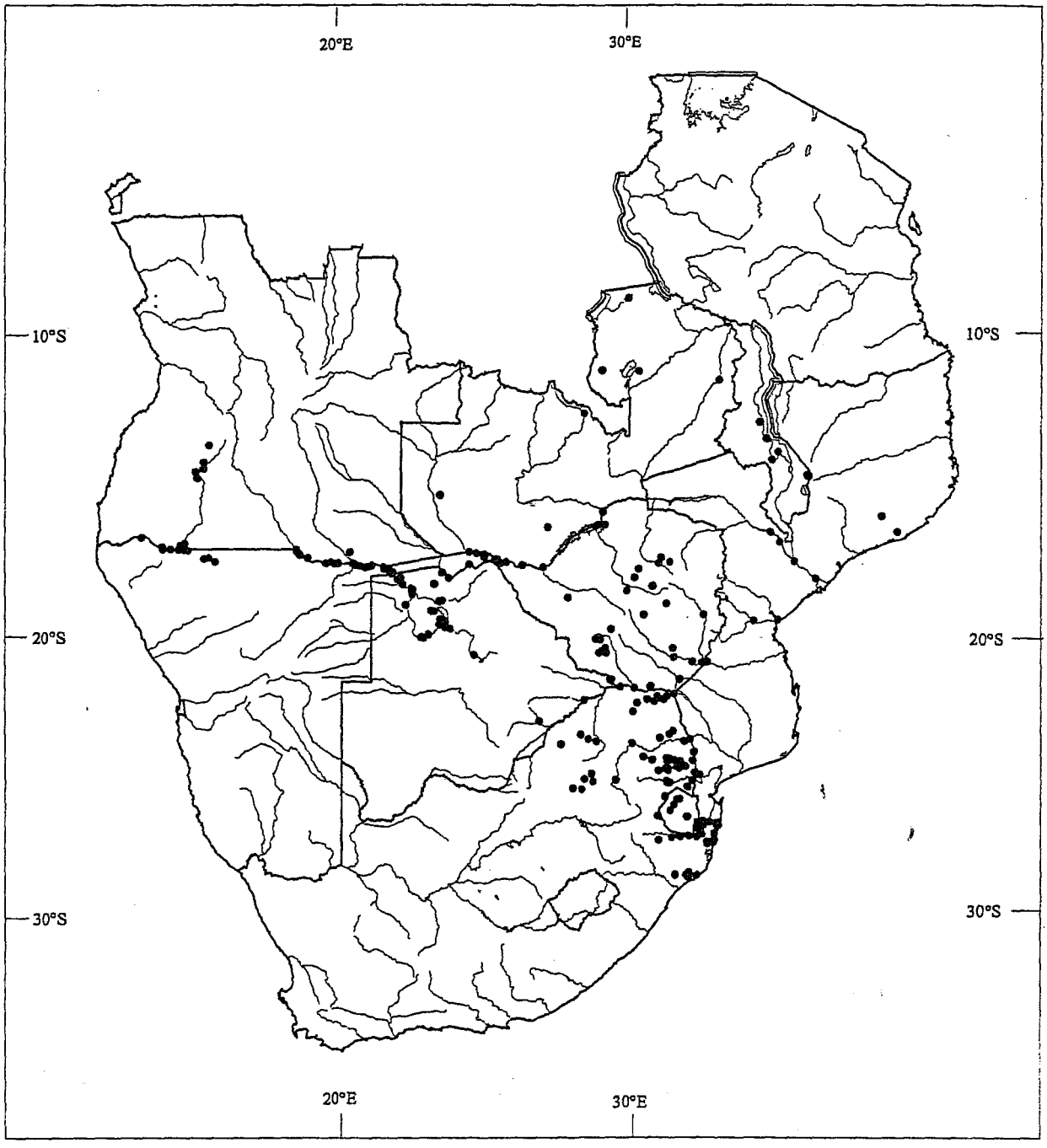


Figure F.437. Point distribution of *Marcusenius macrolepidotus*. Scale approximately 1:25 000 000

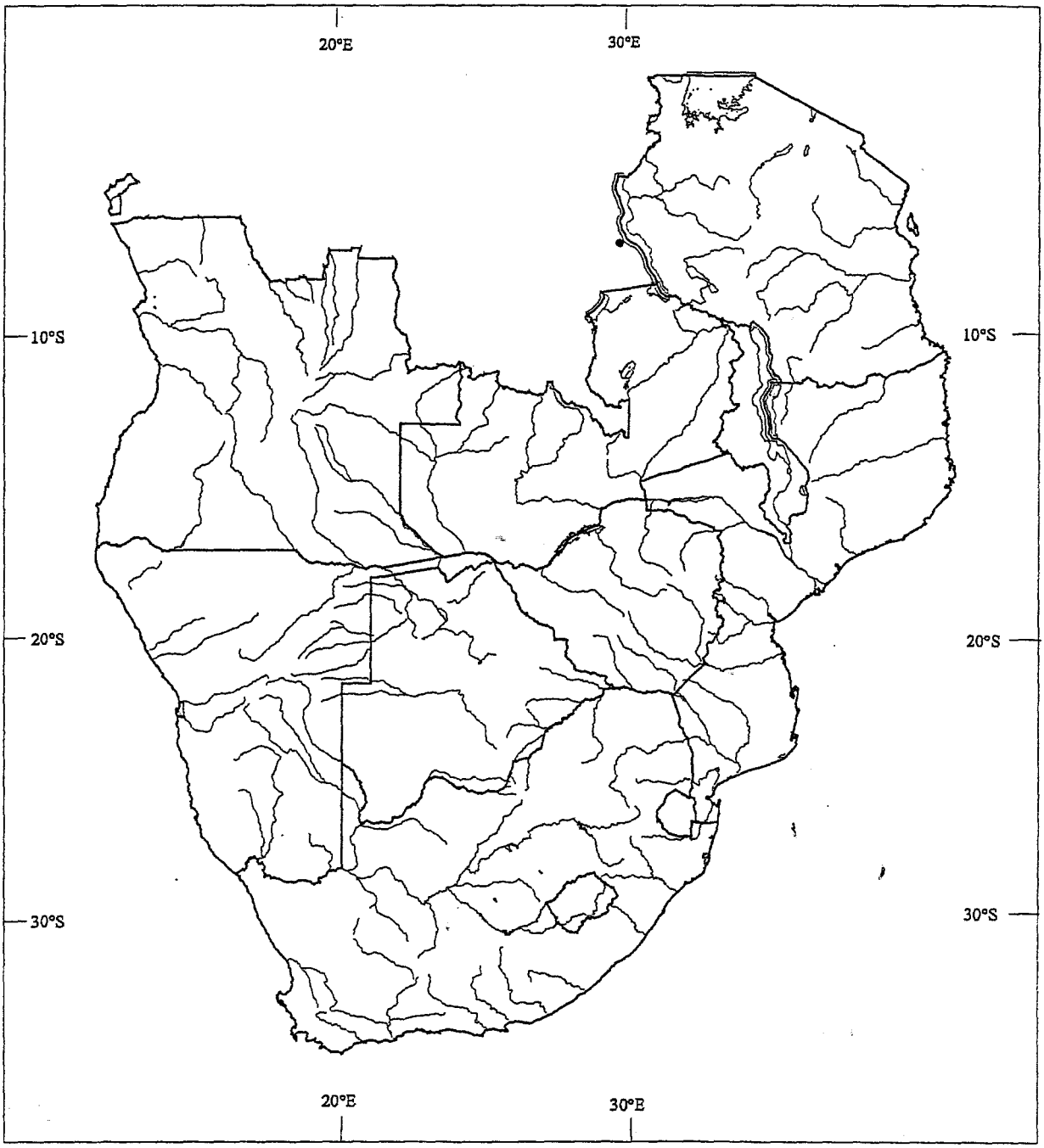


Figure F.438. Point distribution of *Mastacembelus apteryx*. Scale approximately 1:25 000 000

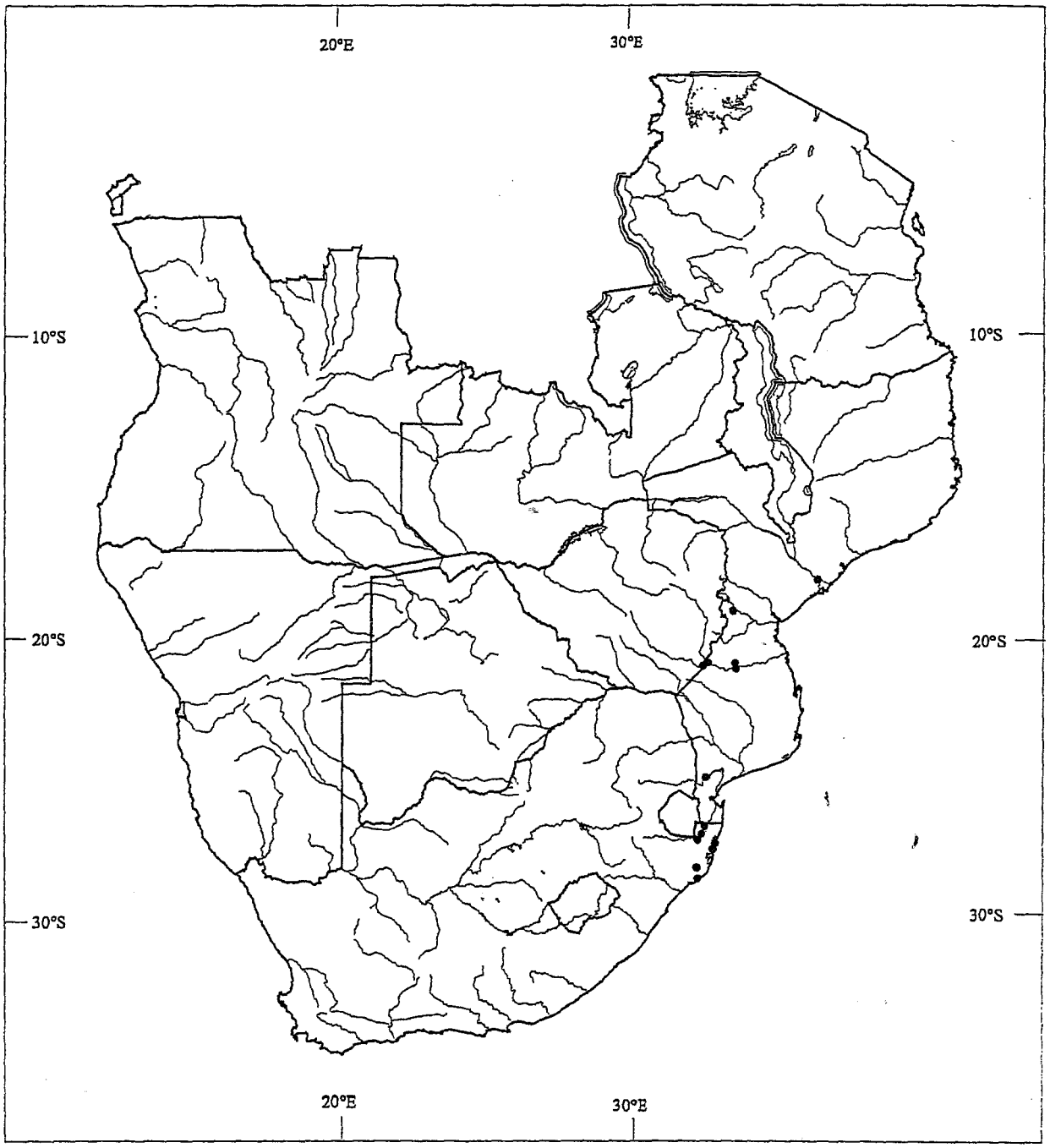


Figure F.439. Point distribution of *Megalops cyprinoides*. Scale approximately 1:25 000 000

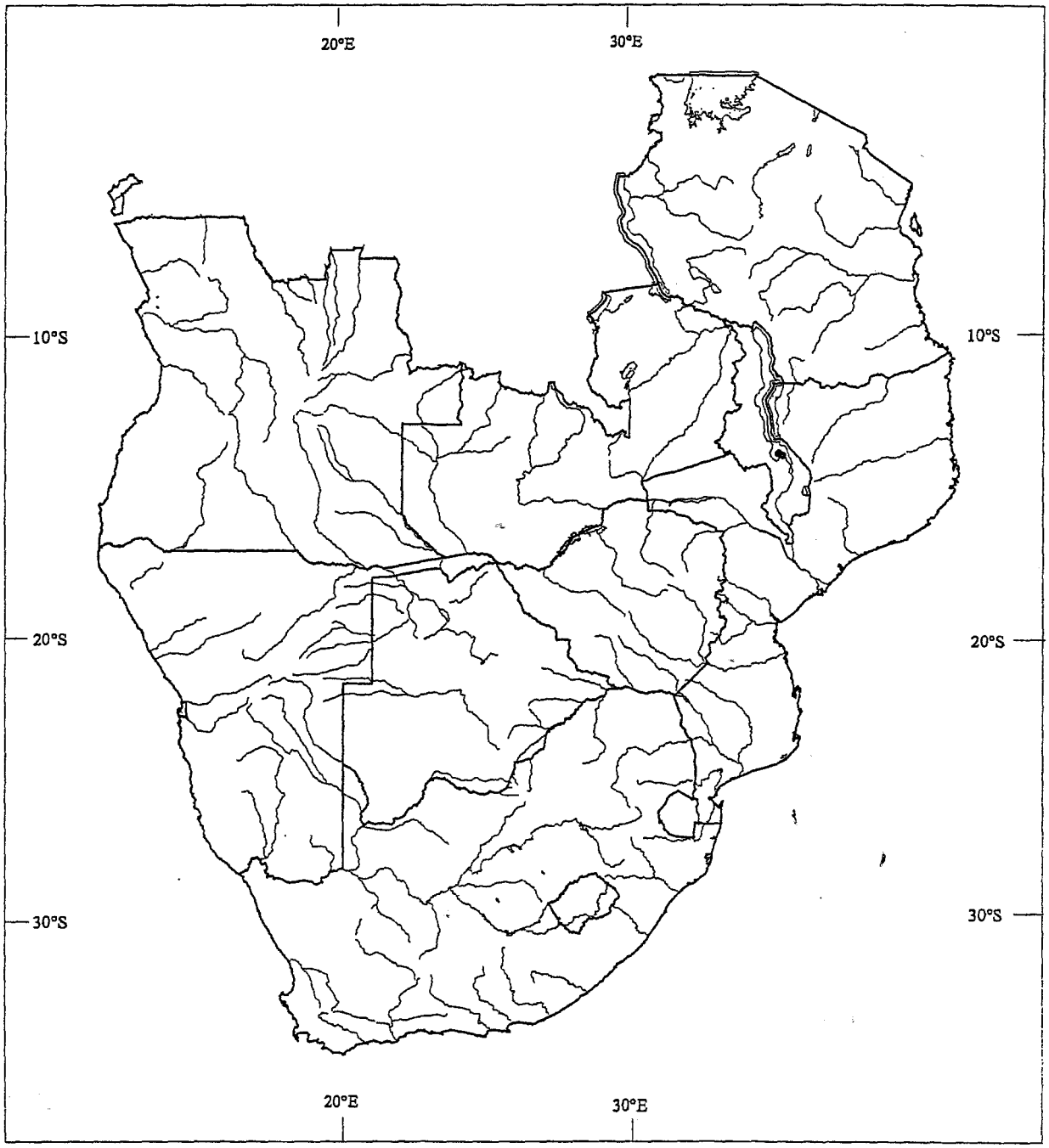


Figure F.440. Point distribution of *Melanochromis auratus*. Scale approximately 1:25 000 000

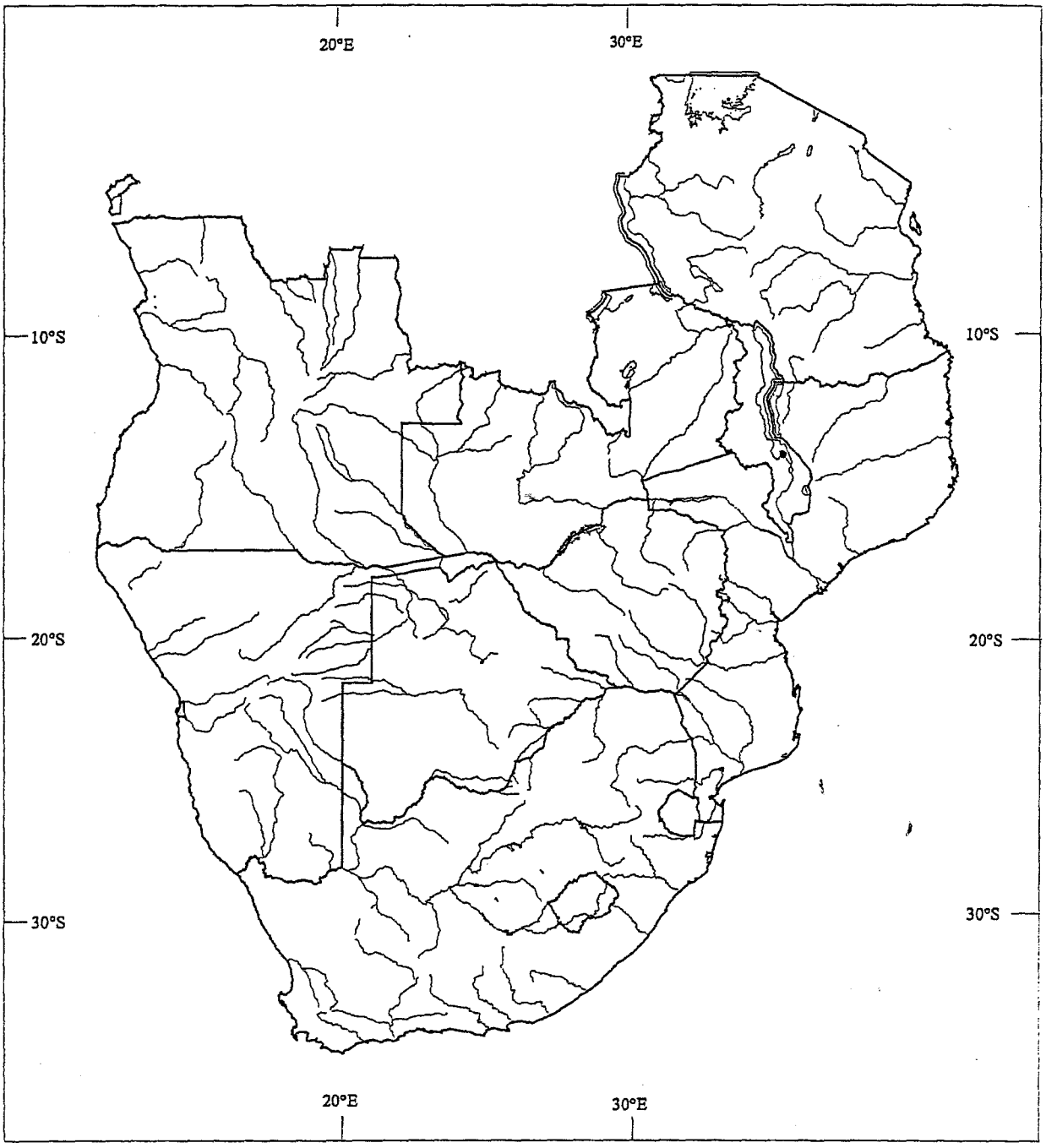


Figure F.441. Point distribution of *Melanochromis brevis*. Scale approximately 1:25 000 000

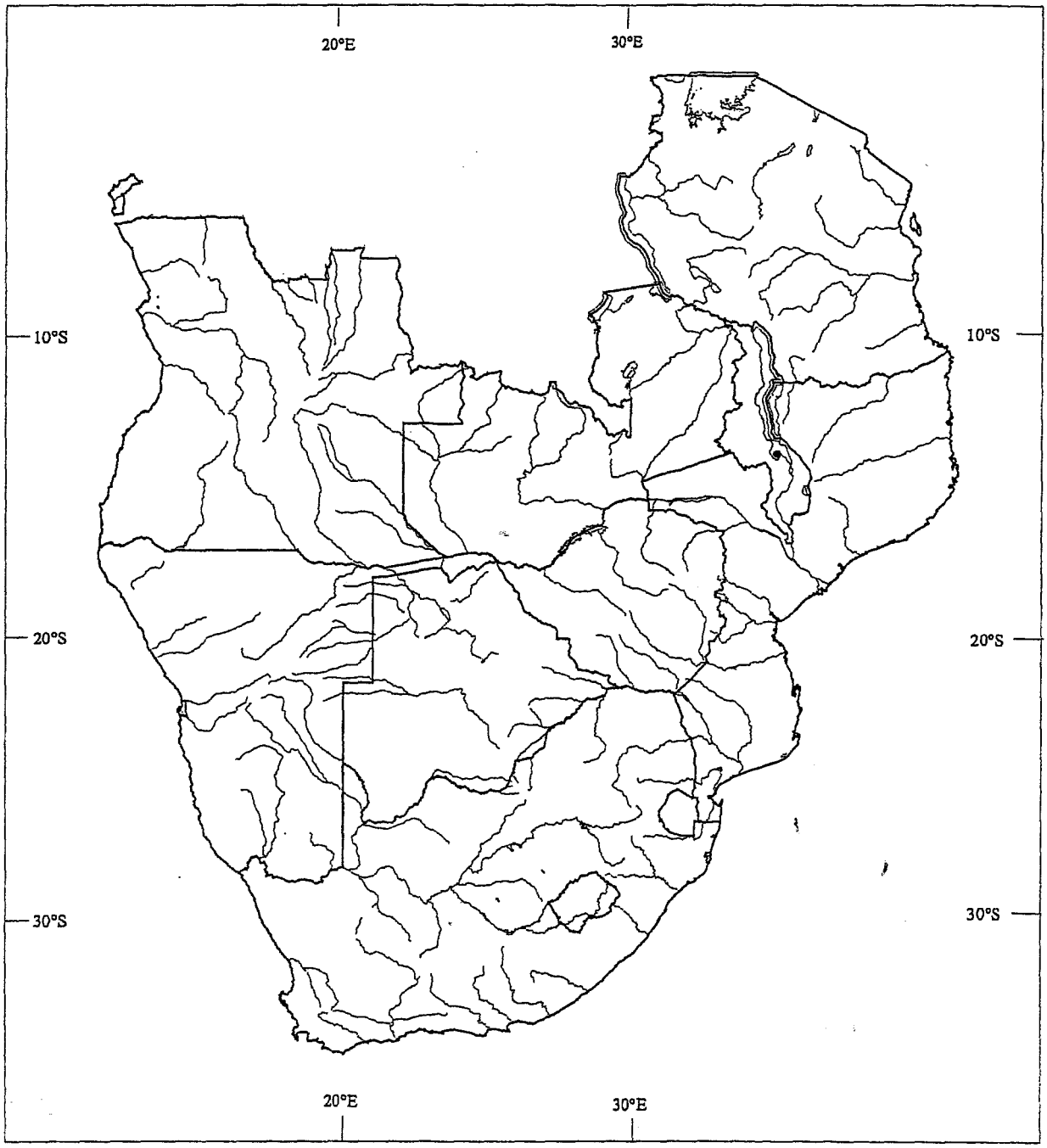


Figure F.442. Point distribution of *Melanochromis chipokne*. Scale approximately 1:25 000 000

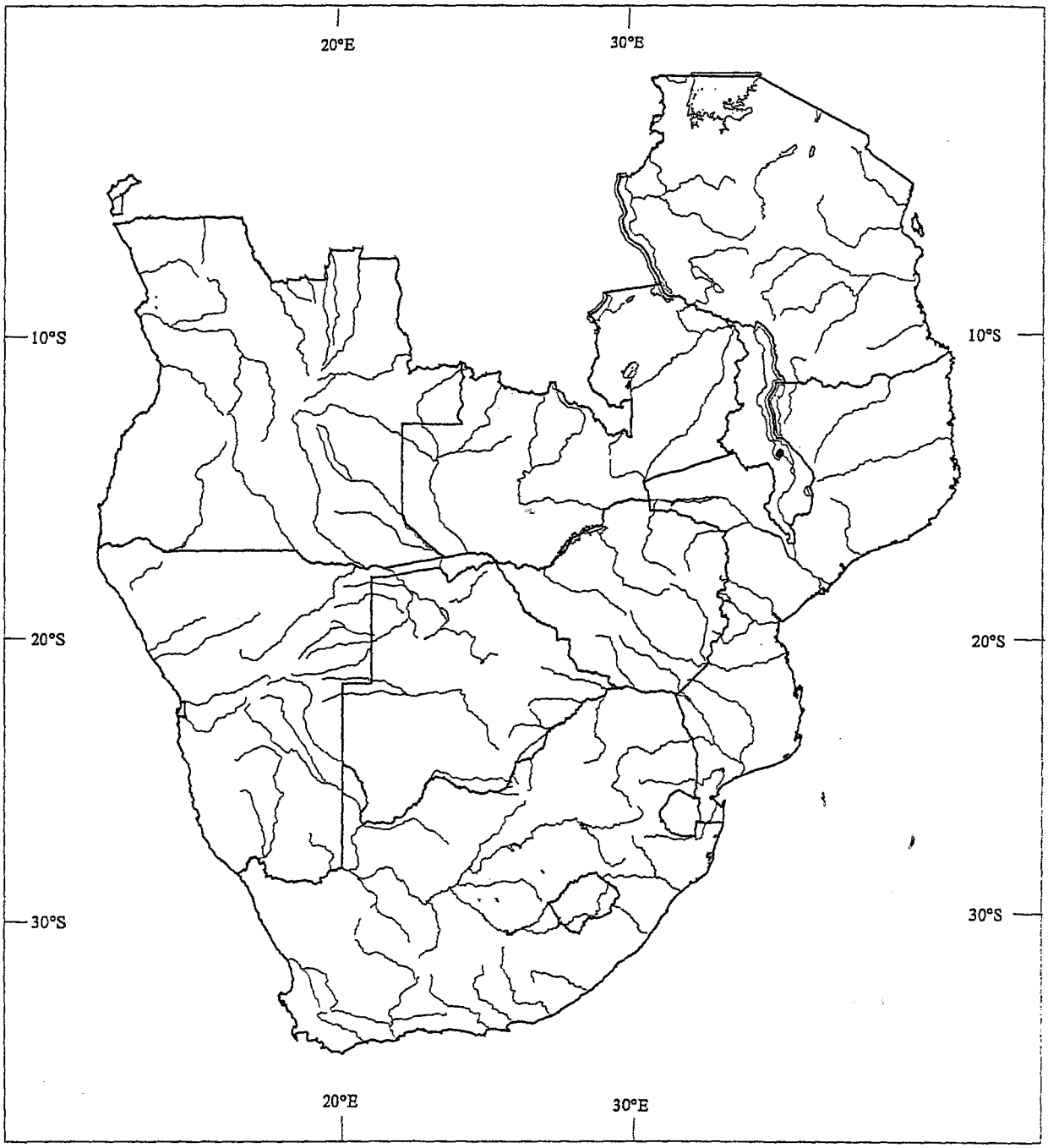


Figure F.443. Point distribution of *Melanochromis joanjohnsonae*. Scale approximately 1:25 000 000

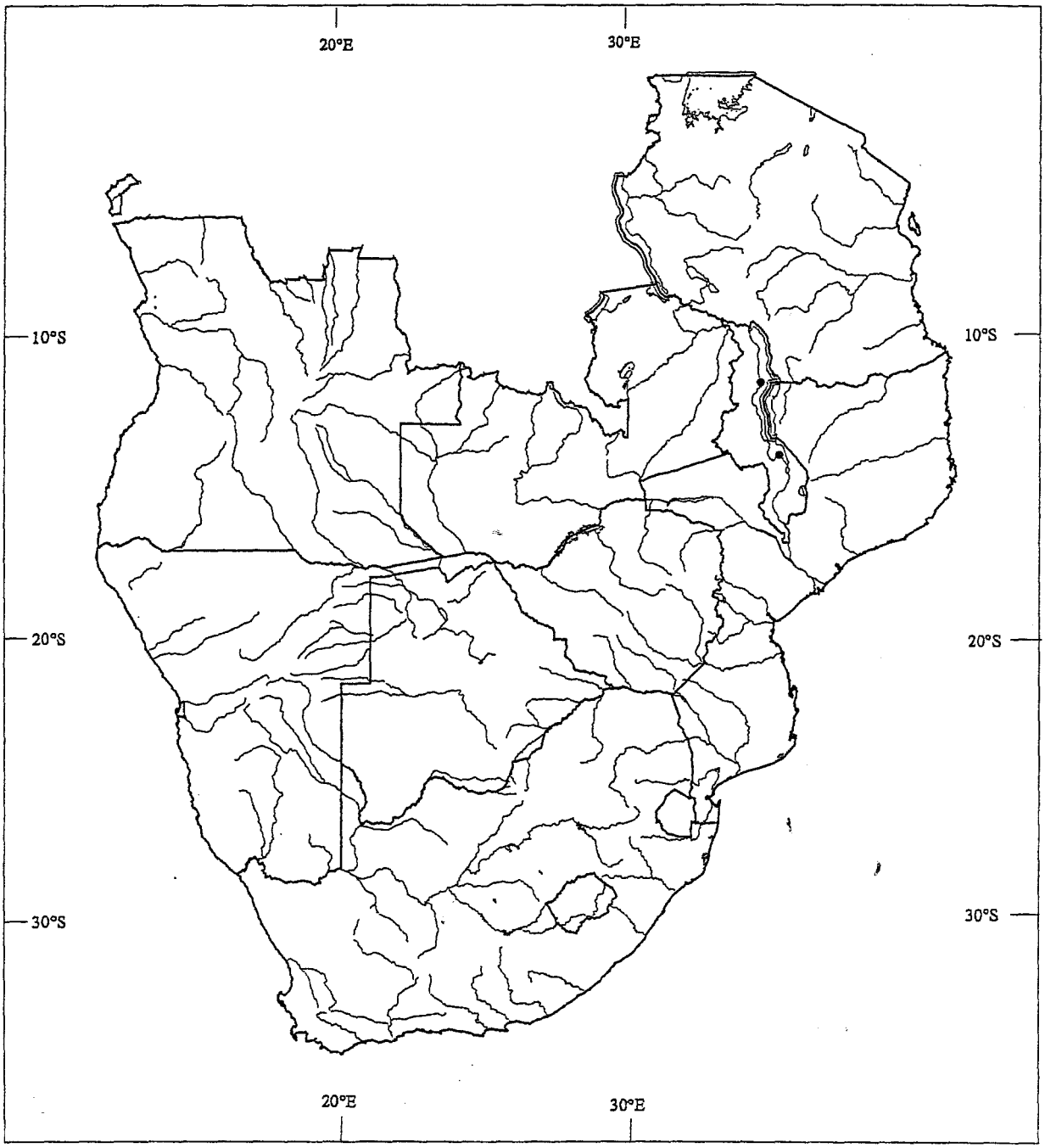


Figure F.444. Point distribution of *Melanochromis melanopterus*. Scale approximately 1:25 000 000

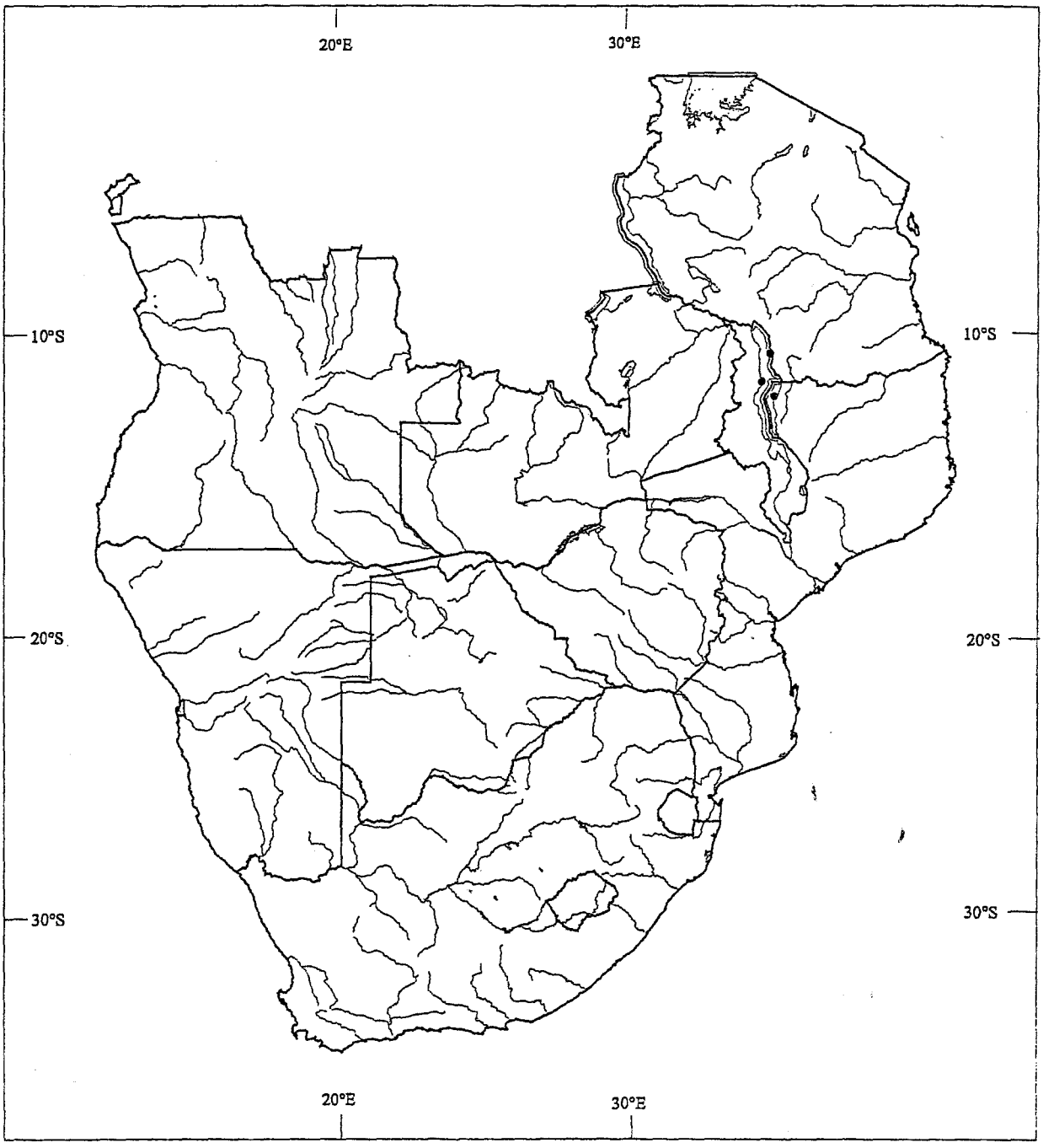


Figure F.445. Point distribution of *Melanochromis parallelus*. Scale approximately 1:25 000 000

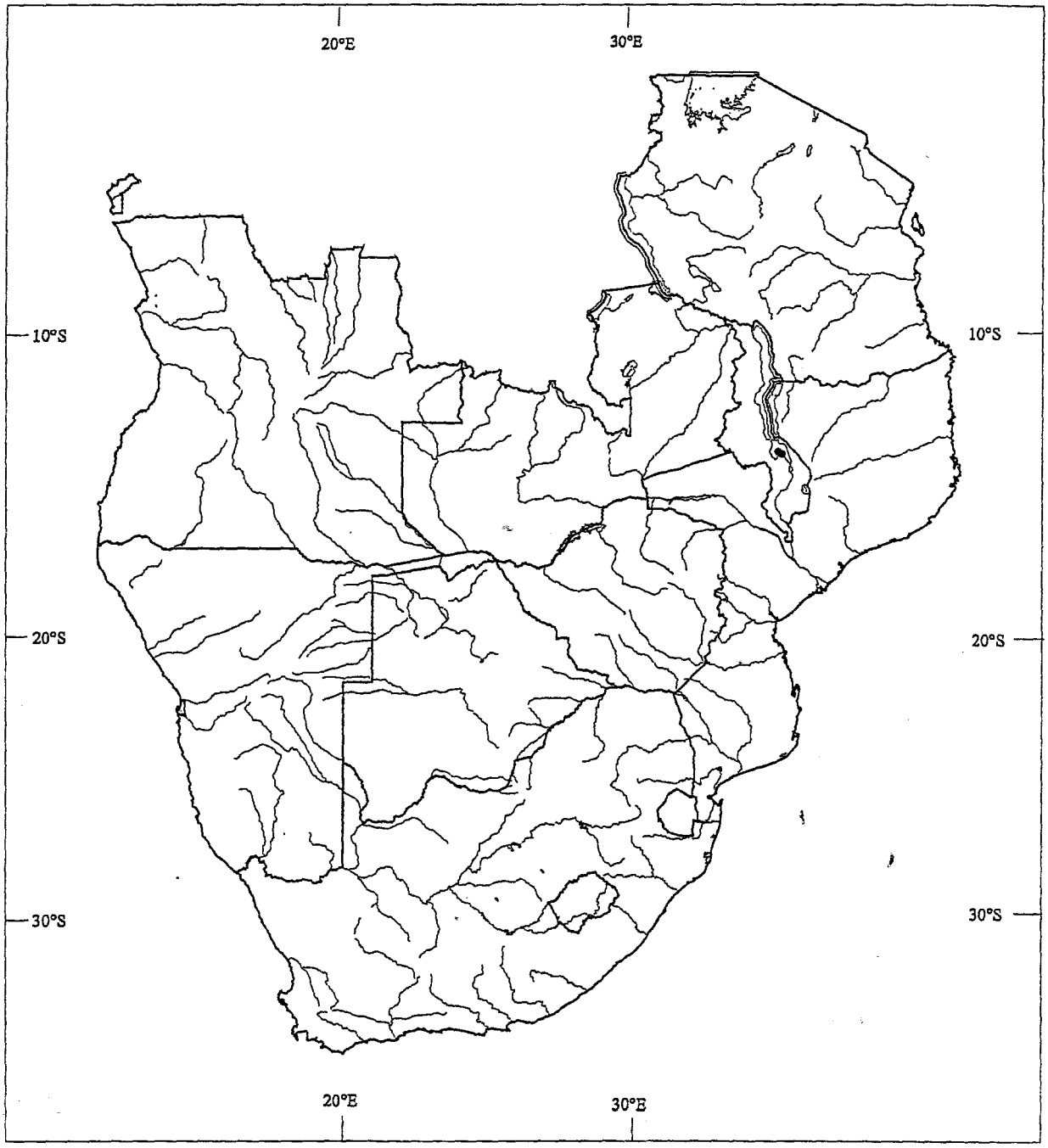


Figure F.446. Point distribution of *Melanochromis vermivorus*. Scale approximately 1:25 000 000

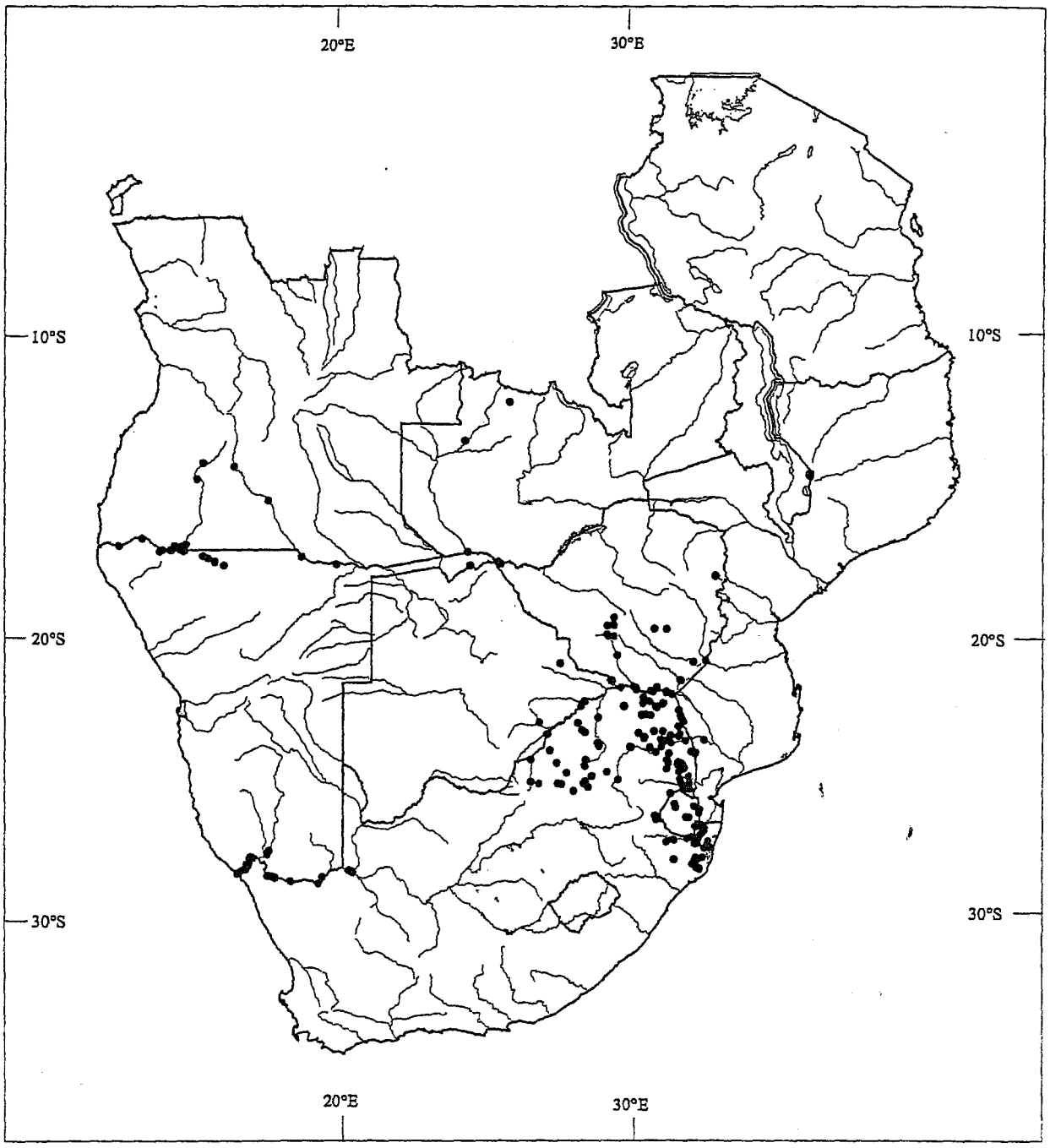


Figure F.447. Point distribution of *Mesobola brevianalis*. Scale approximately 1:25 000 000

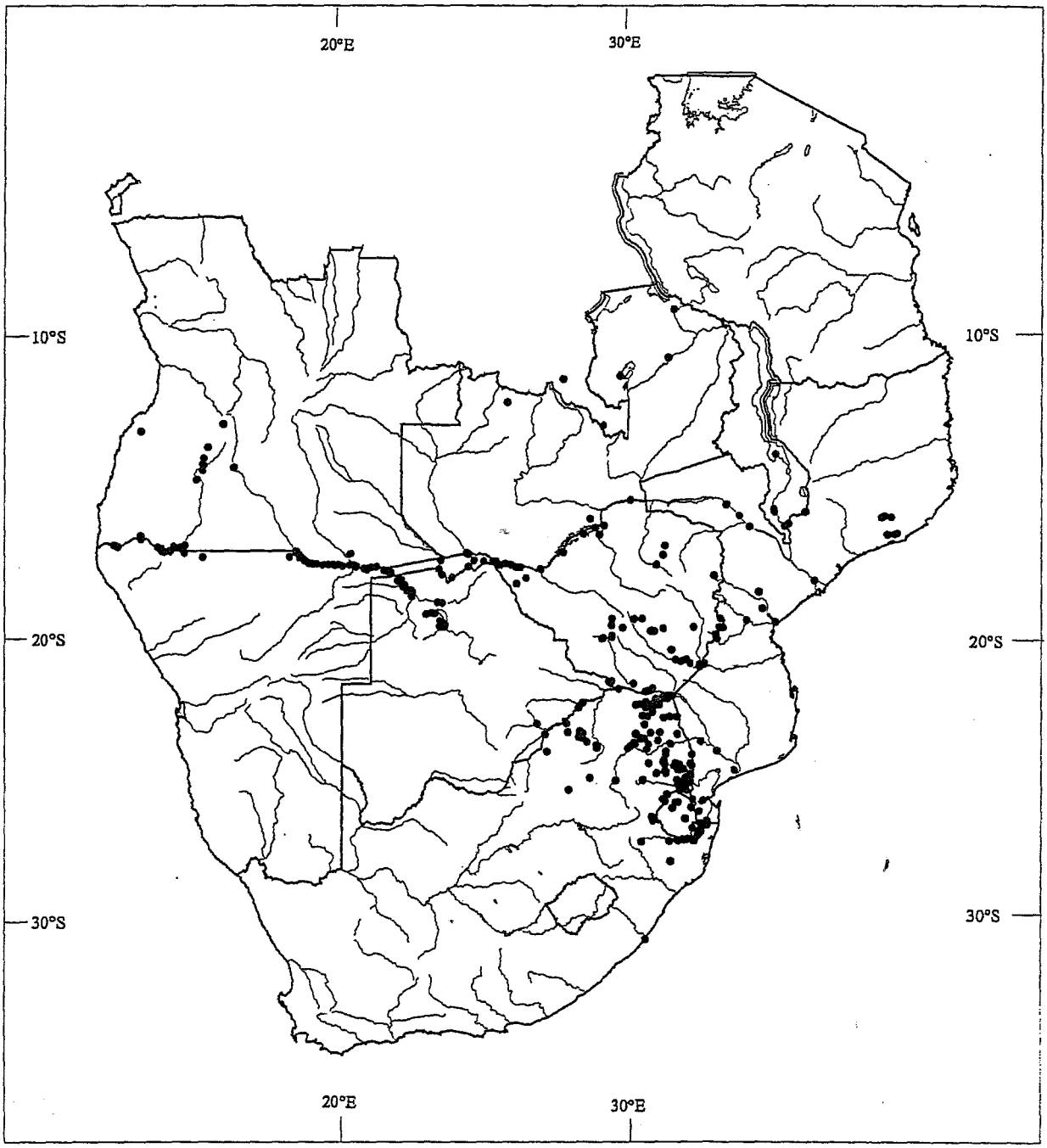


Figure F.448. Point distribution of *Micralestes acutidens*. Scale approximately 1:25 000 000

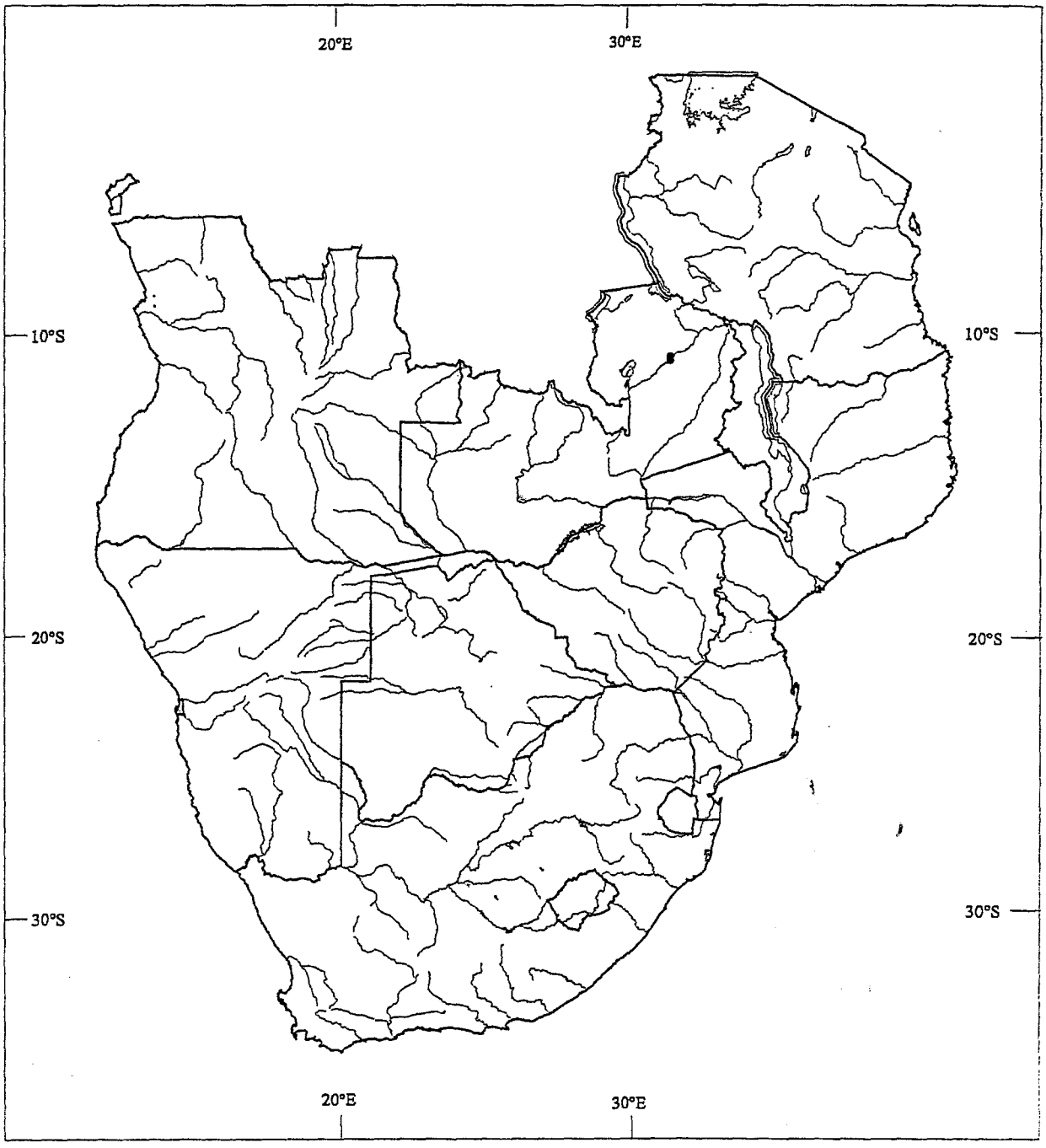


Figure F.449. Point distribution of *Micralestes sardina*. Scale approximately 1:25 000 000

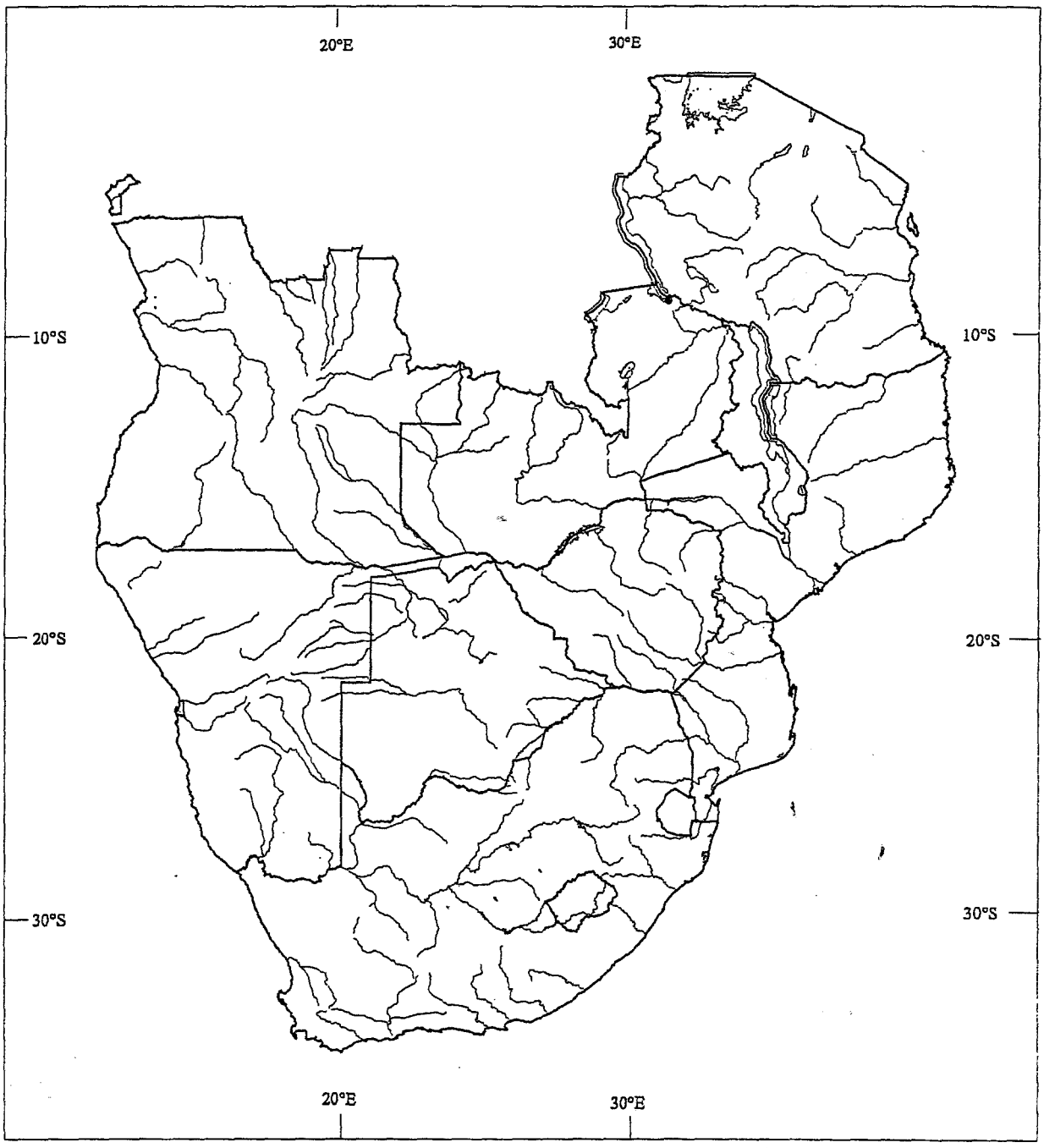


Figure F.450. Point distribution of *Micralestes stormsi*. Scale approximately 1:25 000 000

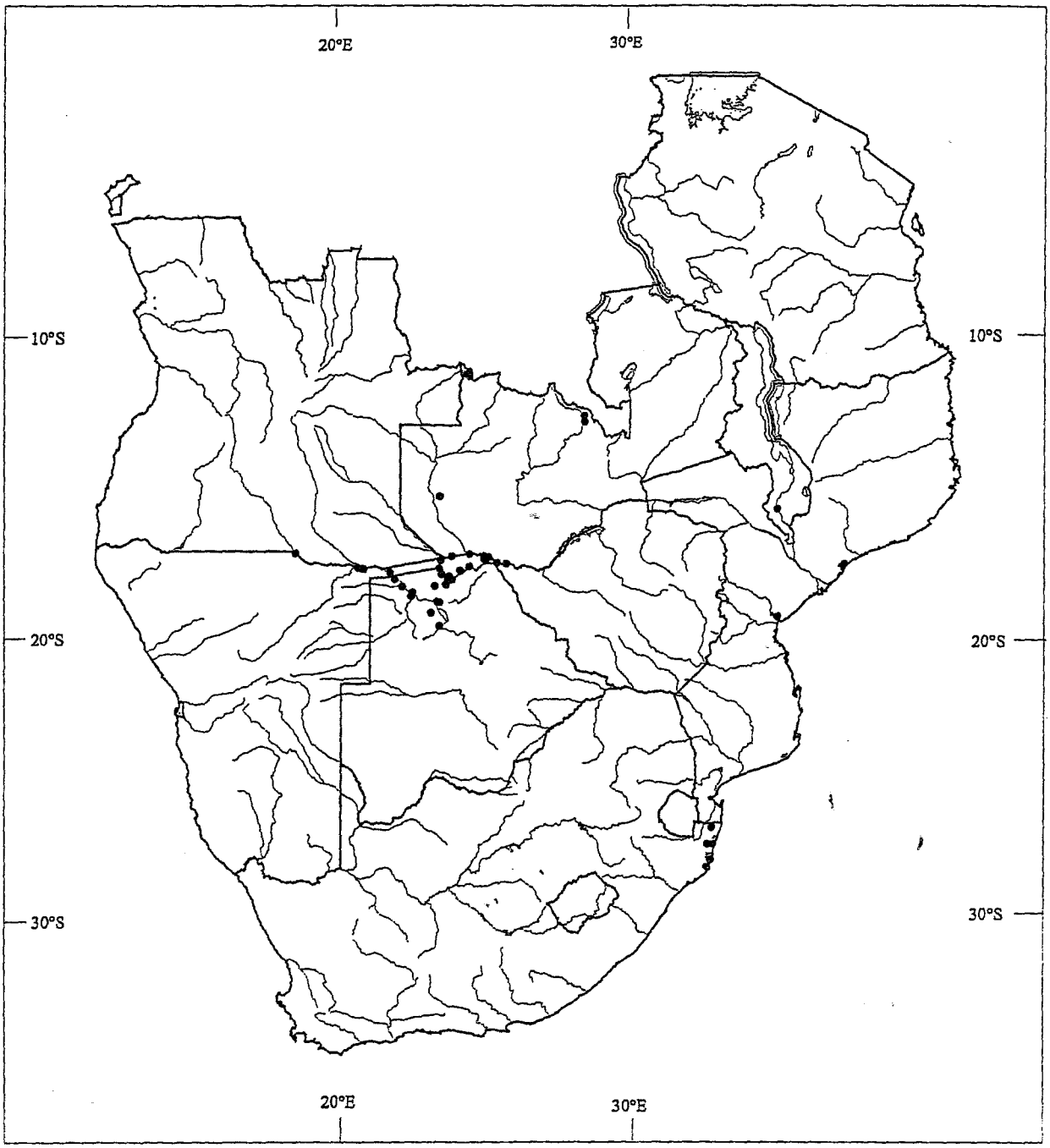


Figure F.451. Point distribution of *Microctenopoma intermedium*. Scale approximately 1:25 000 000

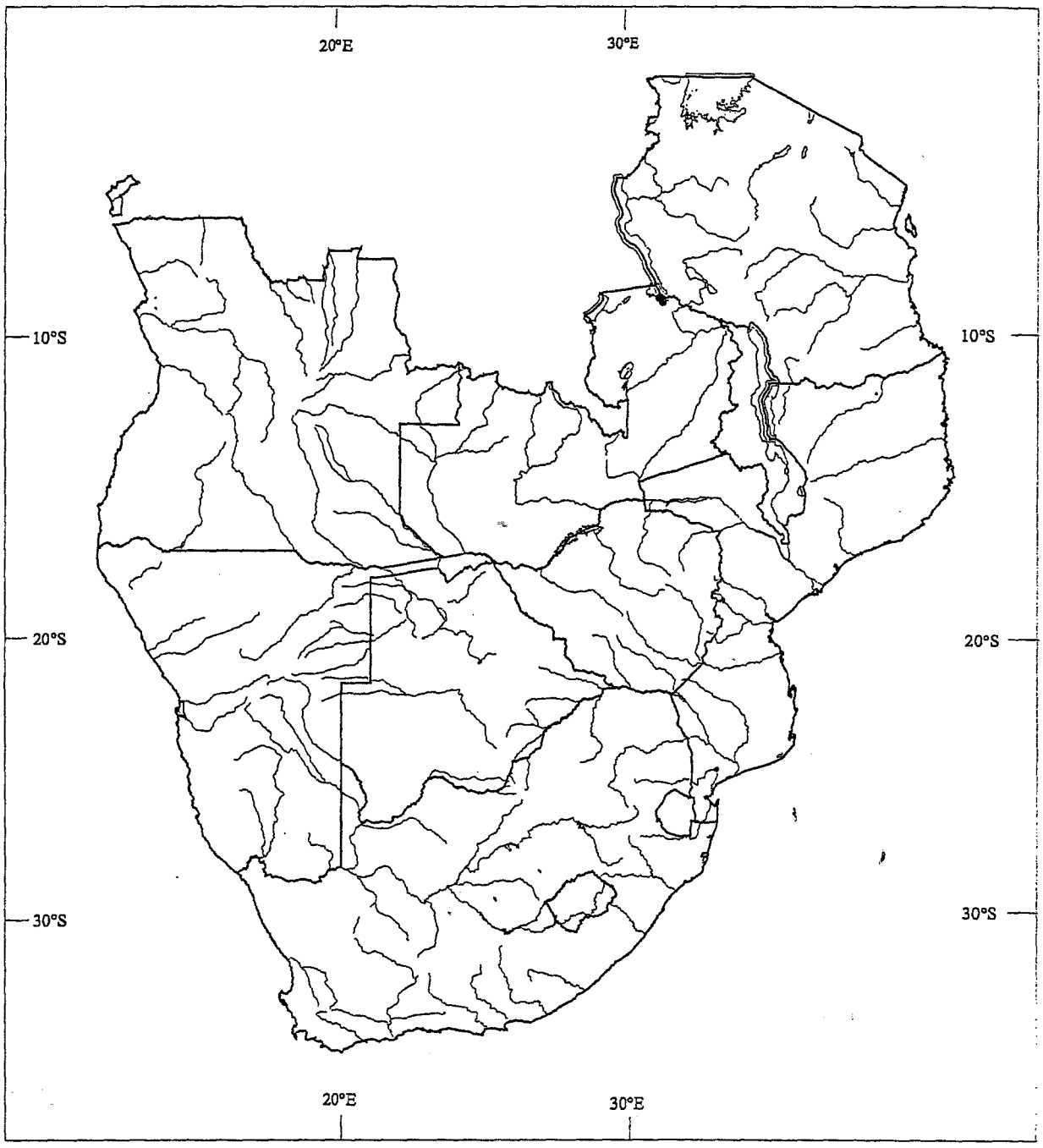


Figure F.452. Point distribution of *Microdontochromis tenuidentata*. Scale approximately 1:25 000 000

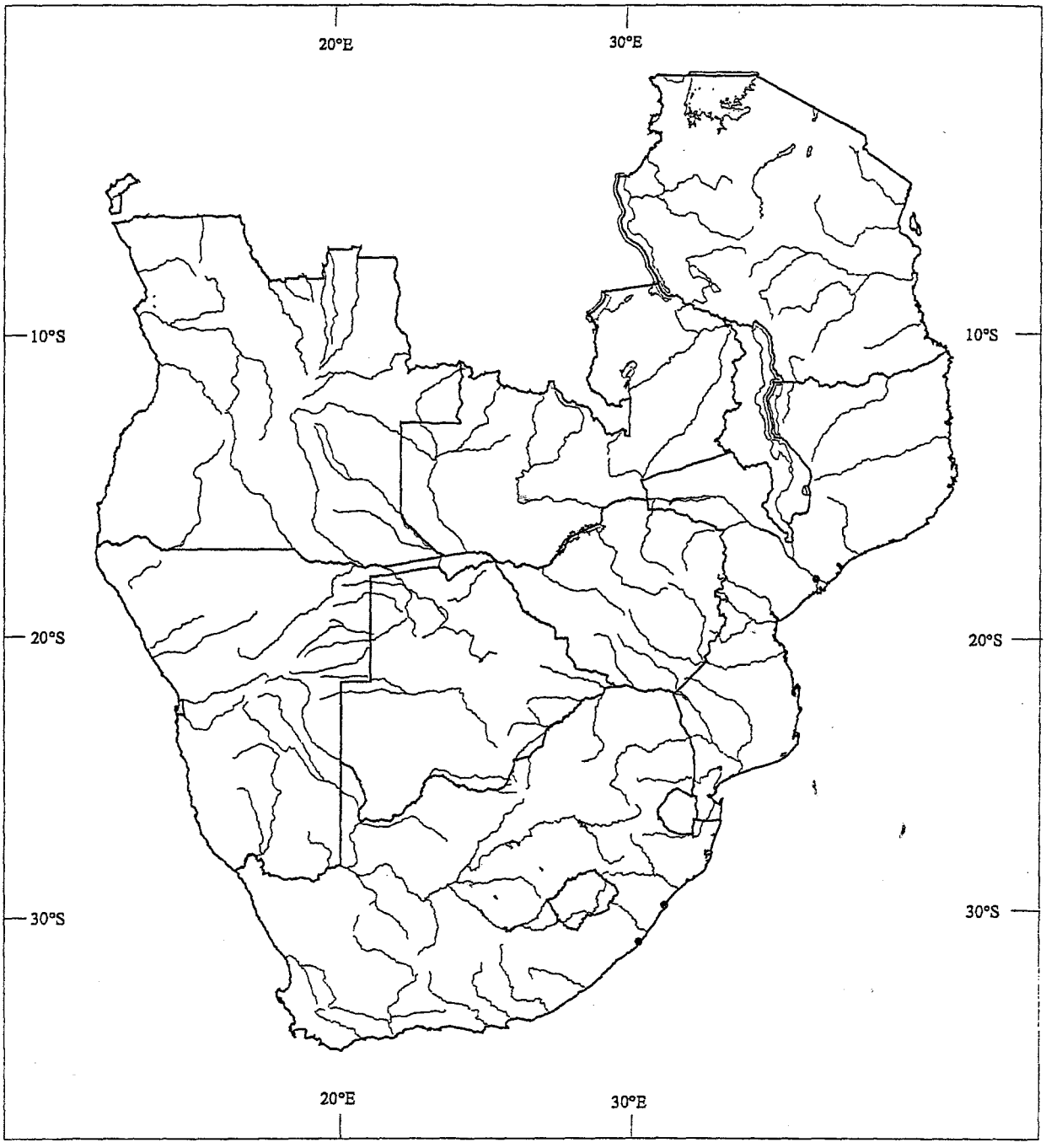


Figure F.453. Point distribution of *Microphis brachyurus*. Scale approximately 1:25 000 000

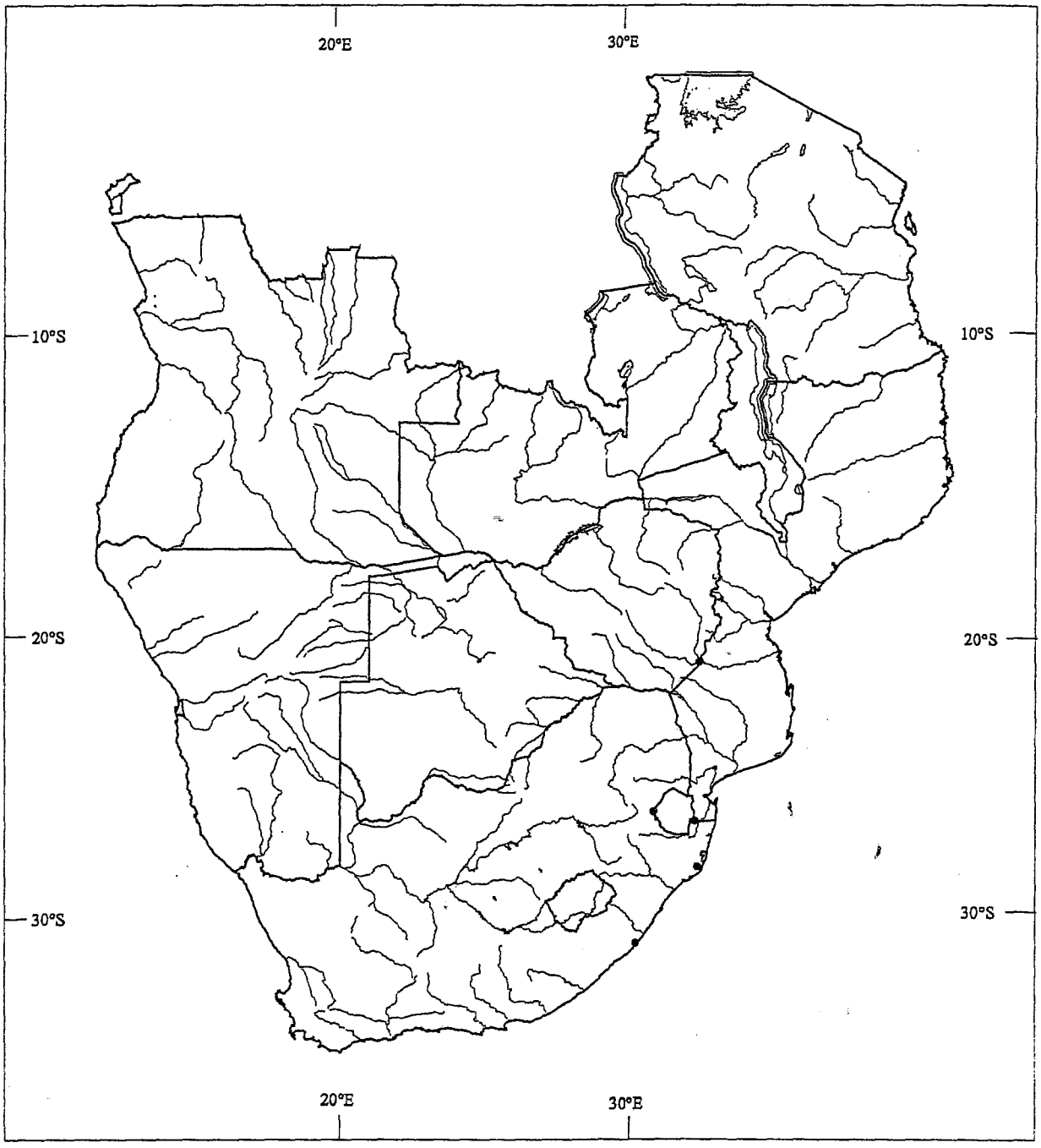


Figure F.454. Point distribution of *Microphis fluviatilis*. Scale approximately 1:25 000 000

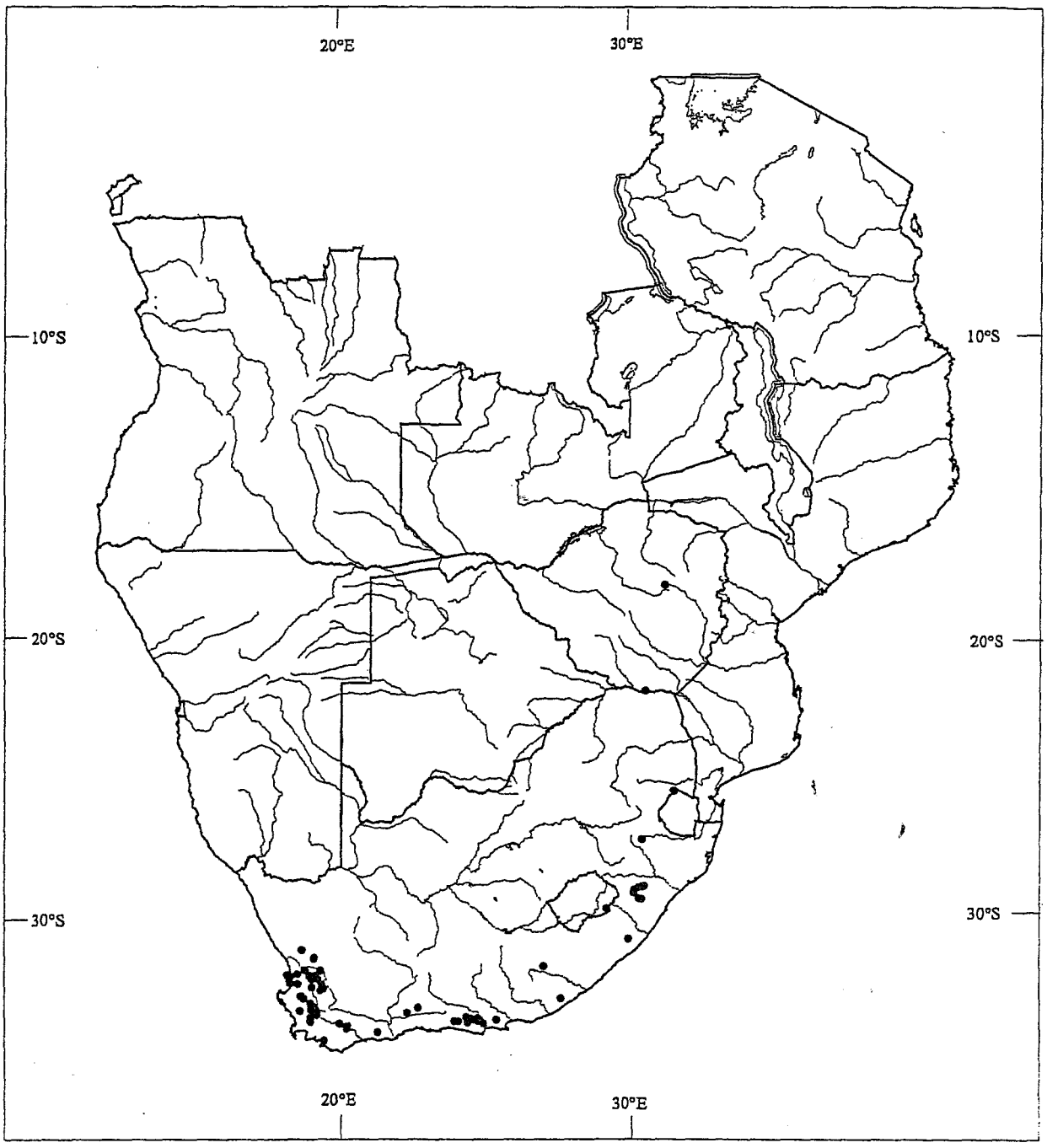


Figure F.455. Point distribution of *Micropterus dolomieu*. Scale approximately 1:25 000 000

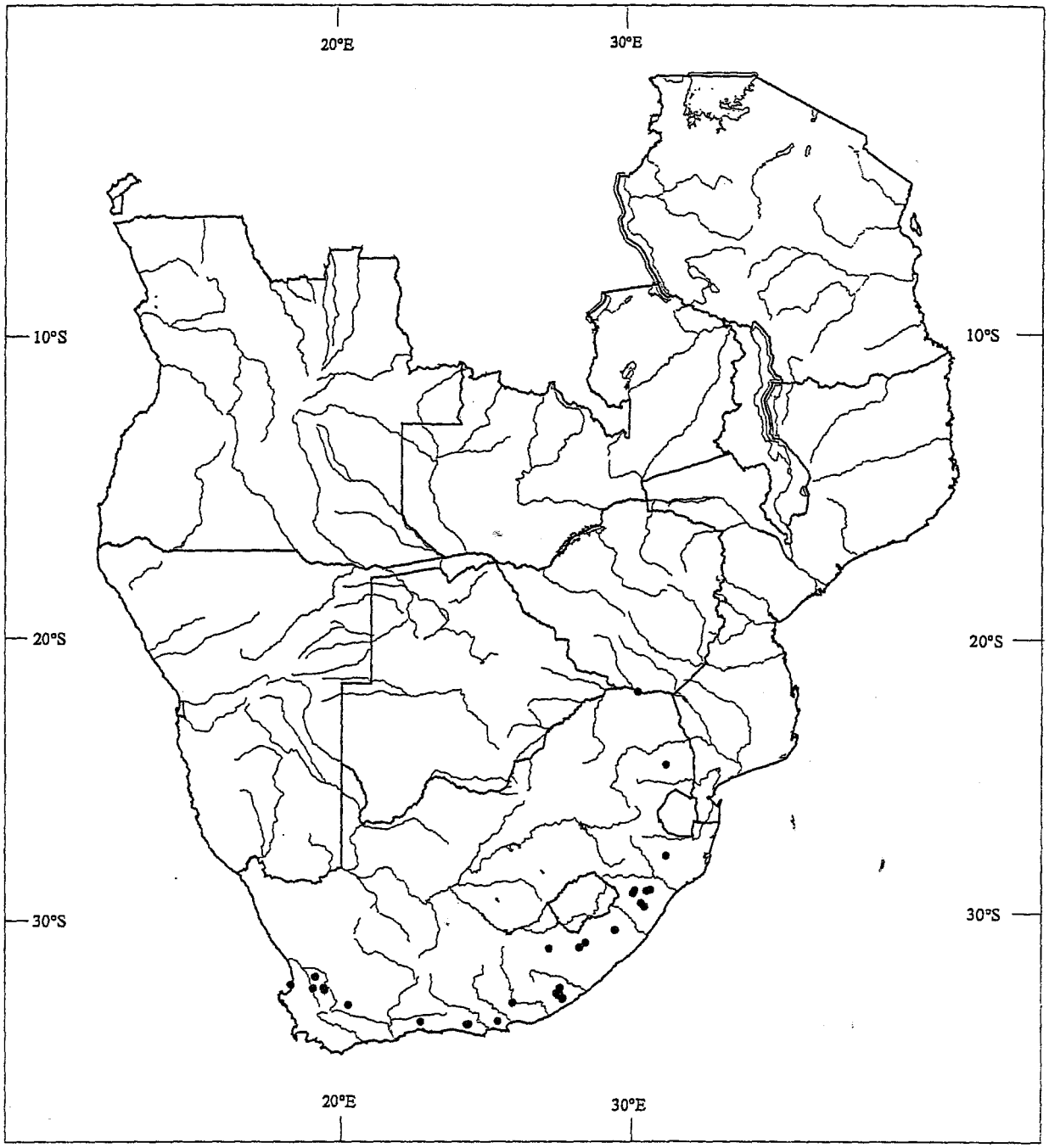


Figure F.456. Point distribution of *Micropterus punctulatus*. Scale approximately 1:25 000 000

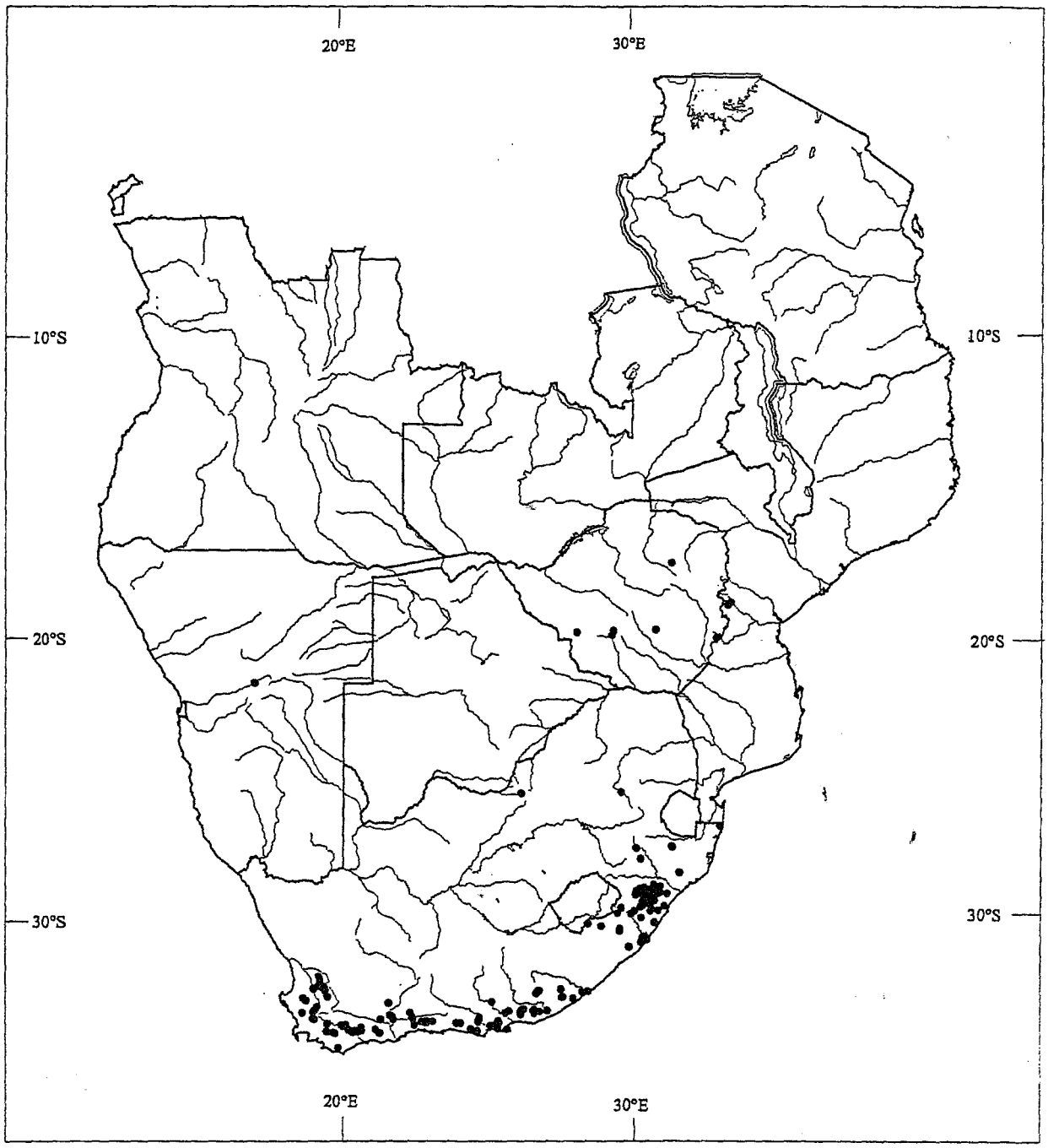


Figure F.457. Point distribution of *Micropterus salmoides*. Scale approximately 1:25 000 000

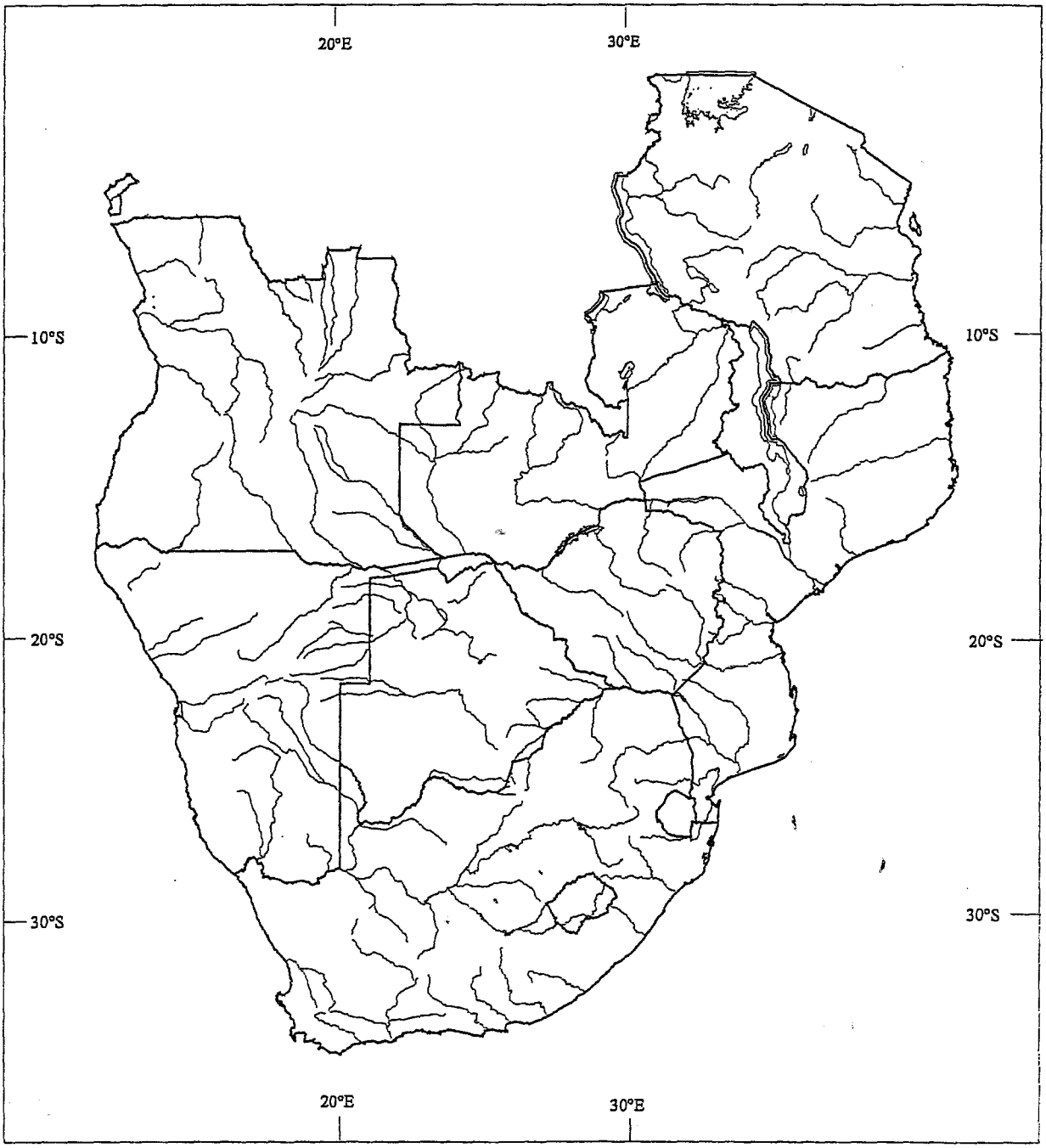


Figure F.458. Point distribution of *Monodactylus argenteus*. Scale approximately 1:25 000 000

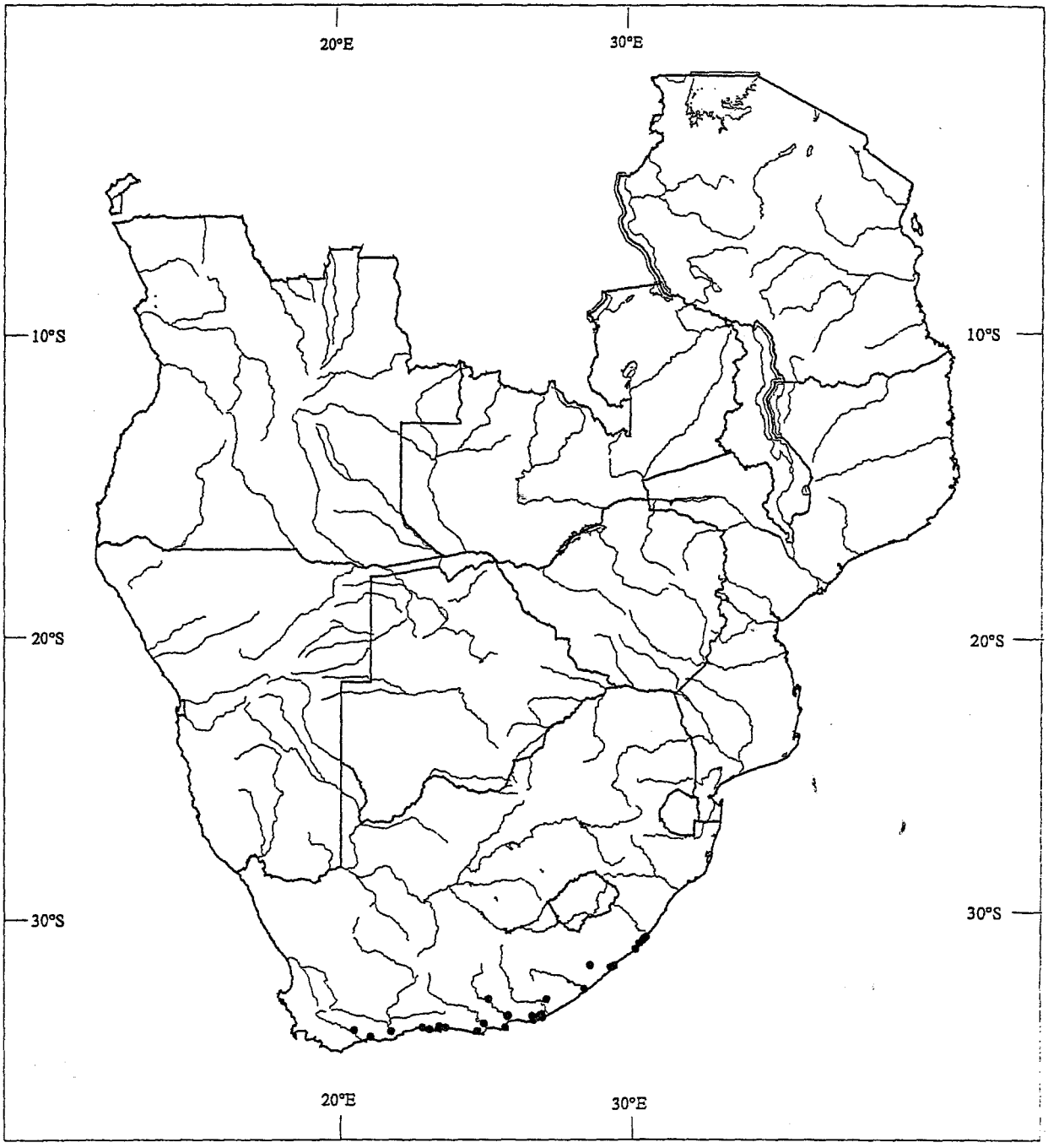


Figure F.459. Point distribution of *Monodactylus falciformis*. Scale approximately 1:25 000 000

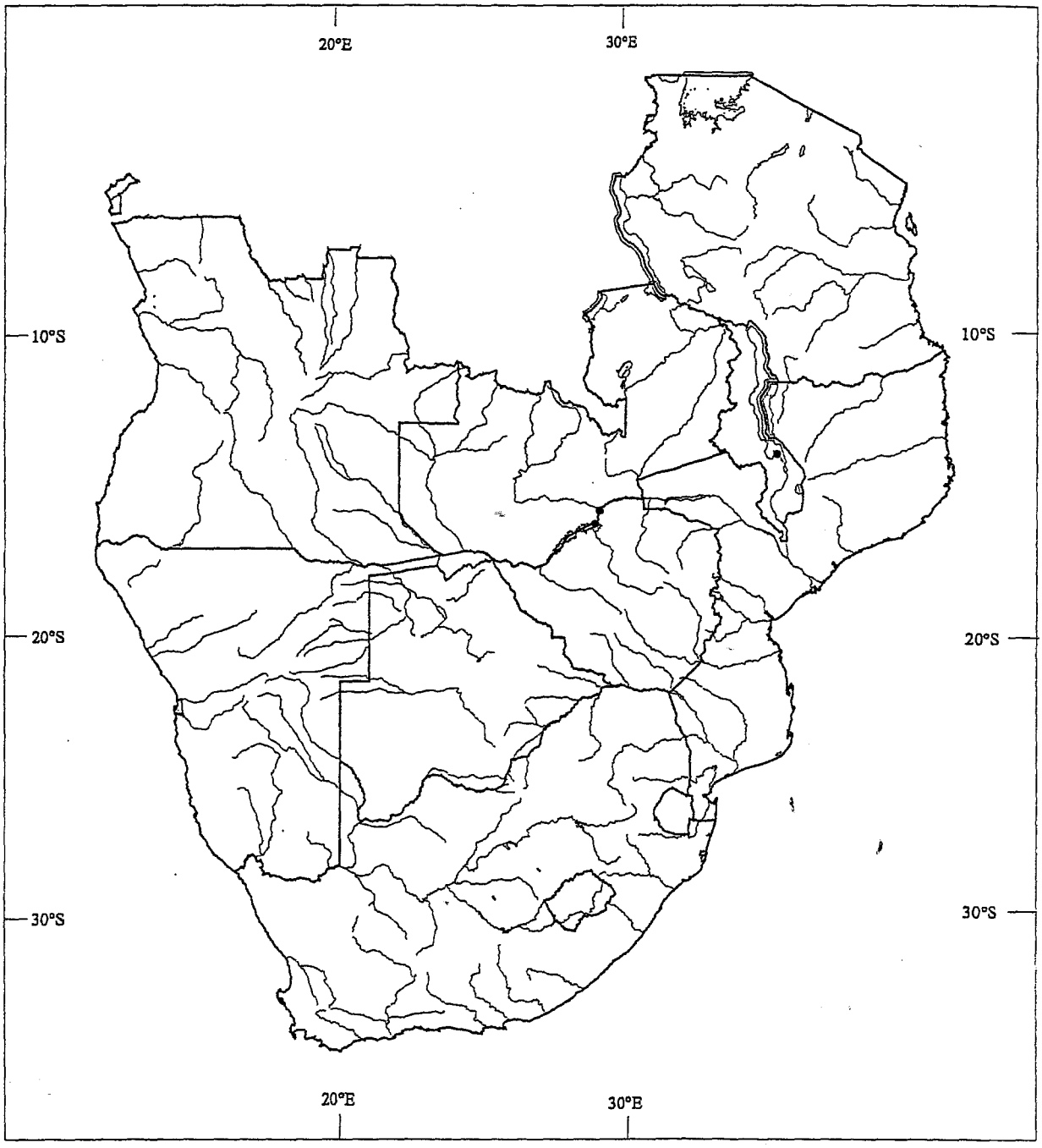


Figure F.460. Point distribution of *Mormyrops anguilloides*. Scale approximately 1:25 000 000

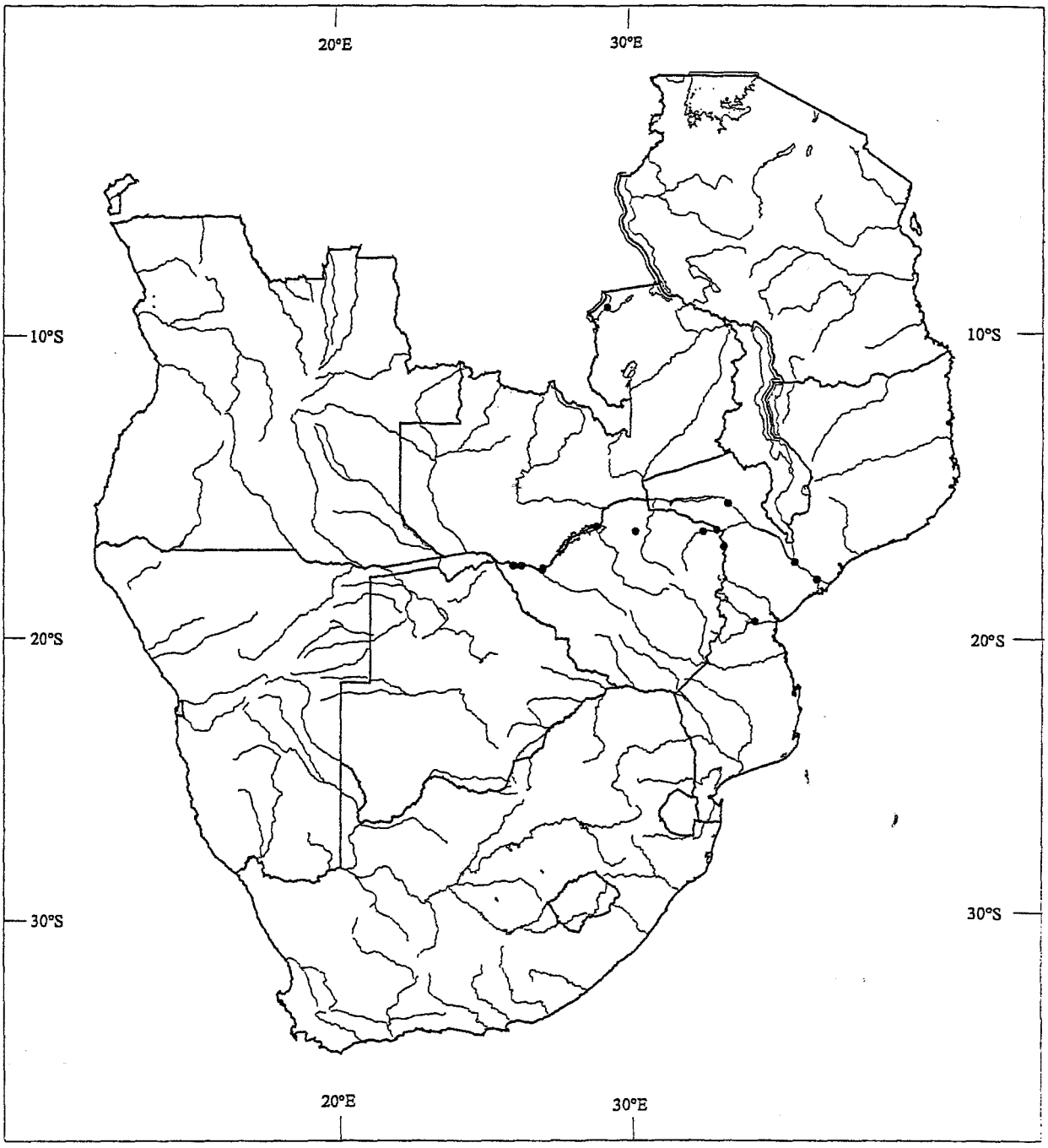


Figure F.461. Point distribution of *Mormyrops deliciosus*. Scale approximately 1:25 000 000

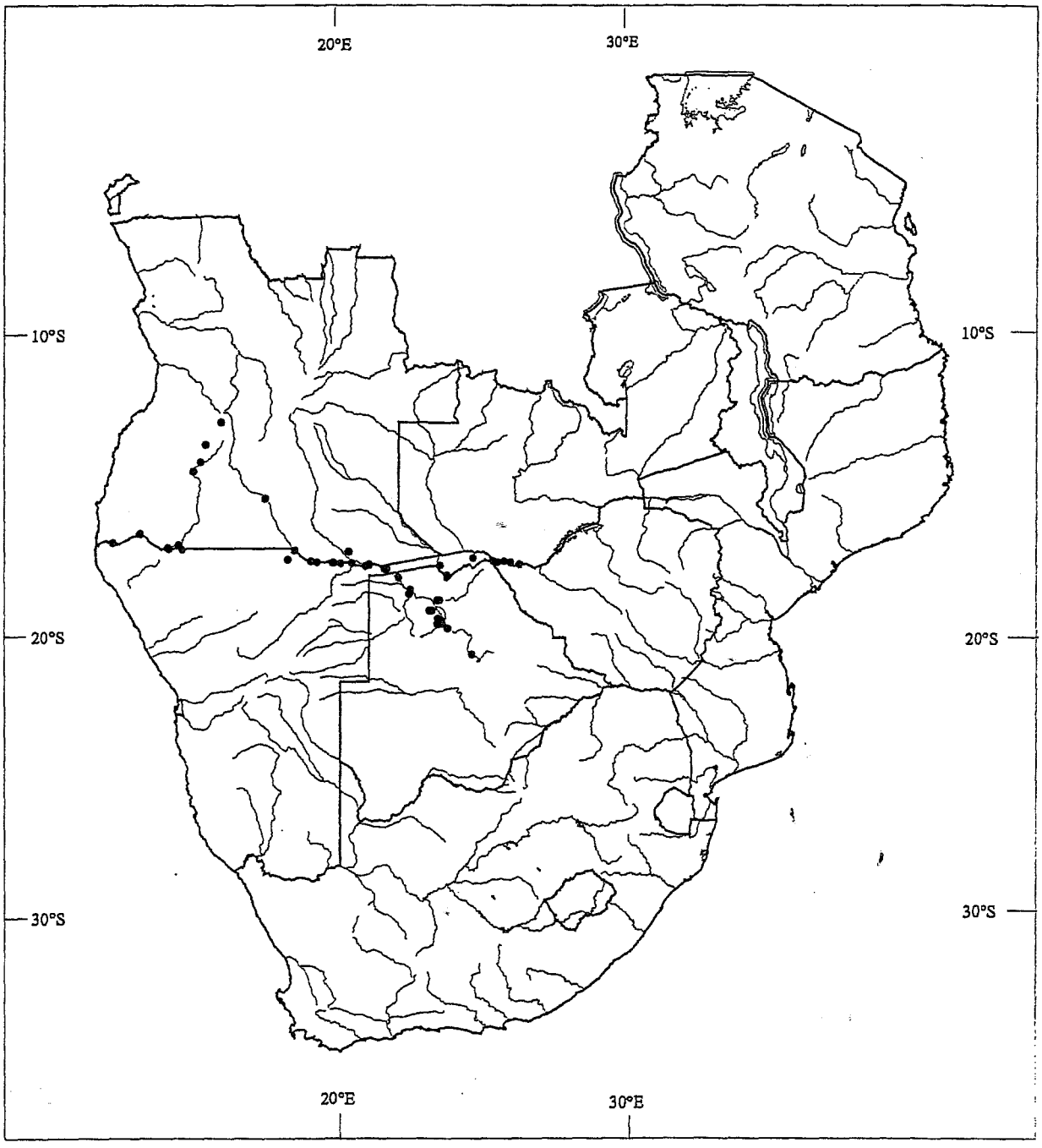


Figure F.462. Point distribution of *Mormyrus lacerda*. Scale approximately 1:25 000 000

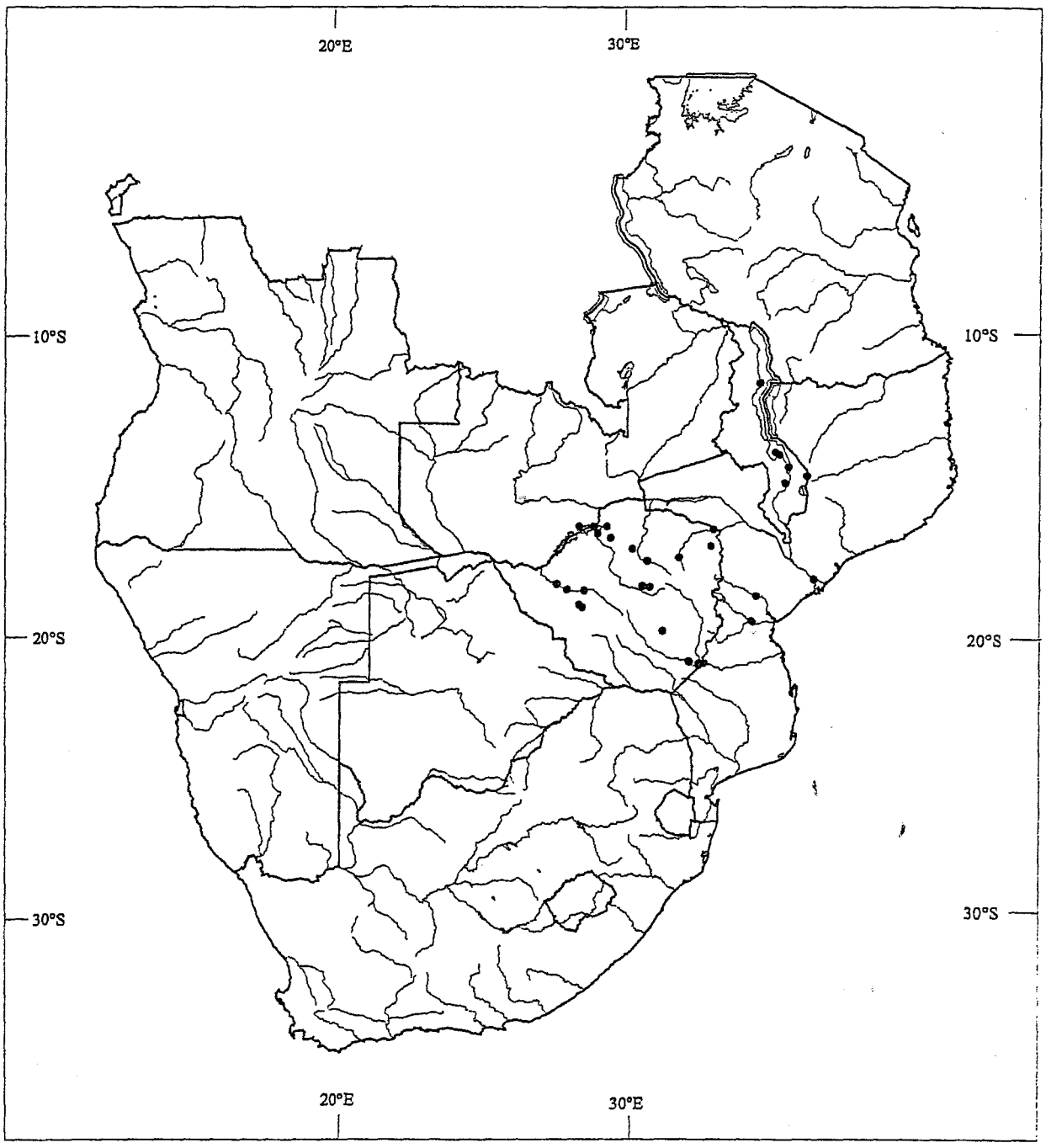


Figure F.463. Point distribution of *Mormyrus longirostris*. Scale approximately 1:25 000 000

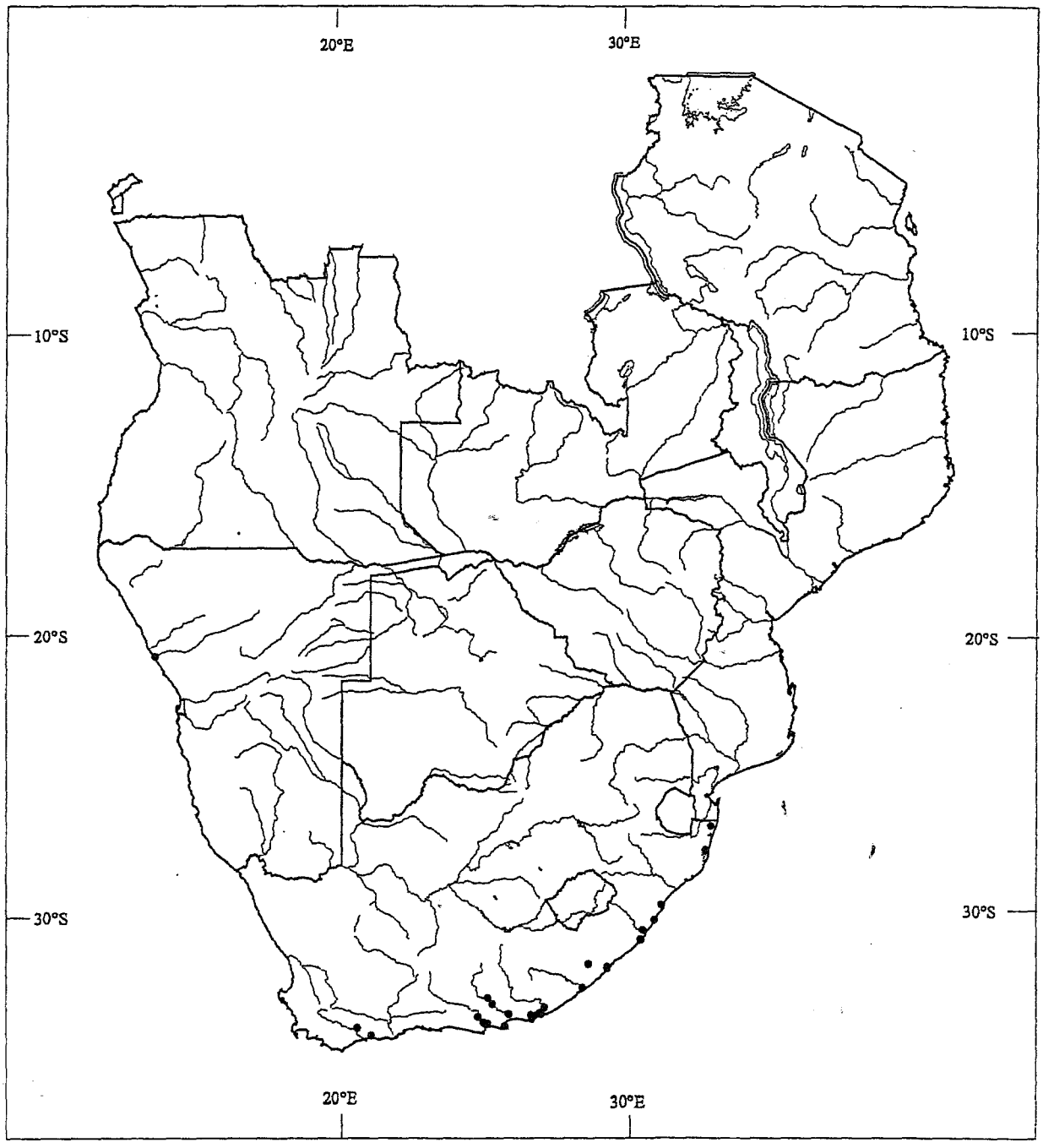


Figure F.464. Point distribution of *Mugil cephalus*. Scale approximately 1:25 000 000

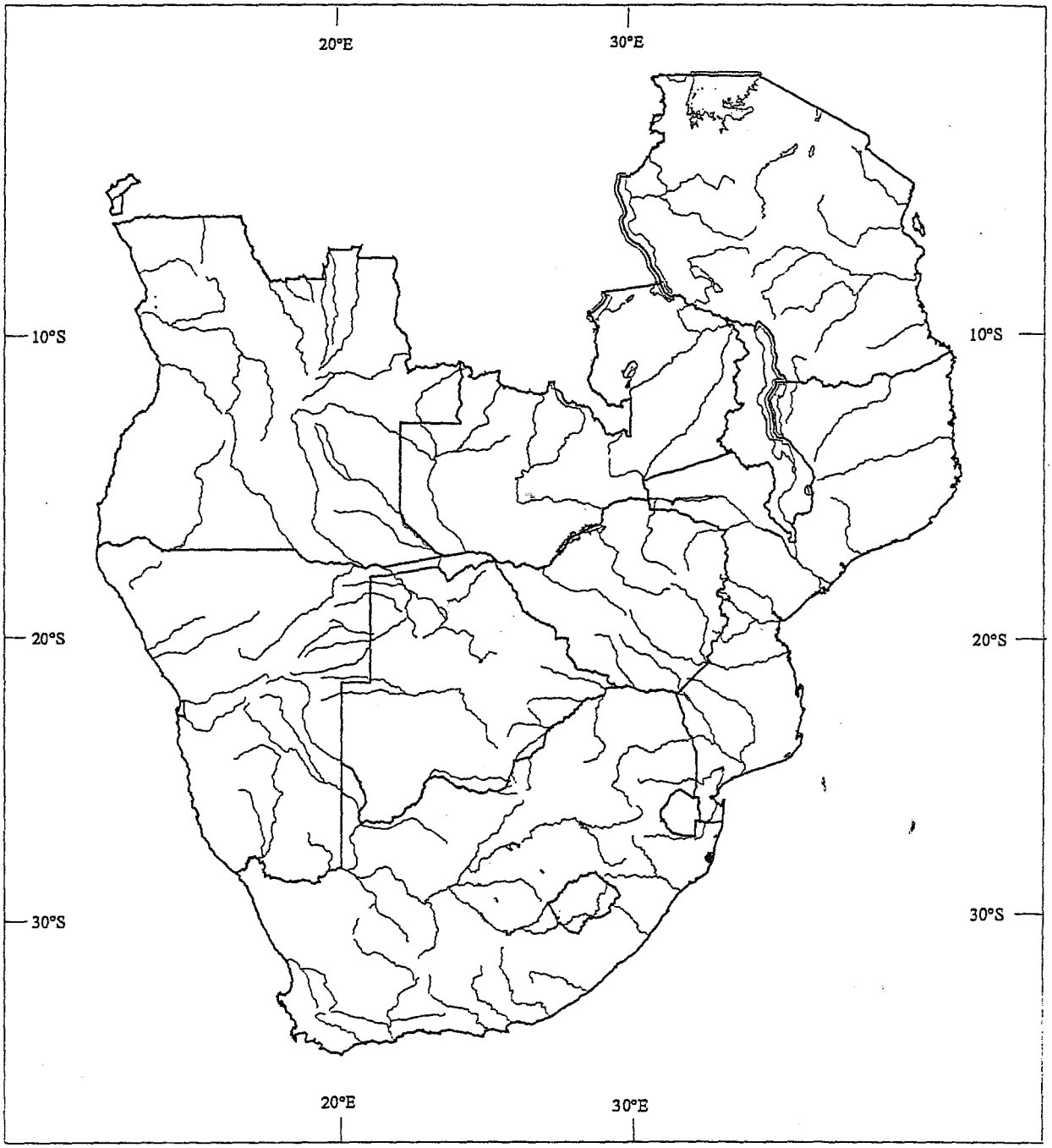


Figure F.465. Point distribution of *Mugilogobius inhacae*. Scale approximately 1:25 000 000

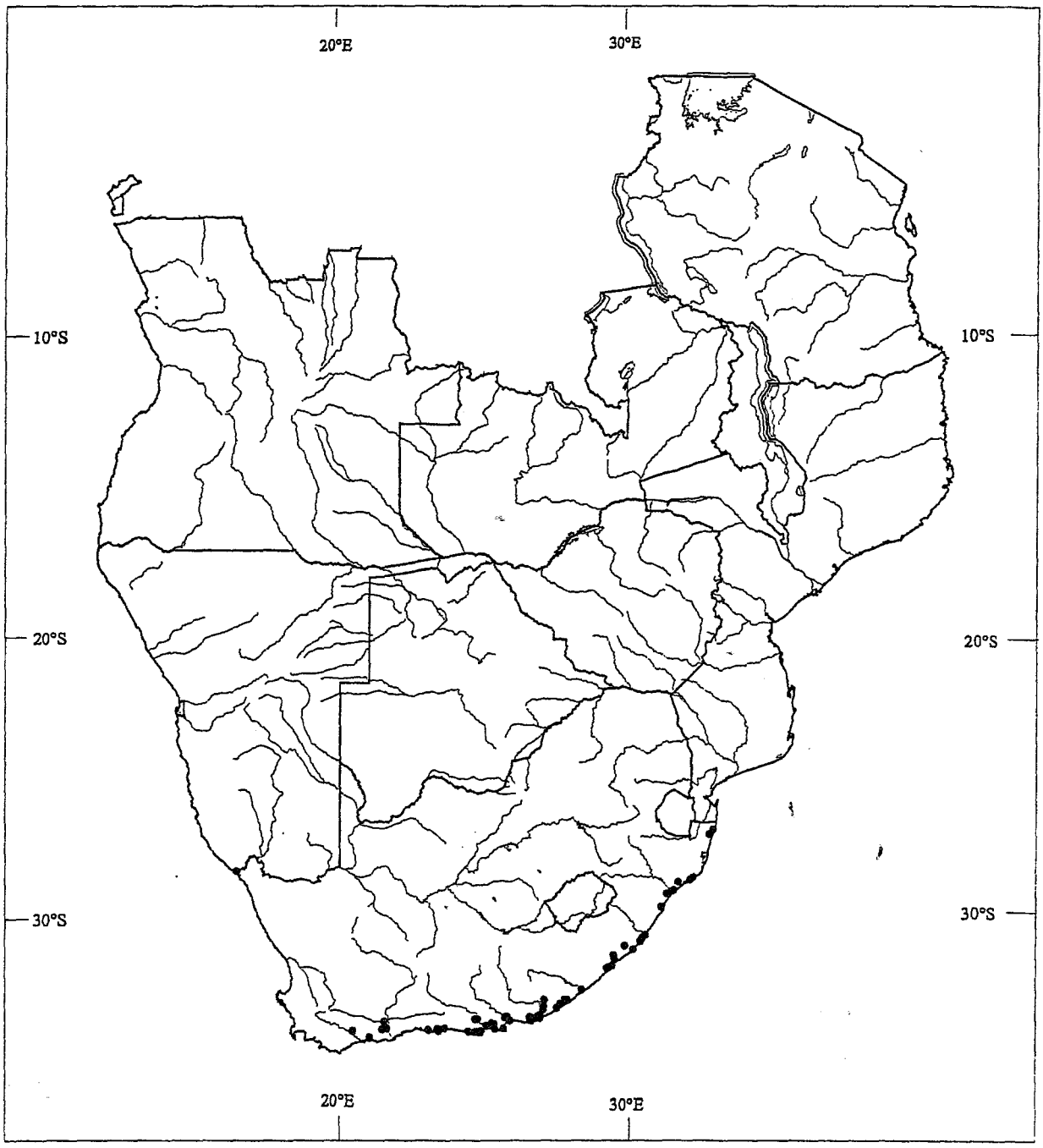


Figure F.466. Point distribution of *Myxus capensis*. Scale approximately 1:25 000 000

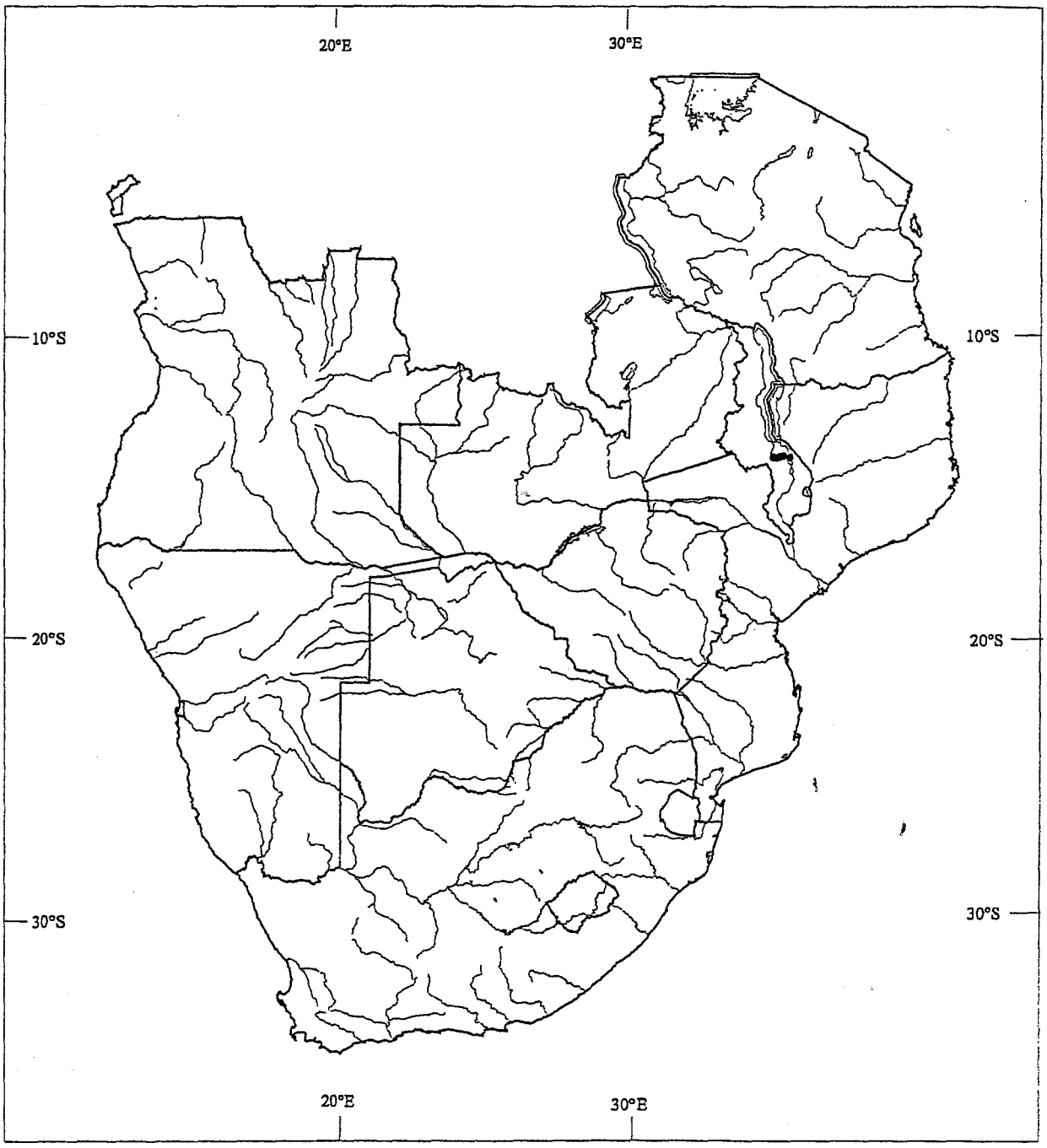


Figure F.467. Point distribution of *Naevochromis chrysogaster*. Scale approximately 1:25 000 000

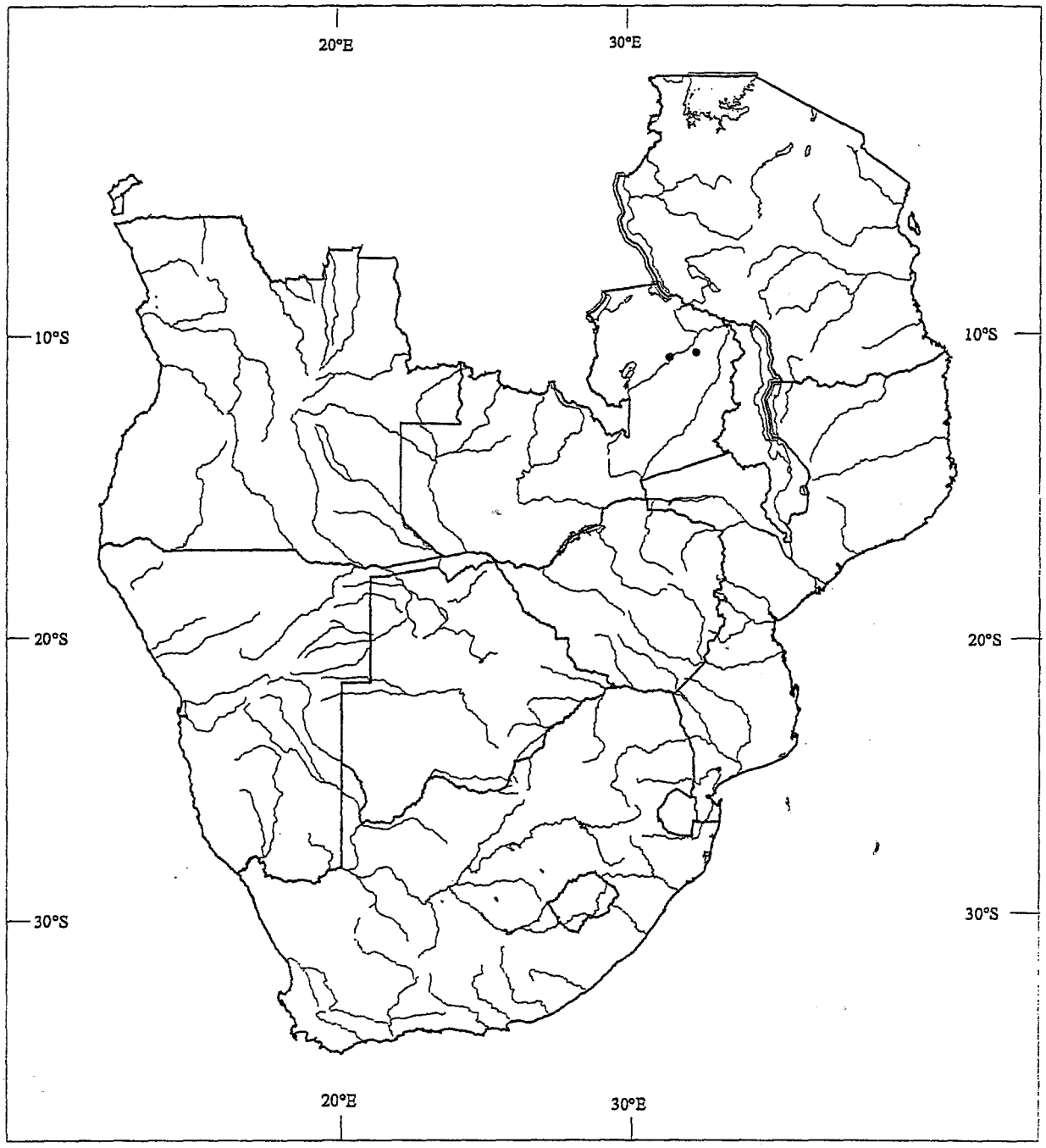


Figure F.468. Point distribution of *Nannocharax gracilis*. Scale approximately 1:25 000 000

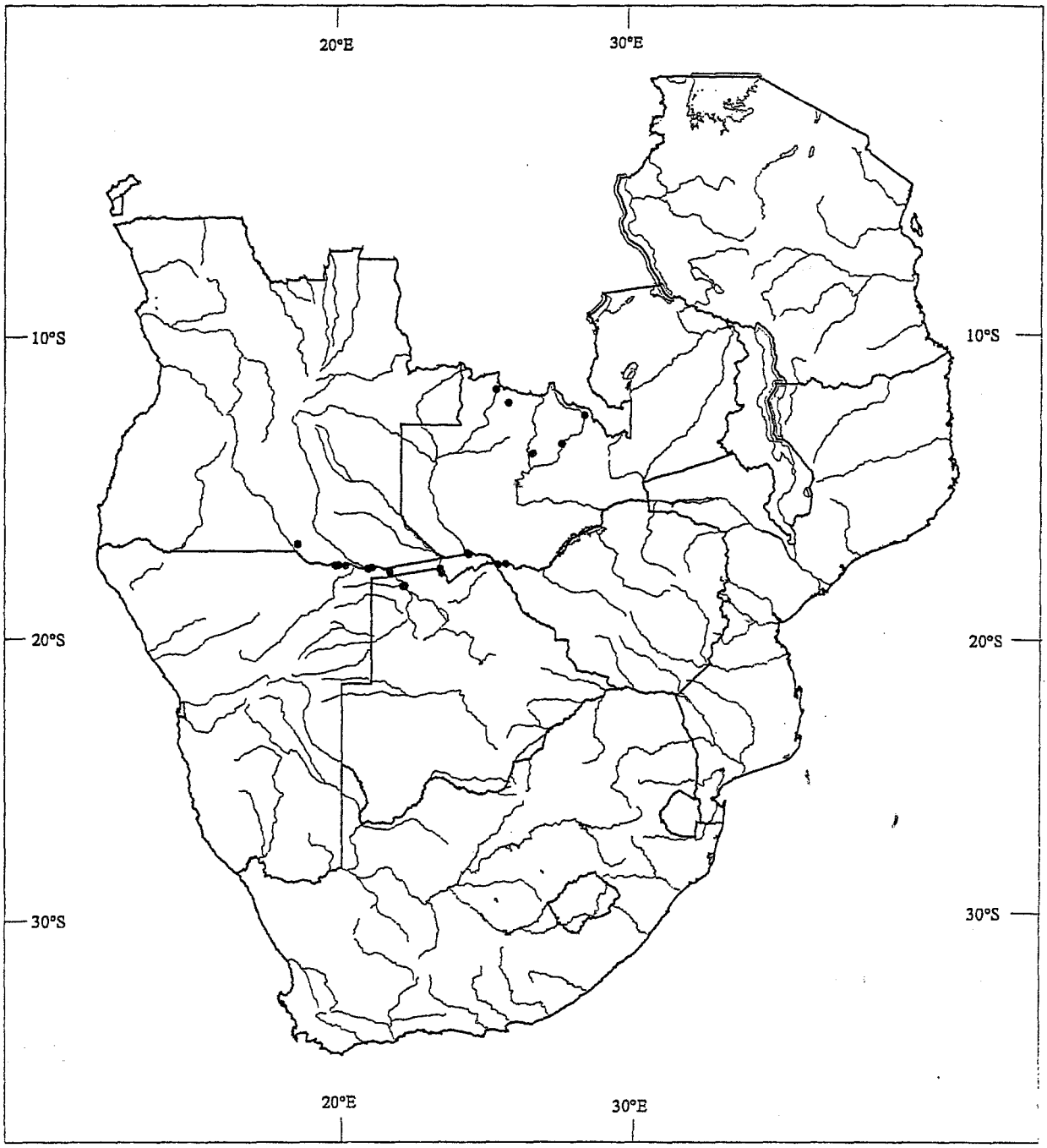


Figure F.469. Point distribution of *Nannocharax macropterus*. Scale approximately 1:25 000 000

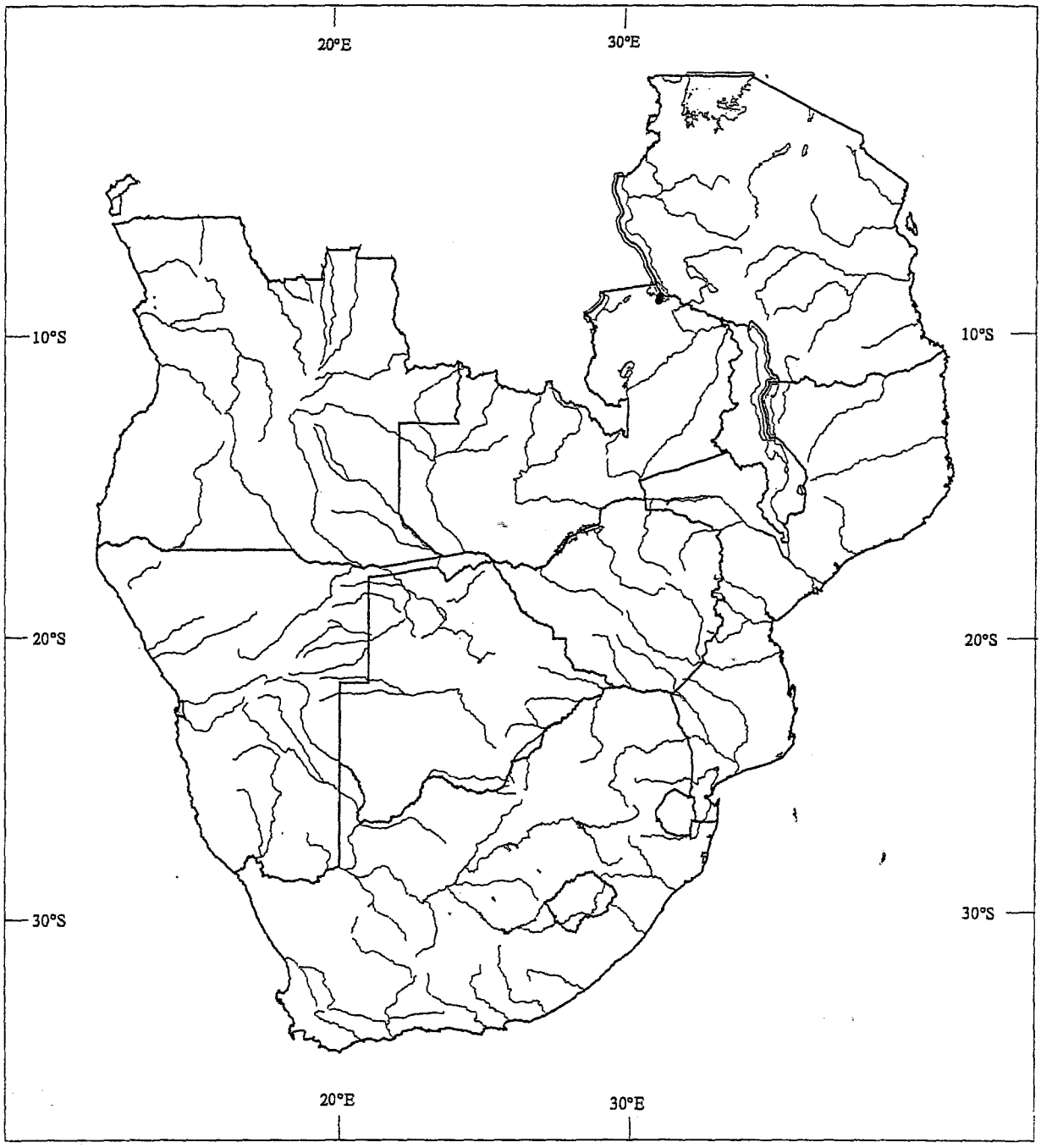


Figure F.470. Point distribution of *Neolamprologus bifasciatus*. Scale approximately 1:25 000 000

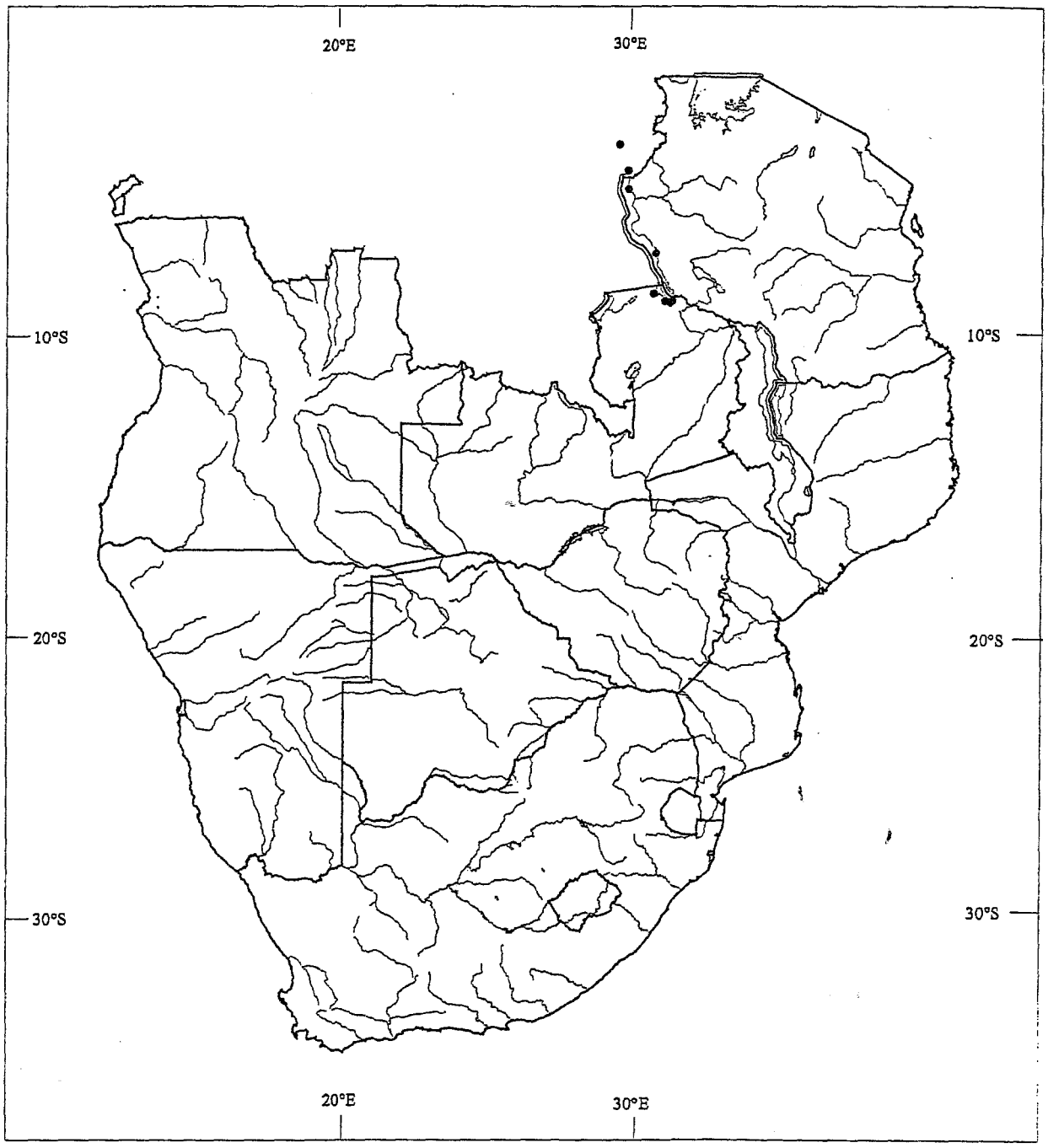


Figure F.471. Point distribution of *Neolamprologus brevis*. Scale approximately 1:25 000 000

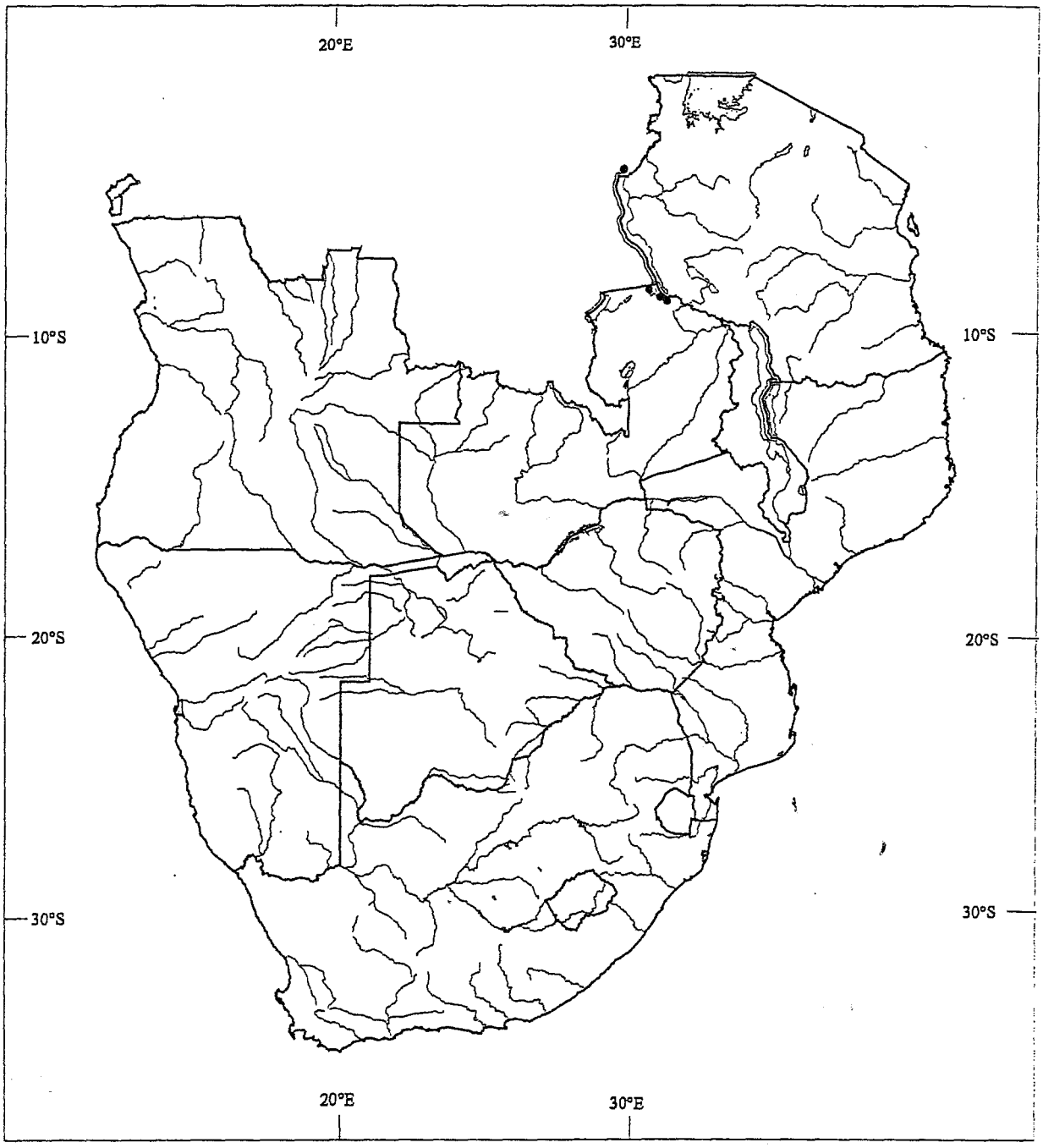


Figure F.472. Point distribution of *Neolamprologus brichardi*. Scale approximately 1:25 000 000

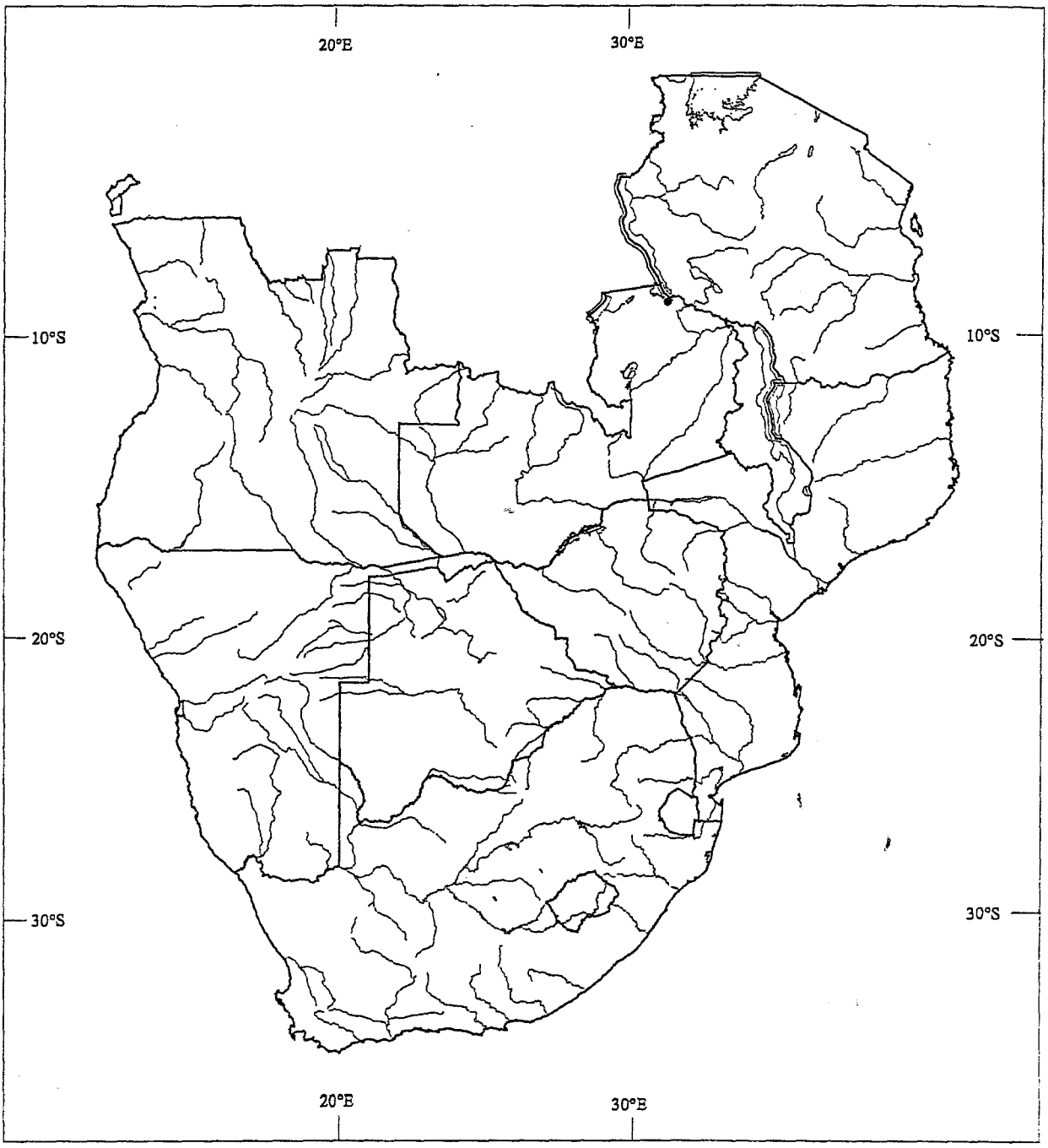


Figure F.473. Point distribution of *Neolamprologus buescheri*. Scale approximately 1:25 000 000

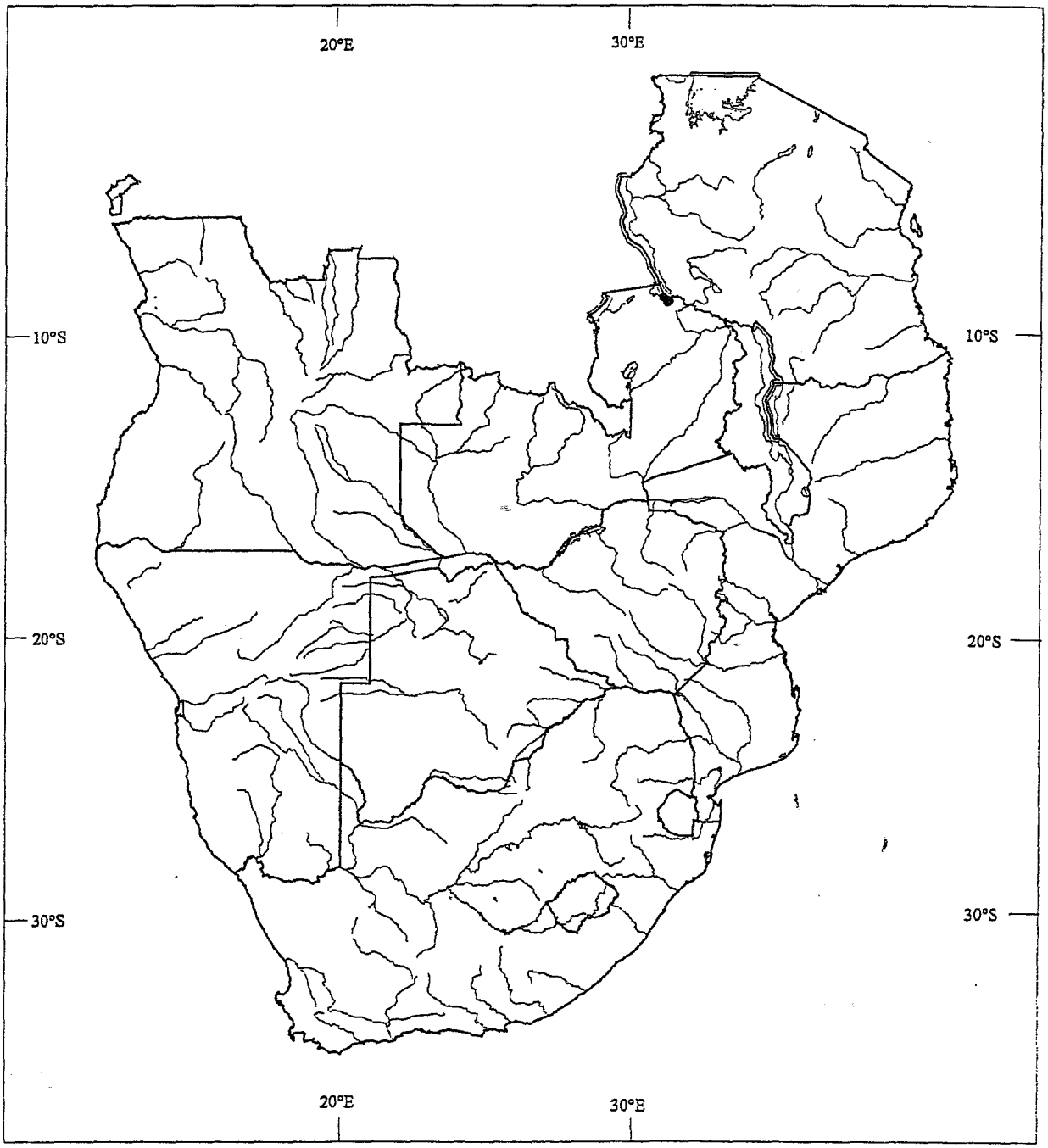


Figure F.474. Point distribution of *Neolamprologus calliurus*. Scale approximately 1:25 000 000

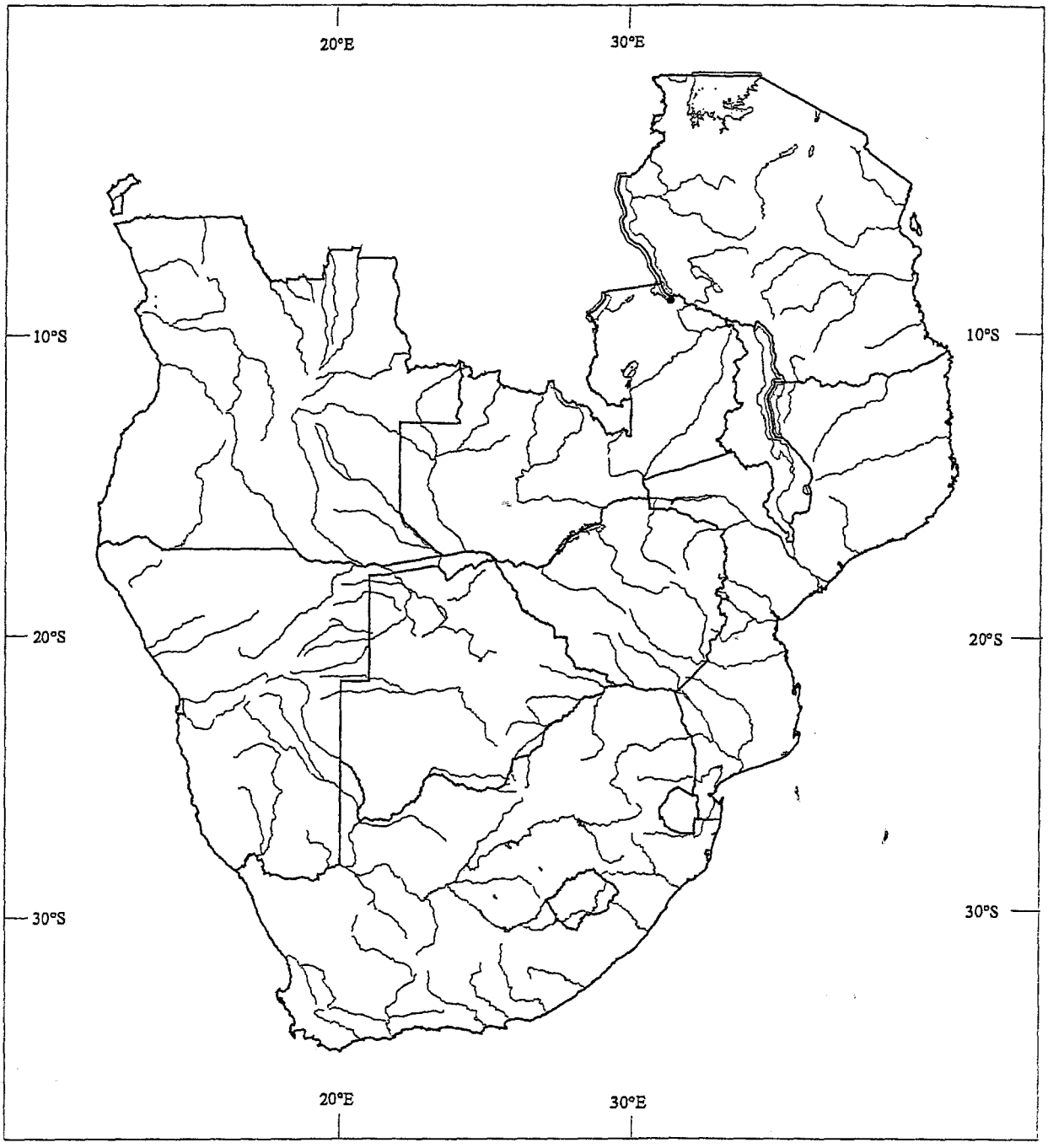


Figure F.475. Point distribution of *Neolamprologus caudopunctatus*. Scale approximately 1:25 000 000

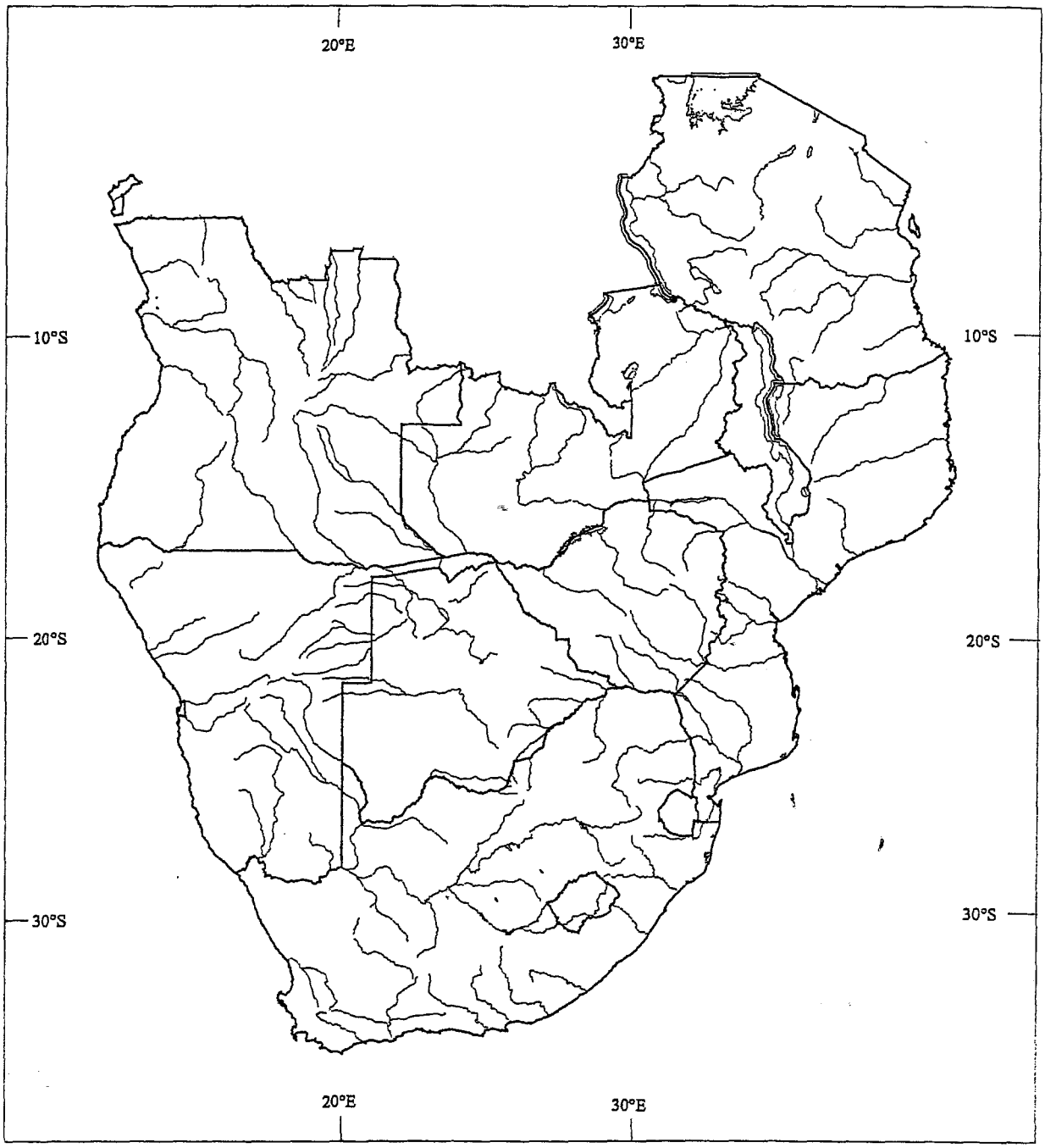


Figure F.476. Point distribution of *Neolamprologus christyi*. Scale approximately 1:25 000 000

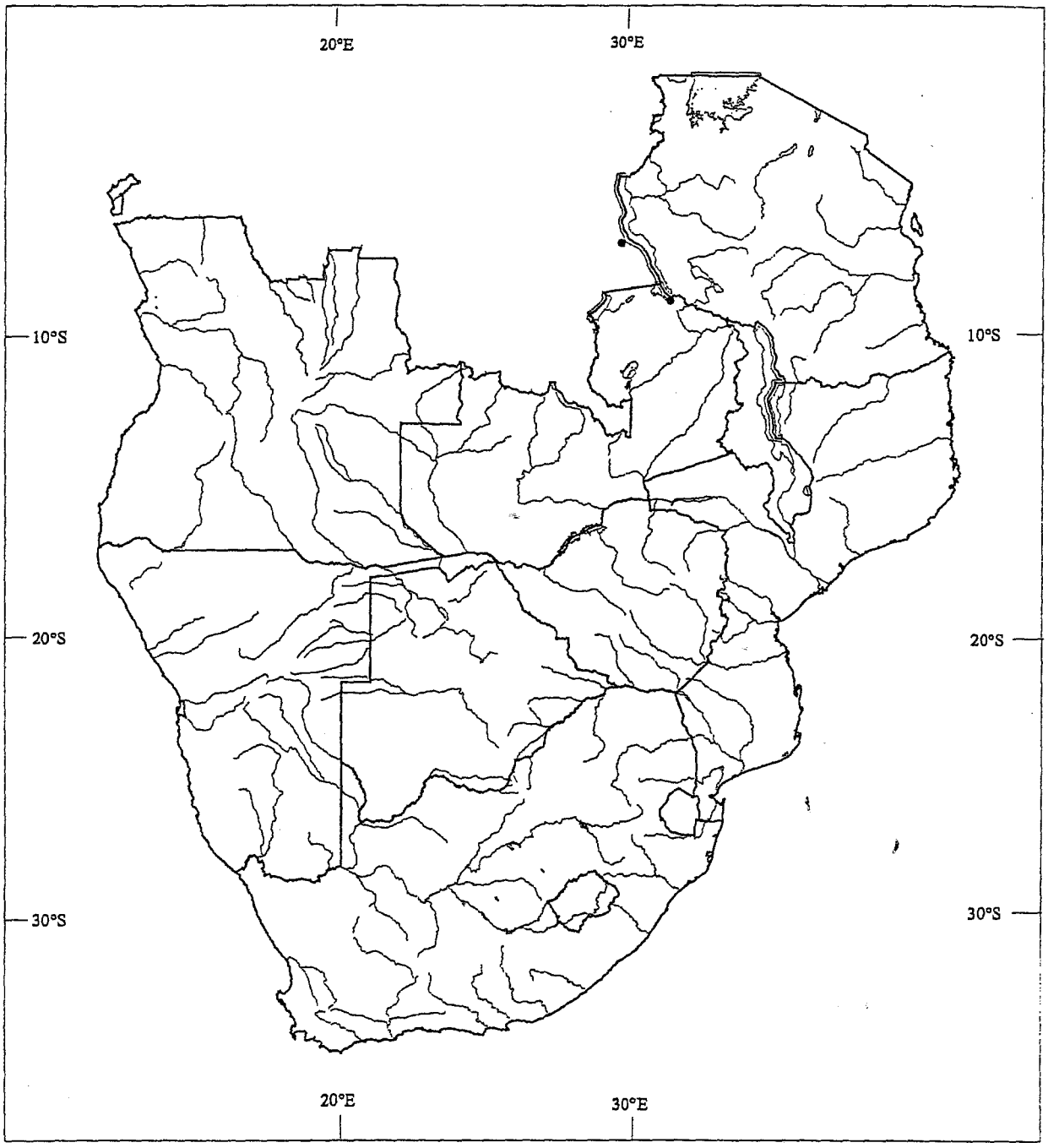


Figure F.477. Point distribution of *Neolamprologus fasciatus*. Scale approximately 1:25 000 000

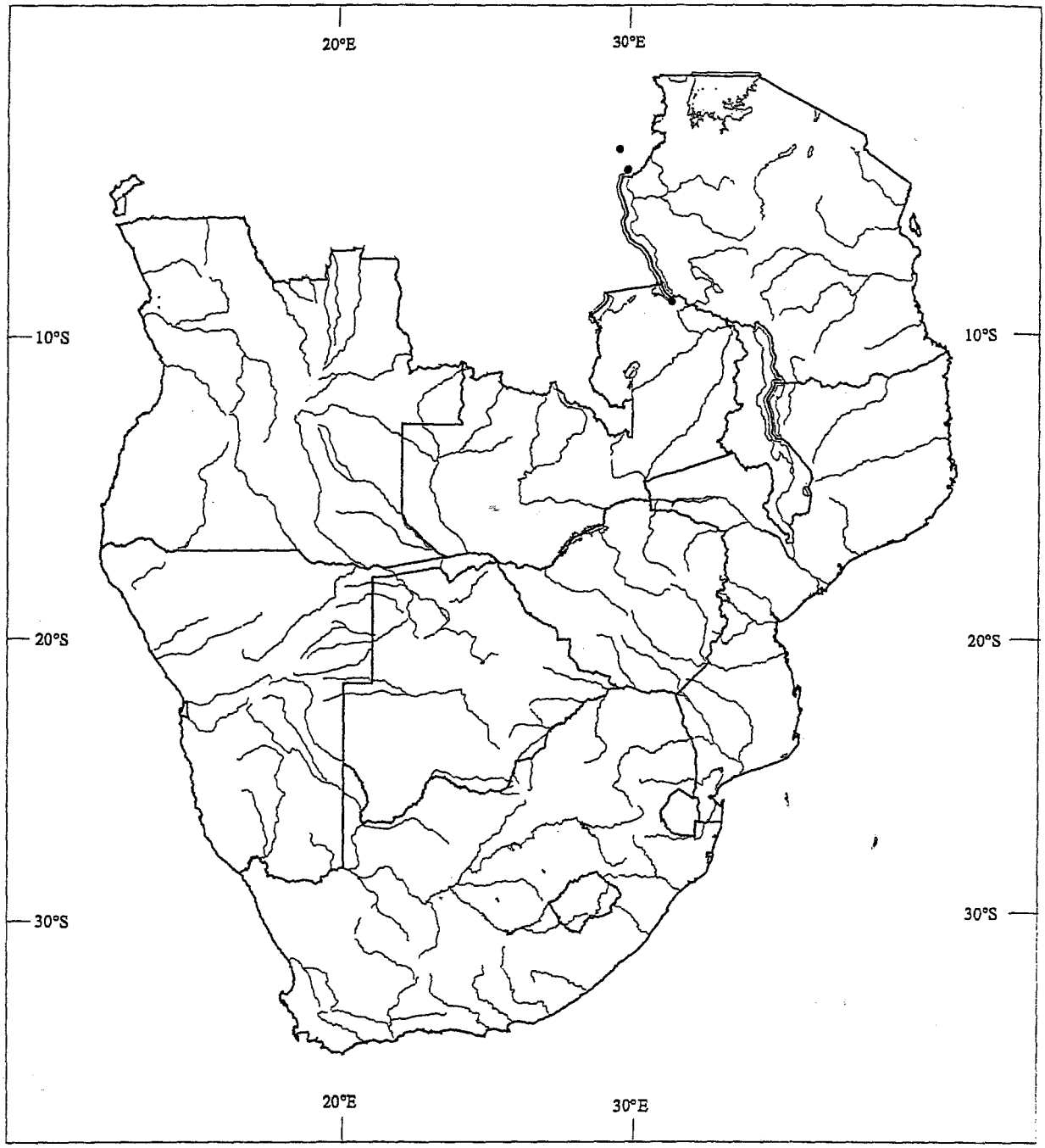


Figure F.478. Point distribution of *Neolamprologus furcifer*. Scale approximately 1:25 000 000

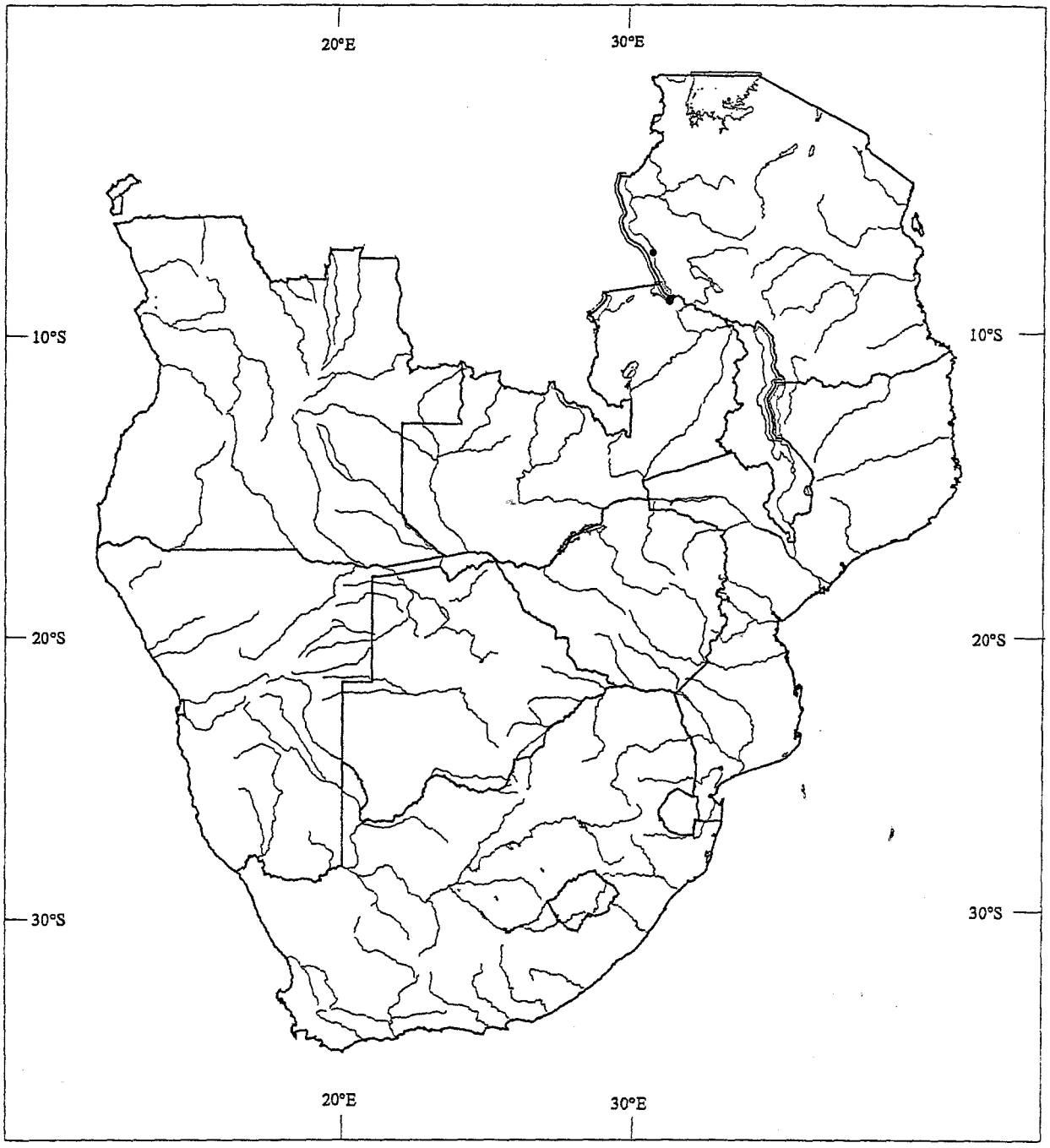


Figure F.479. Point distribution of *Neolamprologus hecqui*. Scale approximately 1:25 000 000

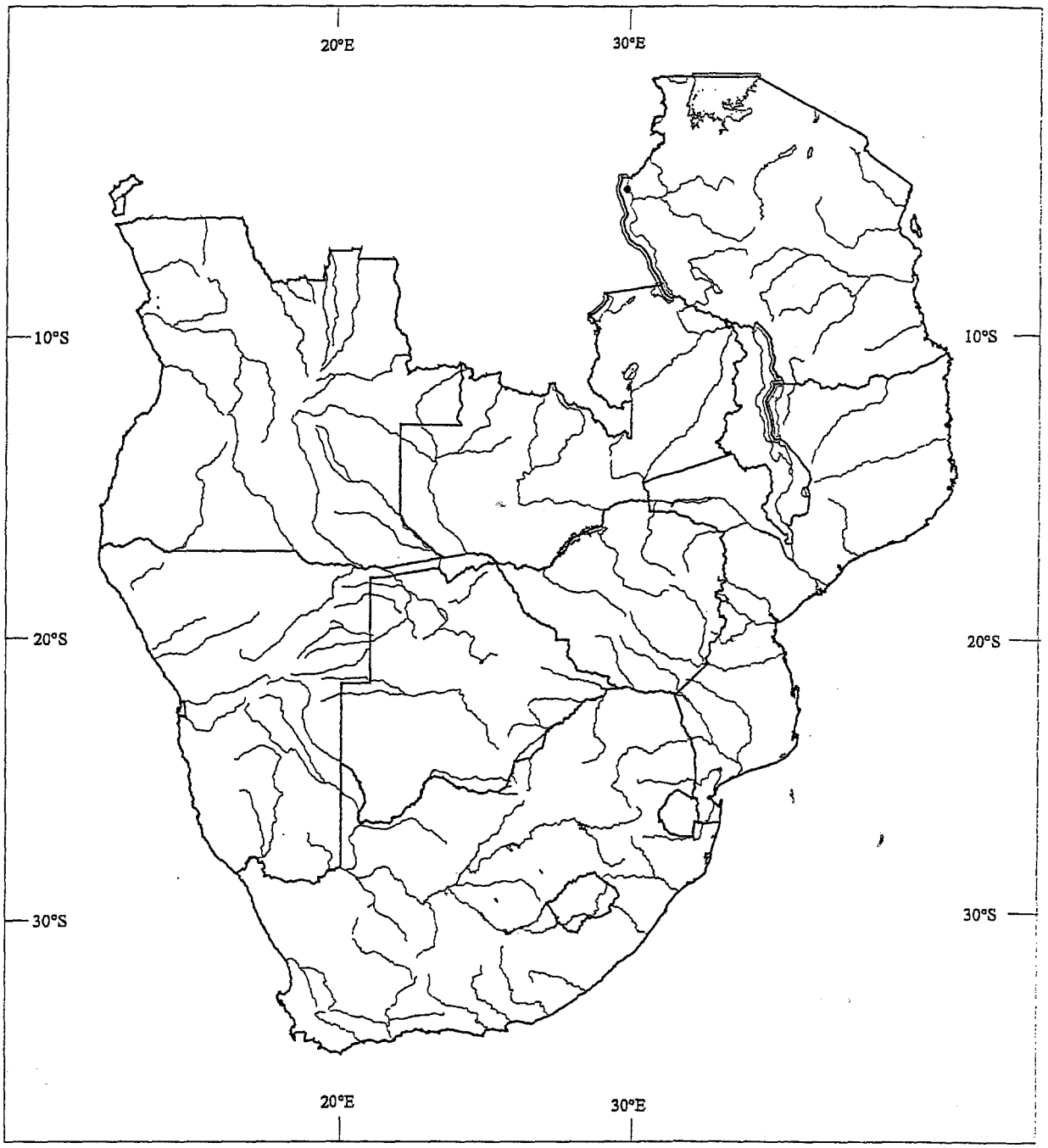


Figure F.480. Point distribution of *Neolamprologus kiritvaitha*. Scale approximately 1:25 000 000

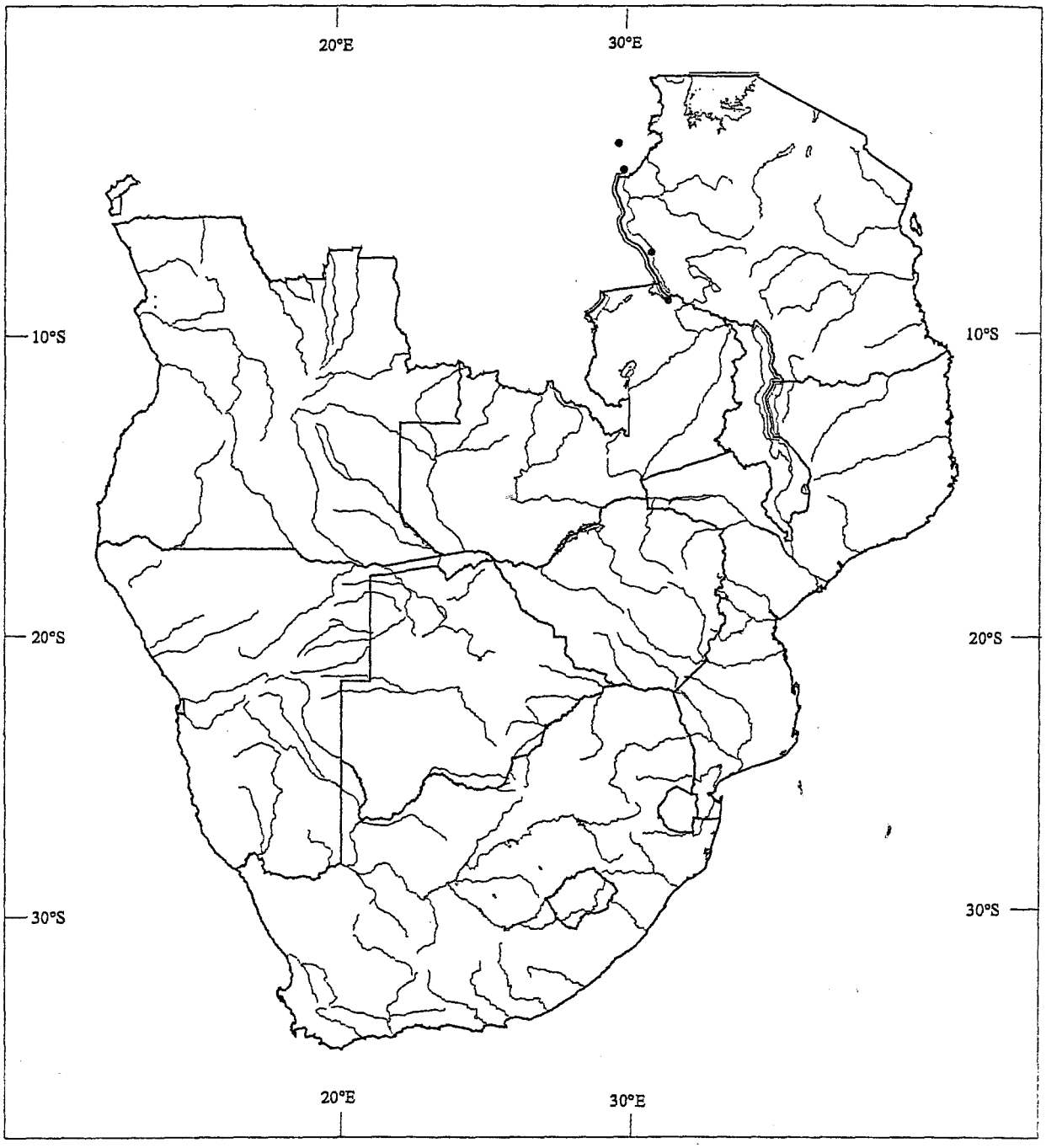


Figure F.481. Point distribution of *Neolamprologus mondabu*. Scale approximately 1:25 000 000

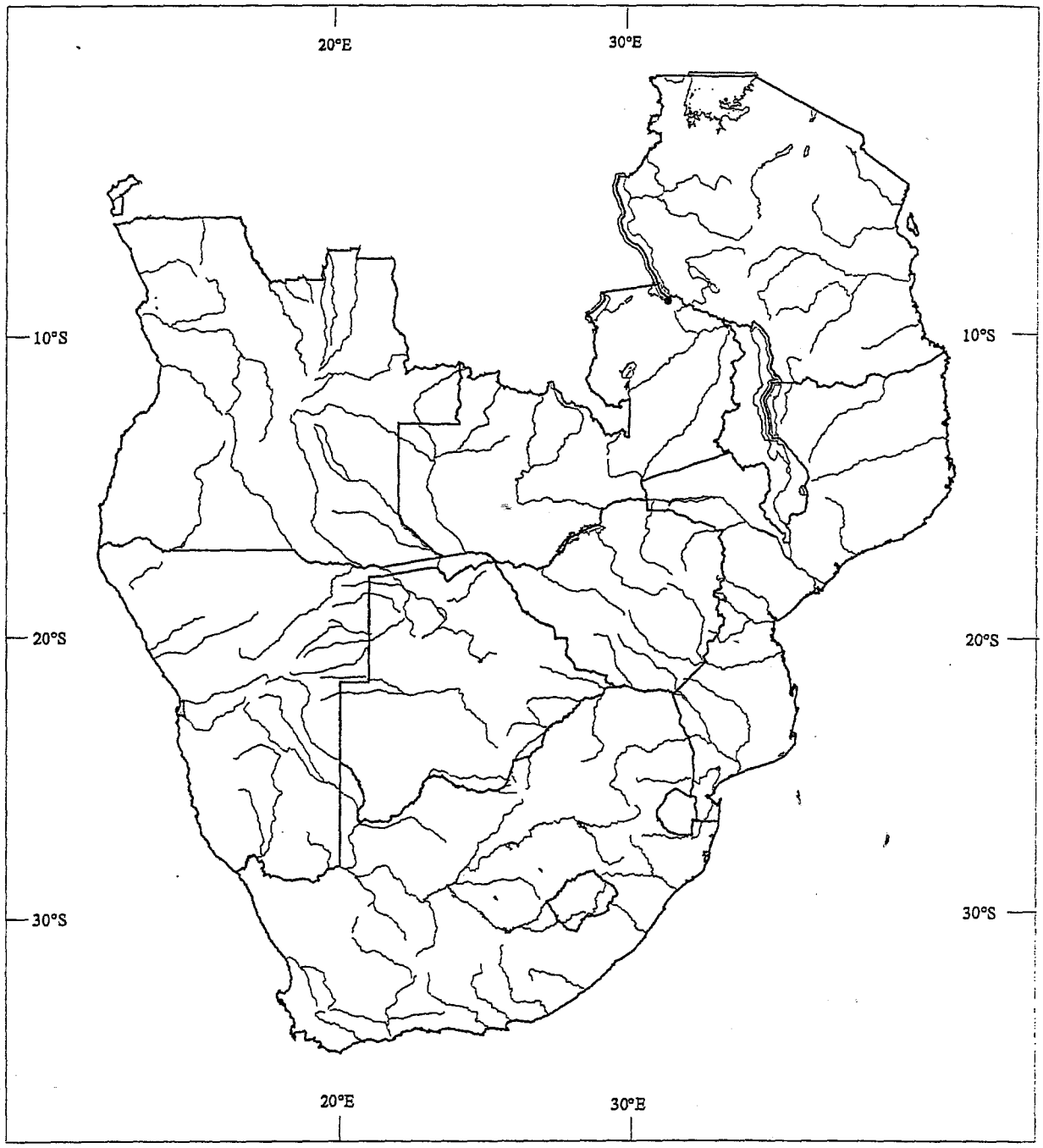


Figure F.482. Point distribution of *Neolamprologus moorei*. Scale approximately 1:25 000 000

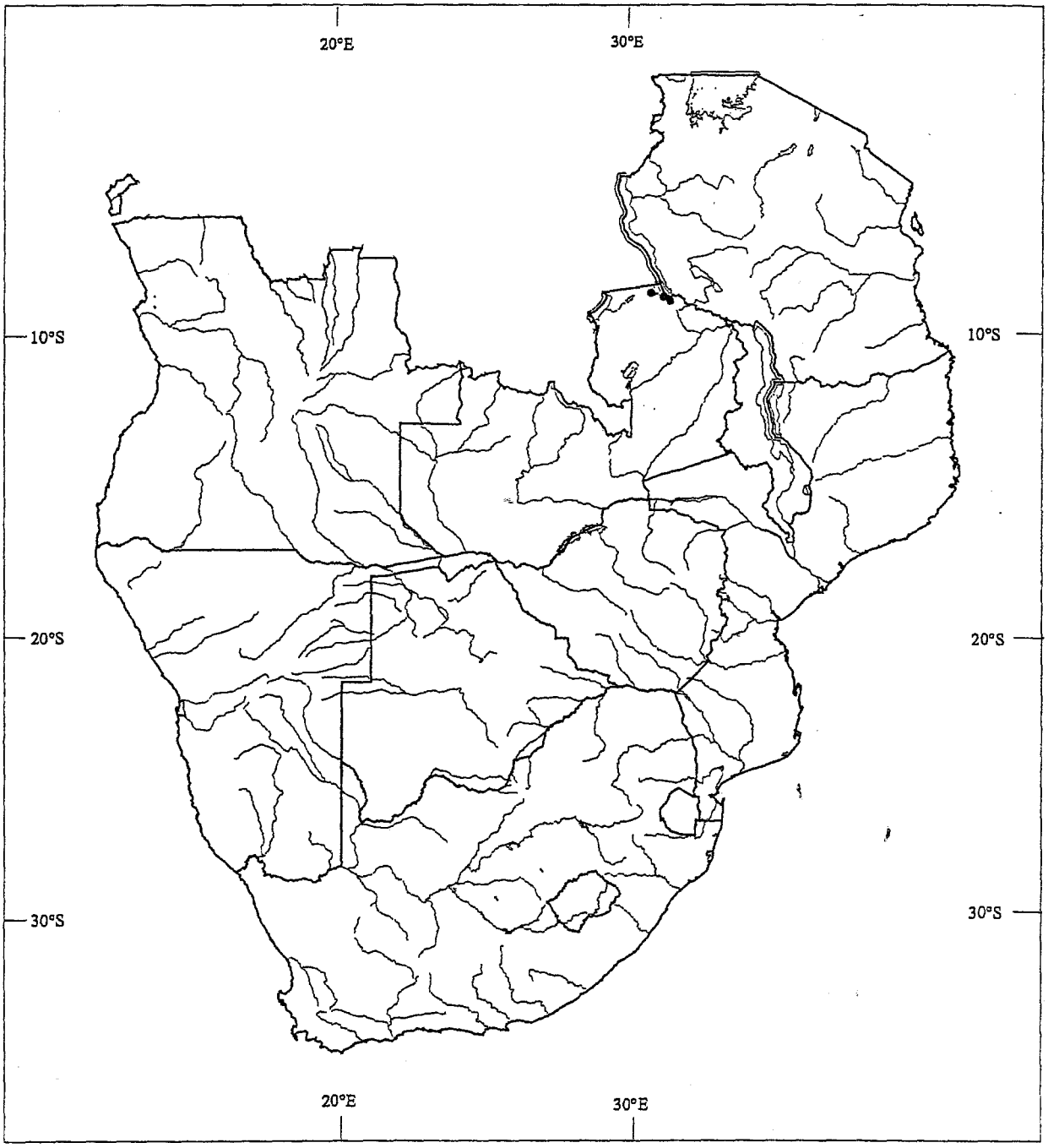


Figure F.483. Point distribution of *Neolamprologus multifasciatus*. Scale approximately 1:25 000 000

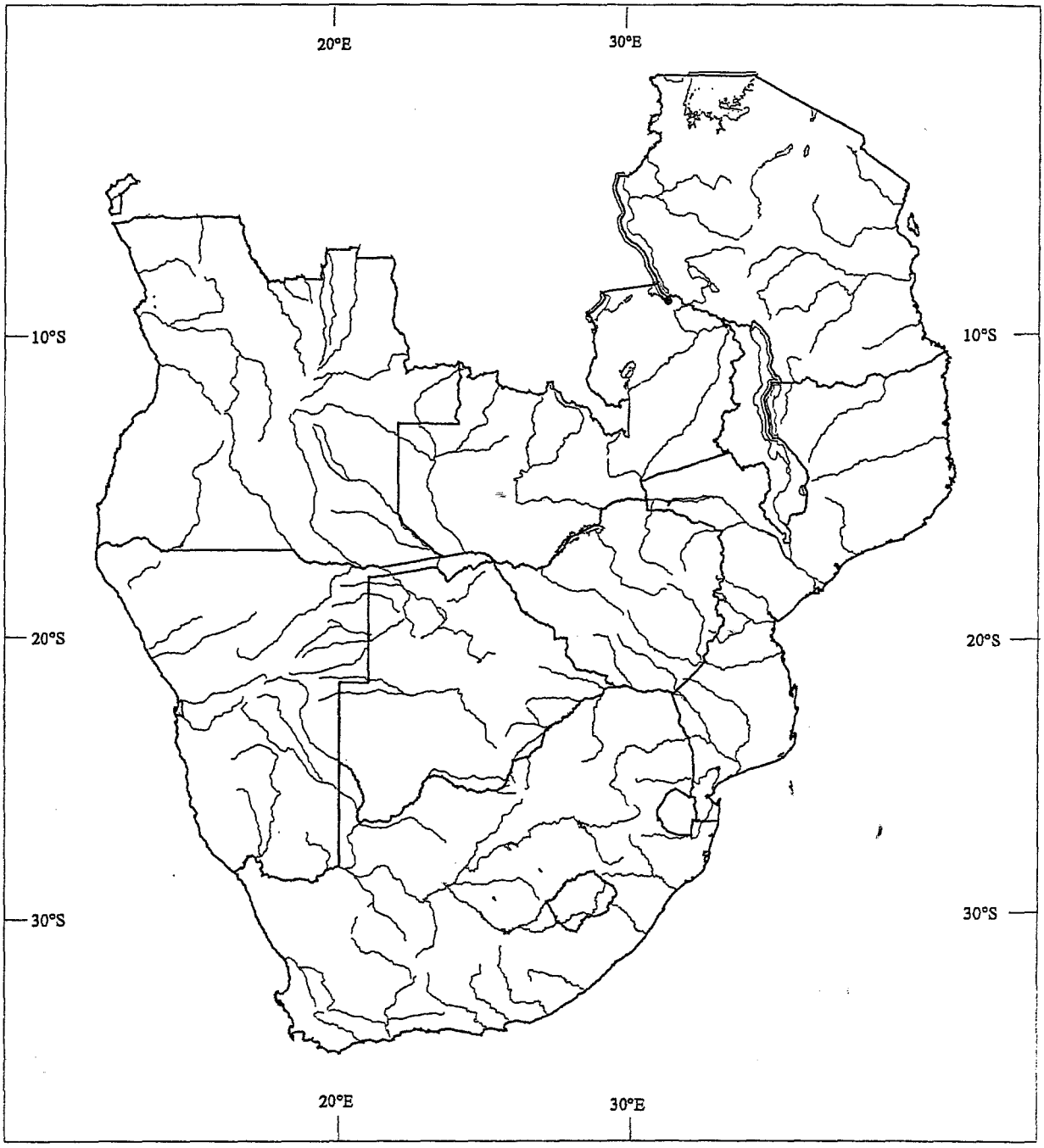


Figure F.484. Point distribution of *Neolamprologus mustax*. Scale approximately 1:25 000 000

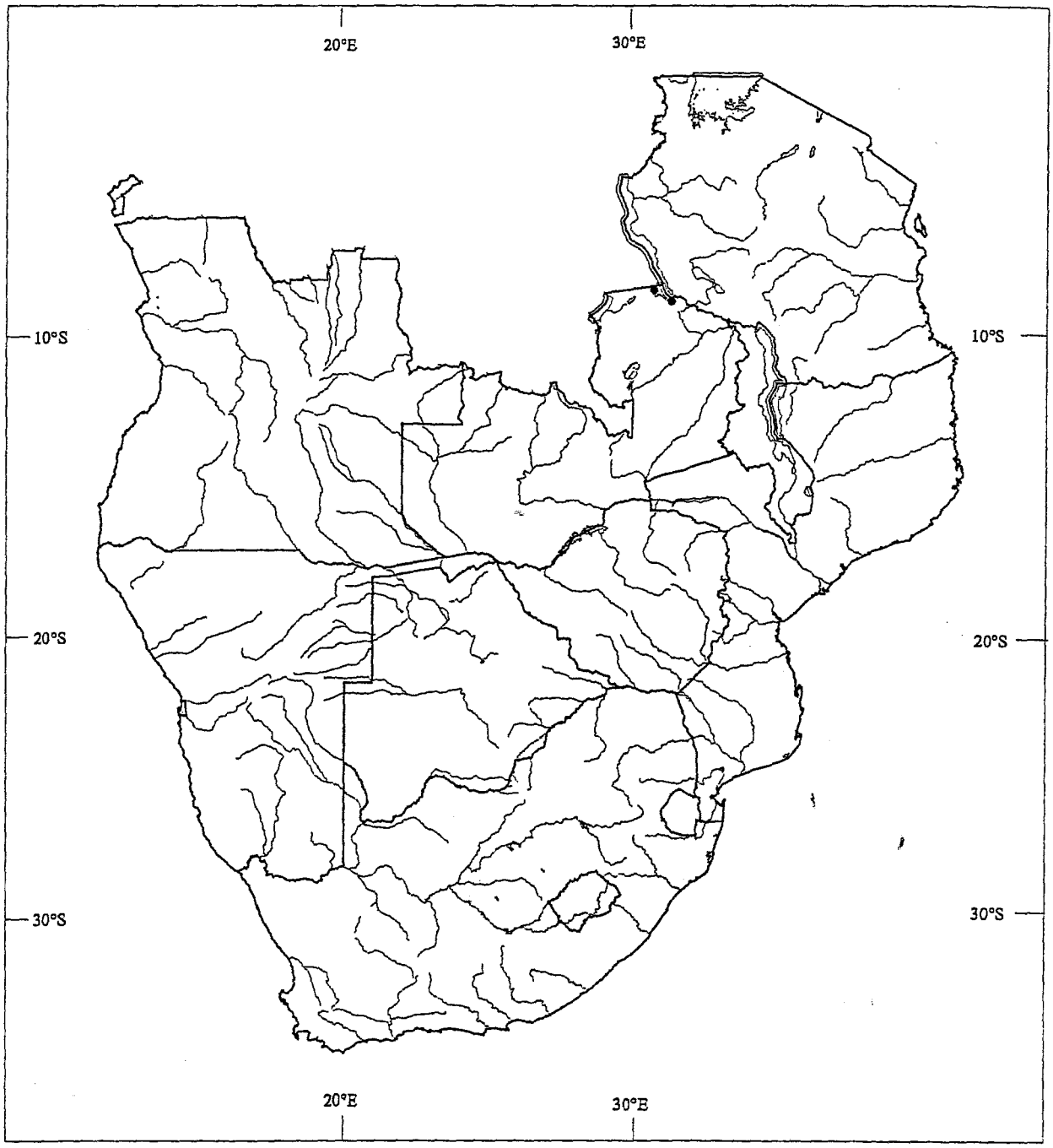


Figure F.485. Point distribution of *Neolamprologus obscurus*. Scale approximately 1:25 000 000

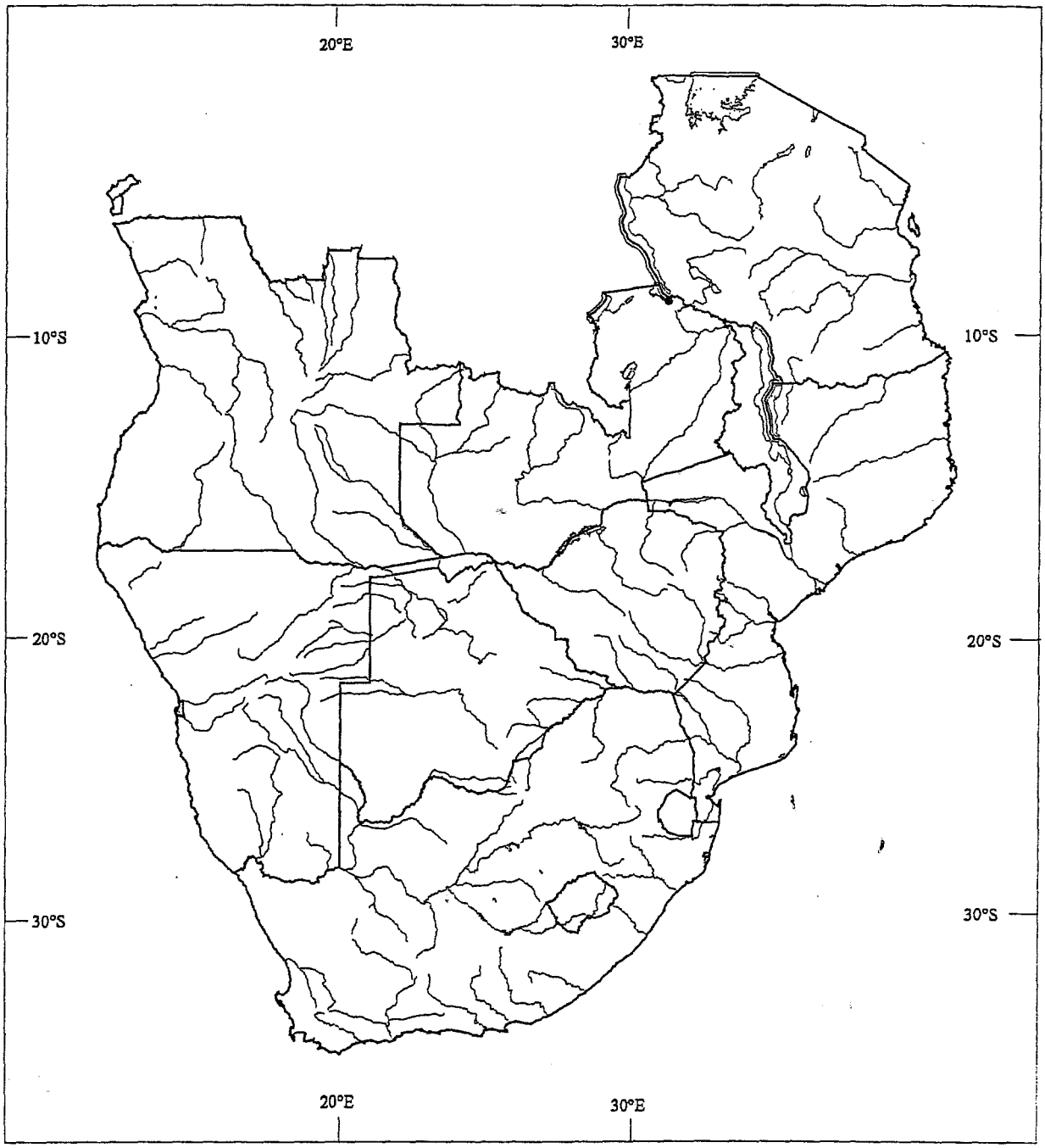


Figure F.486. Point distribution of *Neolamprologus prochilus*. Scale approximately 1:25 000 000

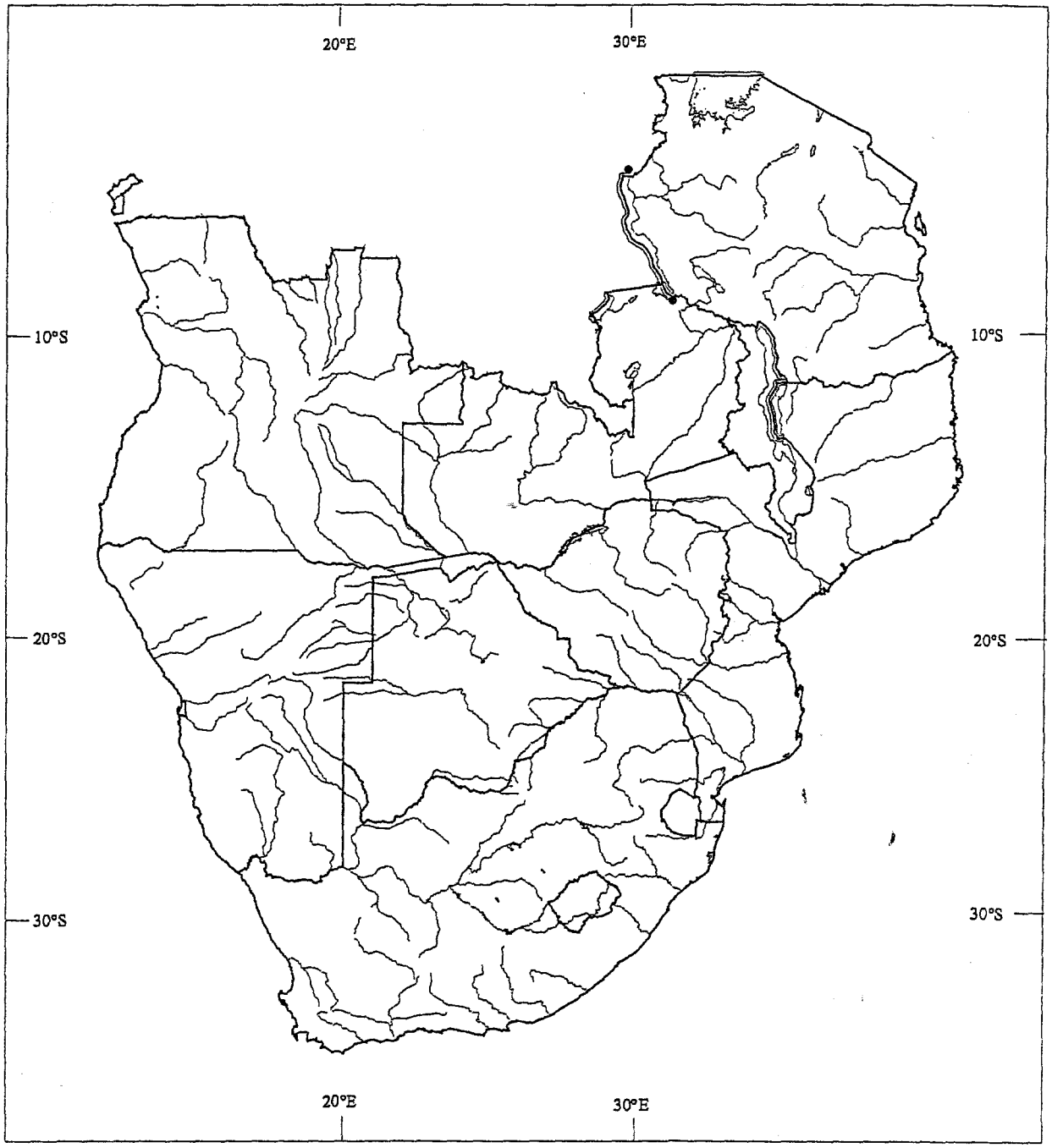


Figure F.487. Point distribution of *Neolamprologus savoryi*. Scale approximately 1:25 000 000

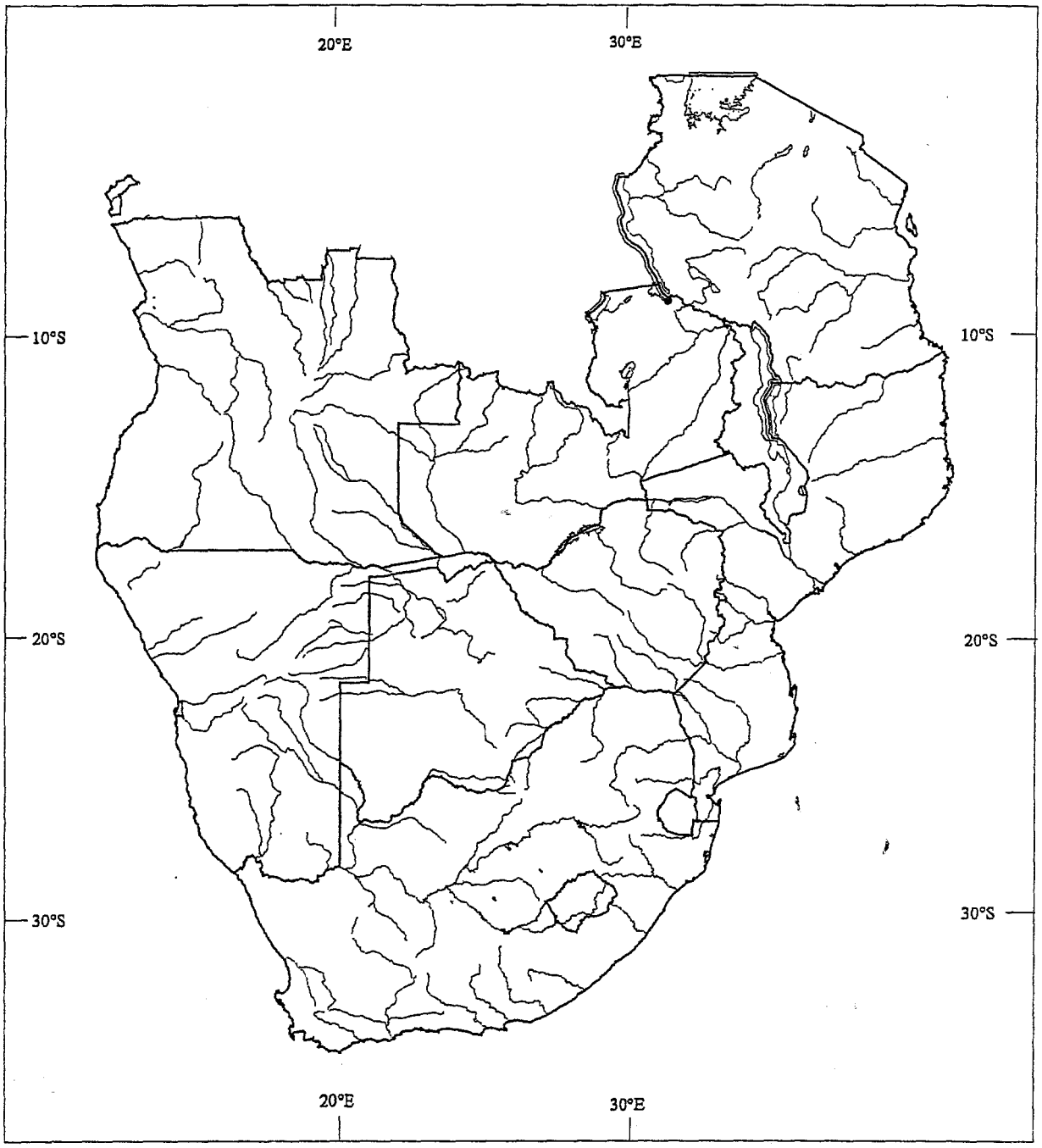


Figure F.488. Point distribution of *Neolamprologus sexfasciatus*. Scale approximately 1:25 000 000

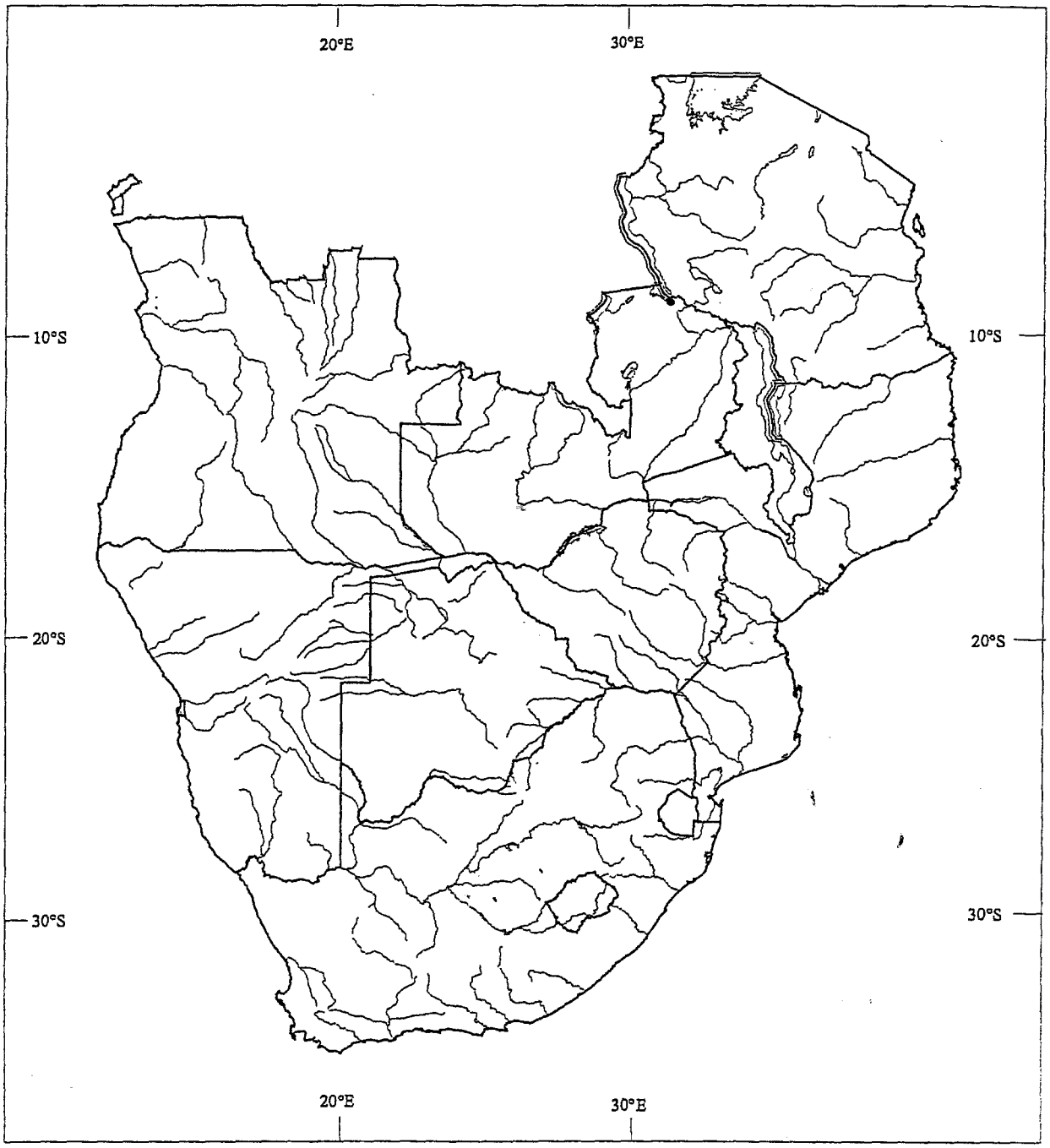


Figure F.489. Point distribution of *Neolamprologus tetracanthus*. Scale approximately 1:25 000 000

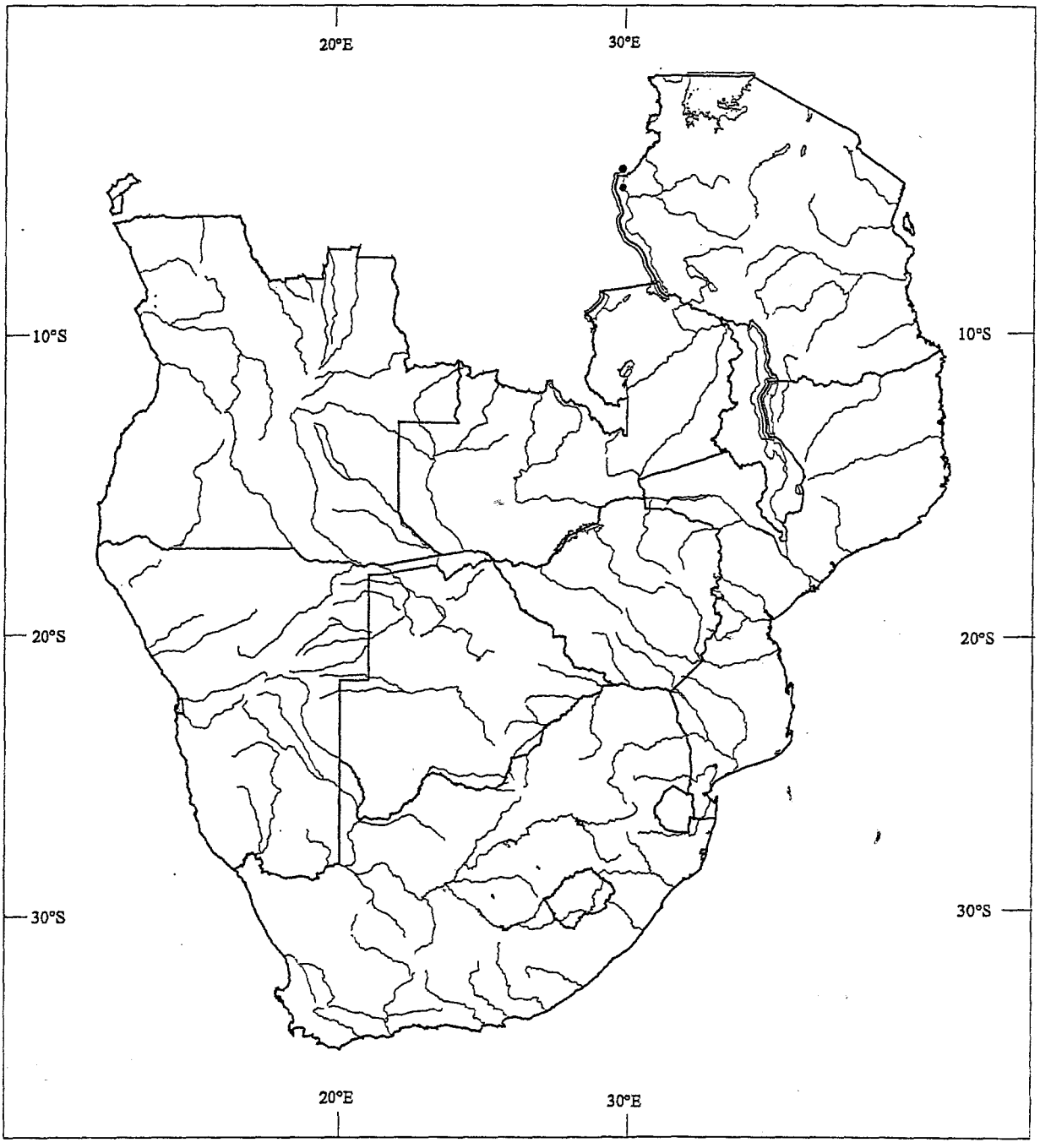


Figure F.490. Point distribution of *Neolamprologus toae*. Scale approximately 1:25 000 000

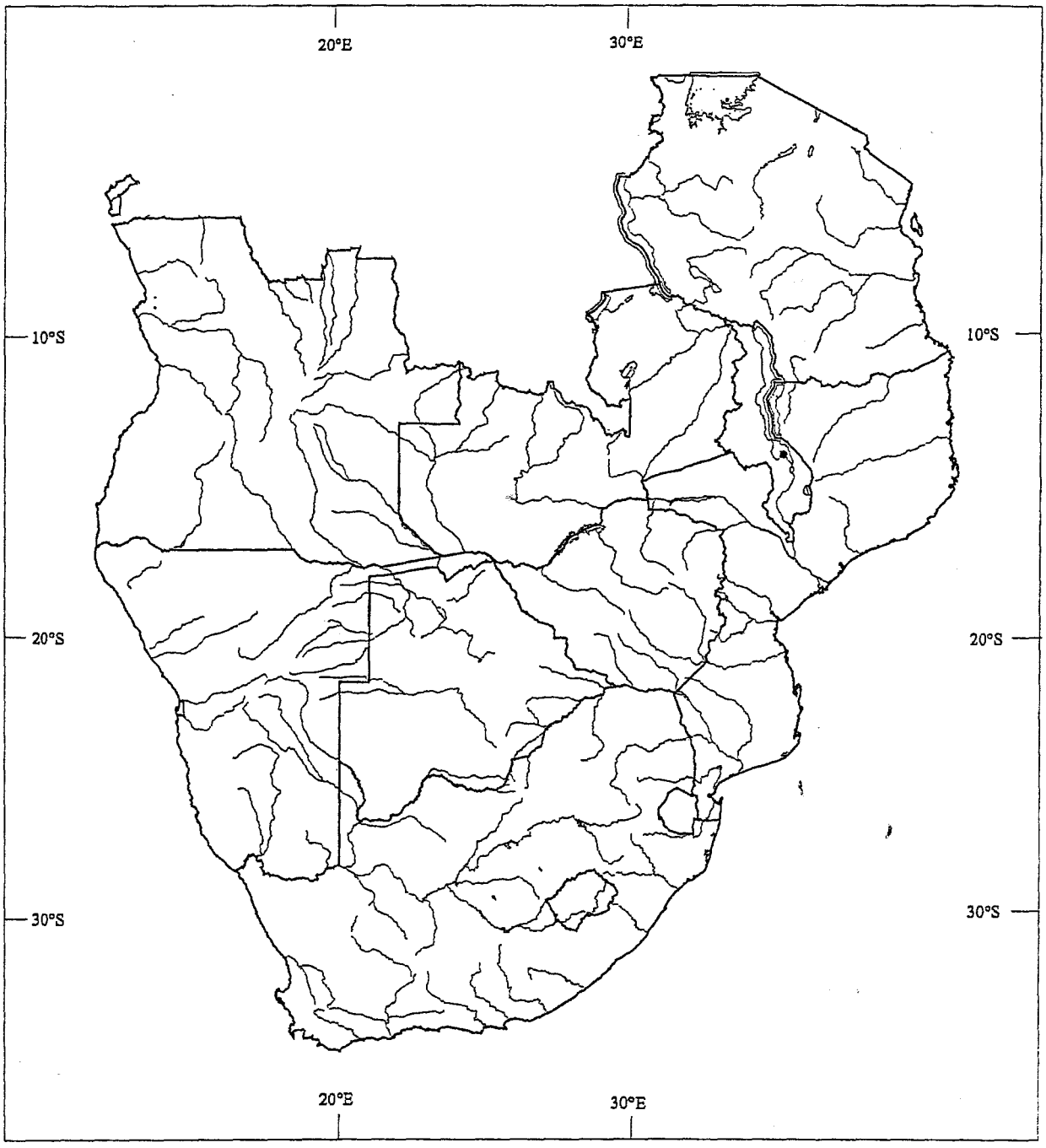


Figure F.491. Point distribution of *Nimbochromis fuscotaeniatus*. Scale approximately 1:25 000 000

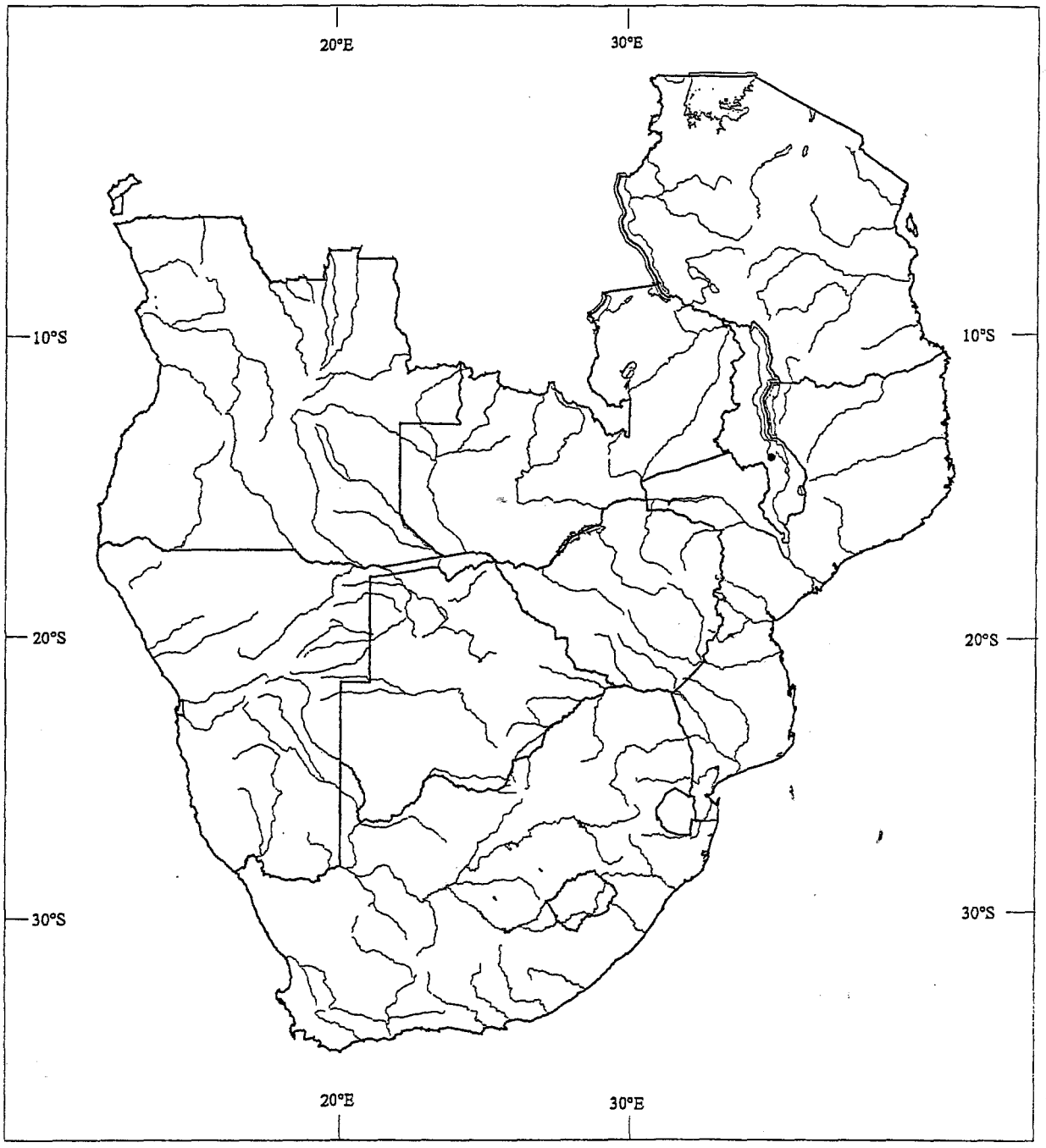


Figure F.492. Point distribution of *Nimbochromis linni*. Scale approximately 1:25 000 000

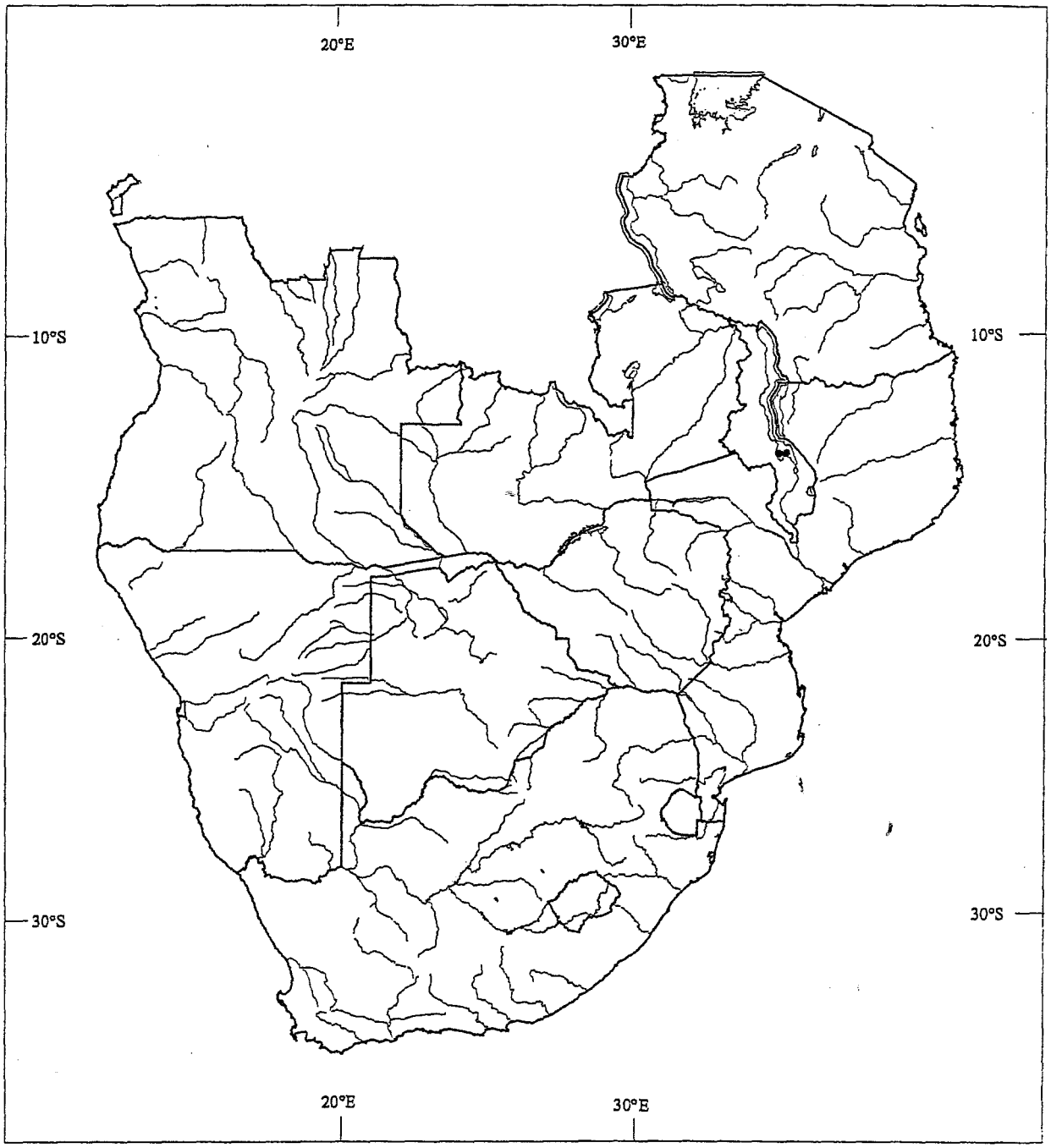


Figure F.493. Point distribution of *Nimbochromis livingstonii*. Scale approximately 1:25 000 000

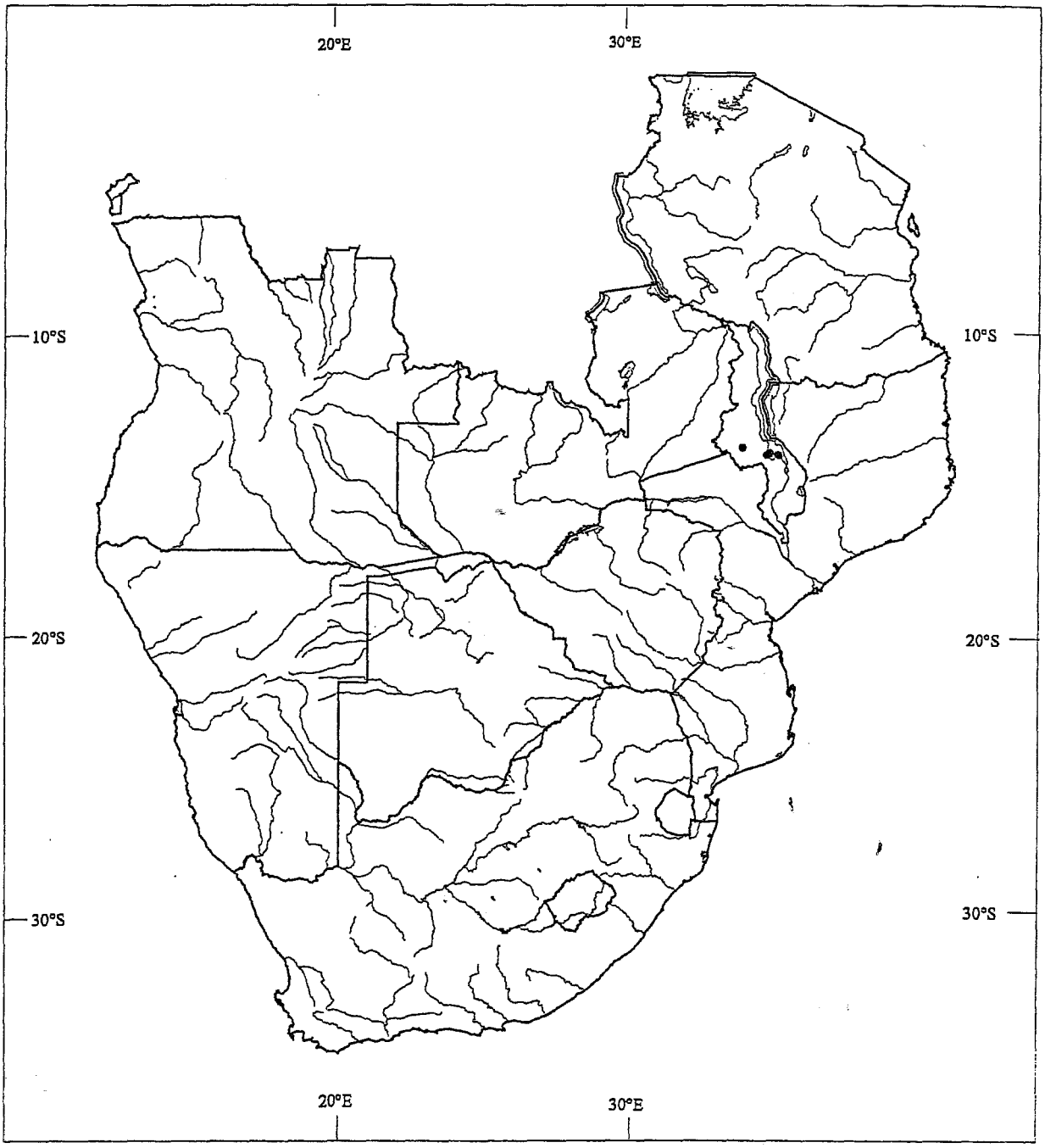


Figure F.494. Point distribution of *Nimbochromis polystigma*. Scale approximately 1:25 000 000

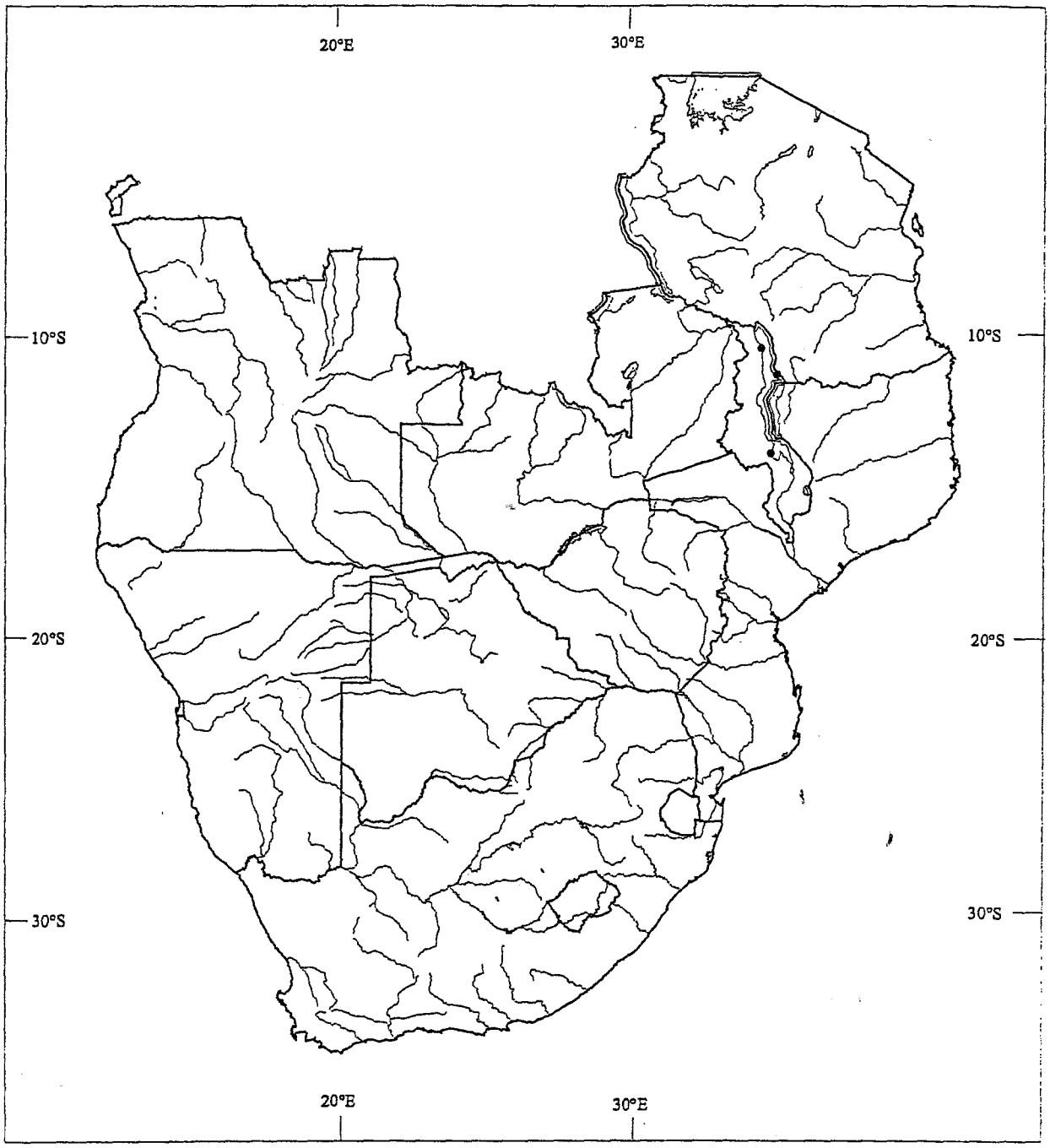


Figure F.495. Point distribution of *Nimbochromis venustus*. Scale approximately 1:25 000 000

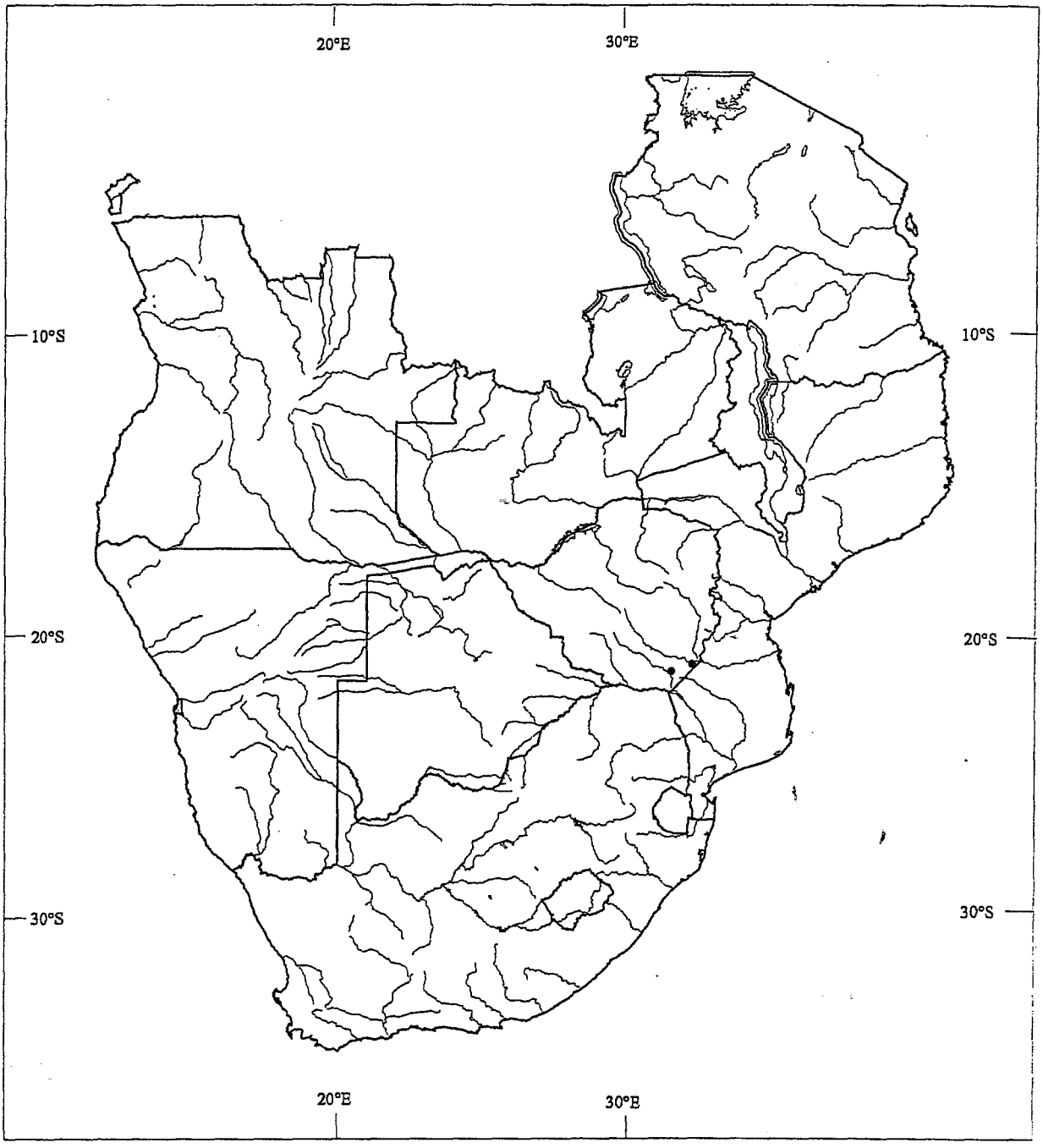


Figure F.496. Point distribution of *Nothobranchius furzeri*. Scale approximately 1:25 000 000

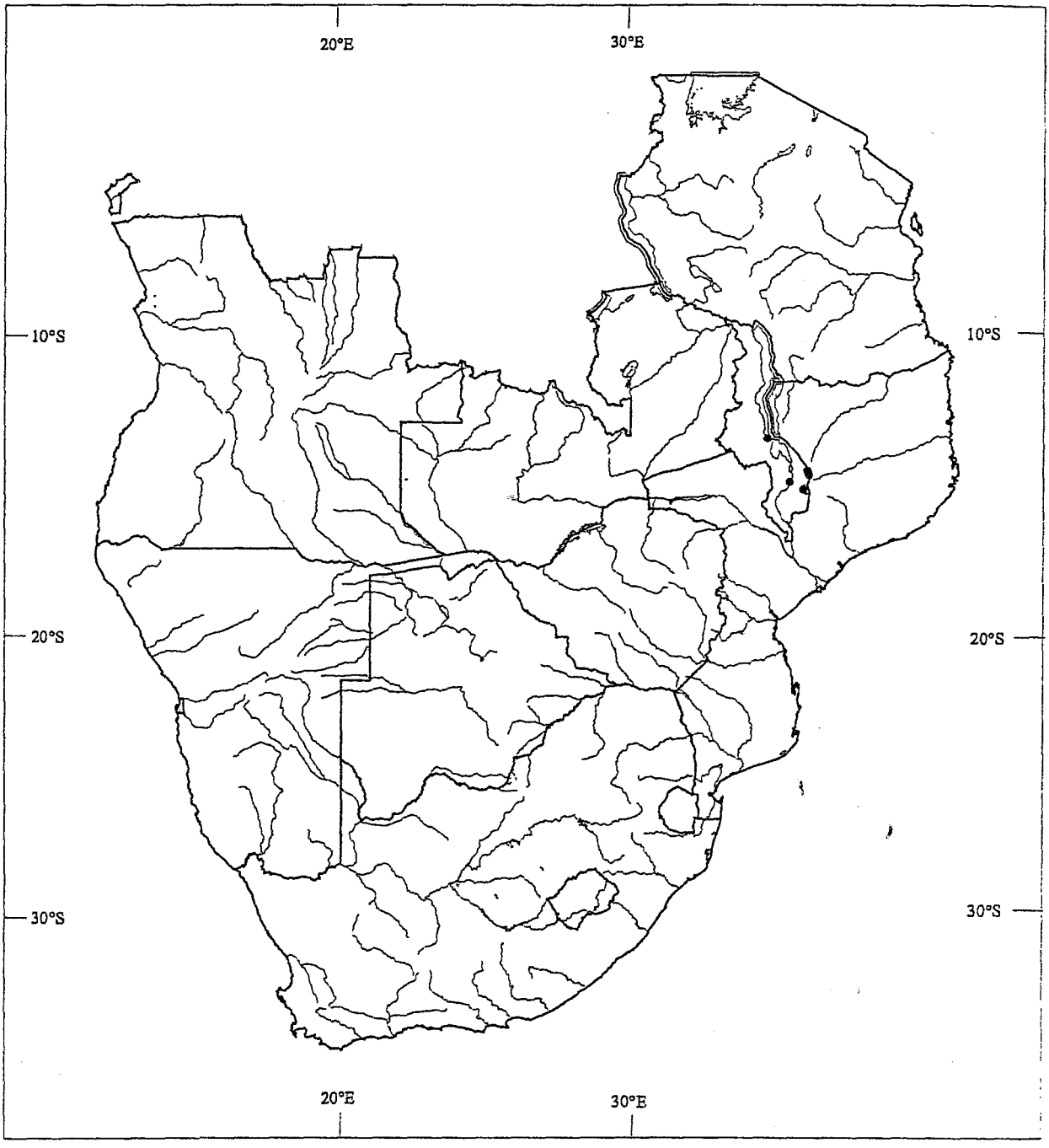


Figure F.497. Point distribution of *Nothobranchius kirki*. Scale approximately 1:25 000 000

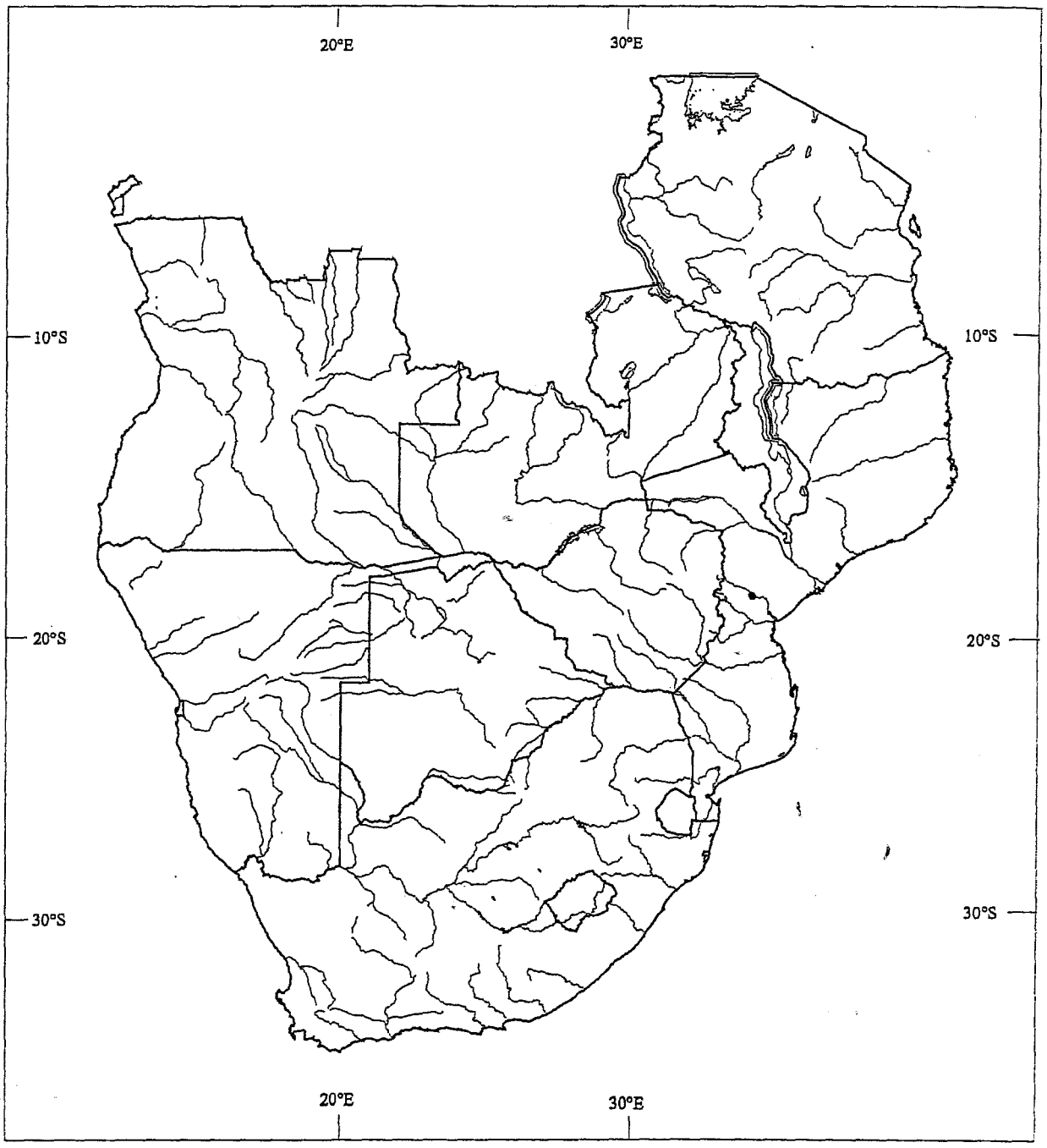


Figure F.498. Point distribution of *Nothobranchius kuhntae*. Scale approximately 1:25 000 000

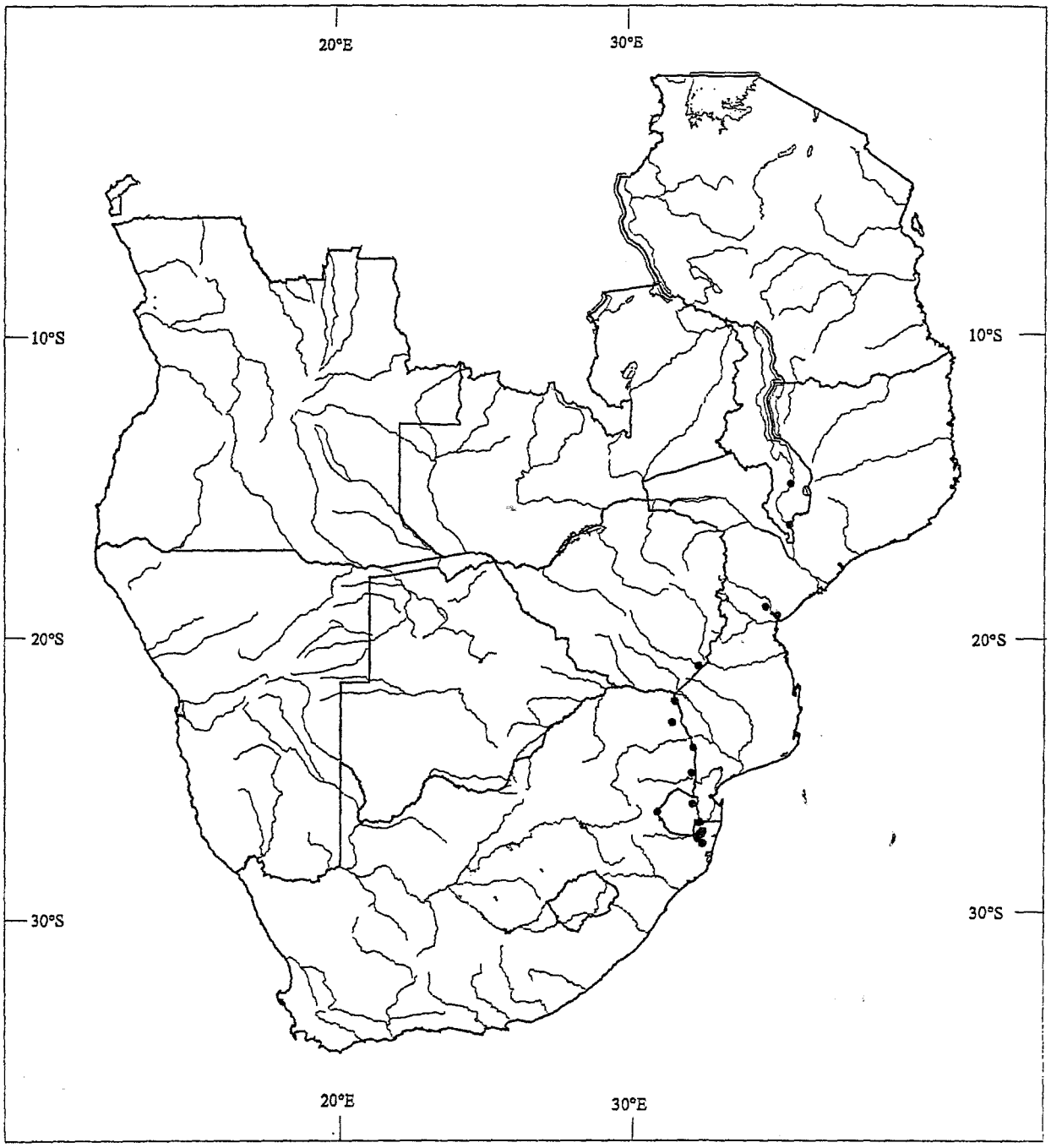


Figure F.499. Point distribution of *Nothobranchius orthonotus*. Scale approximately 1:25 000 000

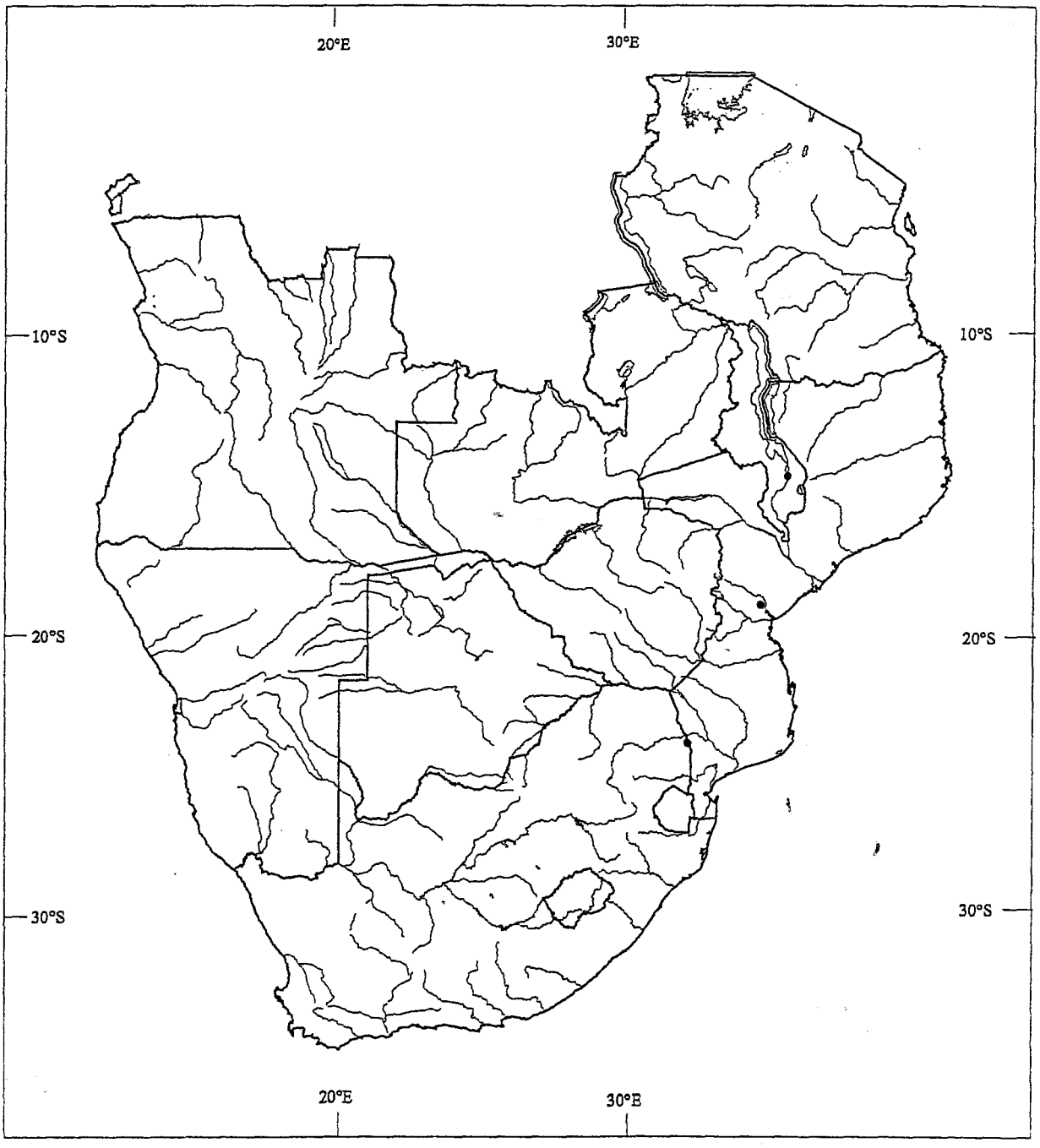


Figure F.500. Point distribution of *Nothobranchius rachovii*. Scale approximately 1:25 000 000

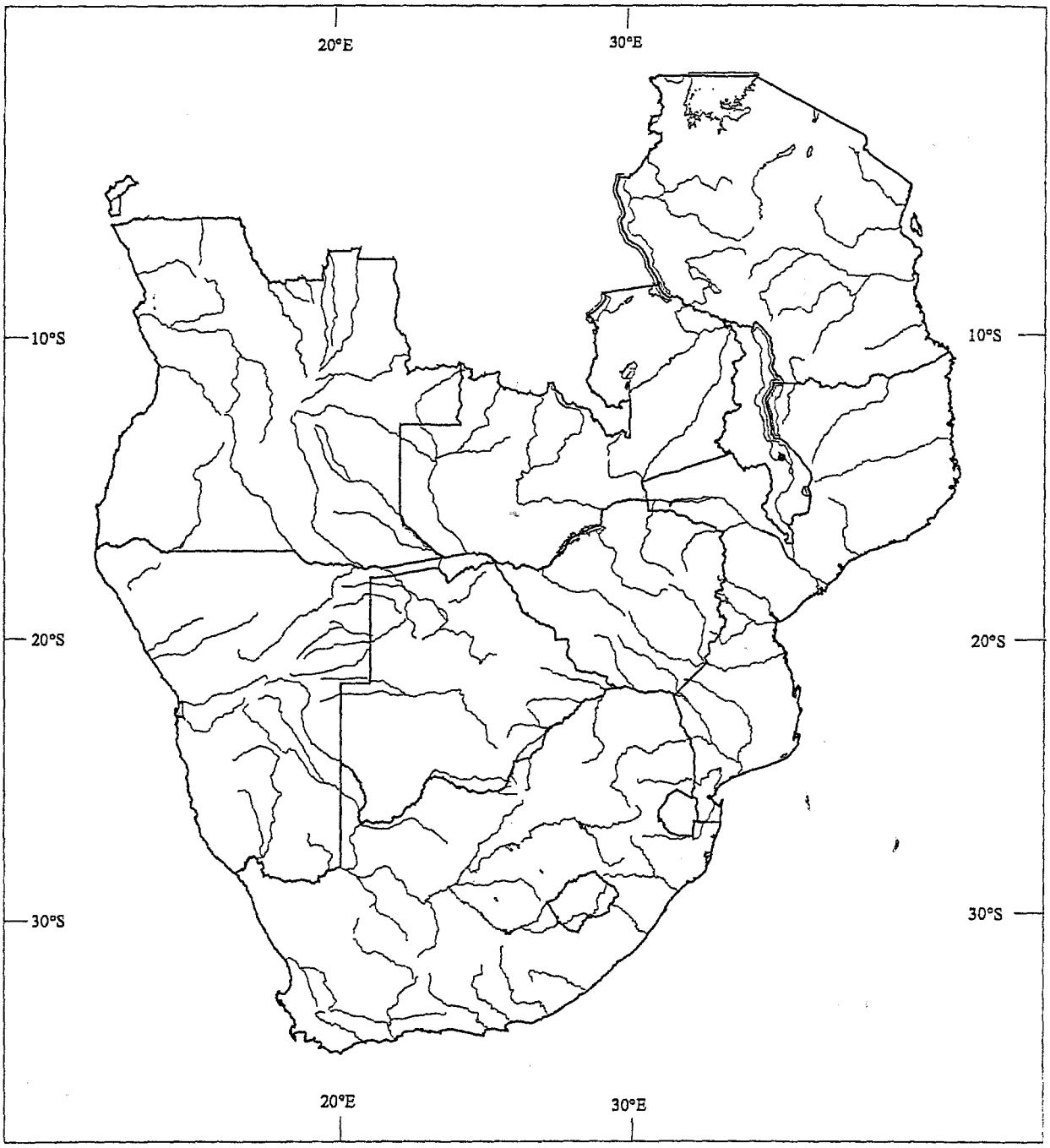


Figure F.501. Point distribution of *Nyassachromis breviceps*. Scale approximately 1:25 000 000

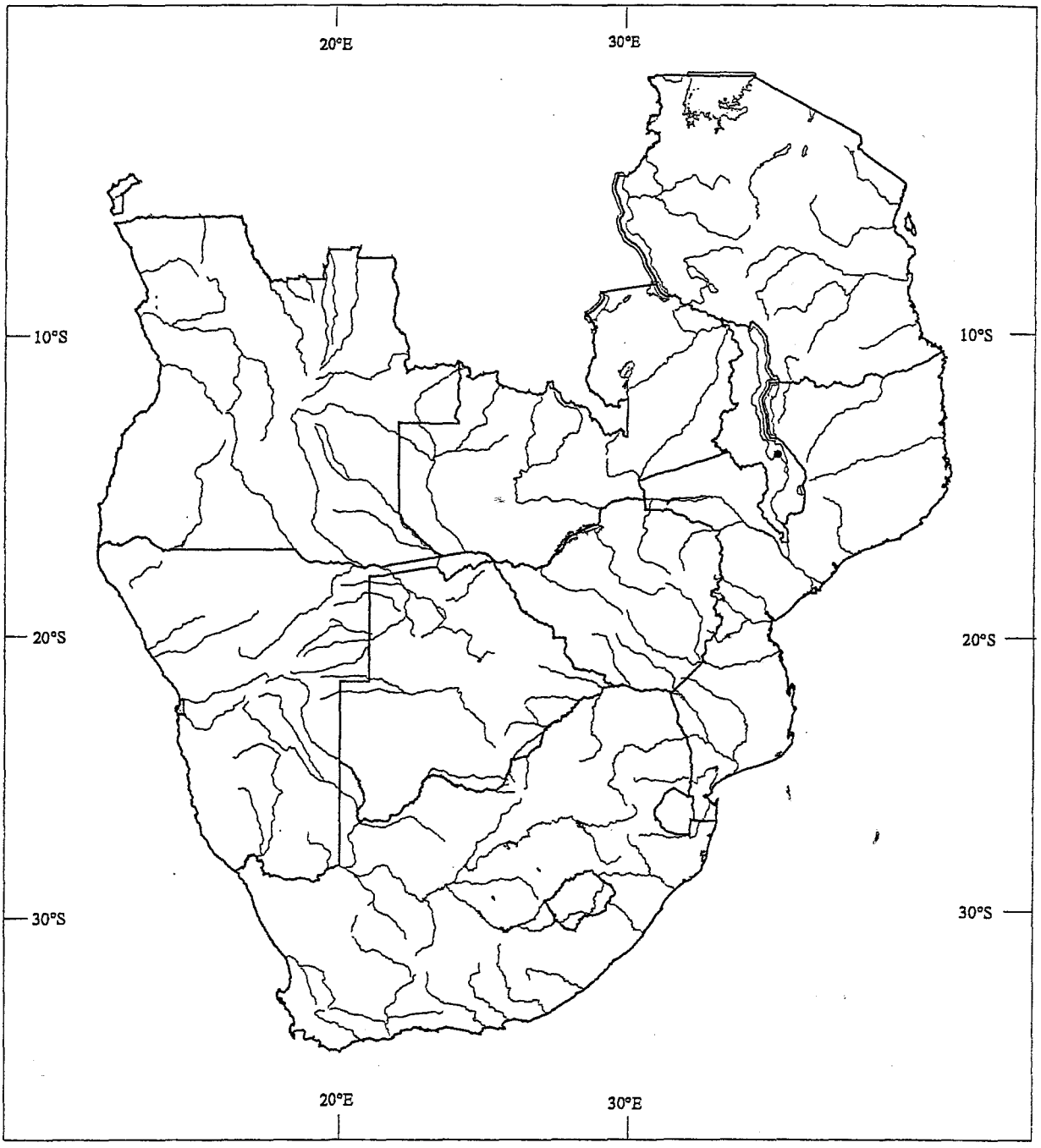


Figure F.502. Point distribution of *Nyassachromis leuciscus*. Scale approximately 1:25 000 000

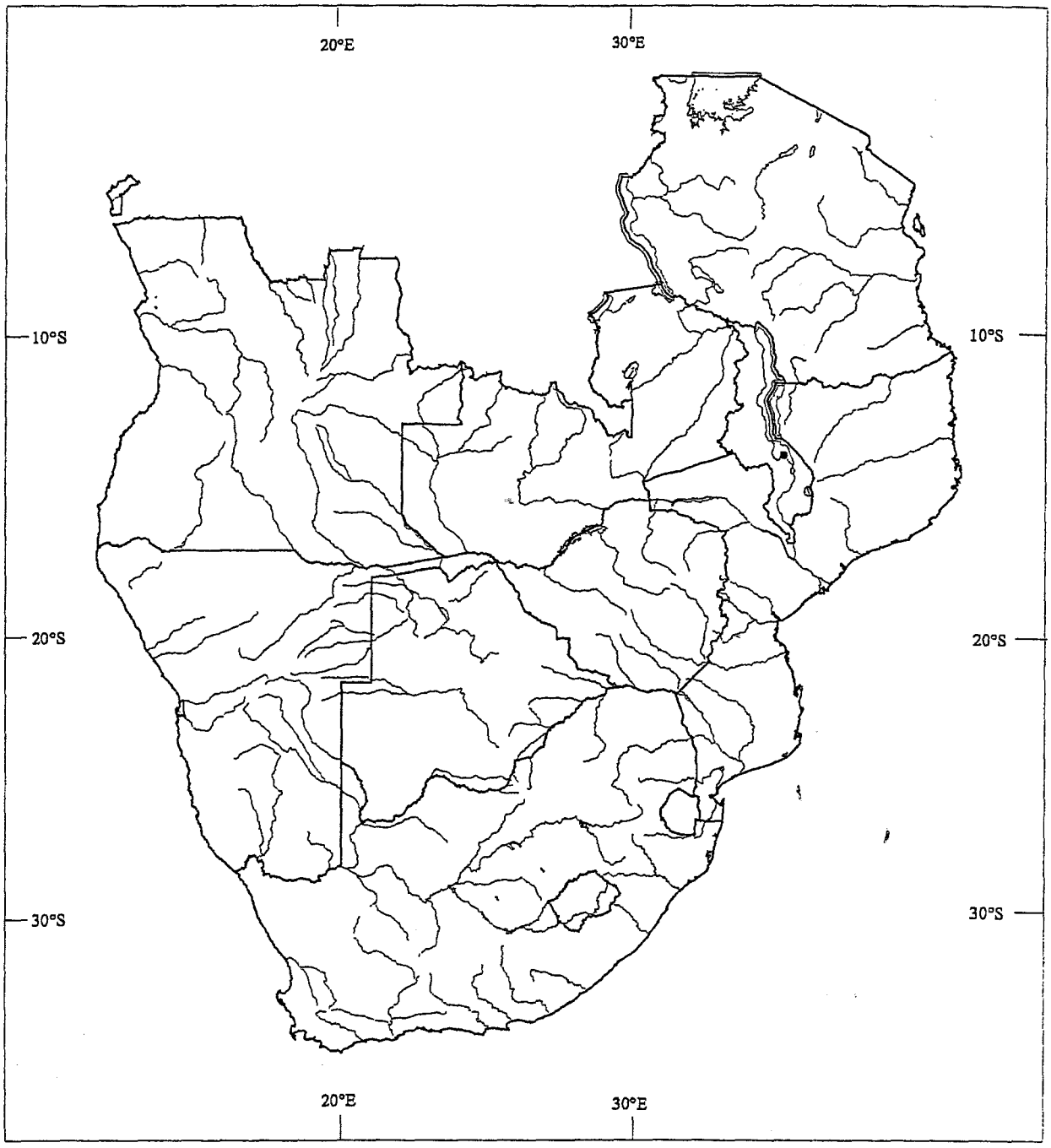


Figure F.503. Point distribution of *Nyassachromis nigritaeniatus*. Scale approximately 1:25 000 000

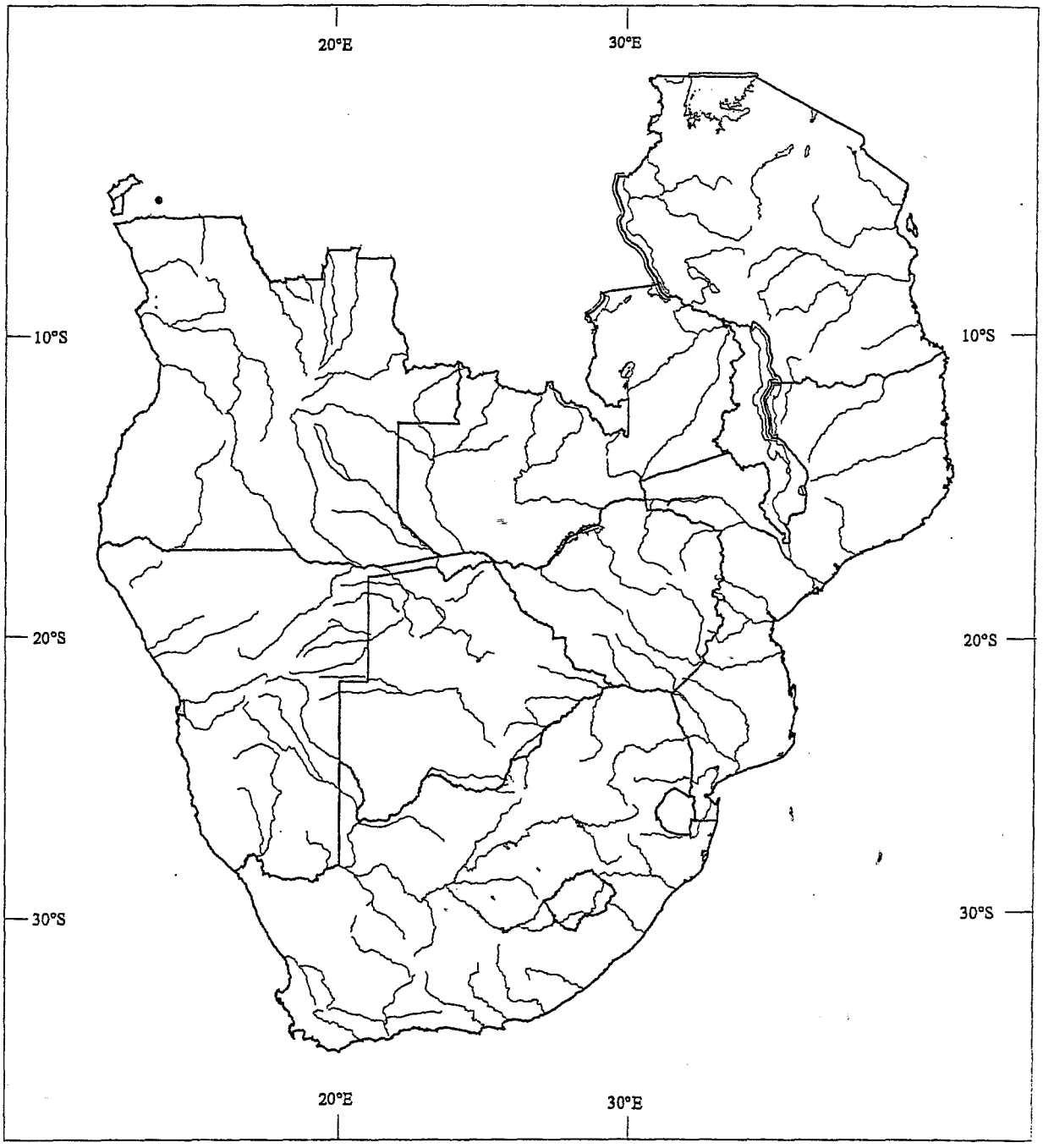


Figure F.504. Point distribution of *Odaxothrissa vittata*. Scale approximately 1:25 000 000

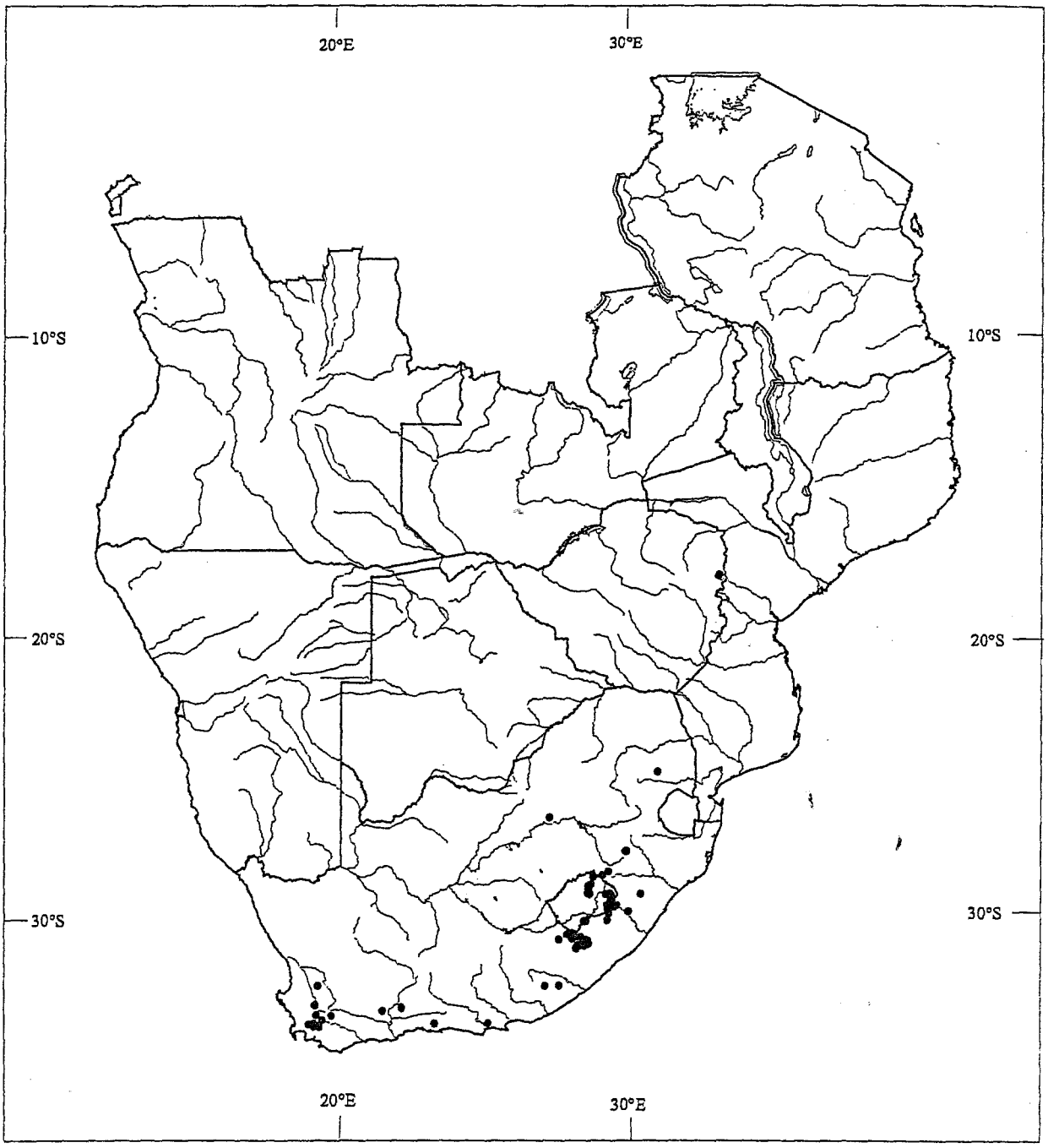


Figure F.505. Point distribution of *Oncorhynchus mykiss*. Scale approximately 1:25 000 000

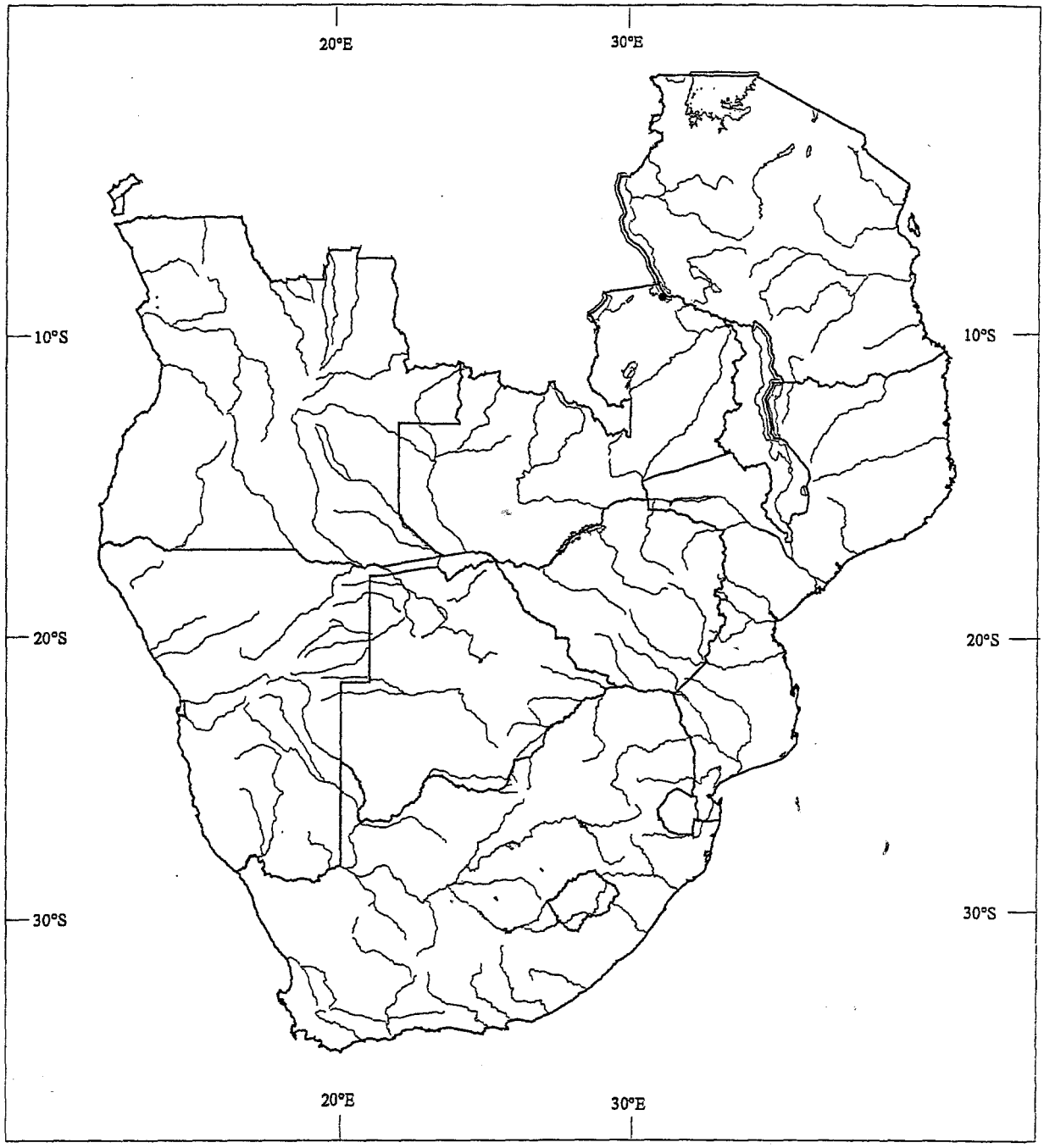


Figure F.506. Point distribution of *Ophthalmotilapia nasuta*. Scale approximately 1:25 000 000

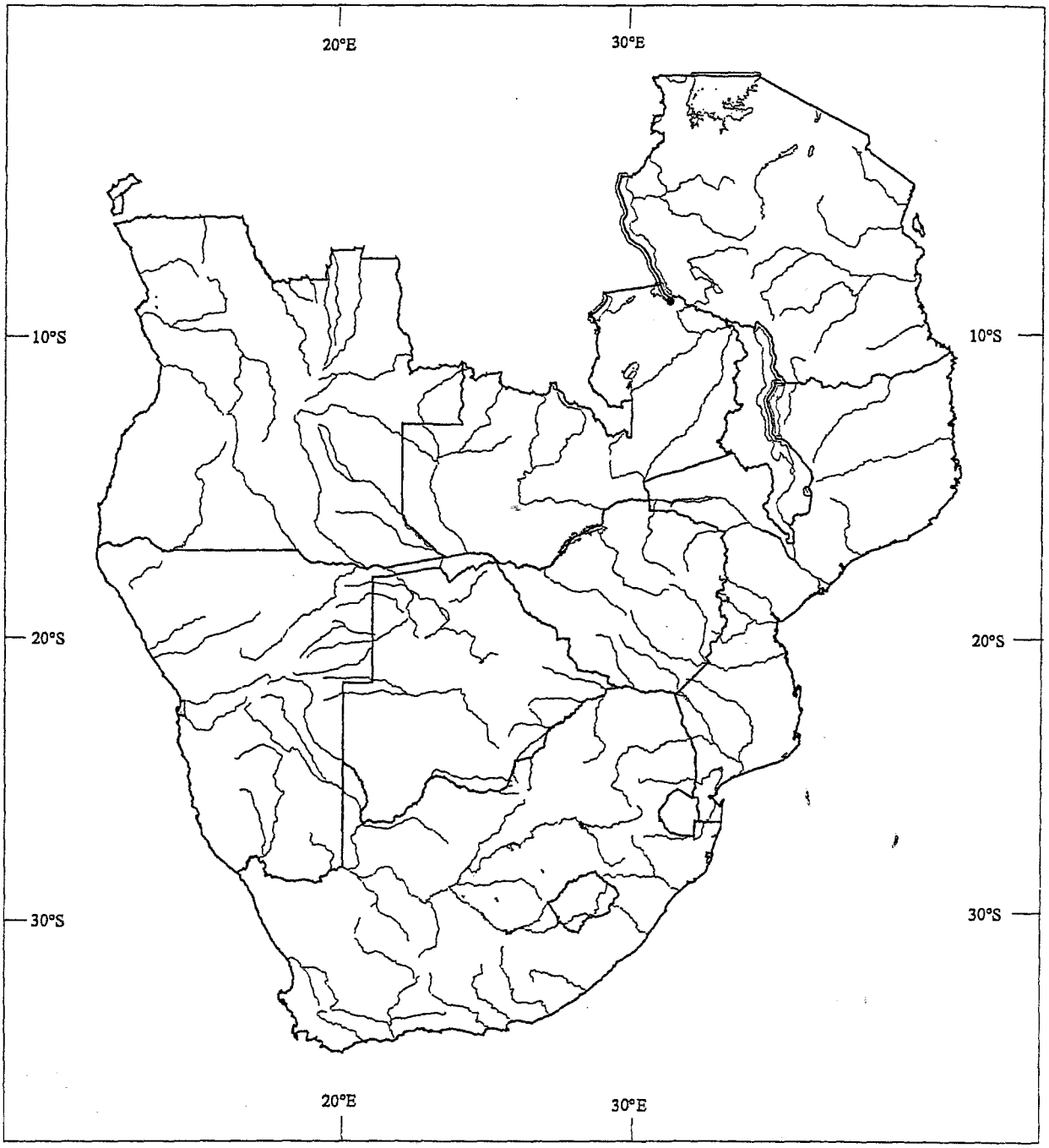


Figure F.507. Point distribution of *Ophthalmotilapia ventralis*. Scale approximately 1:25 000 000

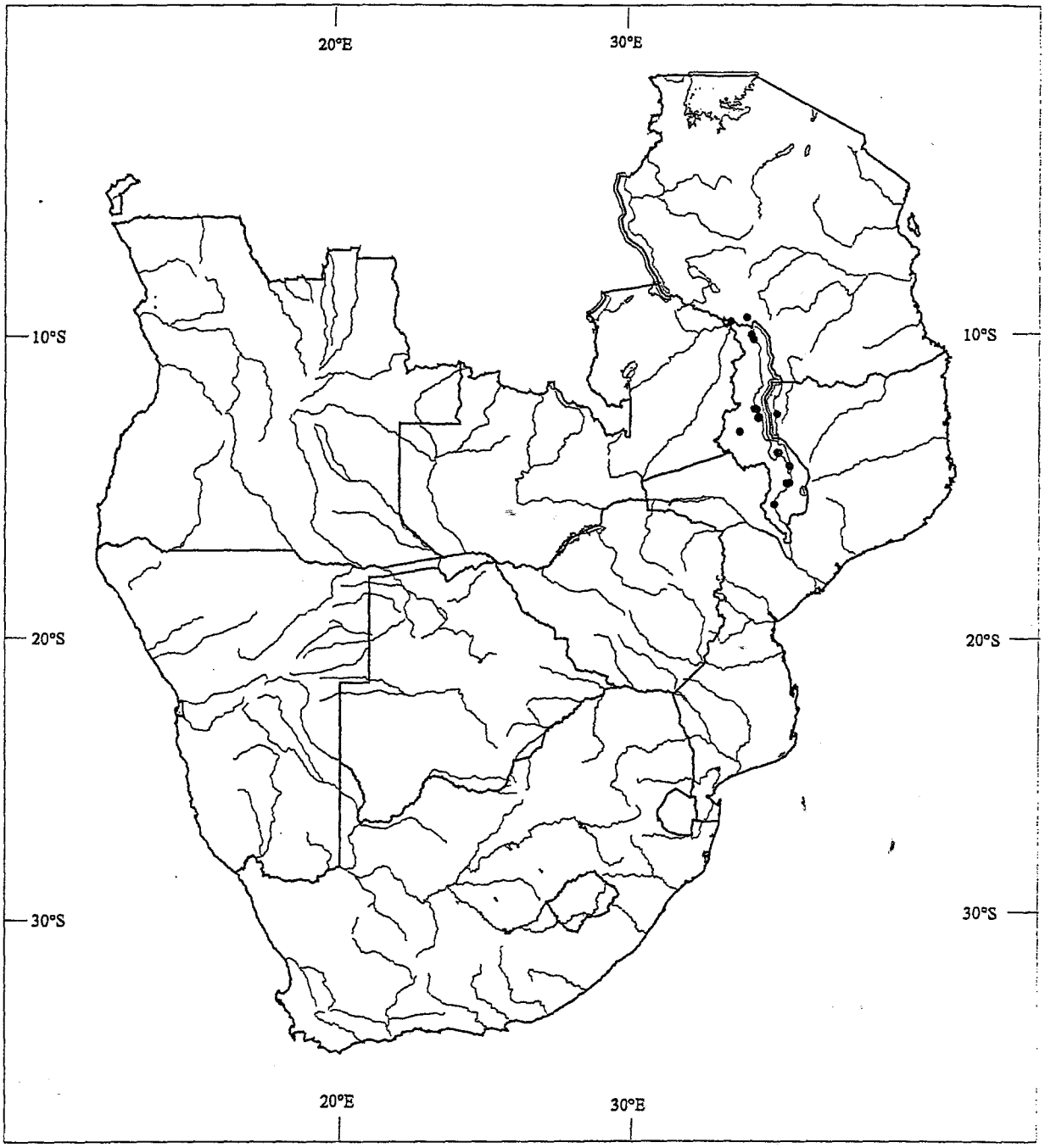


Figure F.508. Point distribution of *Opsaridium microcephalus*. Scale approximately 1:25 000 000

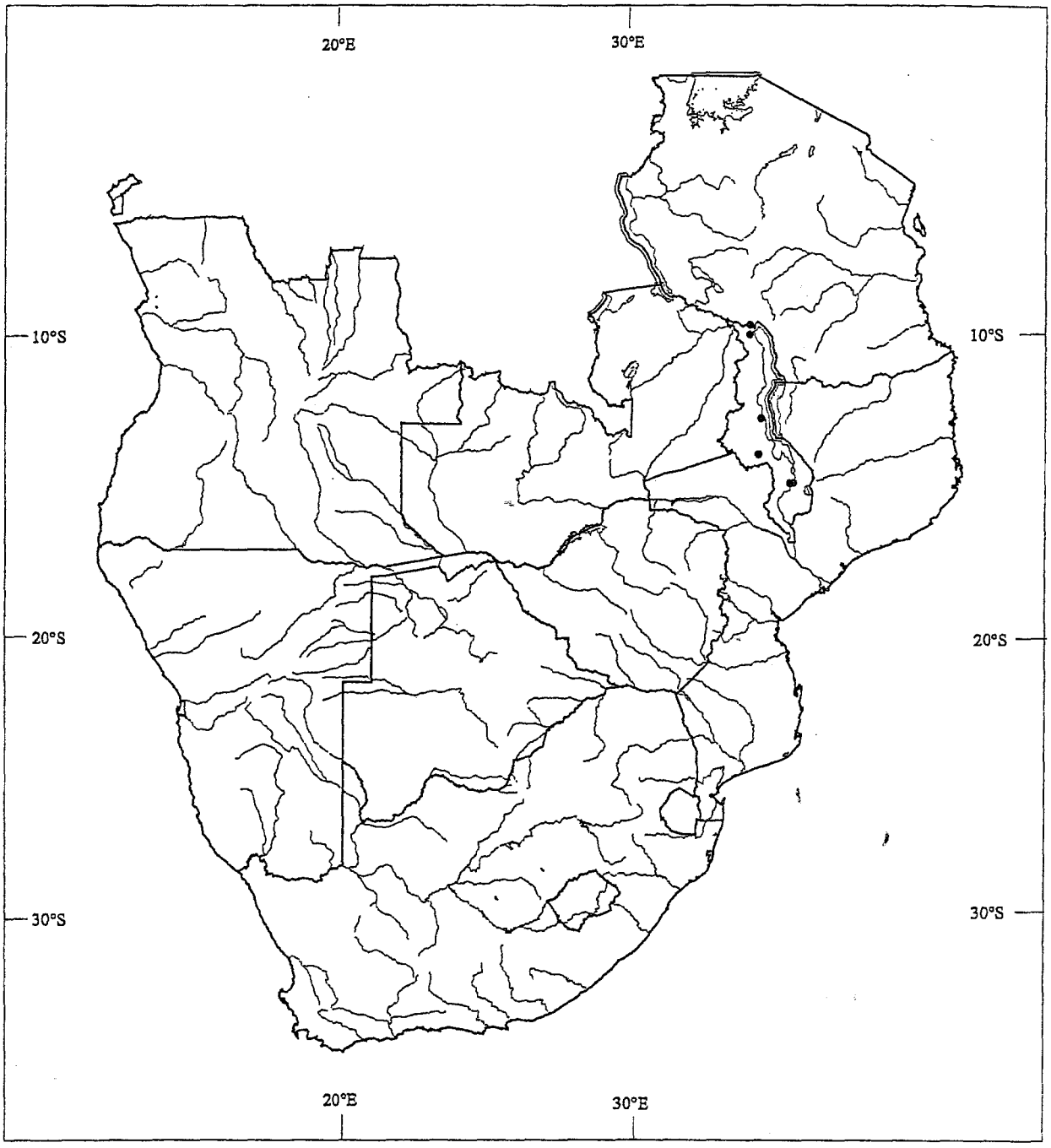


Figure F.509. Point distribution of *Opsaridium microlepis*. Scale approximately 1:25 000 000

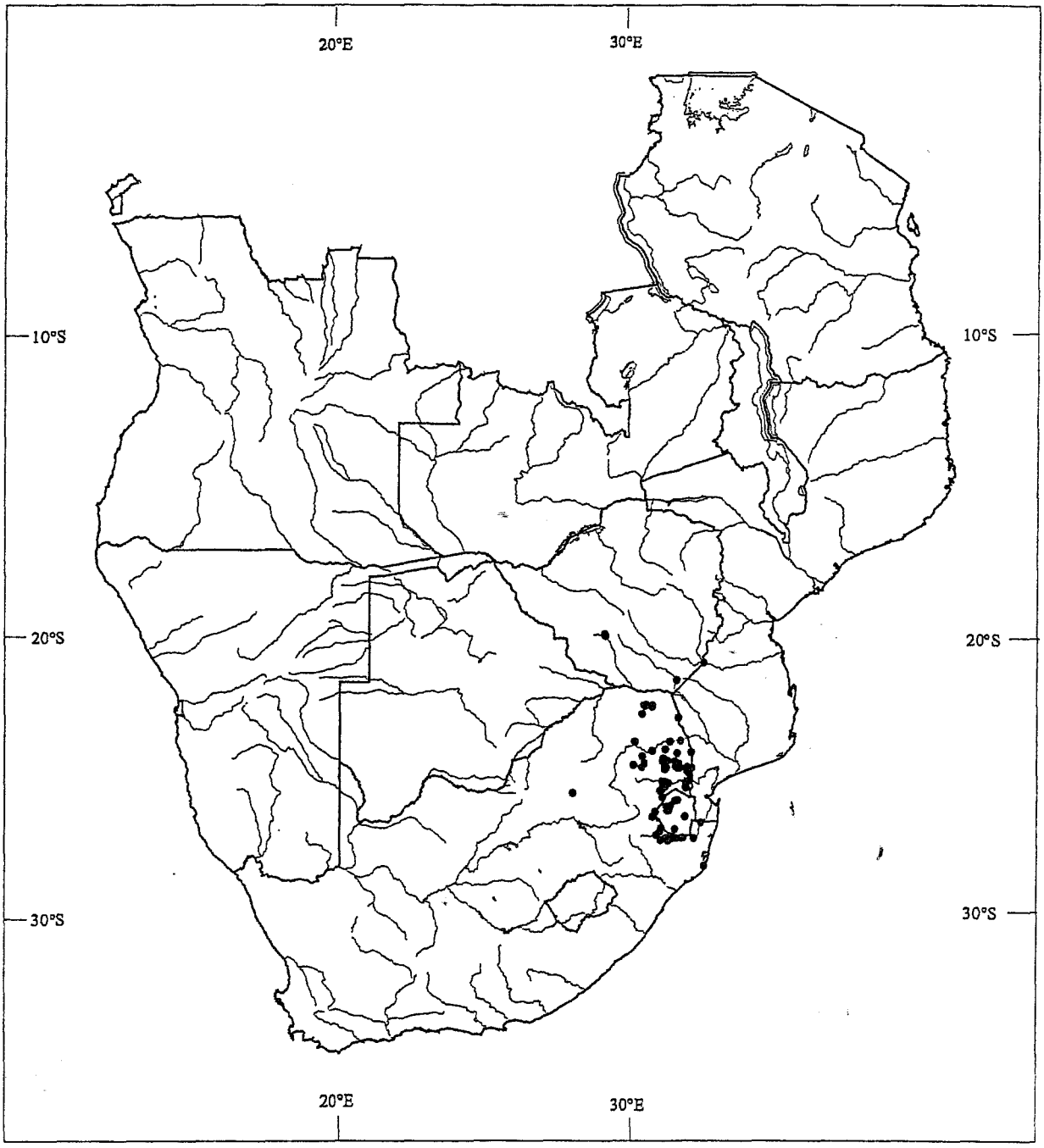


Figure F.510. Point distribution of *Opsaridium peringueyi*. Scale approximately 1:25 000 000

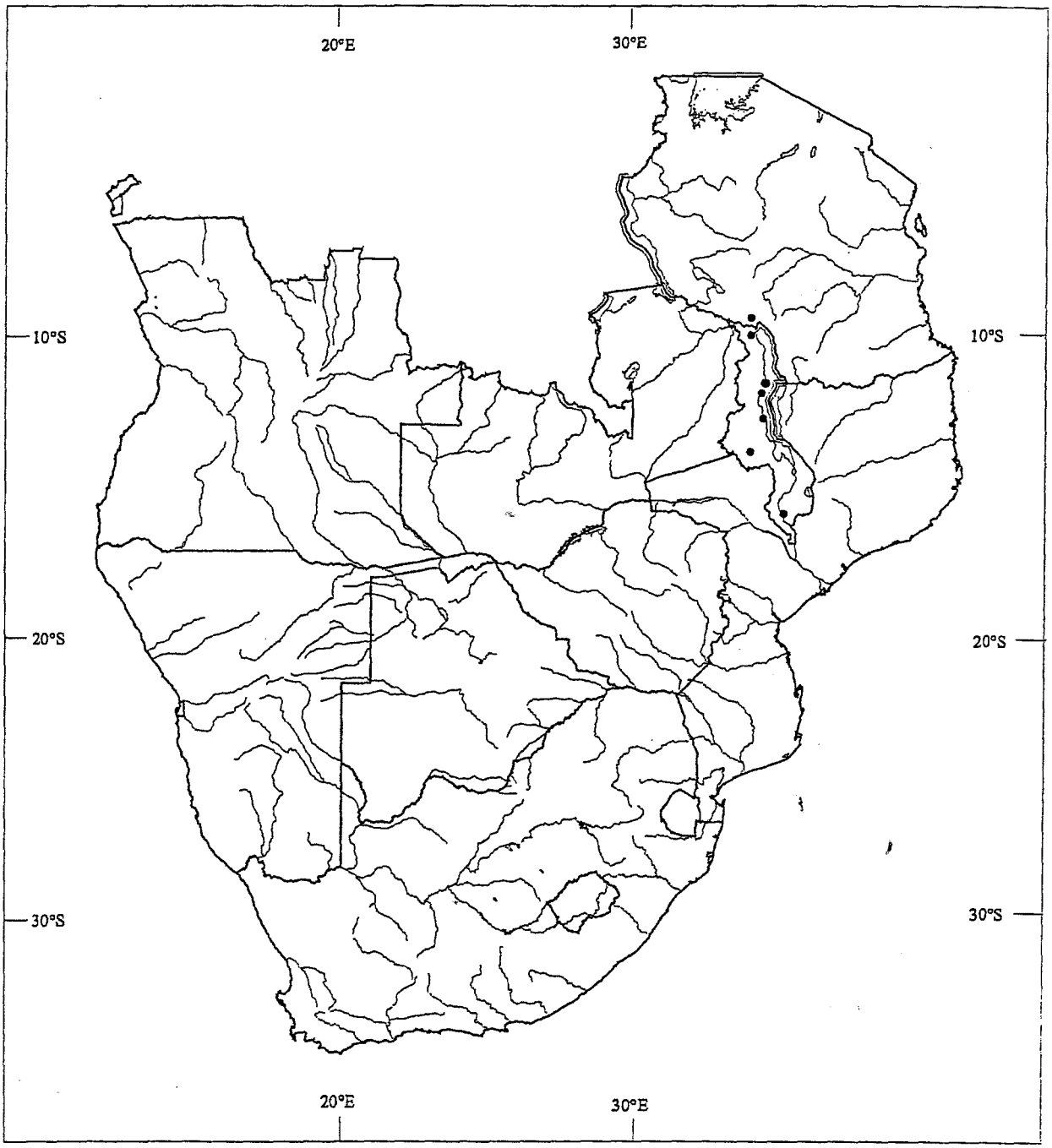


Figure F.511. Point distribution of *Opsaridium tweddleorum*. Scale approximately 1:25 000 000

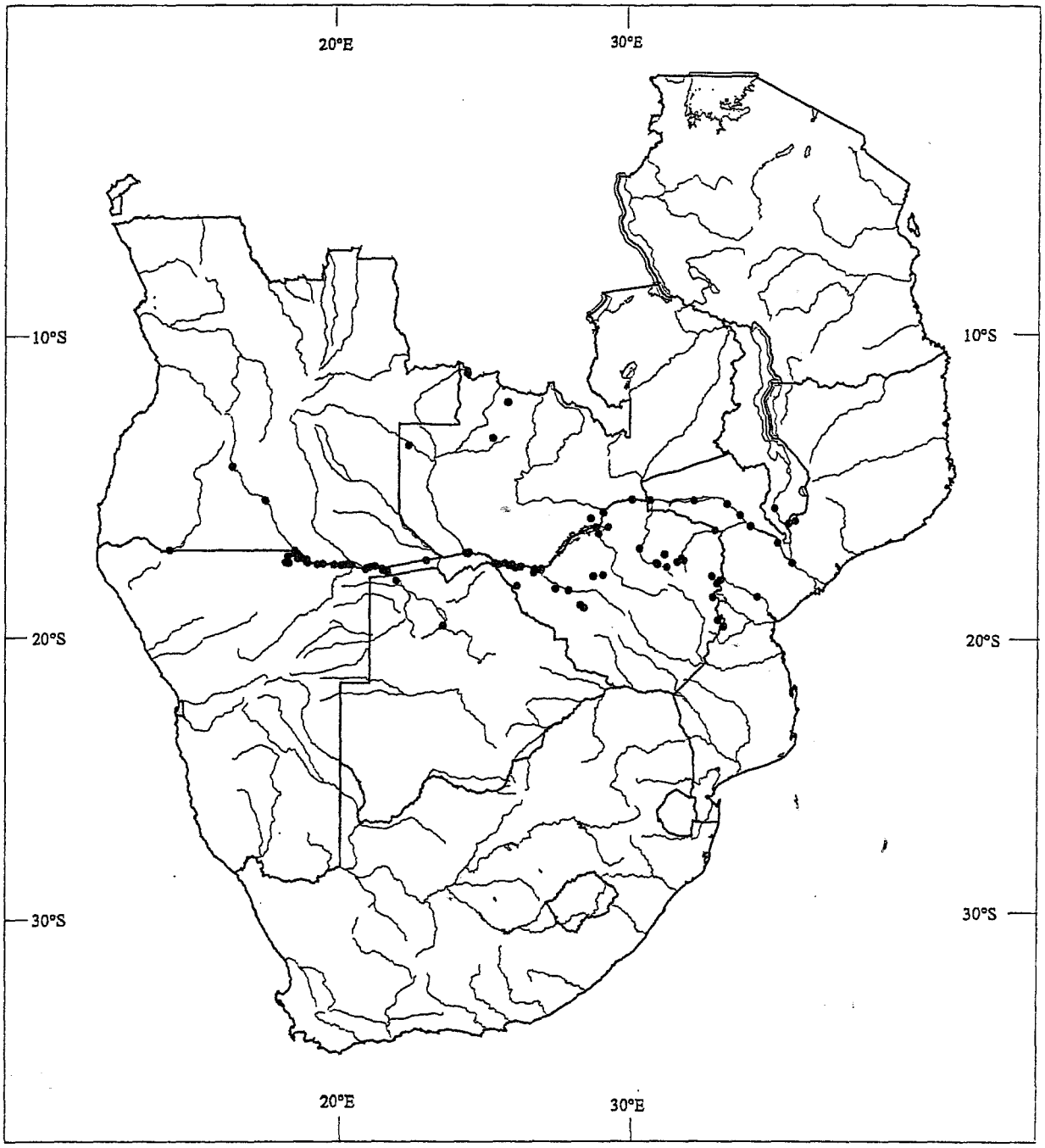


Figure F.512. Point distribution of *Opsaridium zambezense*. Scale approximately 1:25 000 000

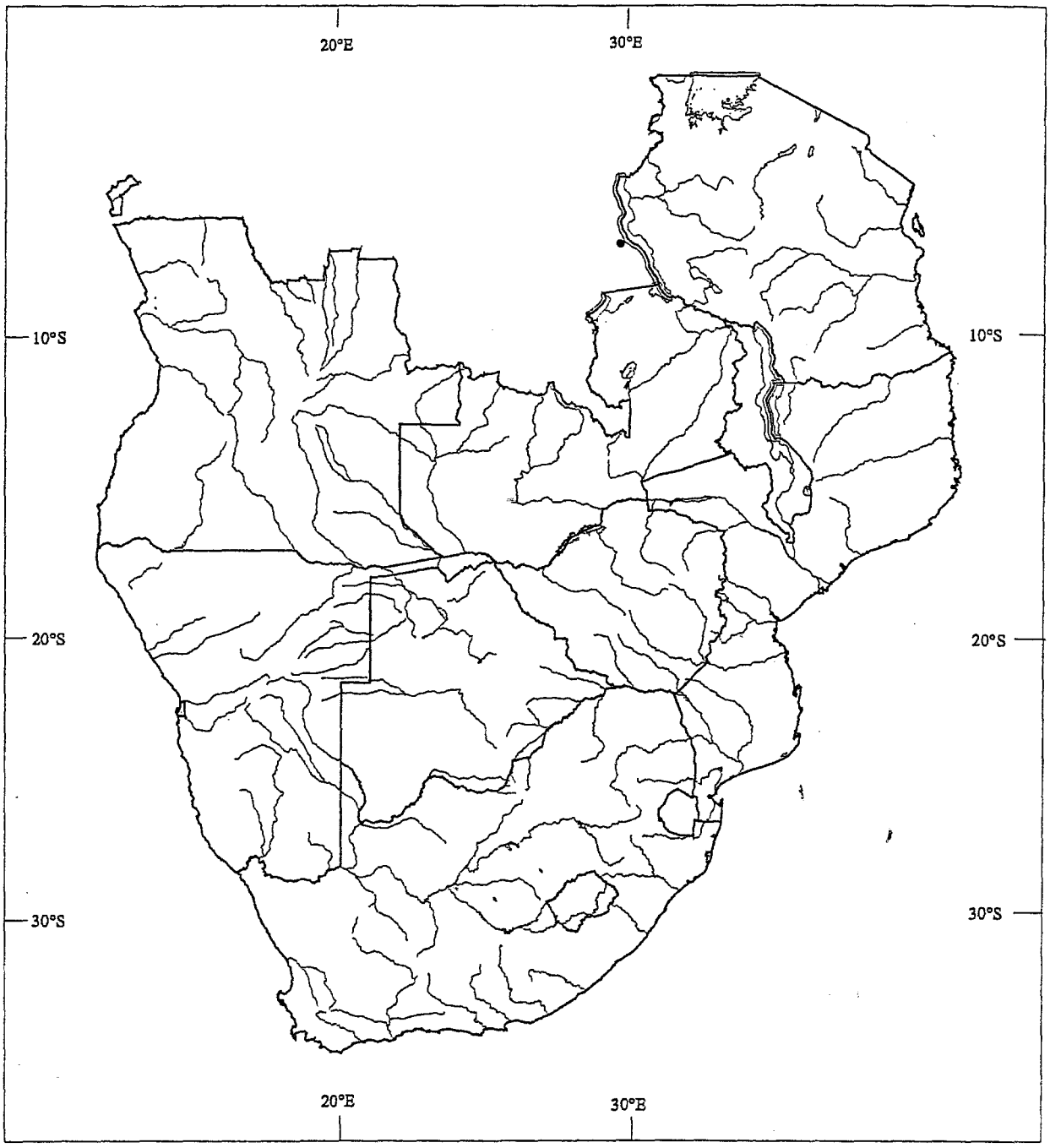


Figure F.513. Point distribution of *Opthalmochromis ventralis*. Scale approximately 1:25 000 000

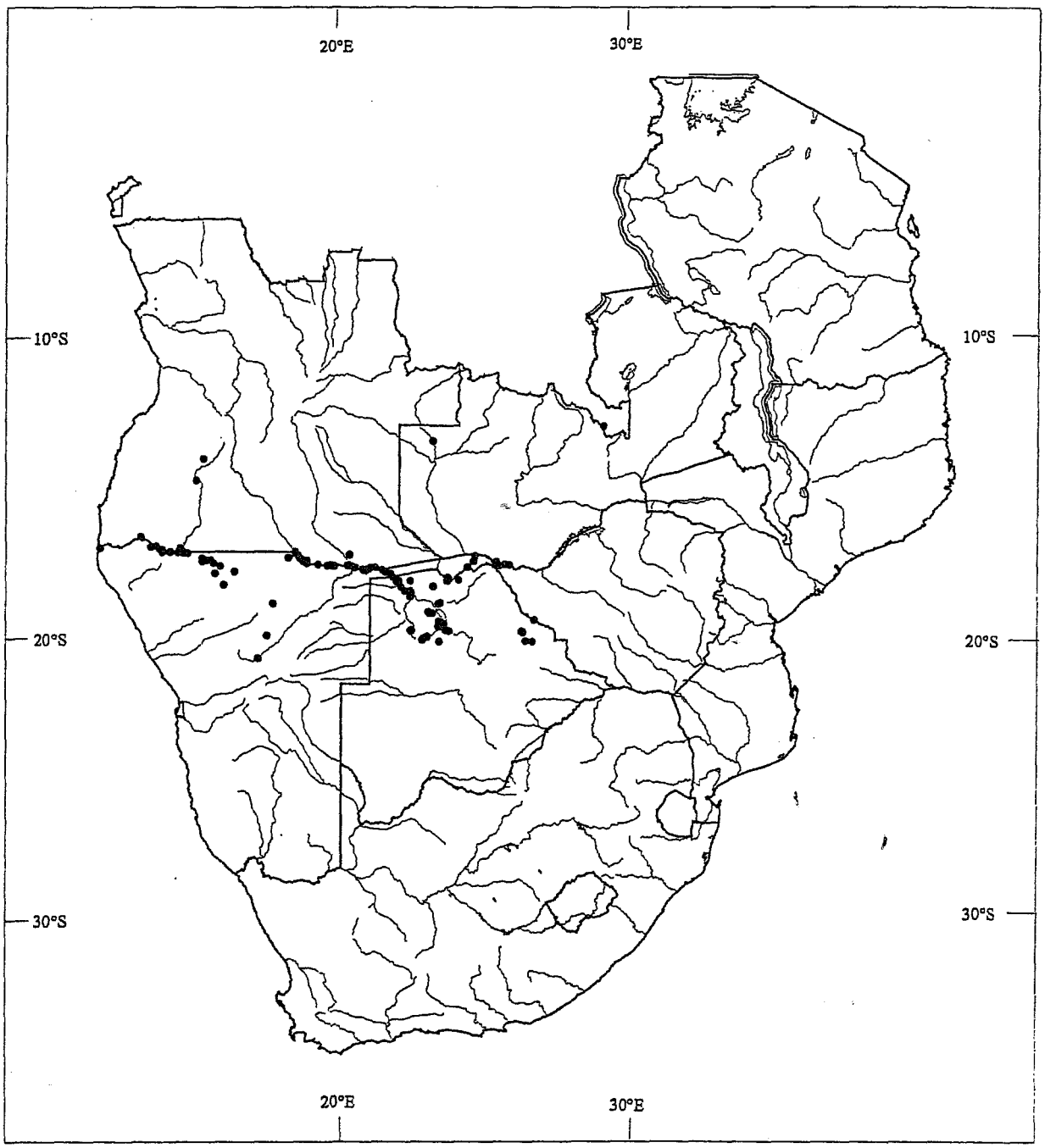


Figure F.514. Point distribution of *Oreochromis andersonii*. Scale approximately 1:25 000 000

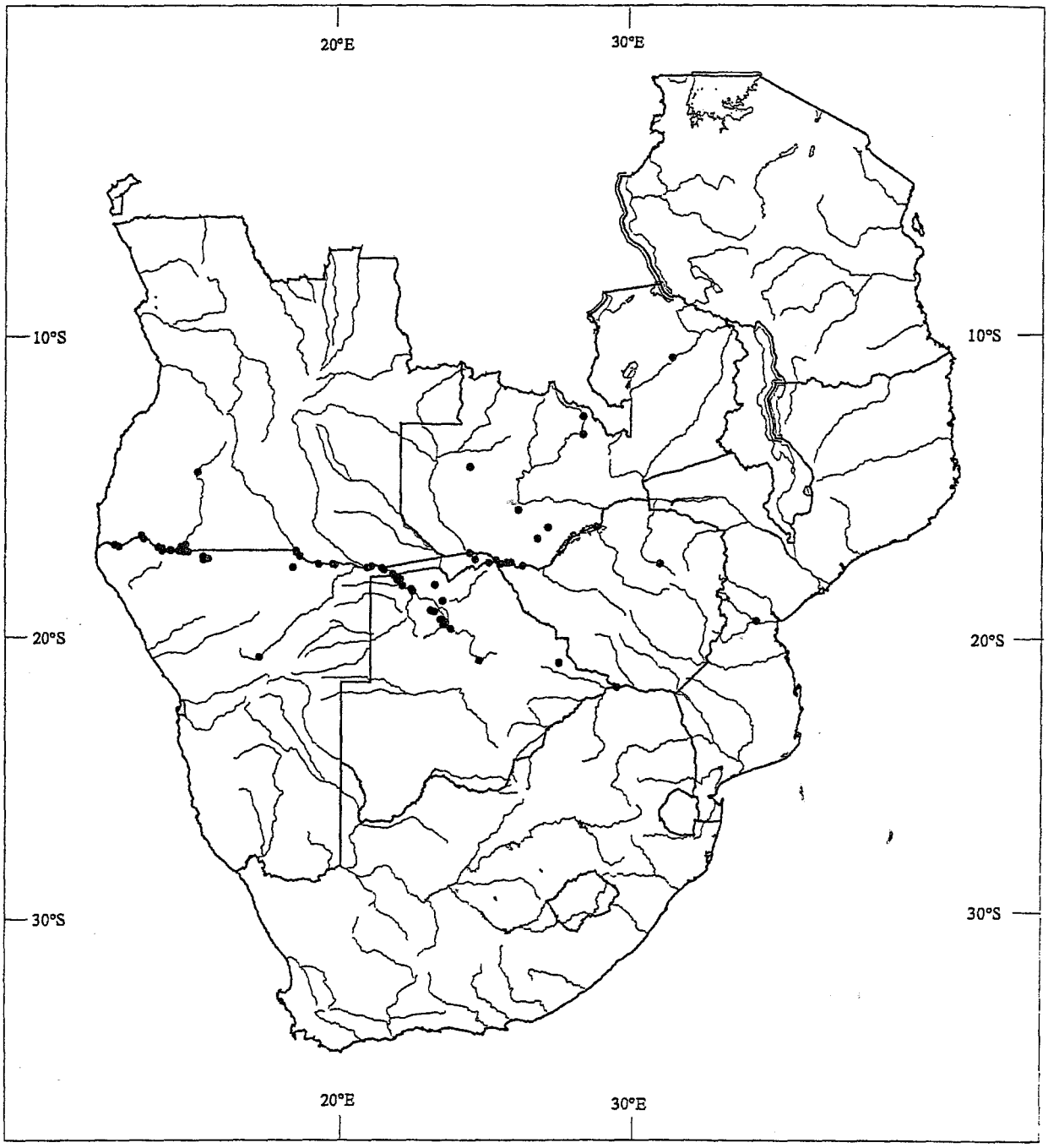


Figure F.515. Point distribution of *Oreochromis macrochir*. Scale approximately 1:25 000 000

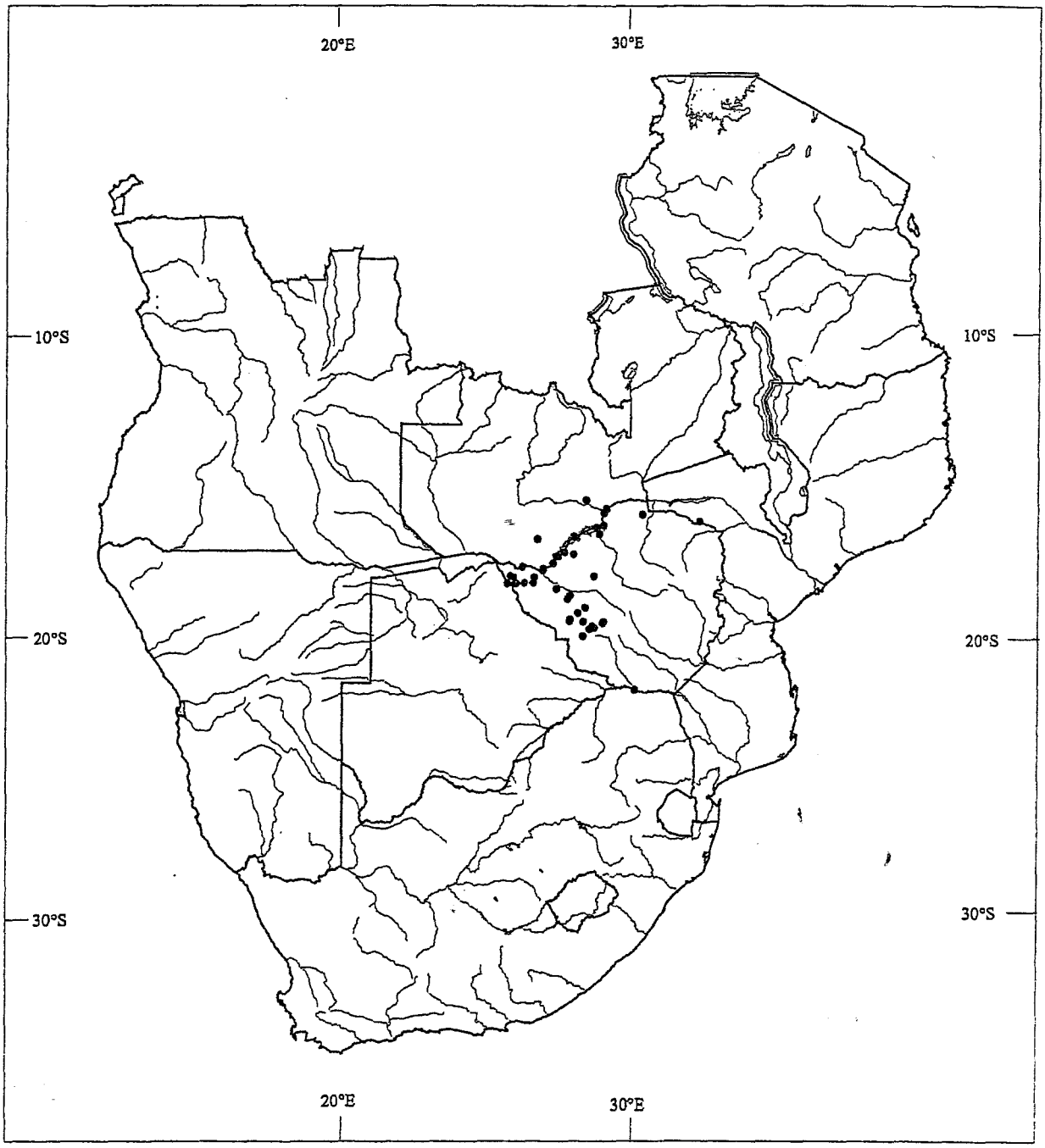


Figure F.516. Point distribution of *Oreochromis mortimeri*. Scale approximately 1:25 000 000

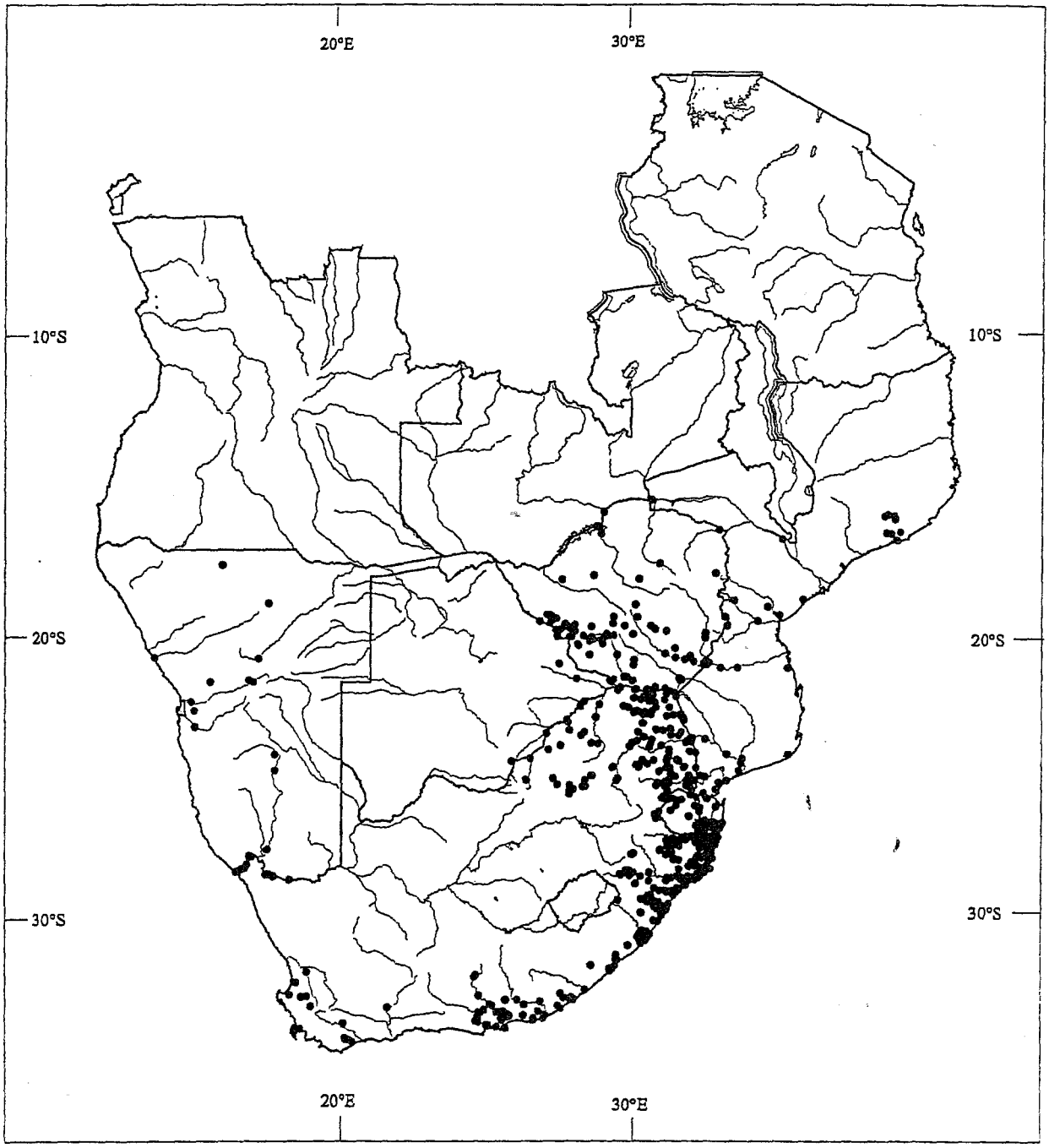


Figure F.517. Point distribution of *Oreochromis mossambicus*. Scale approximately 1:25 000 000

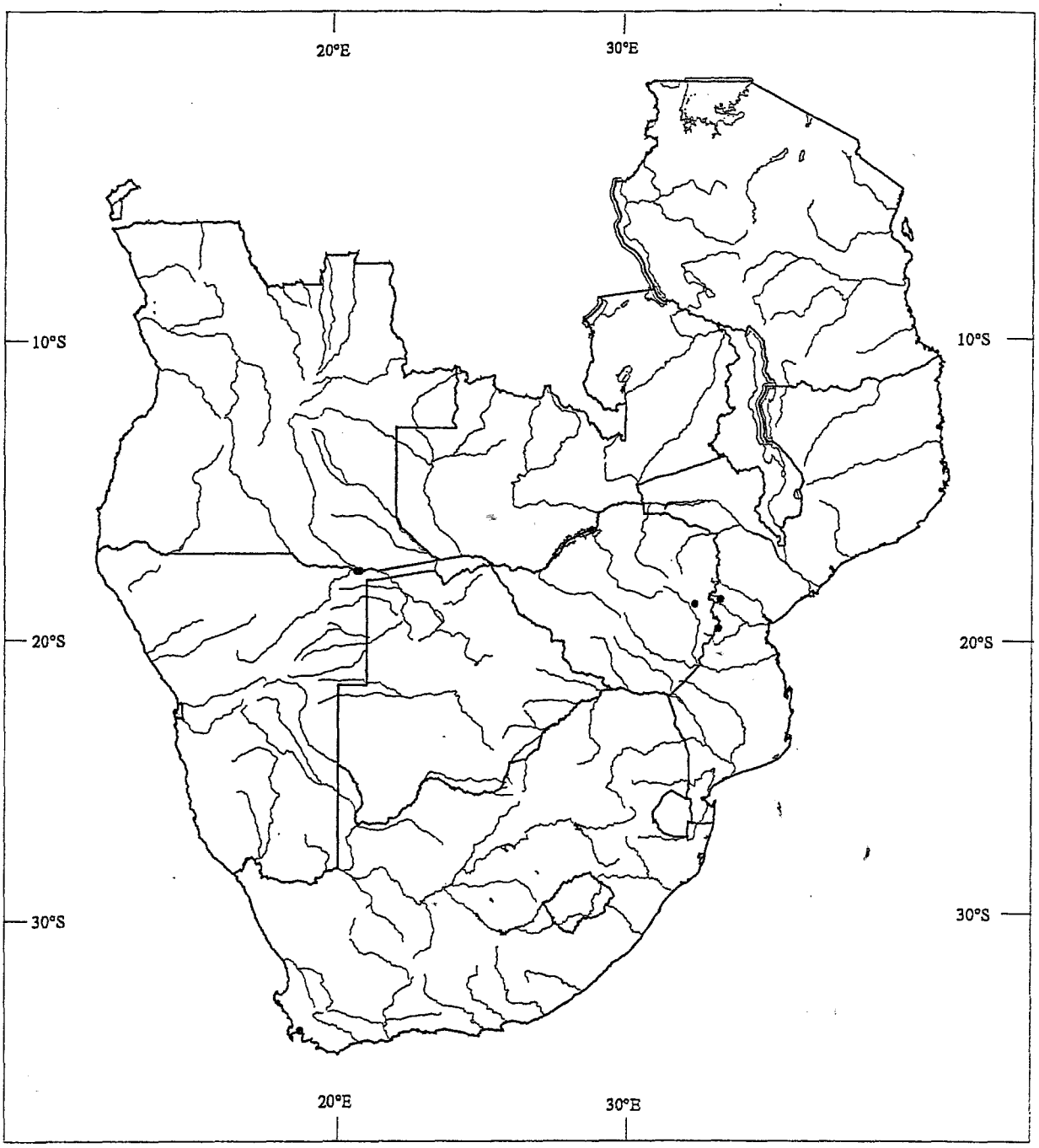


Figure F.518. Point distribution of *Oreochromis niloticus*. Scale approximately 1:25 000 000

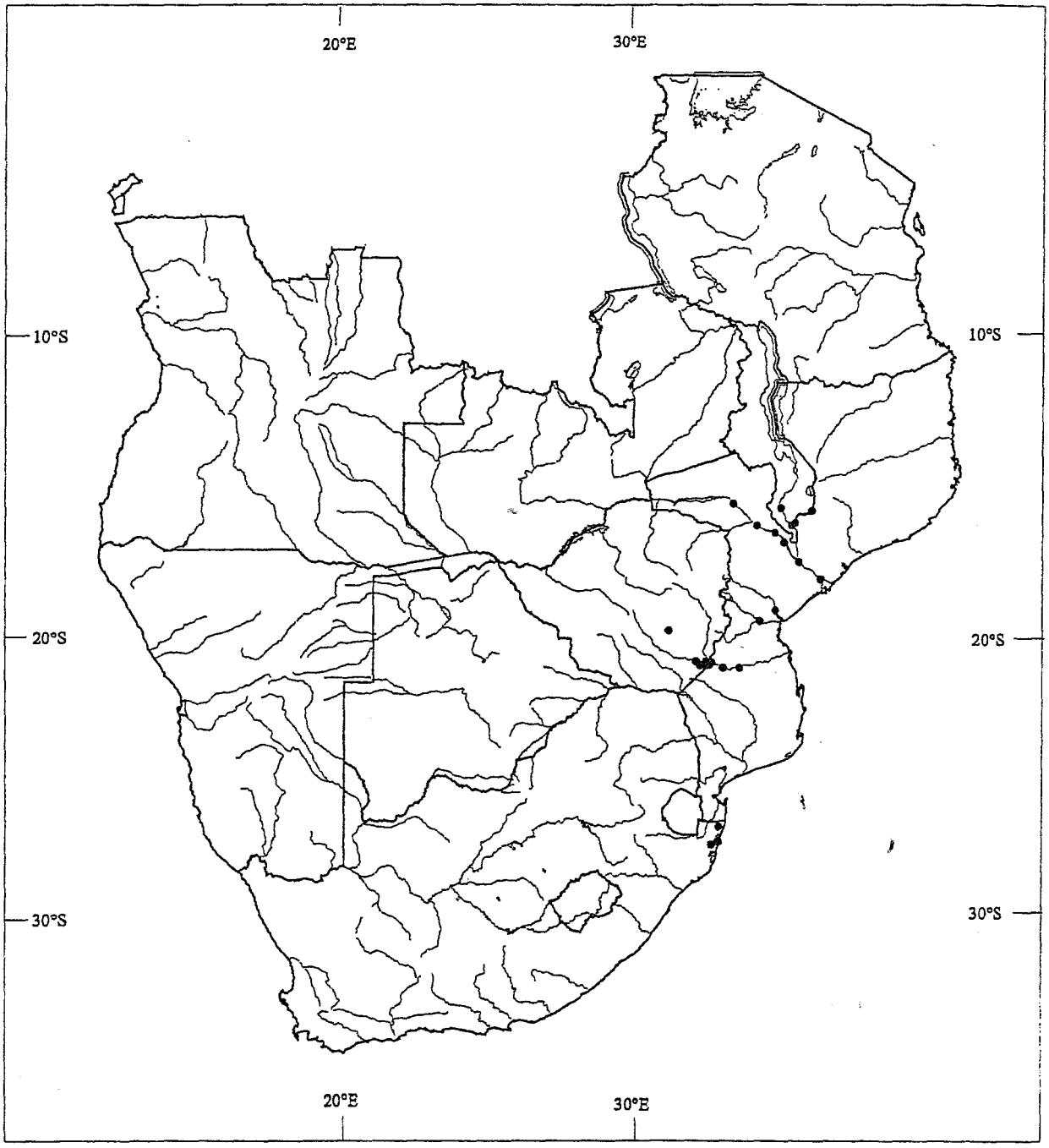


Figure F.519. Point distribution of *Oreochromis placidus*. Scale approximately 1:25 000 000

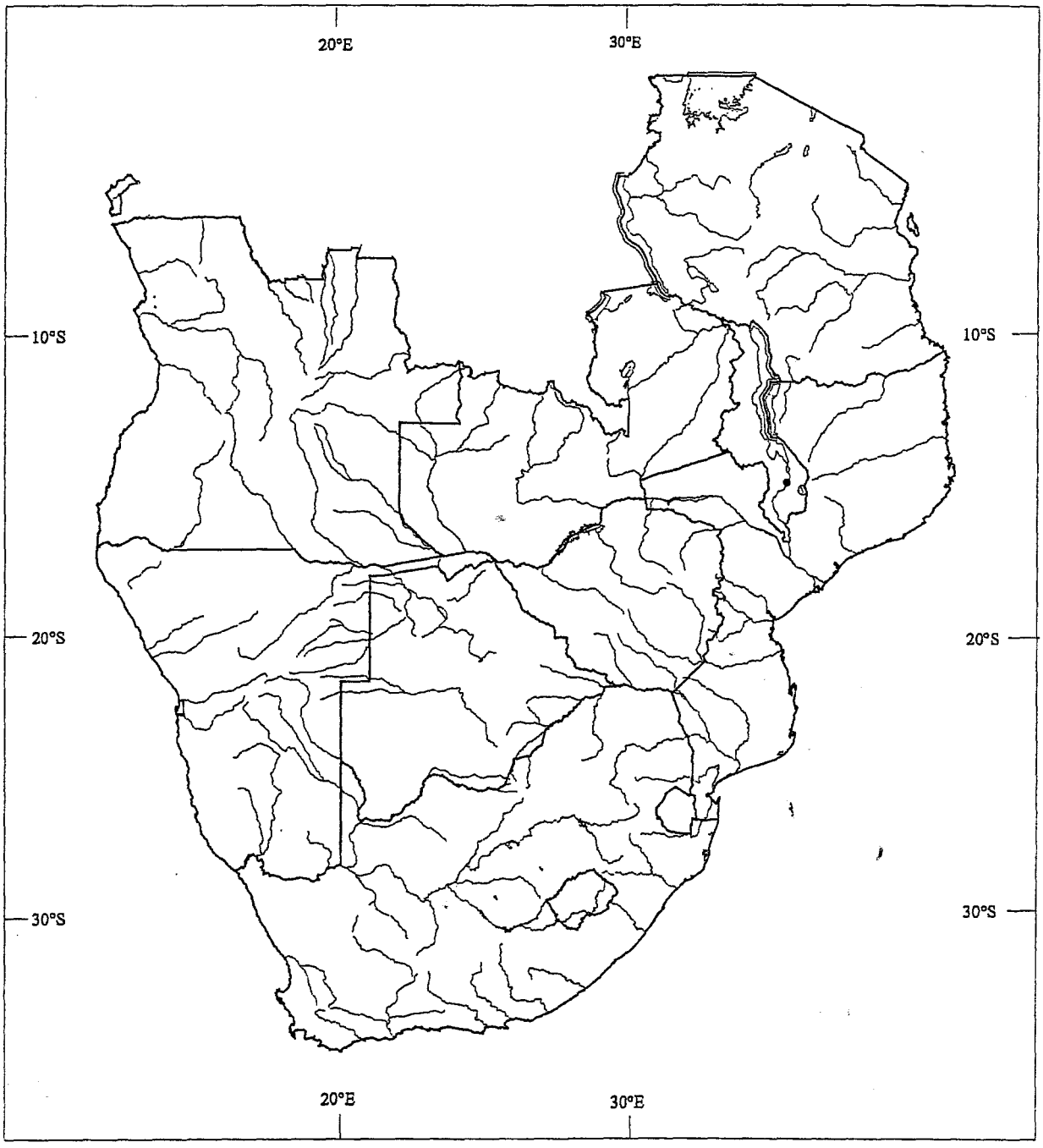


Figure F.520. Point distribution of *Oreochromis saka*. Scale approximately 1:25 000 000

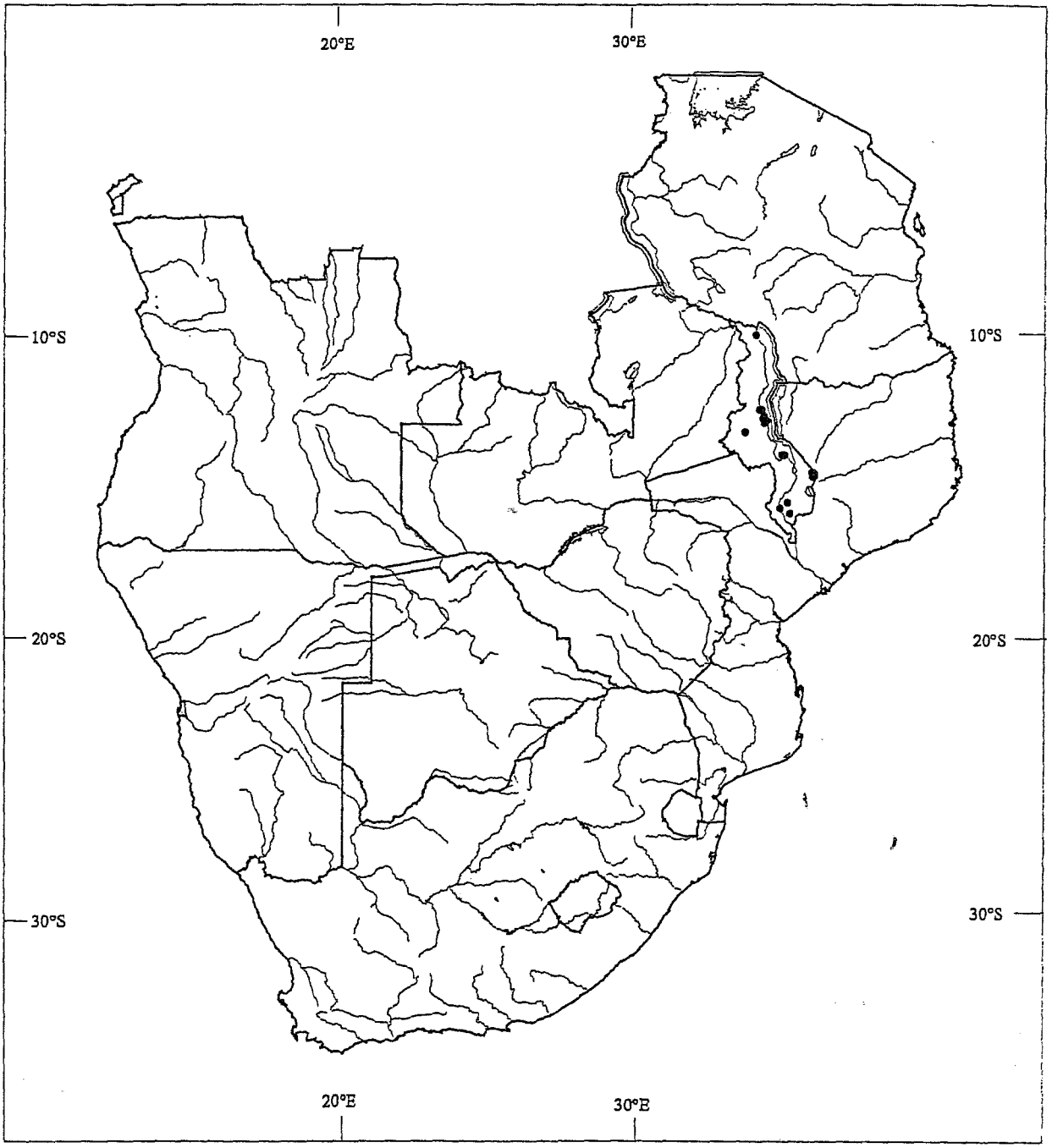


Figure F.521. Point distribution of *Oreochromis shiranus*. Scale approximately 1:25 000 000

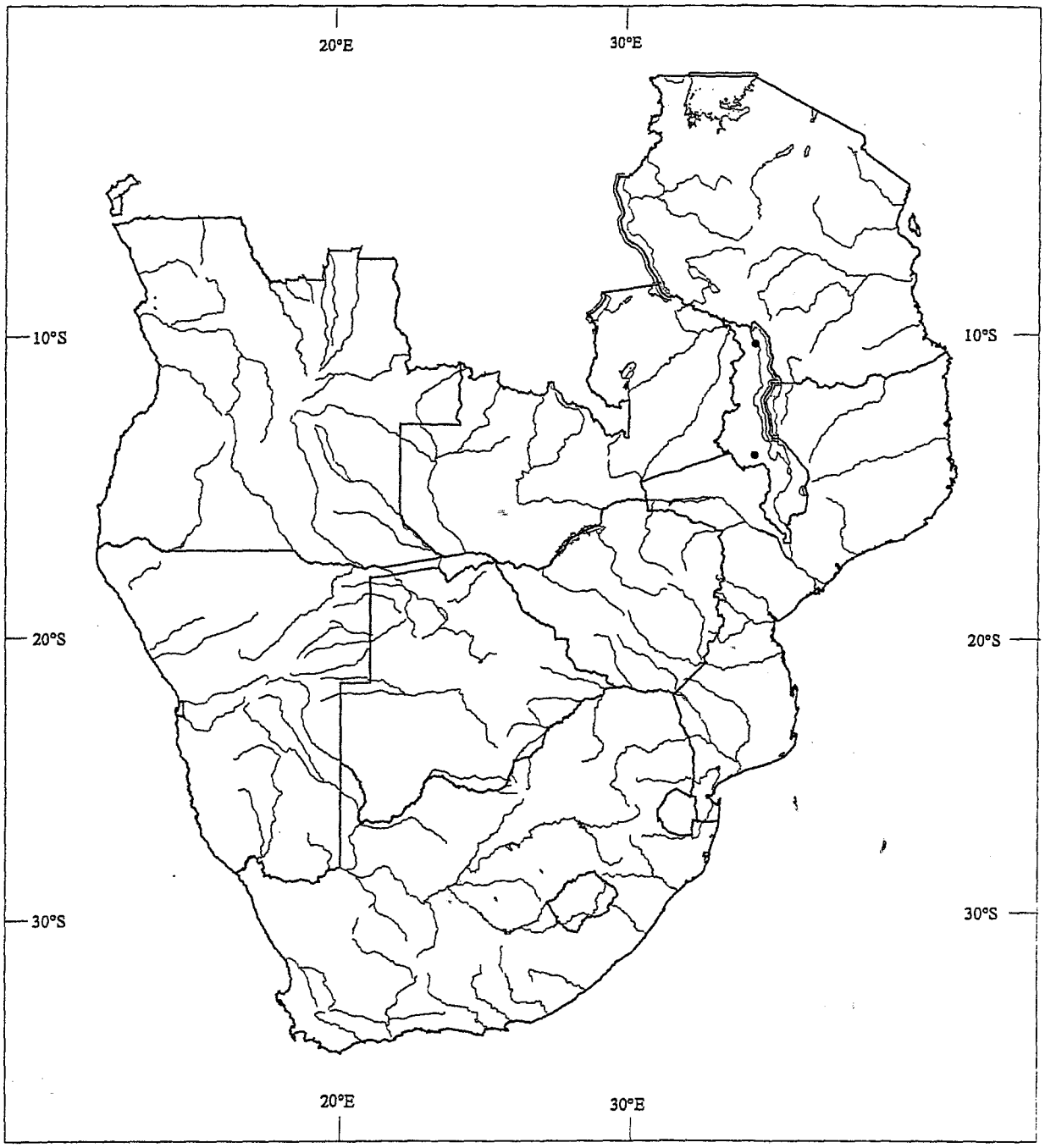


Figure F.522. Point distribution of *Oreochromis squamipinnis*. Scale approximately 1:25 000 000

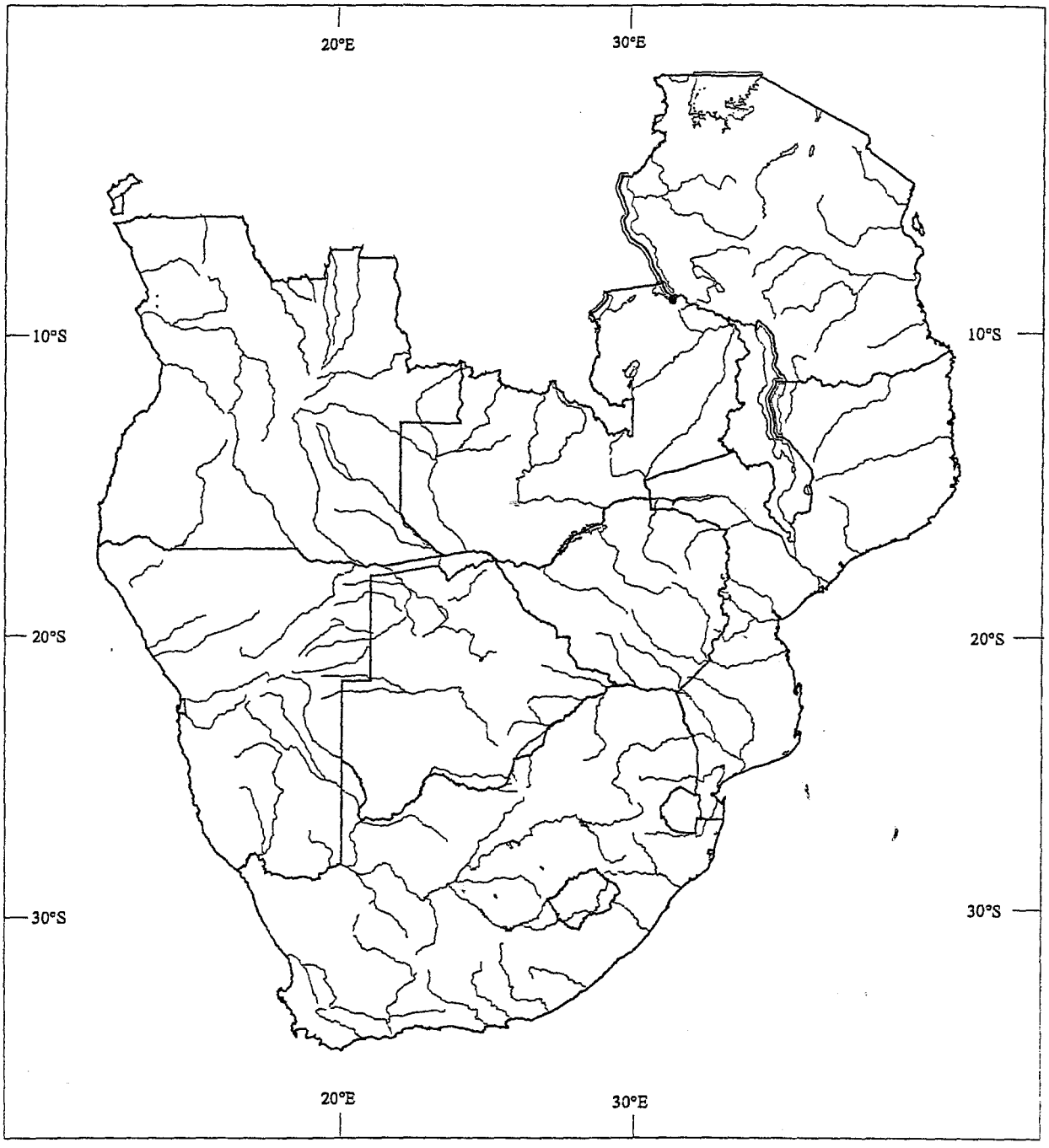


Figure F.523. Point distribution of *Oreochromis tanganyicae*. Scale approximately 1:25 000 000

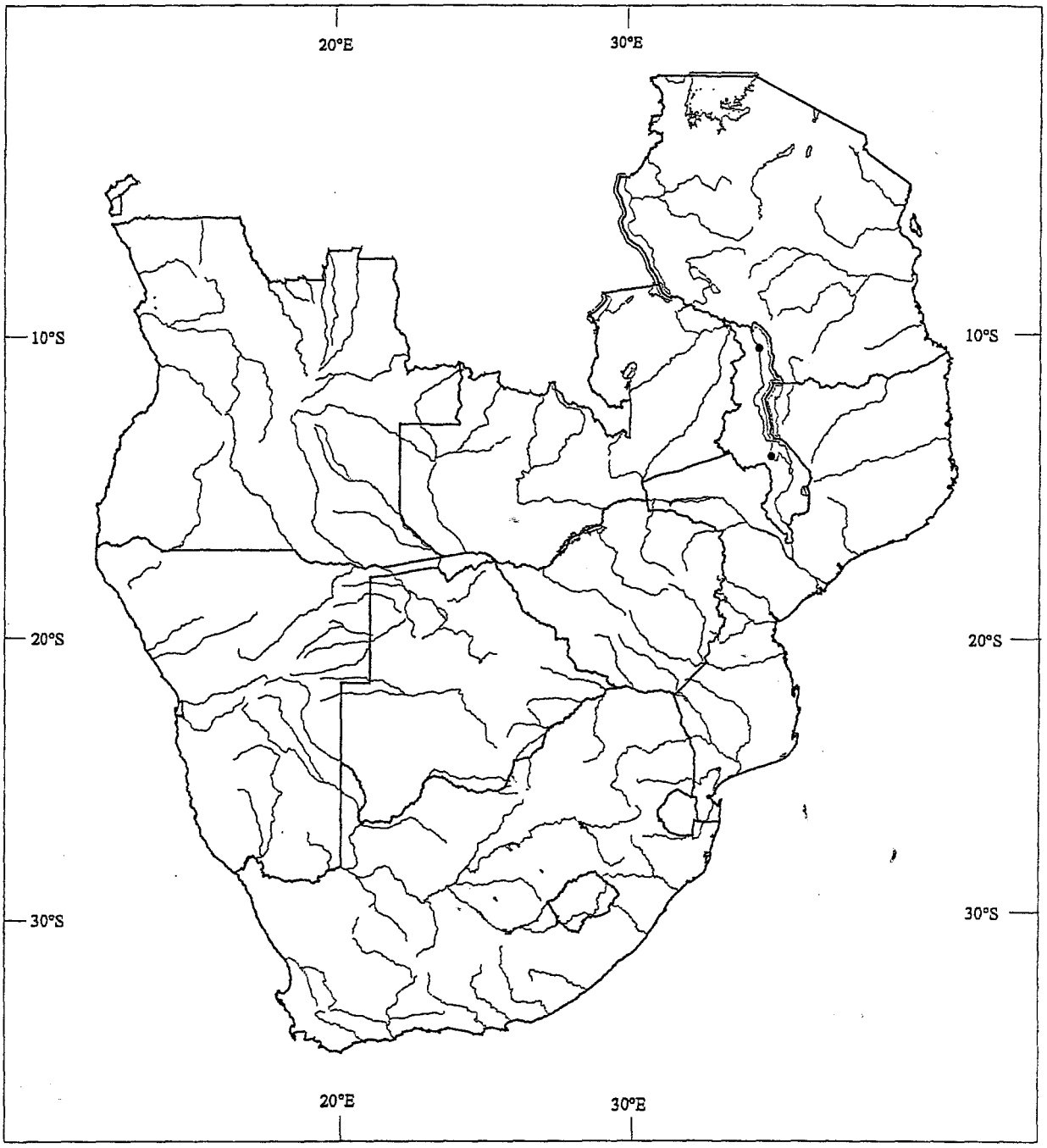


Figure F.524. Point distribution of *Otopharynx argyrosoma*. Scale approximately 1:25 000 000

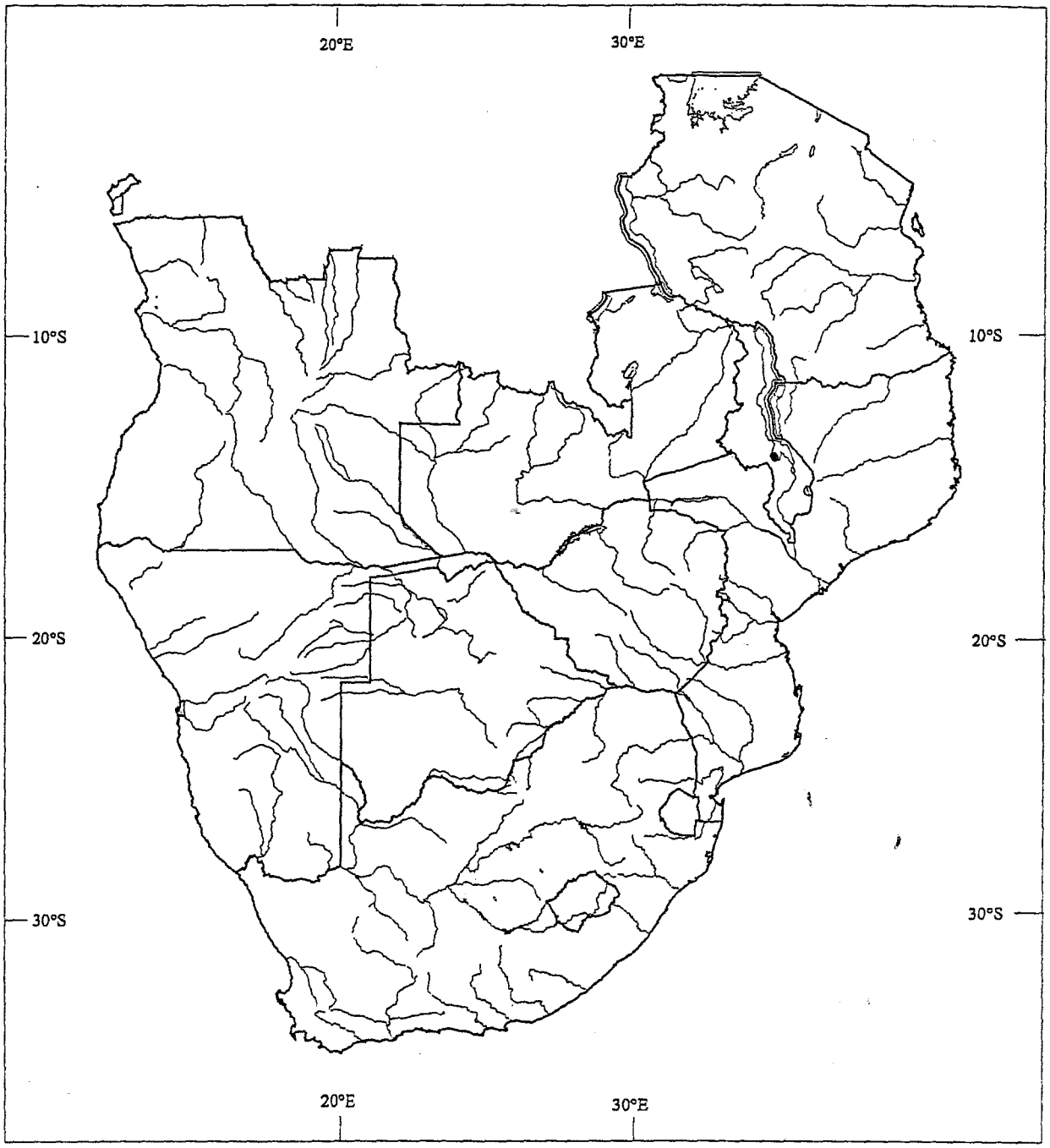


Figure F.525. Point distribution of *Otopharynx auromarginatus*. Scale approximately 1:25 000 000

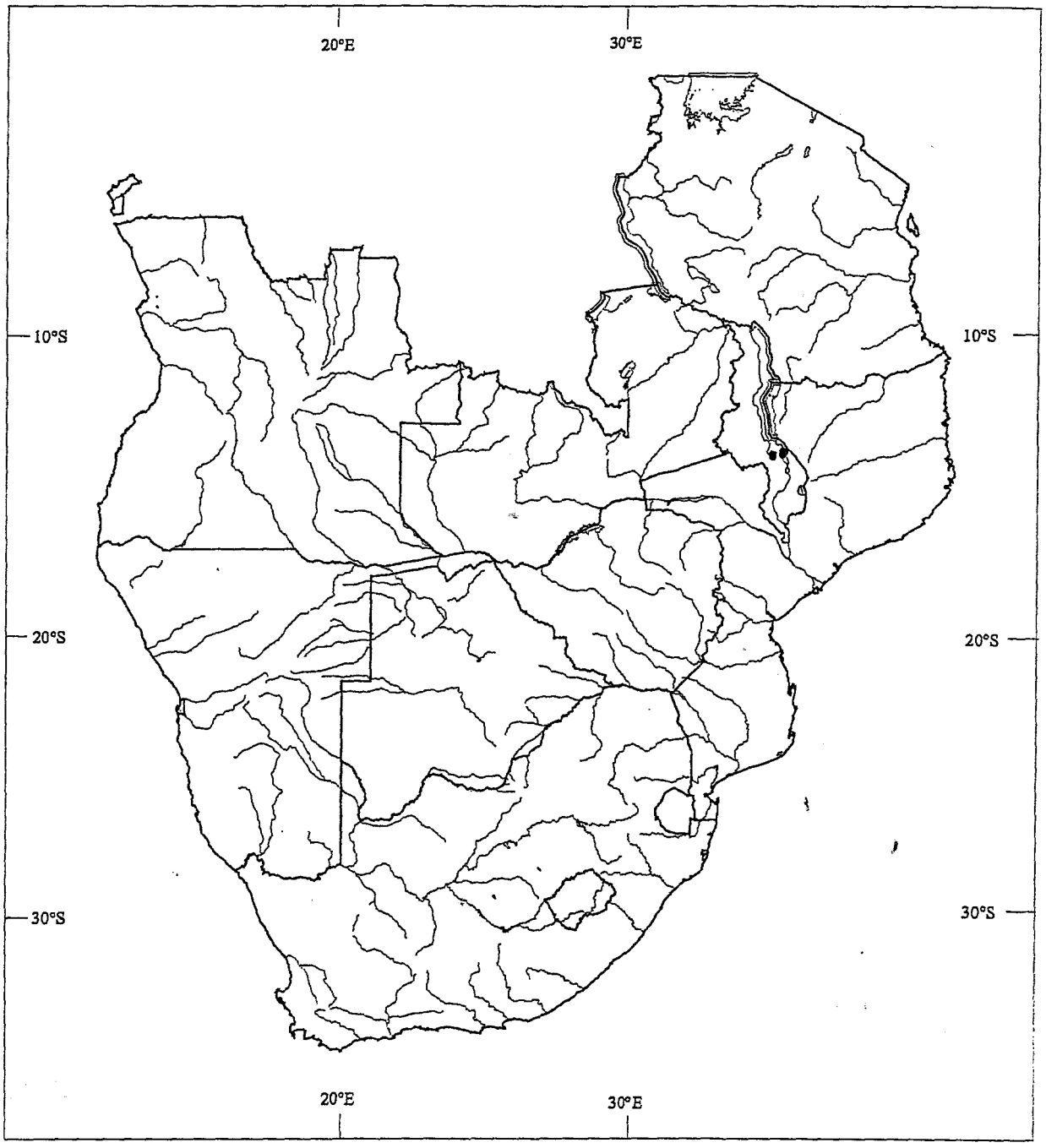


Figure F.526. Point distribution of *Otopharynx brooksi*. Scale approximately 1:25 000 000

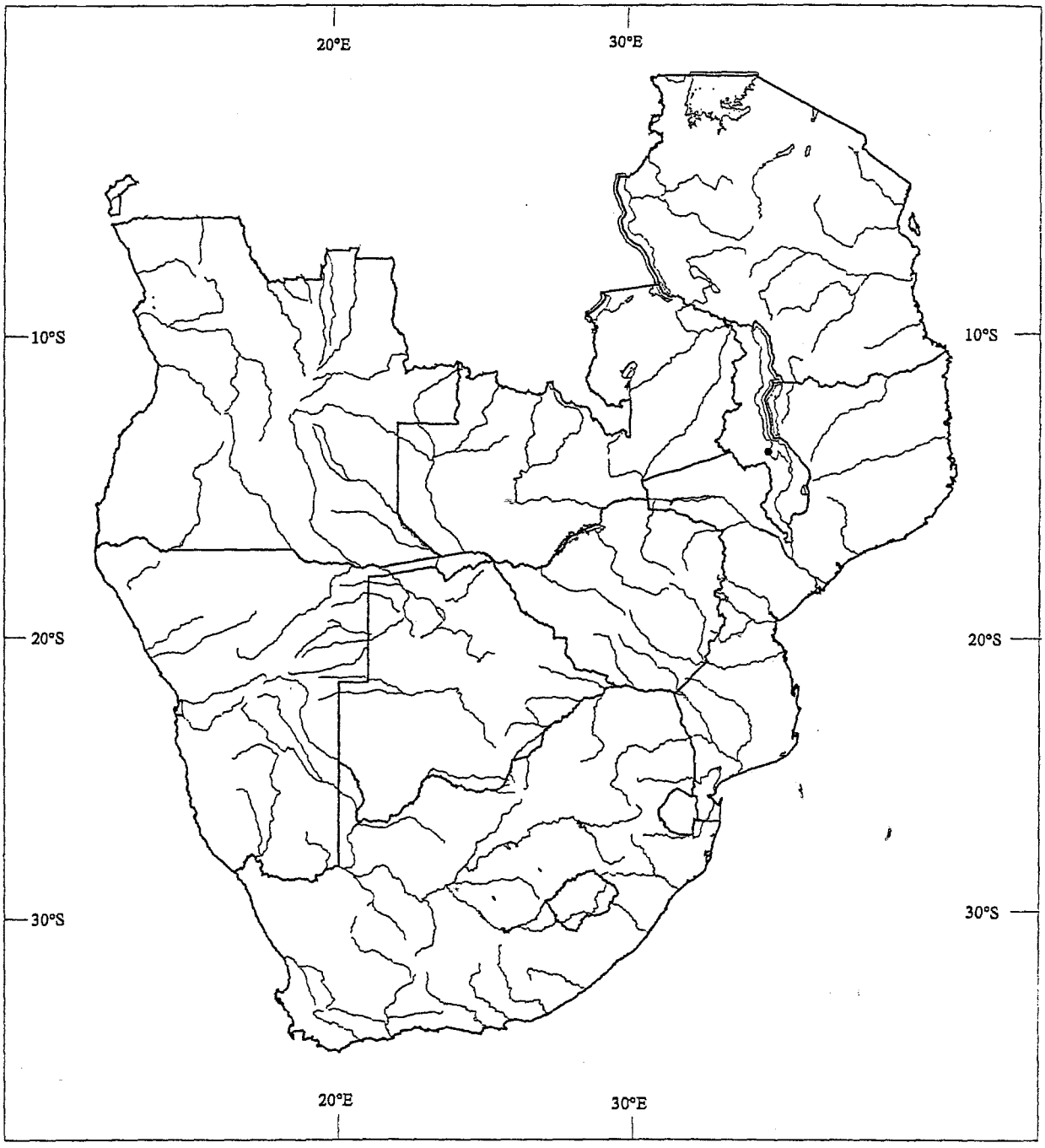


Figure F.527. Point distribution of *Otopharynx decorus*. Scale approximately 1:25 000 000

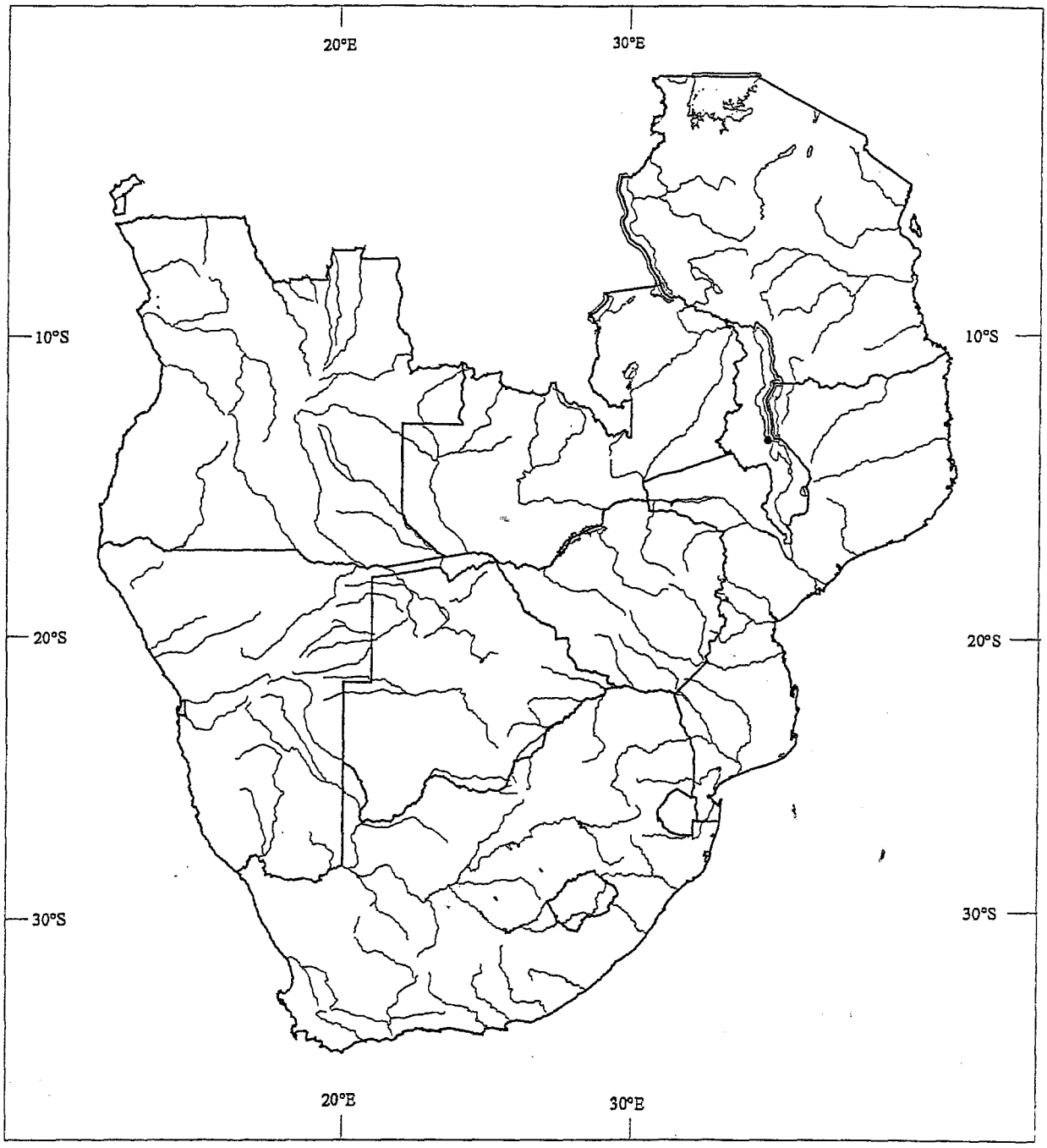


Figure F.528. Point distribution of *Otopharynx heterodon*. Scale approximately 1:25 000 000

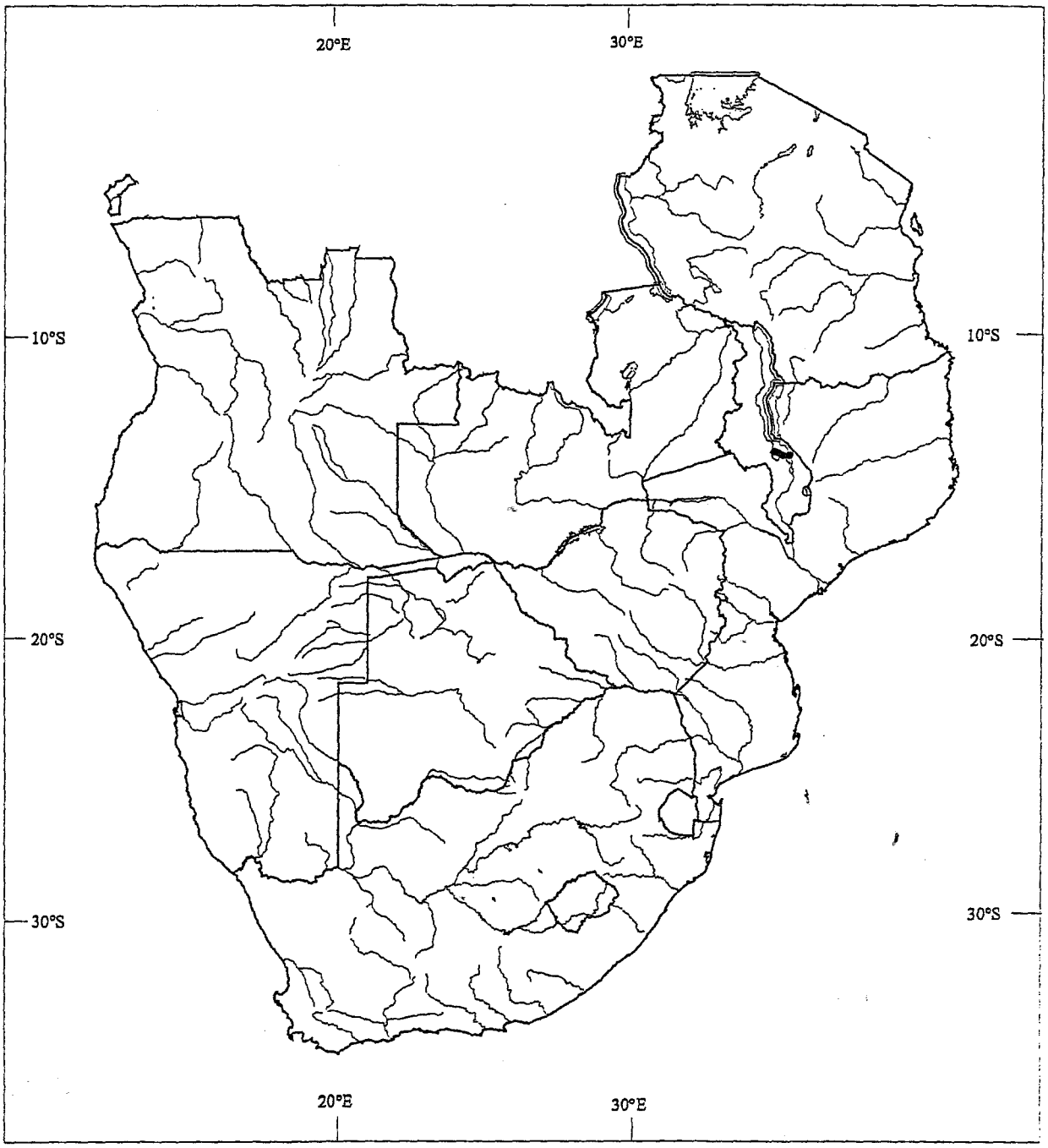


Figure F.529. Point distribution of *Otopharynx speciosus*. Scale approximately 1:25 000 000

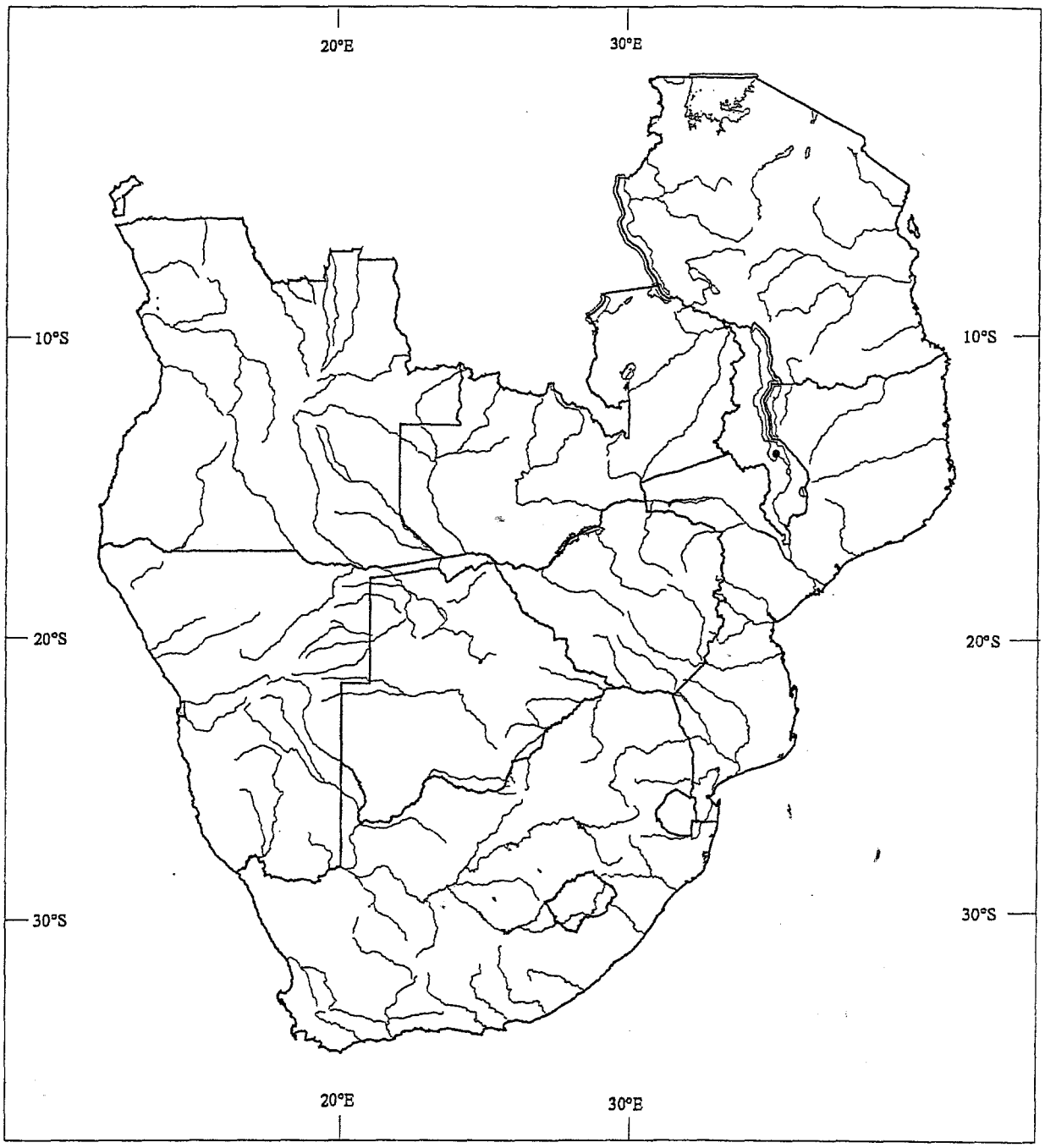


Figure F.530. Point distribution of *Otopharynx tetraspilus*. Scale approximately 1:25 000 000

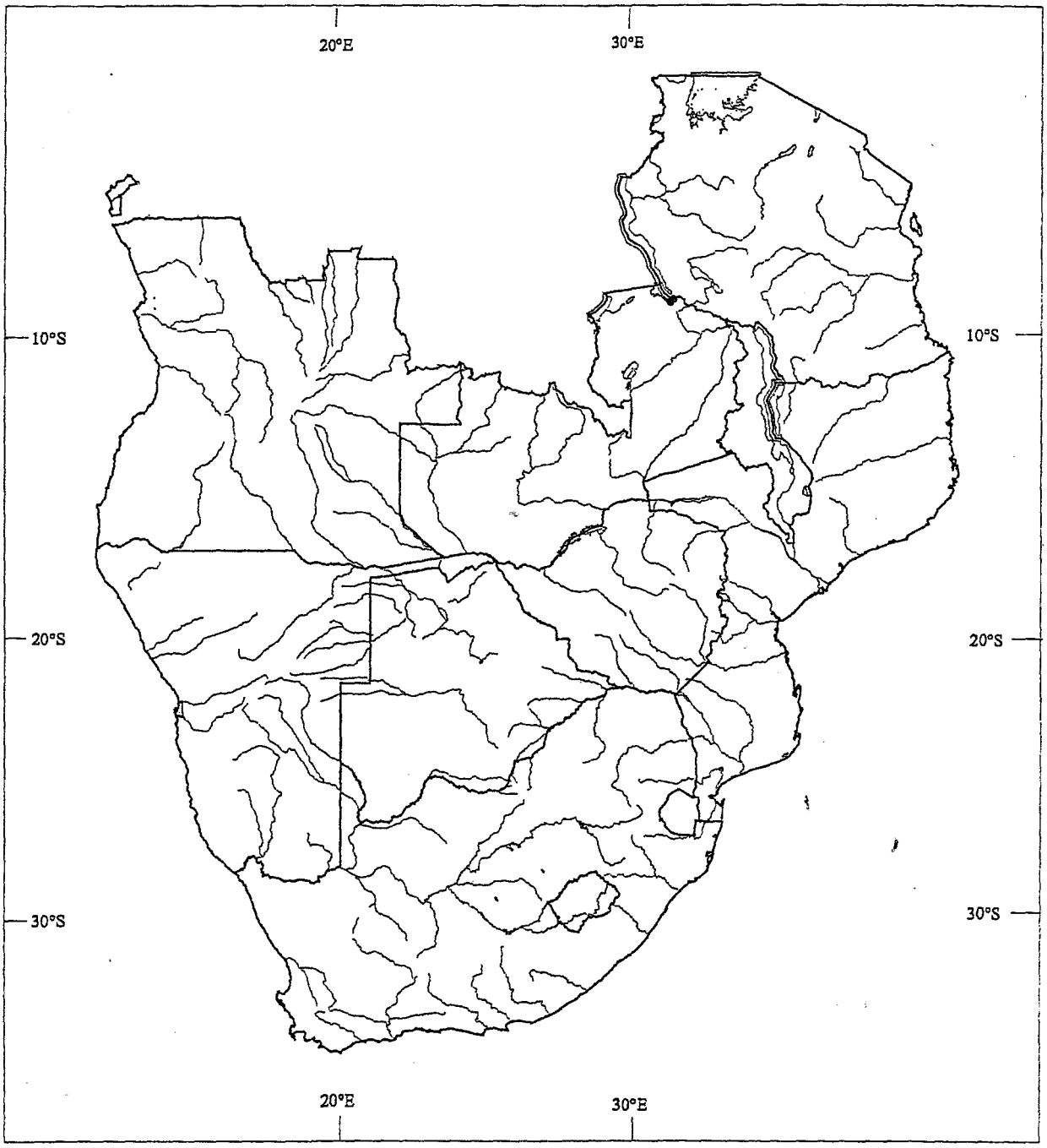


Figure F.531. Point distribution of *Paracyprichromis brieni*. Scale approximately 1:25 000 000

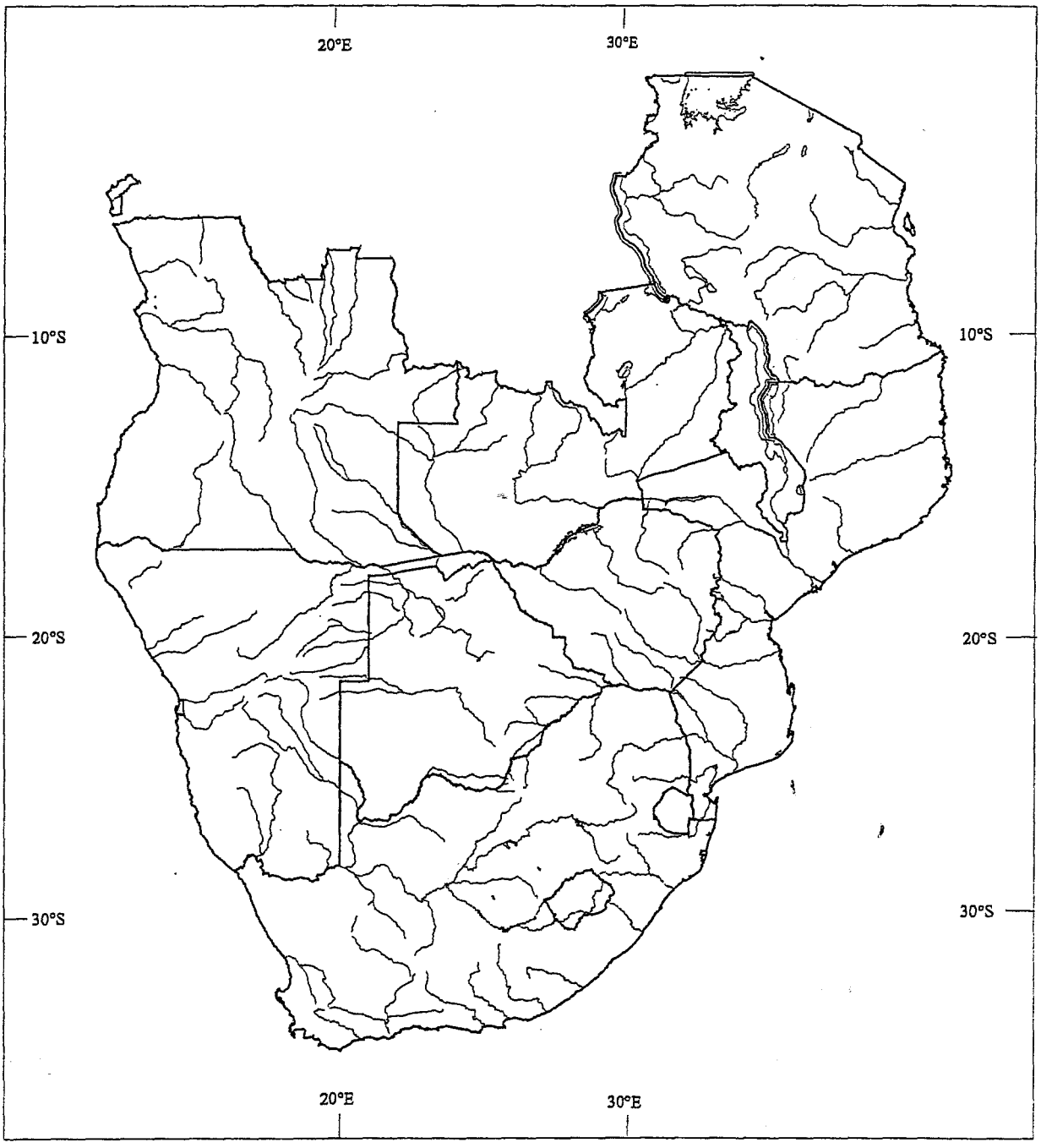


Figure F.532. Point distribution of *Paracyprichromis nigripinnis*. Scale approximately 1:25 000 000

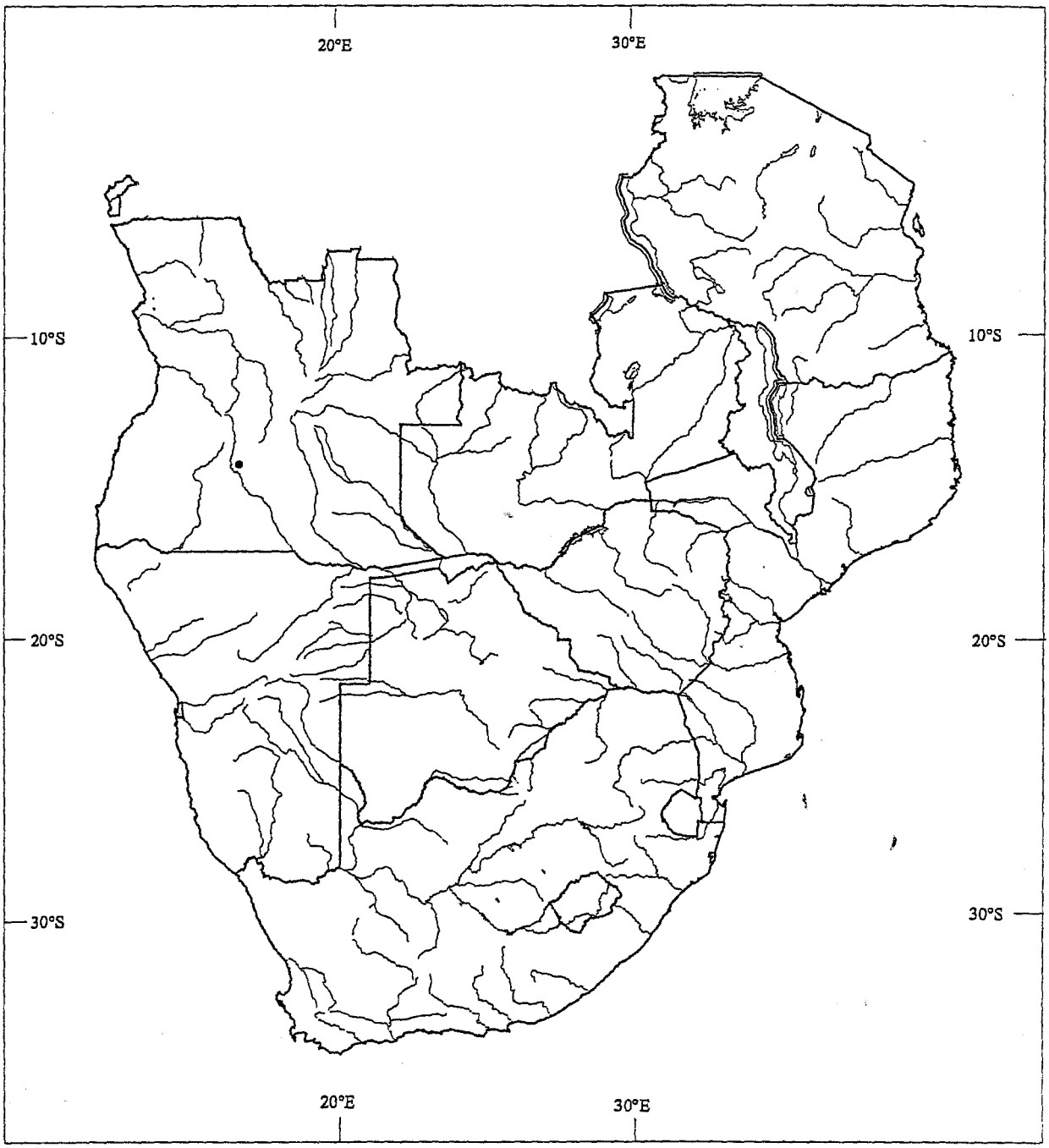


Figure F.533. Point distribution of *Parakneria fortuita*. Scale approximately 1:25 000 000

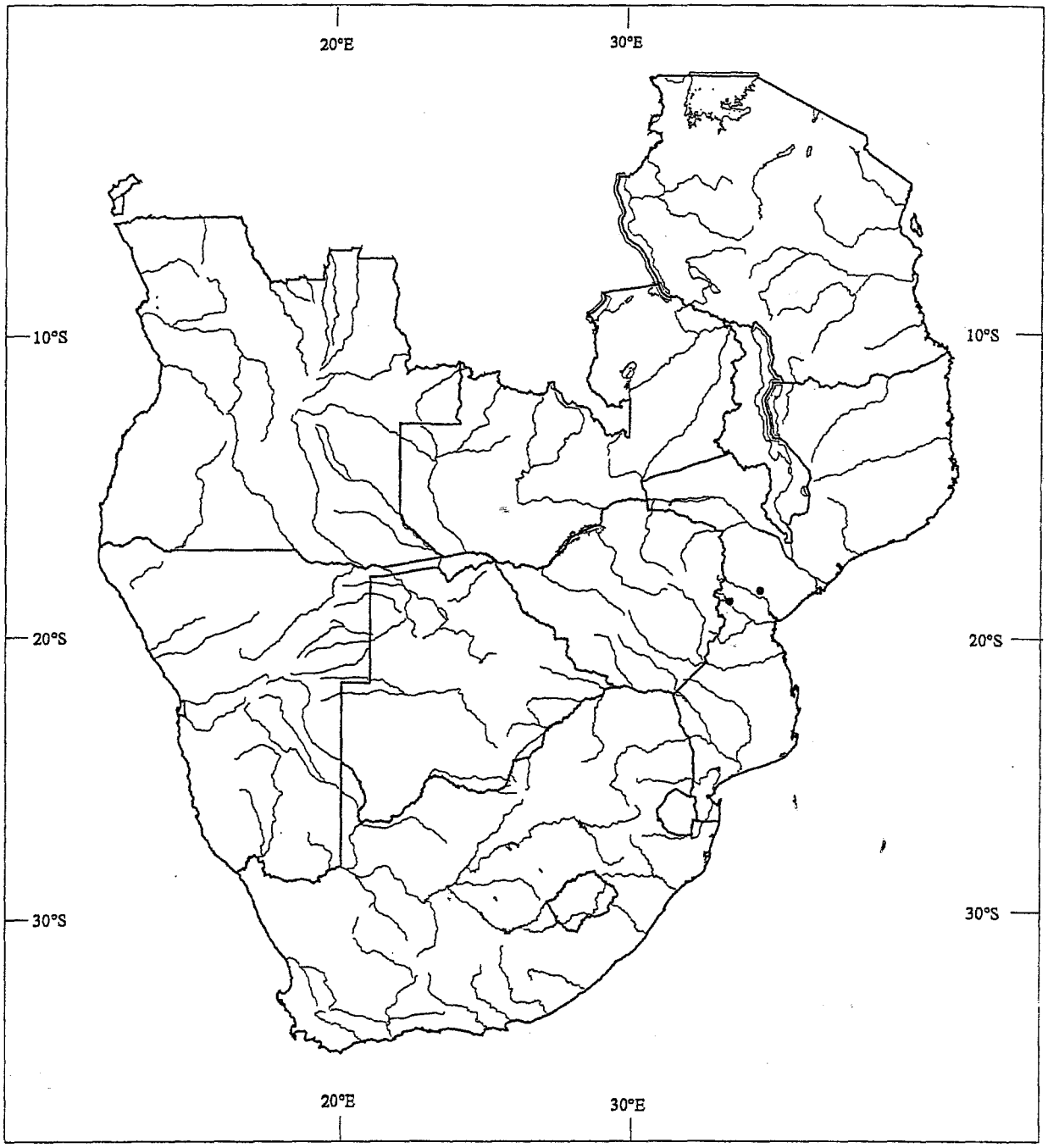


Figure F.534. Point distribution of *Parakneria mossambica*. Scale approximately 1:25 000 000

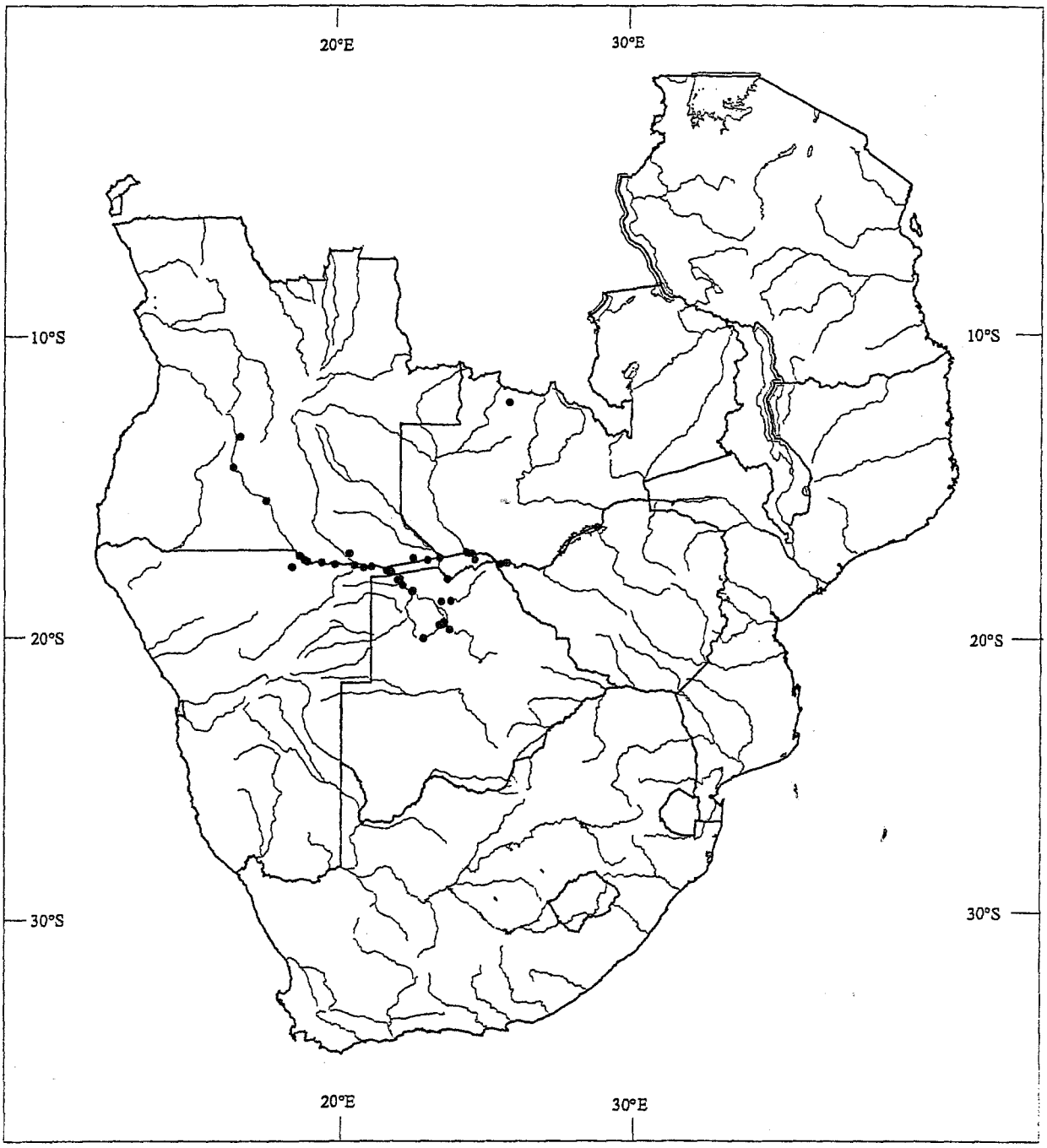


Figure F.535. Point distribution of *Parauchenoglanis ngamensis*. Scale approximately 1:25 000 000

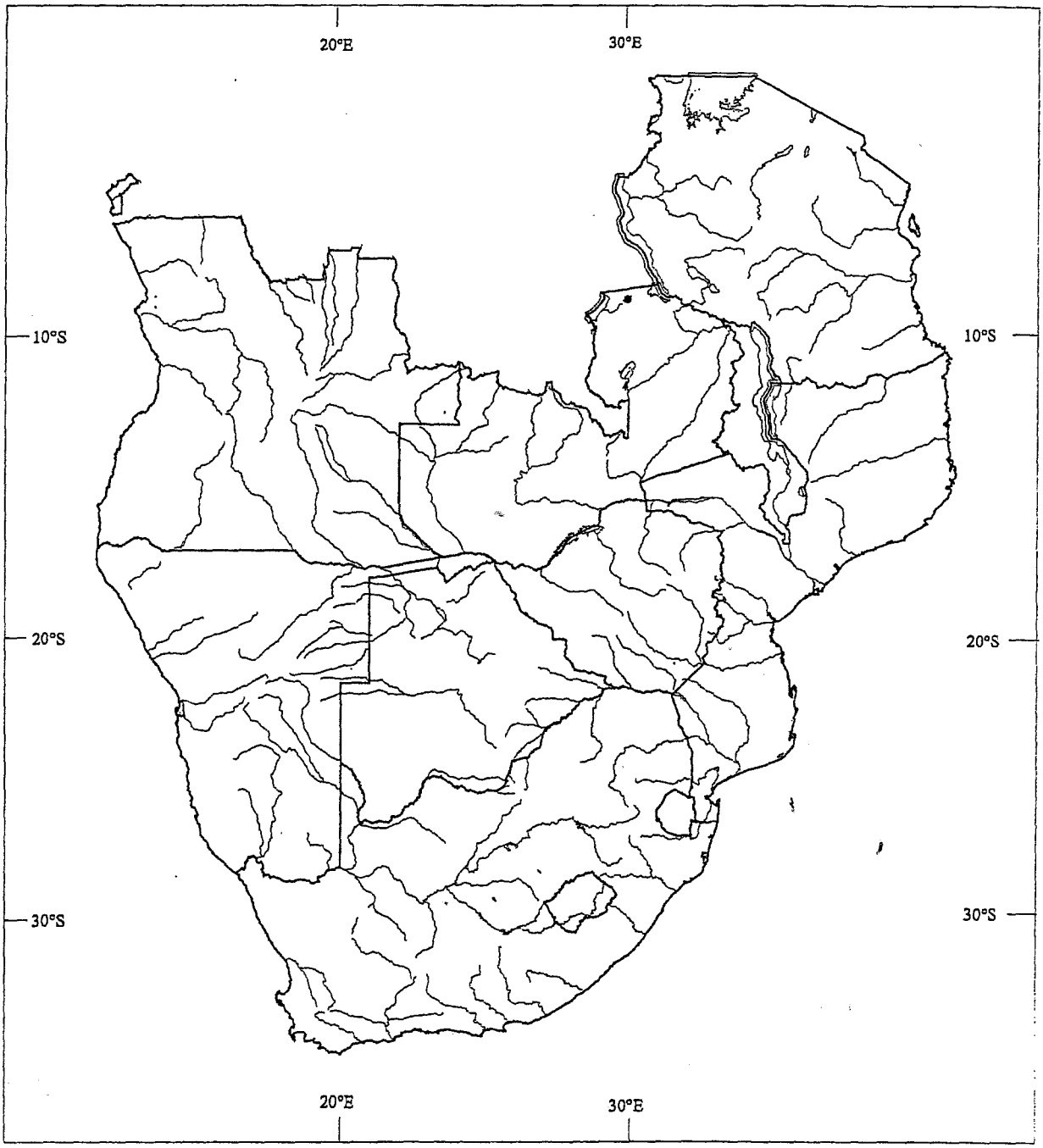


Figure F.536. Point distribution of *Parauchenoglanis occidentalis*. Scale approximately 1:25 000 000

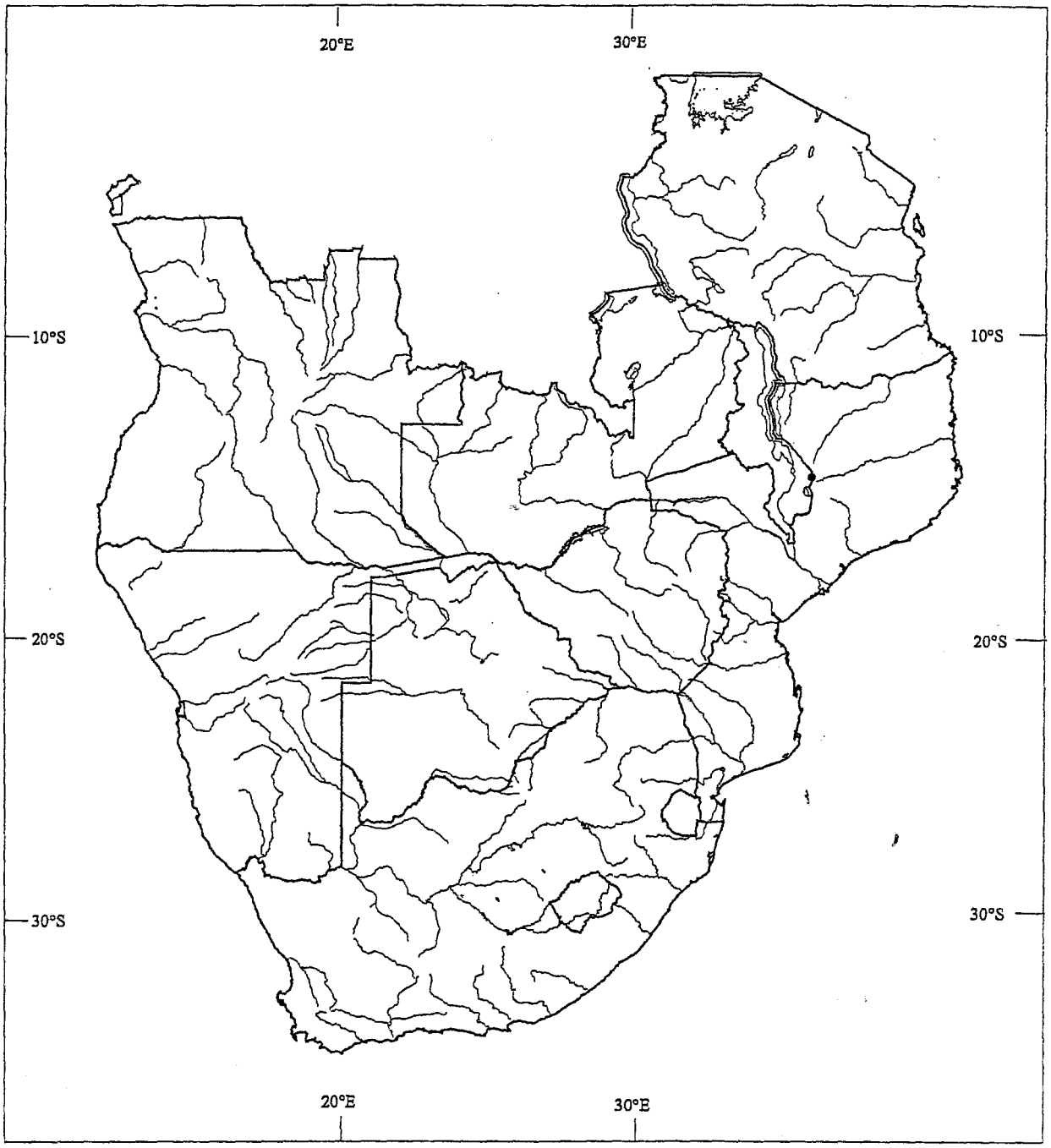


Figure F.537. Point distribution of *Pareutropius longifilis*. Scale approximately 1:25 000 000

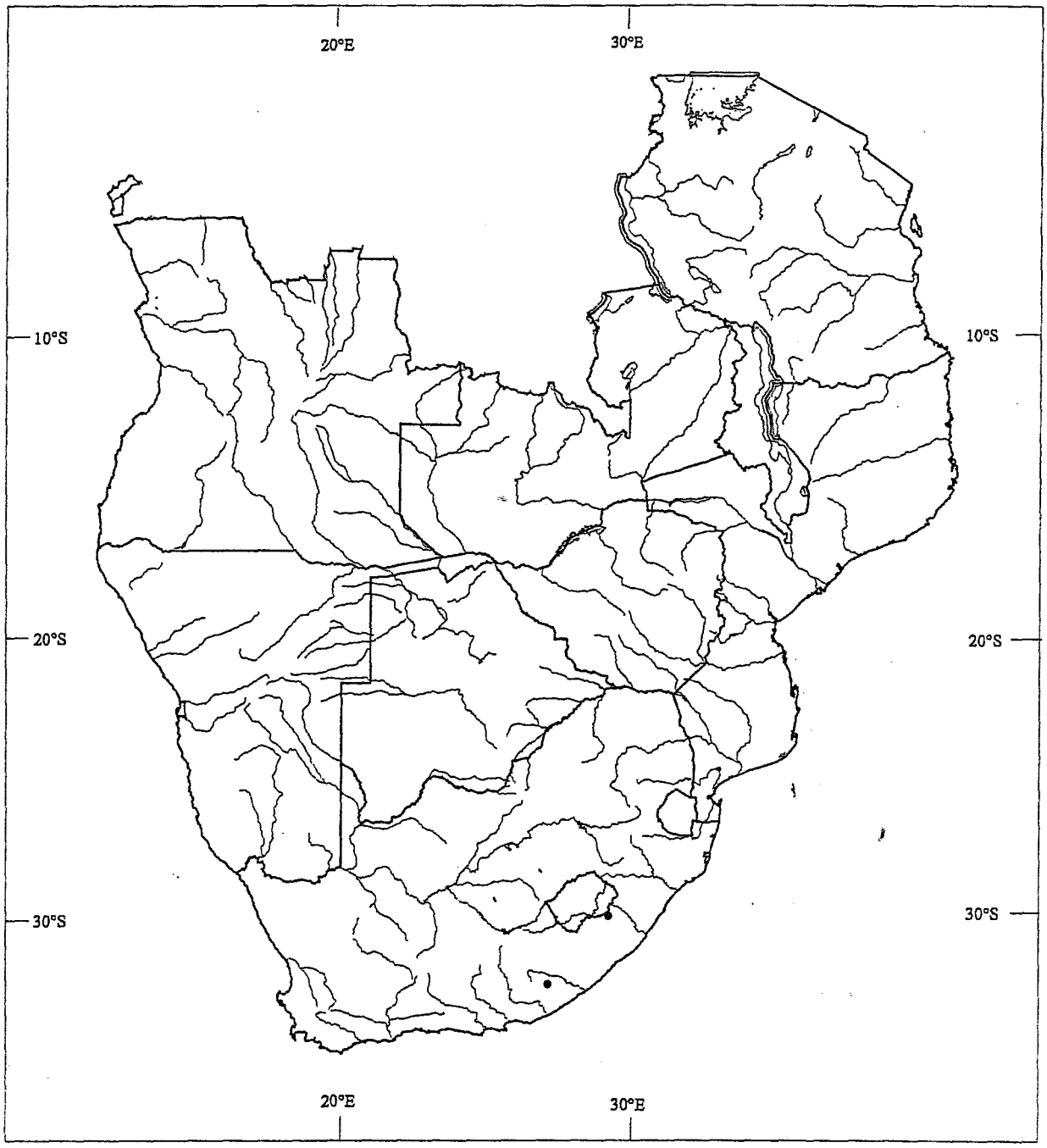


Figure F.538. Point distribution of *Perca fluviatilis*. Scale approximately 1:25 000 000

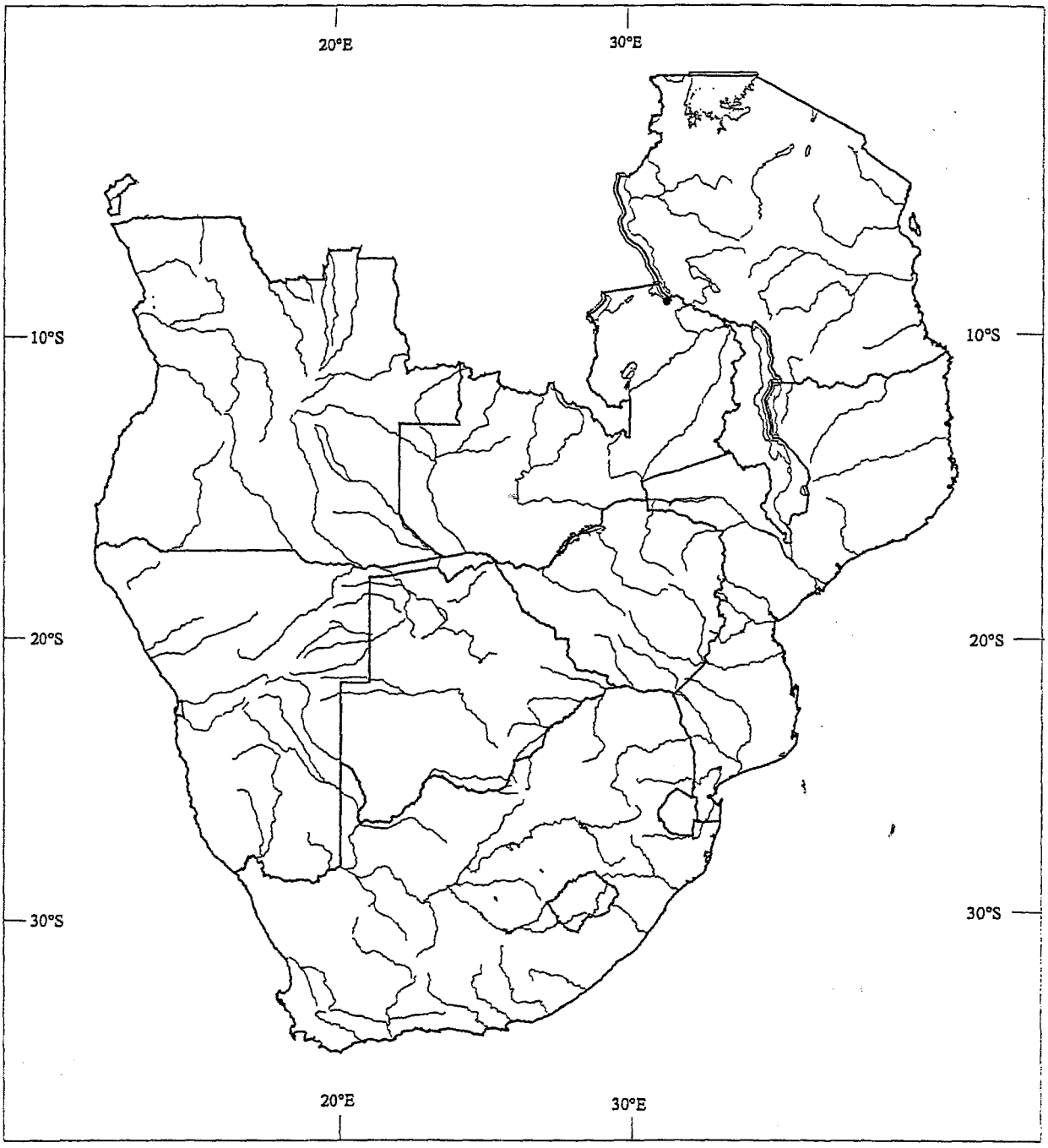


Figure F.539. Point distribution of *Perissodus lecqui*. Scale approximately 1:25 000 000

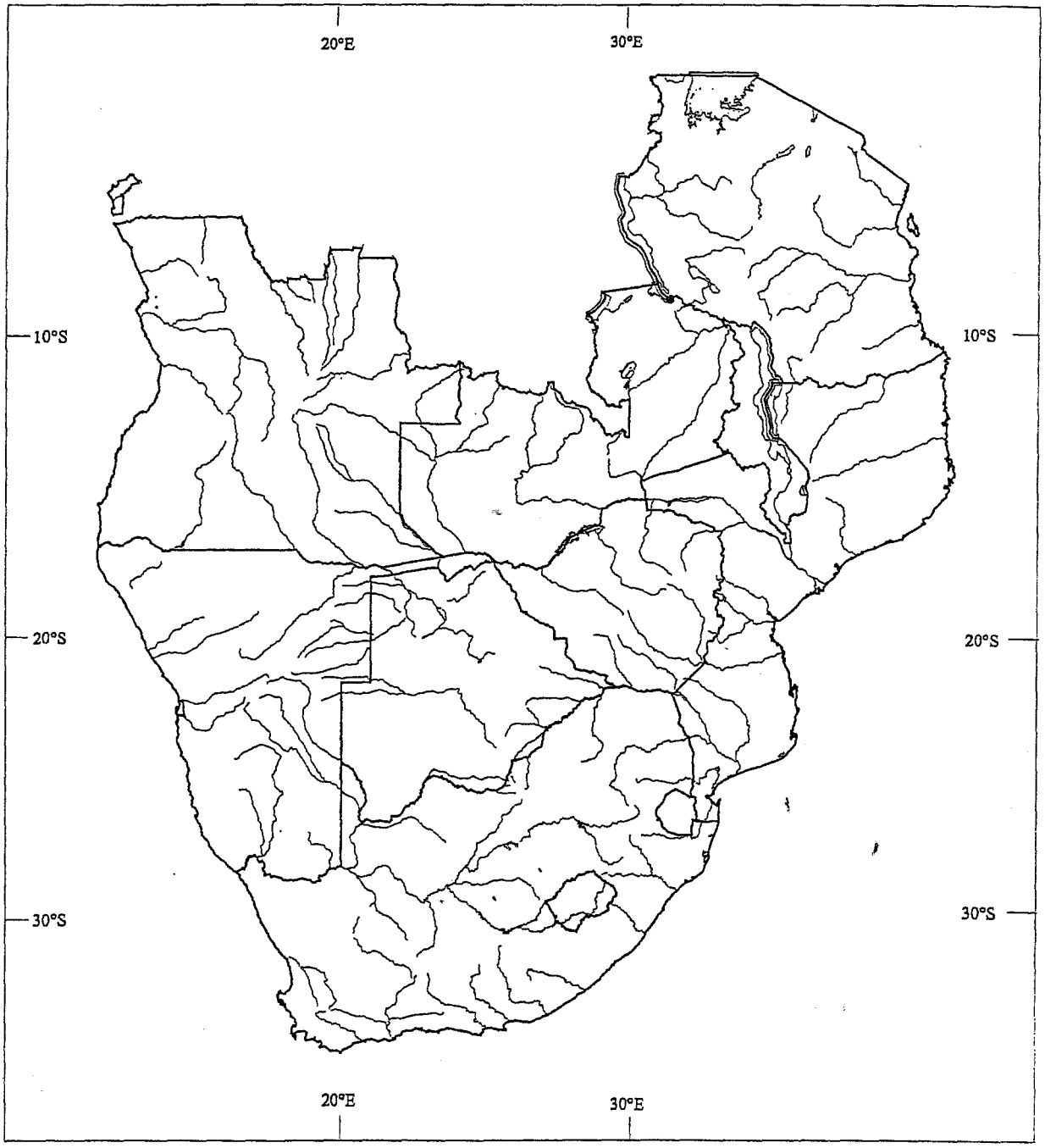


Figure F.540. Point distribution of *Perissodus microlepis*. Scale approximately 1:25 000 000

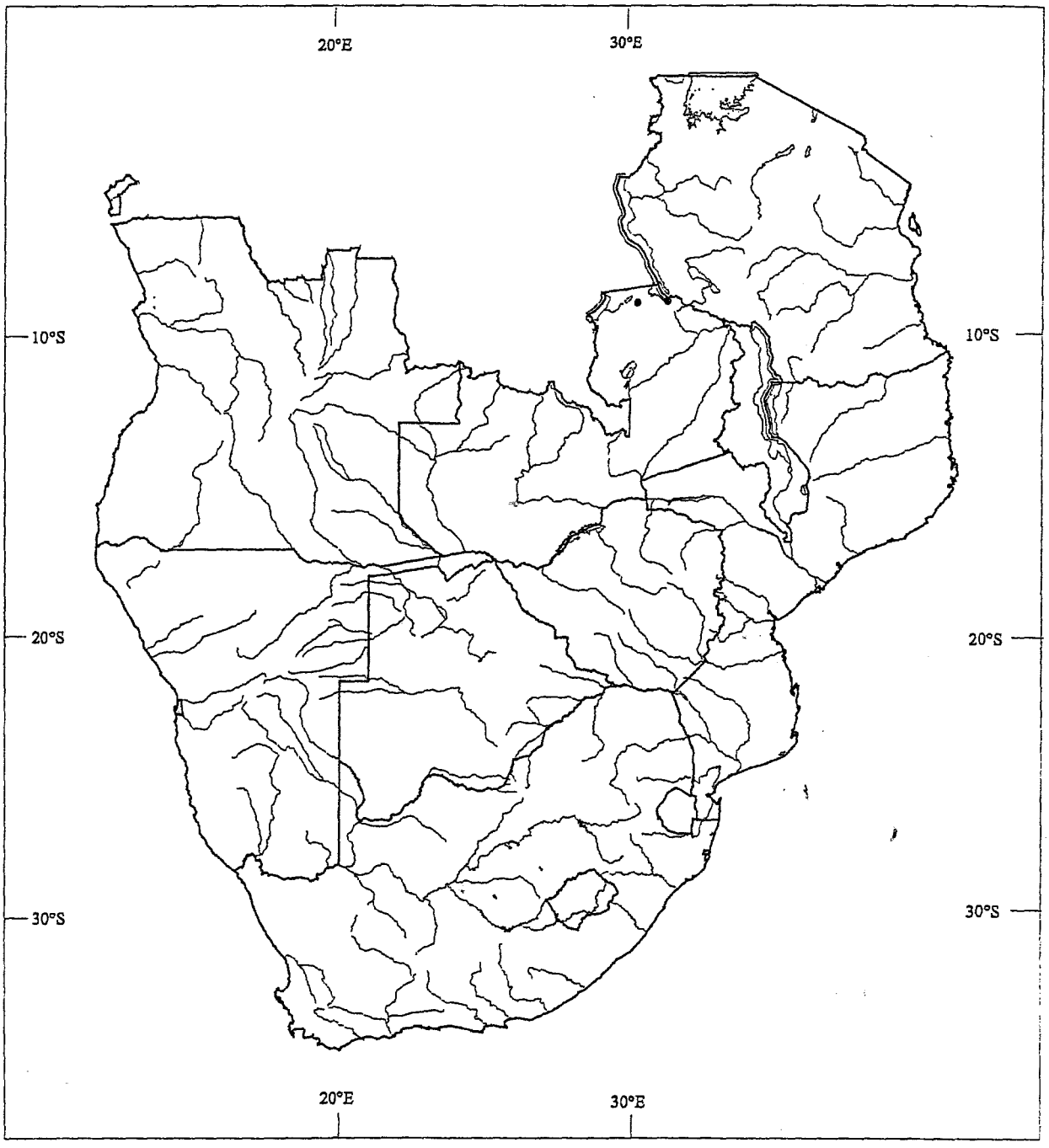


Figure F.541. Point distribution of *Perissodus multidentatus*. Scale approximately 1:25 000 000

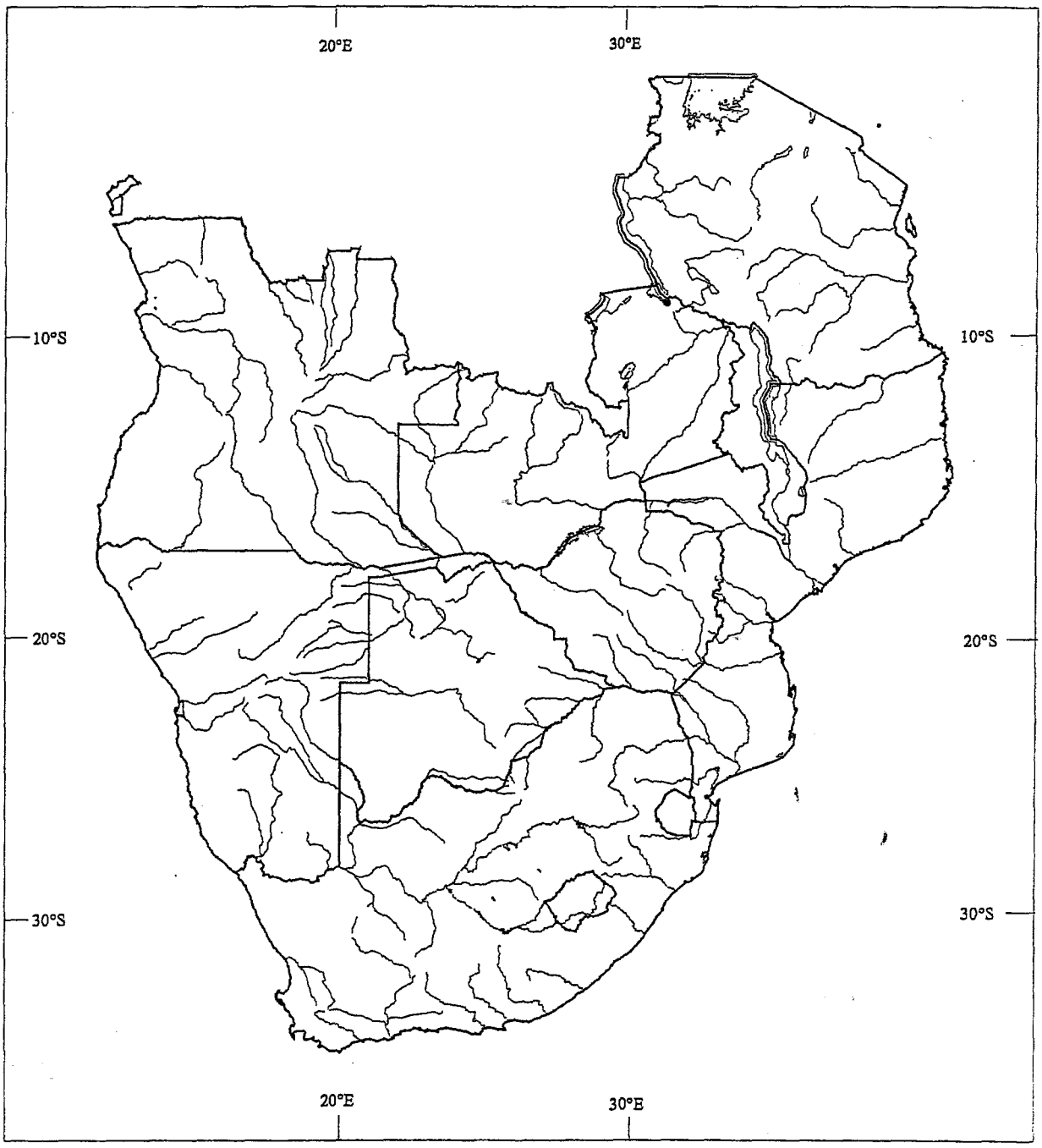


Figure F.542. Point distribution of *Perissodus paradoxus*. Scale approximately 1:25 000 000

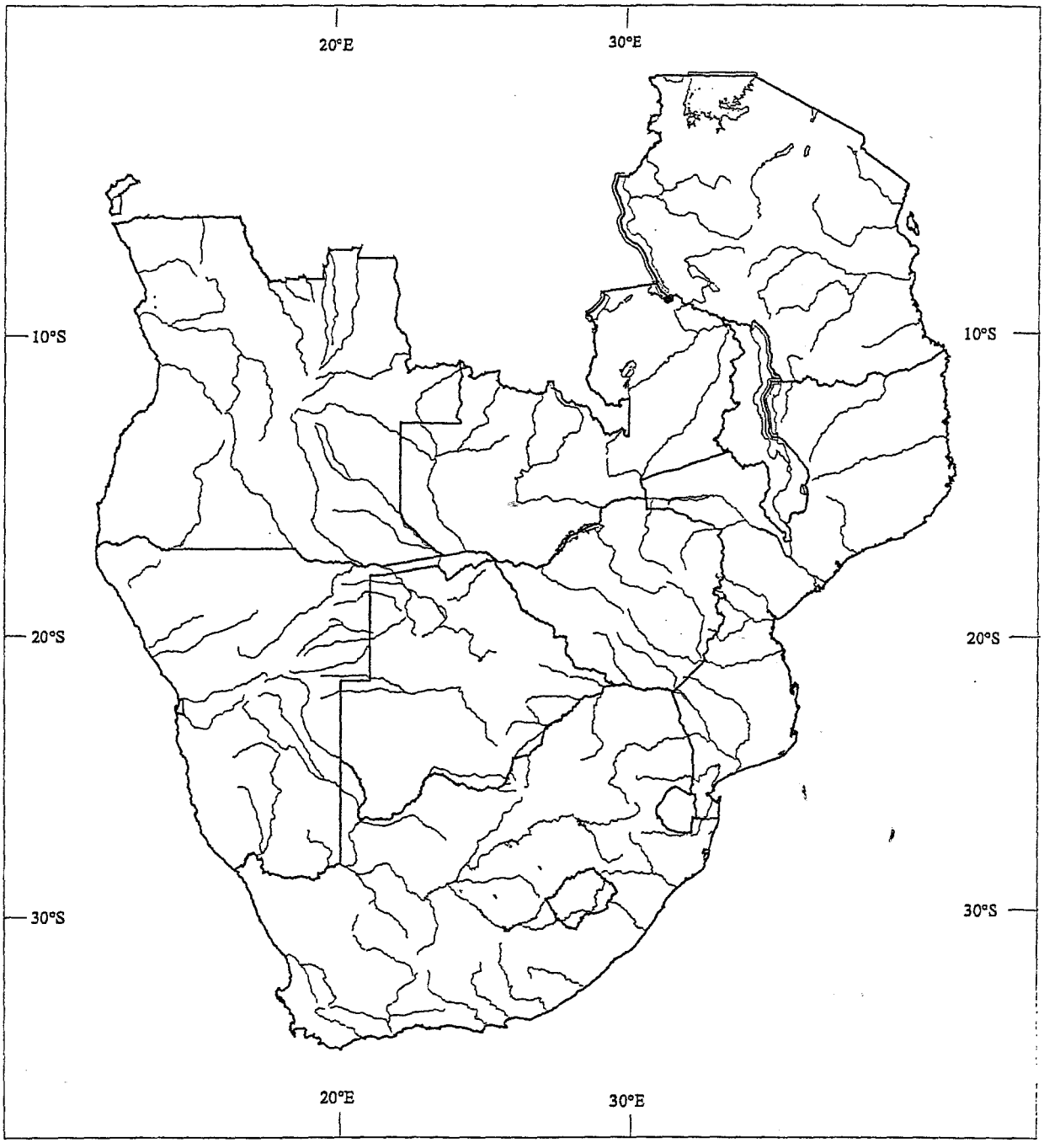


Figure F.543. Point distribution of *Perissodus straeleni*. Scale approximately 1:25 000 000

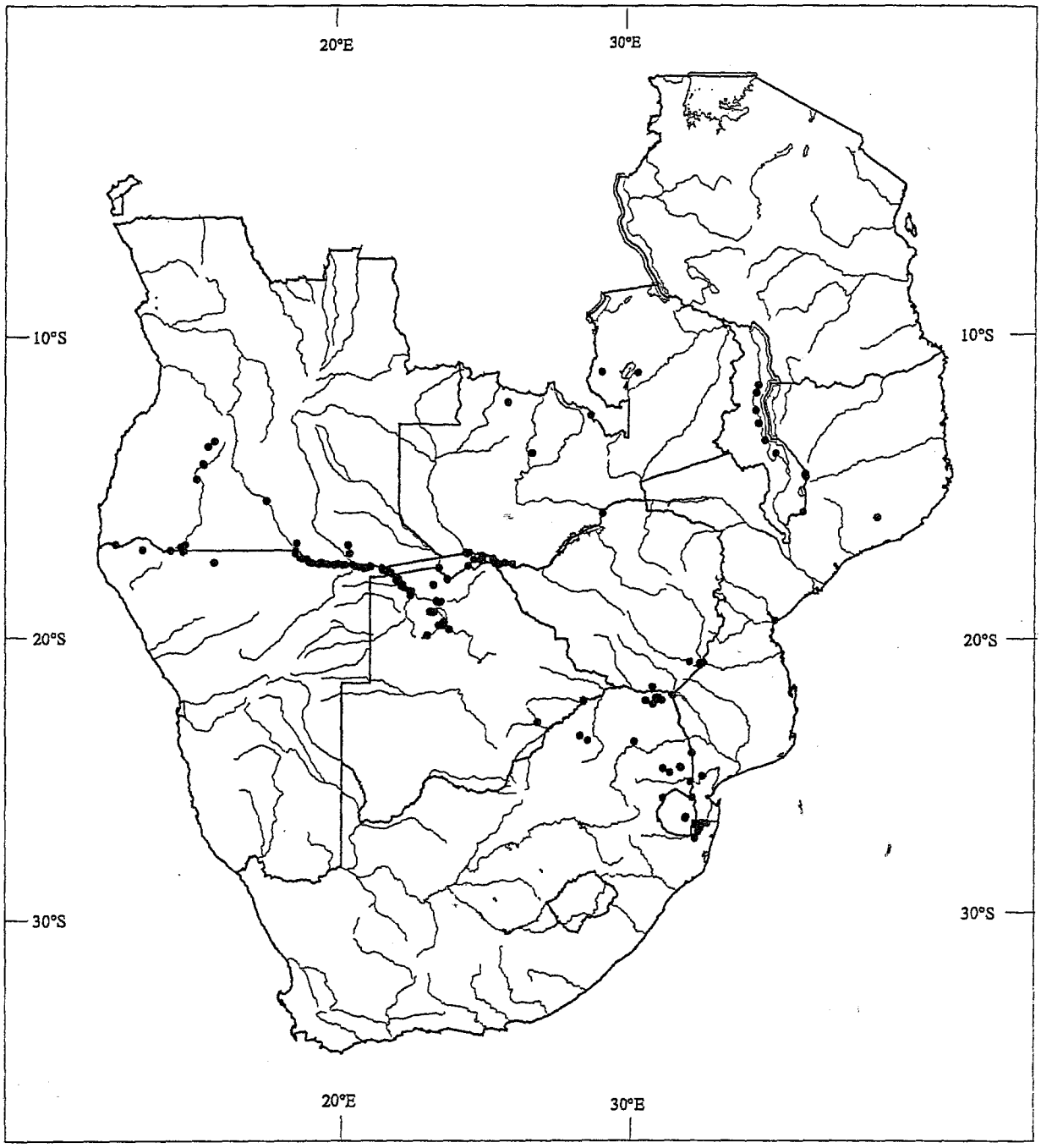


Figure F.544. Point distribution of *Petrocephalus catostoma*. Scale approximately 1:25 000 000

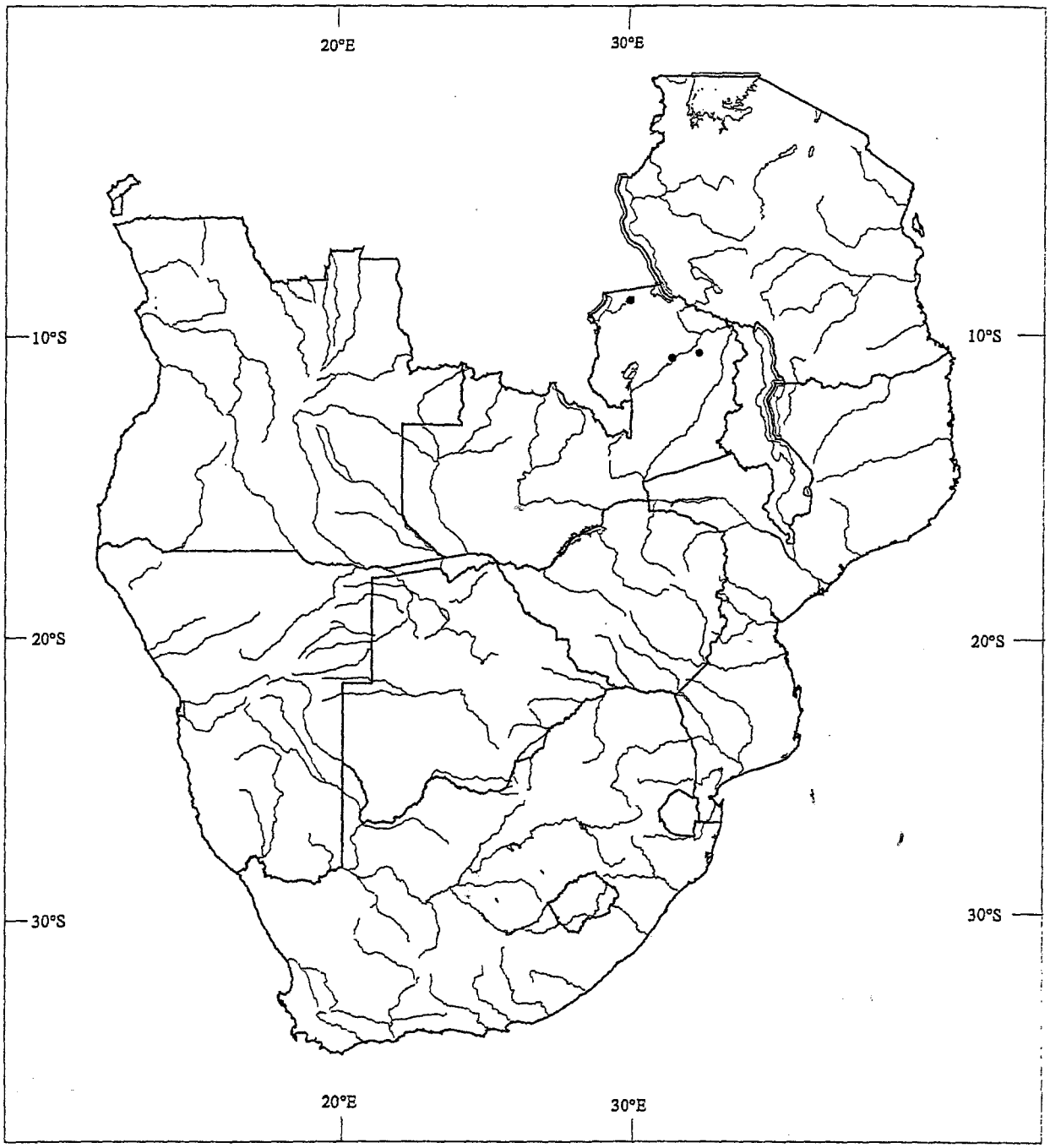


Figure F.545. Point distribution of *Petrocephalus simus*. Scale approximately 1:25 000 000

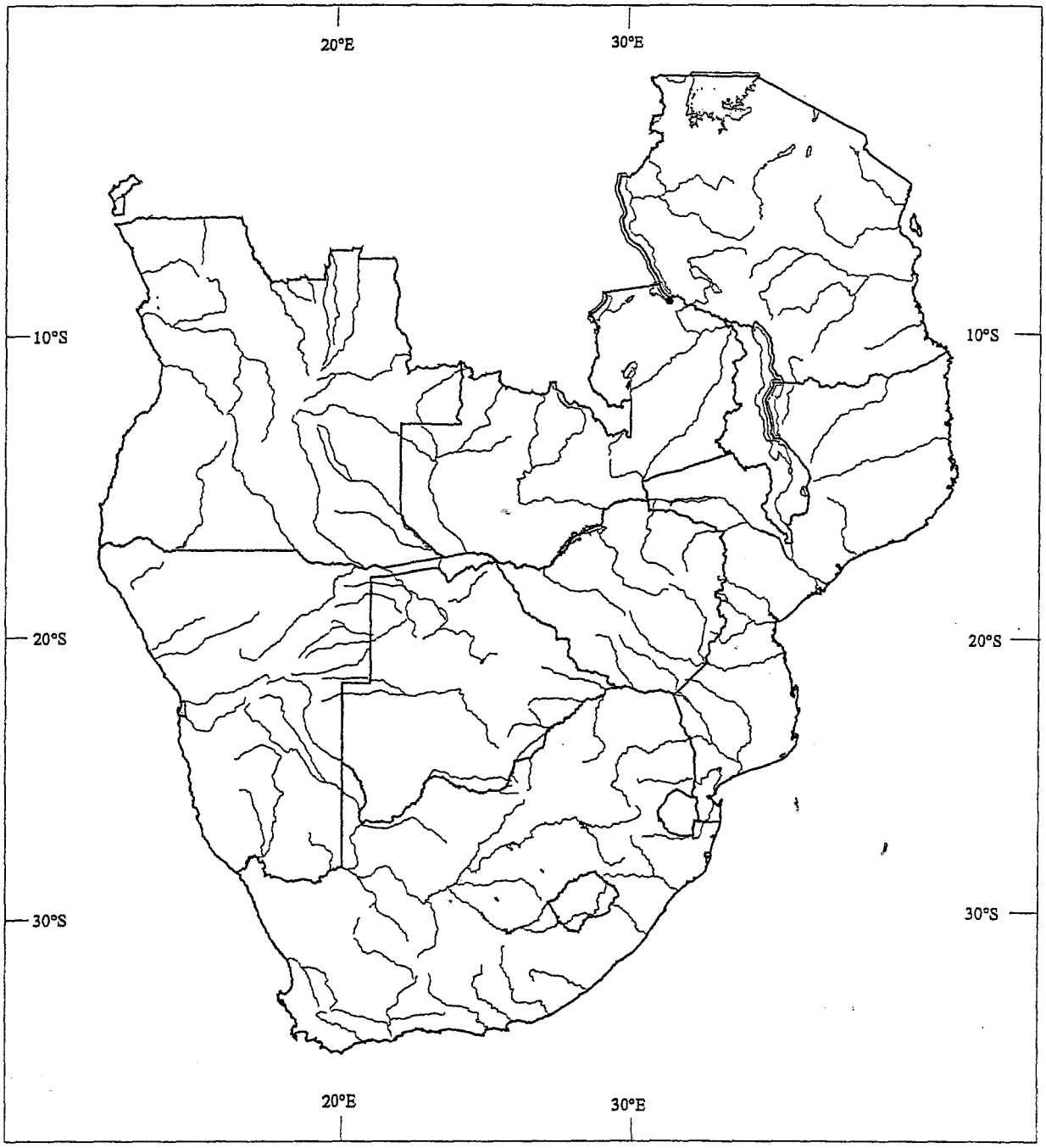


Figure F.546. Point distribution of *Petrochromis ephippium*. Scale approximately 1:25 000 000

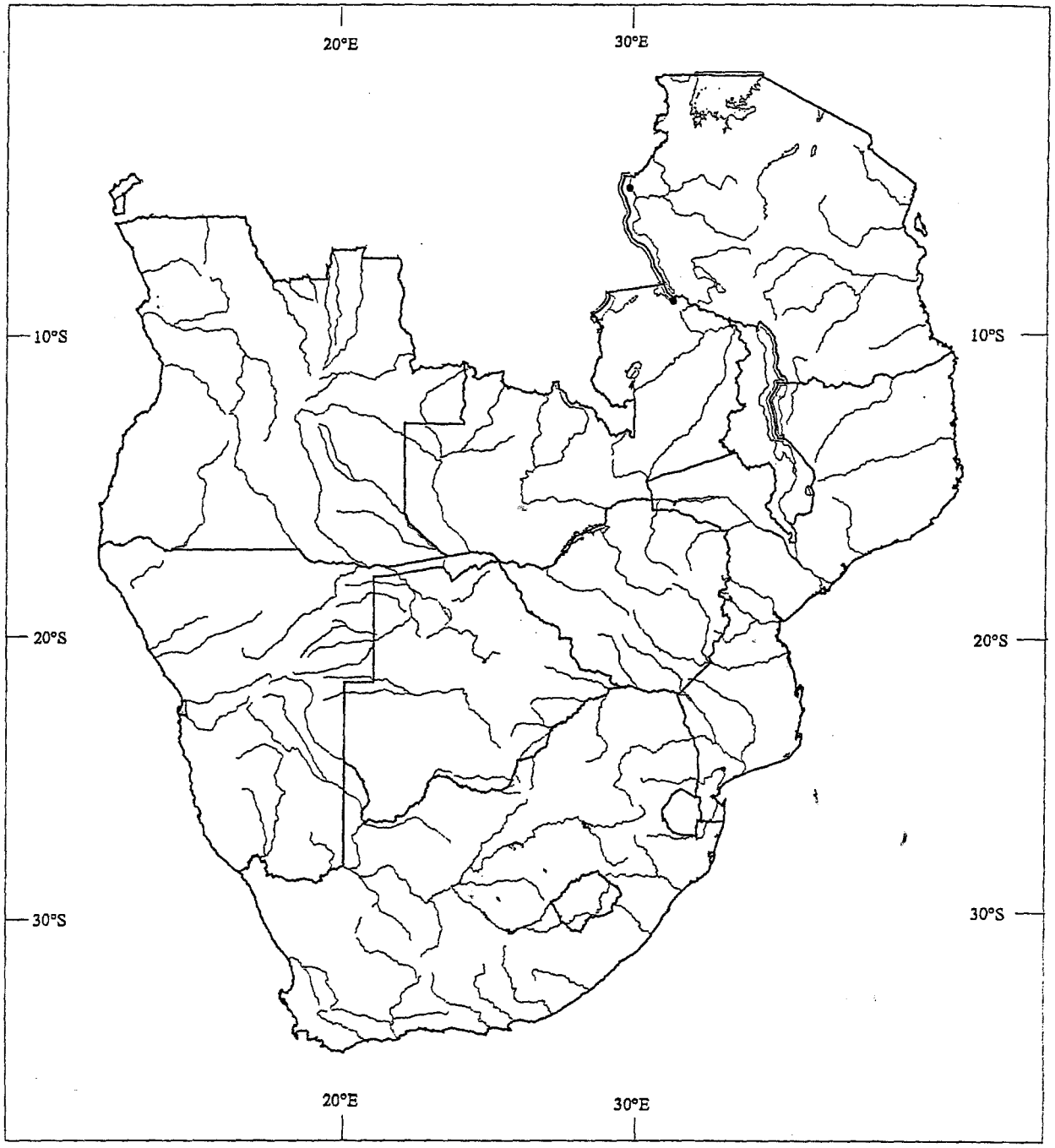


Figure F.547. Point distribution of *Petrochromis famula*. Scale approximately 1:25 000 000

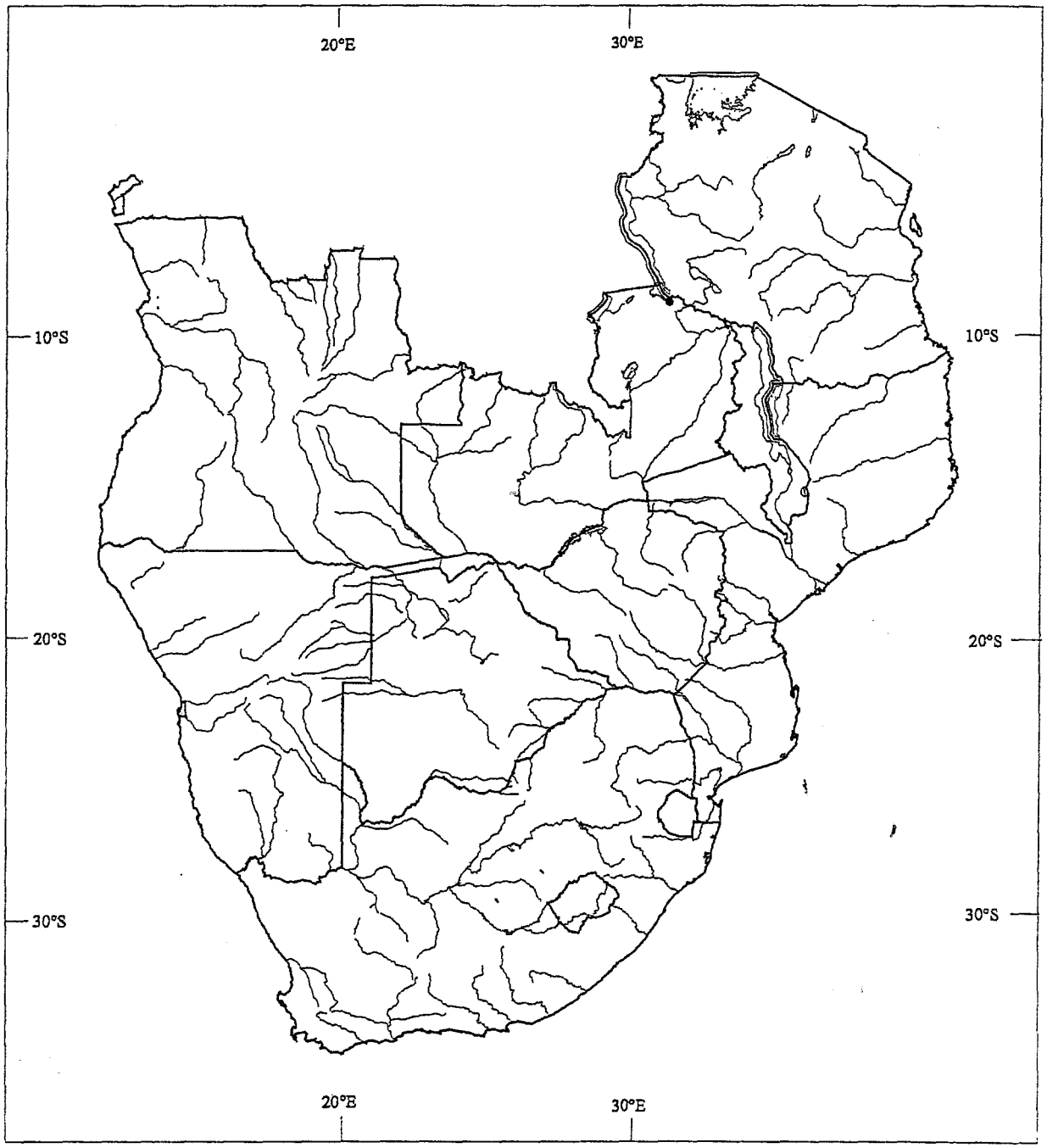


Figure F.548. Point distribution of *Petrochromis fasciolatus*. Scale approximately 1:25 000 000

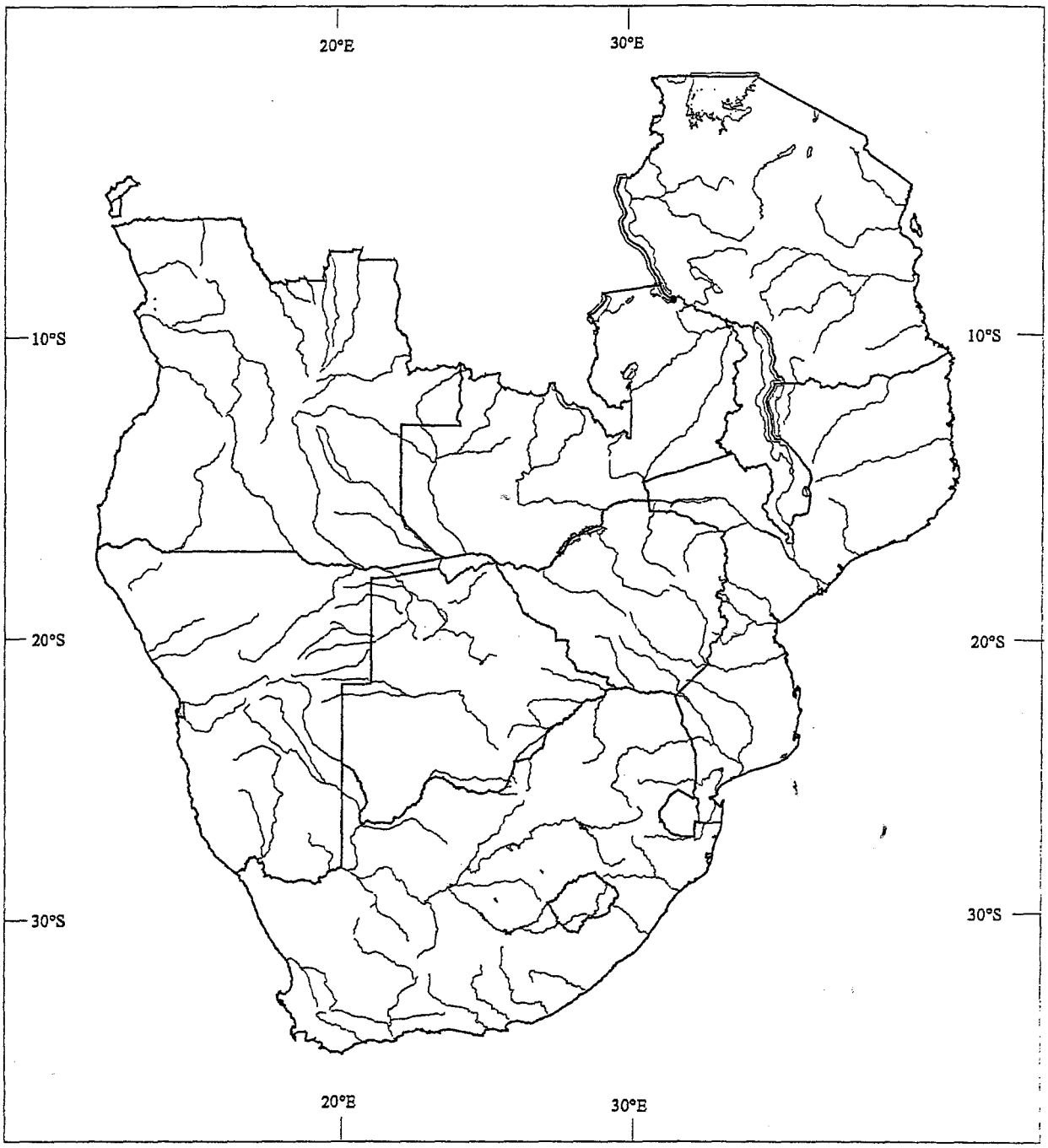


Figure F.549. Point distribution of *Petrochromis macrognathus*. Scale approximately 1:25 000 000

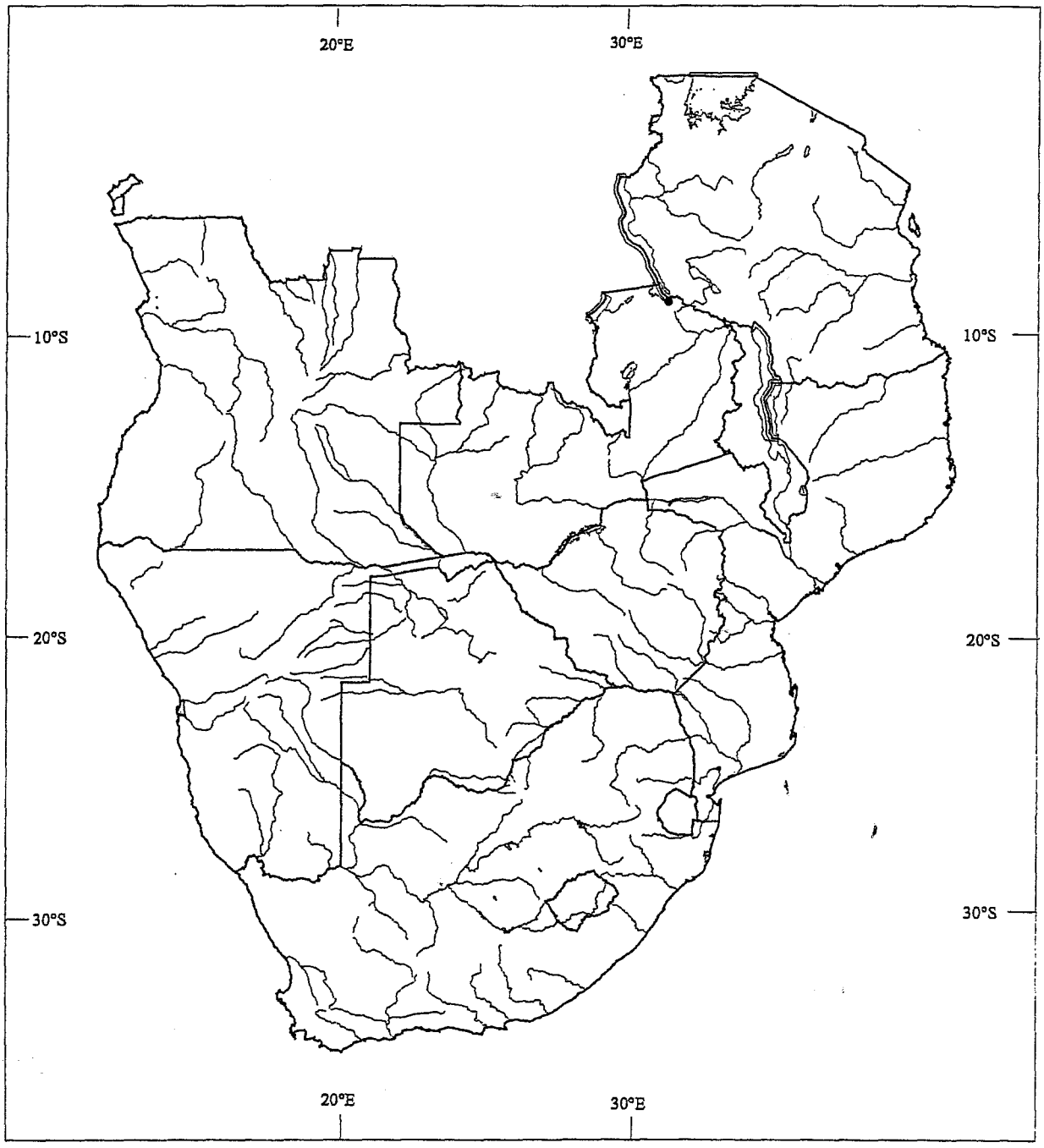


Figure F.550. Point distribution of *Petrochromis orthognathus*. Scale approximately 1:25 000 000

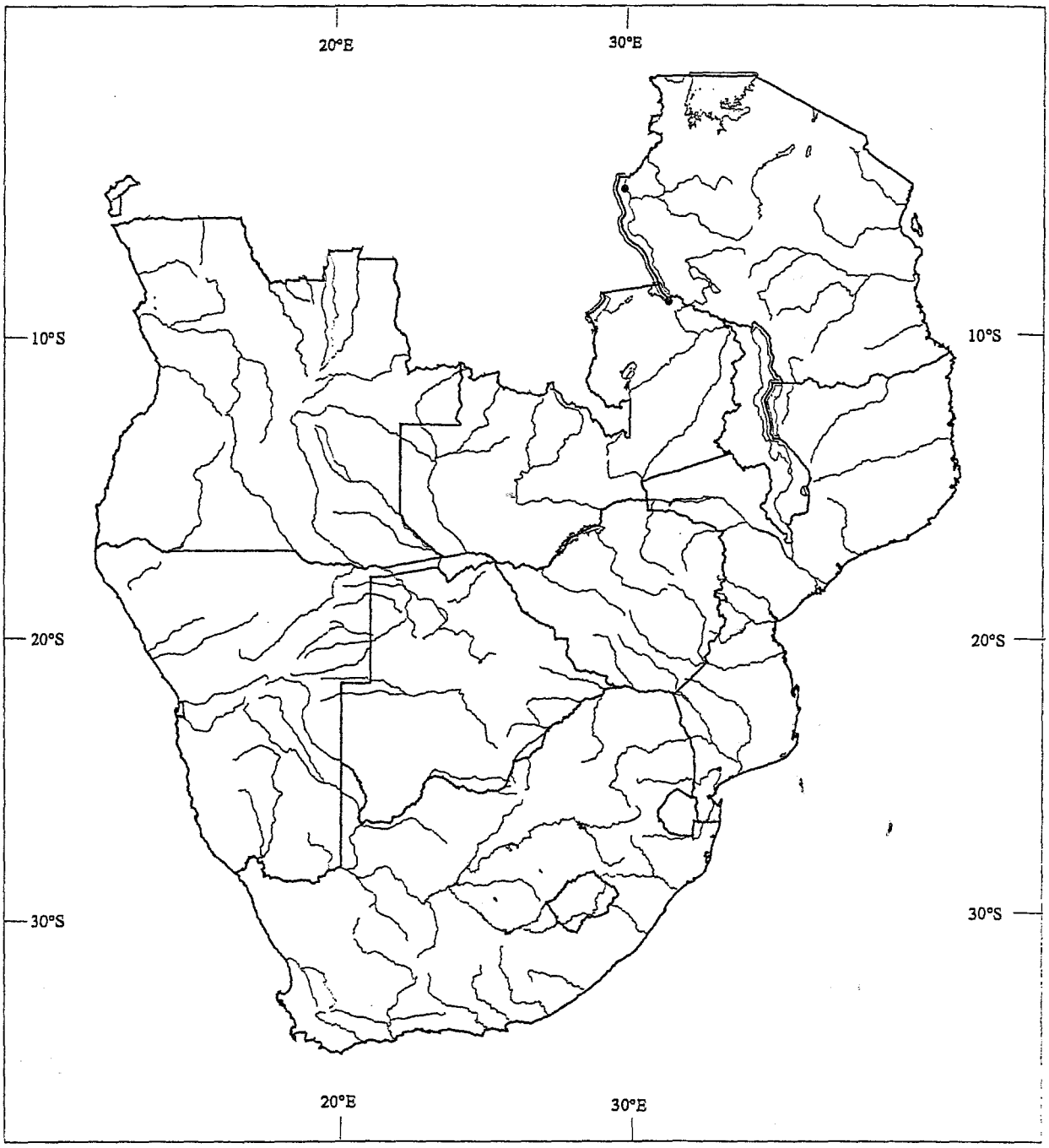


Figure F.551. Point distribution of *Petrochromis polyodon*. Scale approximately 1:25 000 000

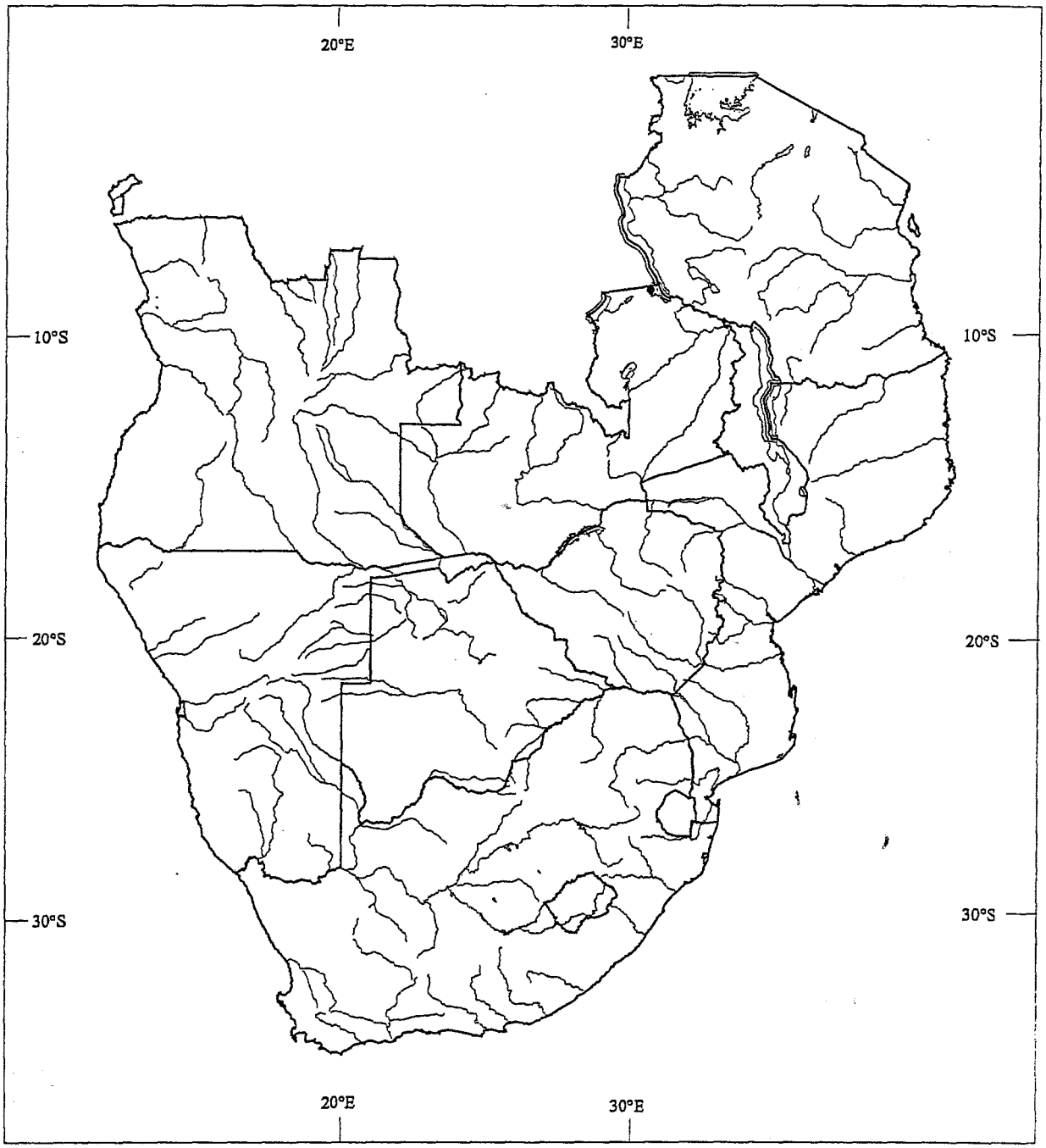


Figure F.552. Point distribution of *Petrochromis trewavasae*. Scale approximately 1:25 000 000

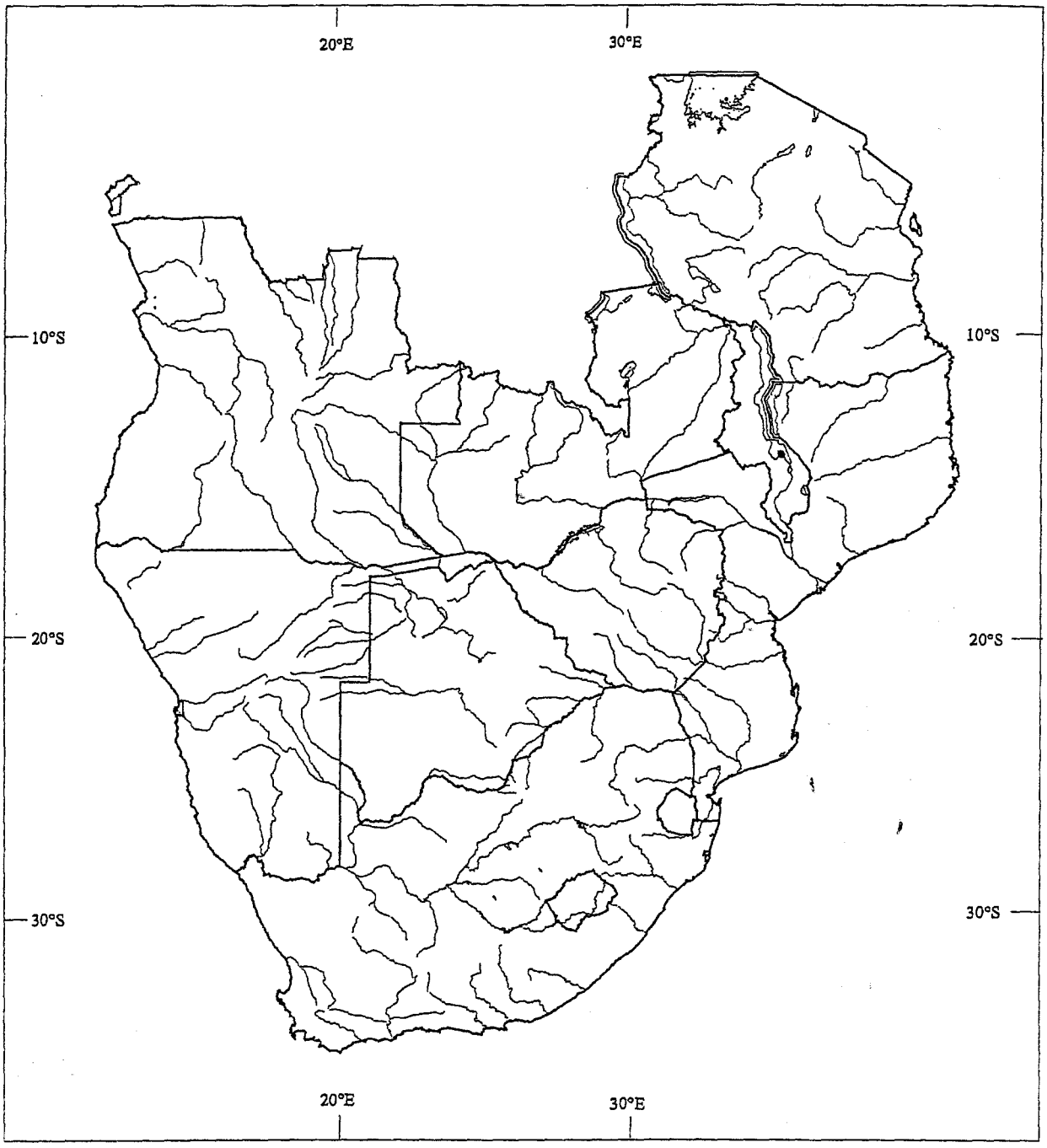


Figure F.553. Point distribution of *Petrotilapia genalutea*. Scale approximately 1:25 000 000

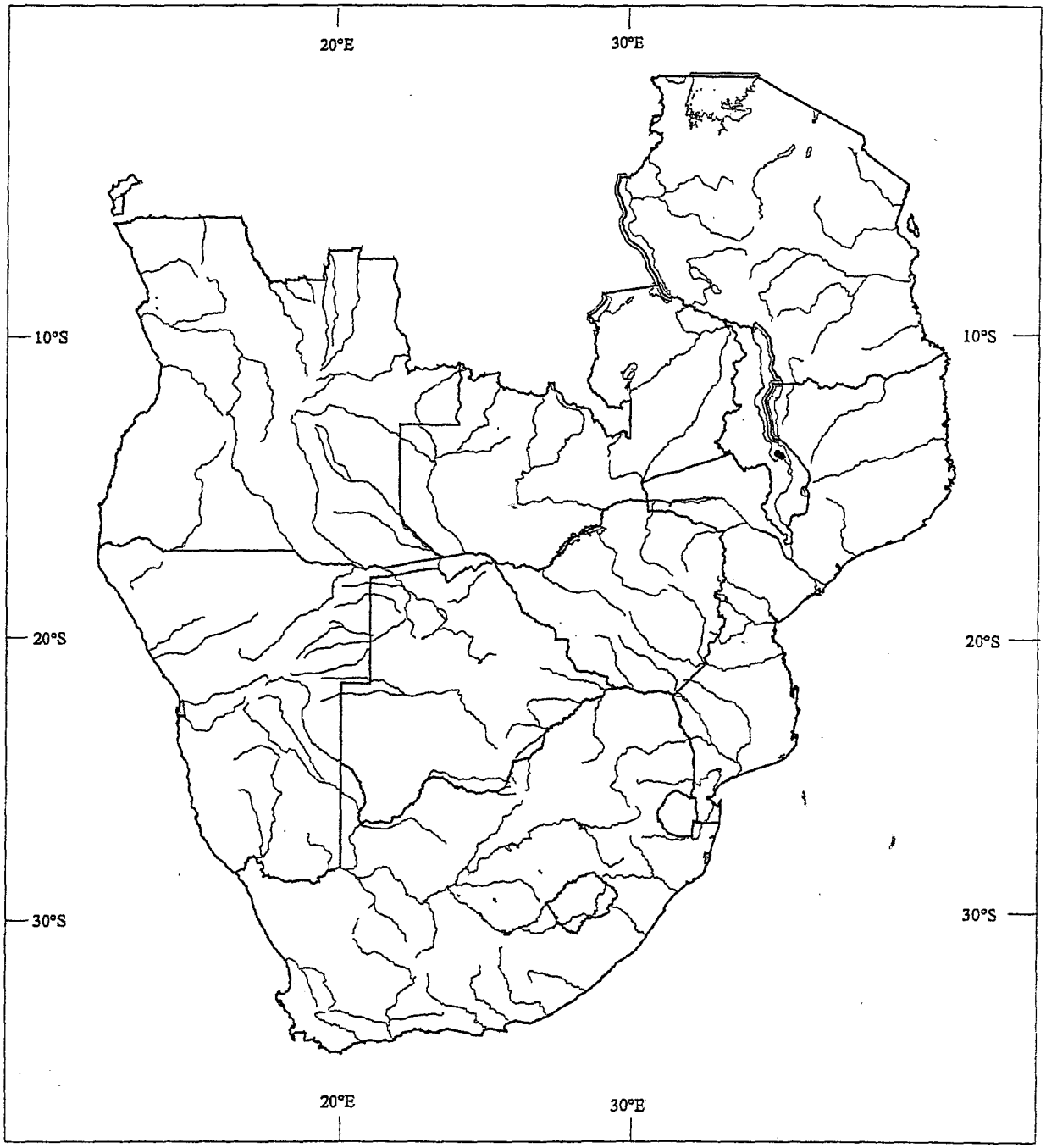


Figure F.554. Point distribution of *Petrotilapia nigra*. Scale approximately 1:25 000 000

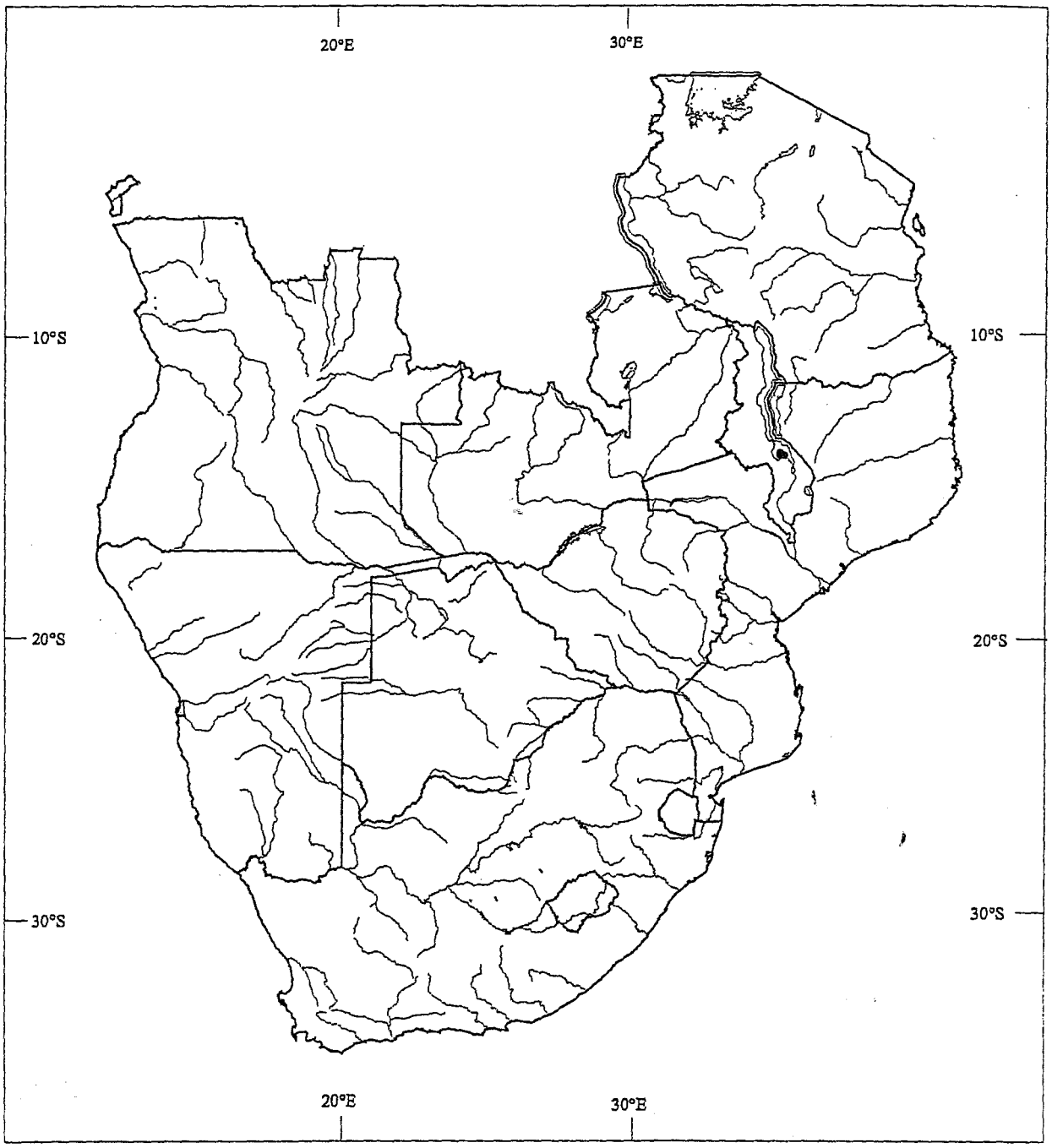


Figure F.555. Point distribution of *Petrotilapia tridentiger*. Scale approximately 1:25 000 000

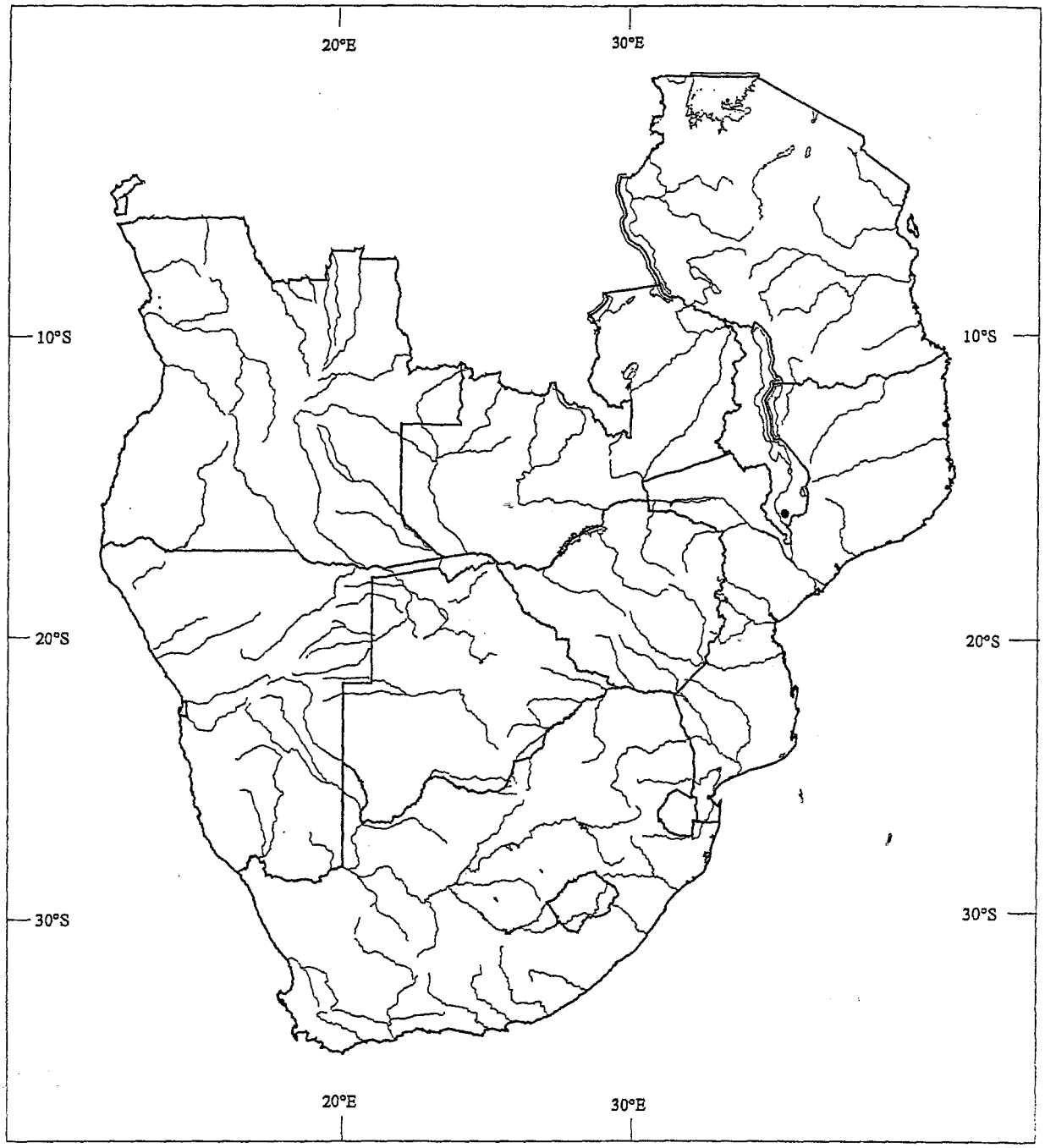


Figure F.556. Point distribution of *Phalloceros caudimaculatus*. Scale approximately 1:25 000 000

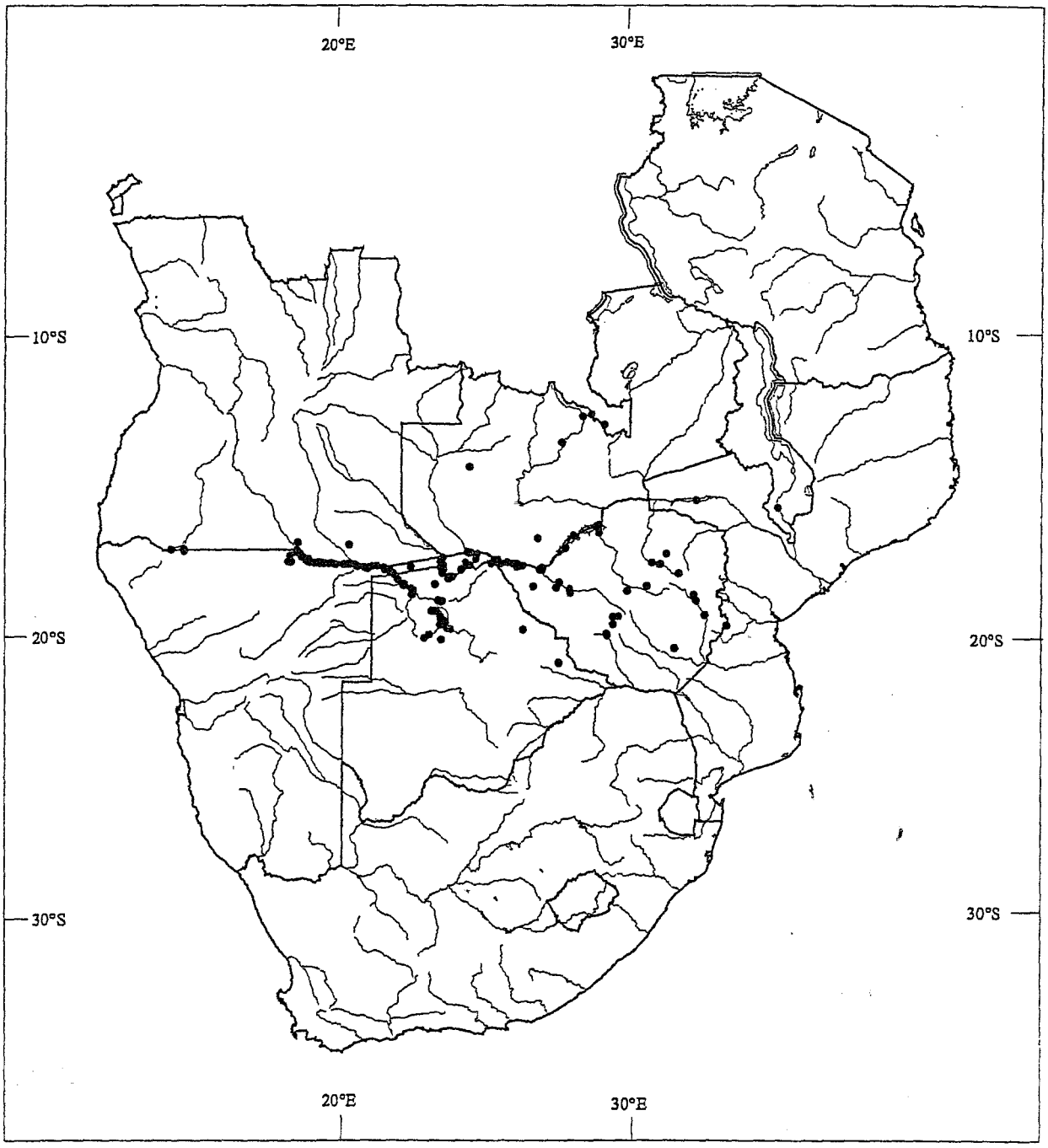


Figure F.557. Point distribution of *Pharyngochromis acuticeps*. Scale approximately 1:25 000 000

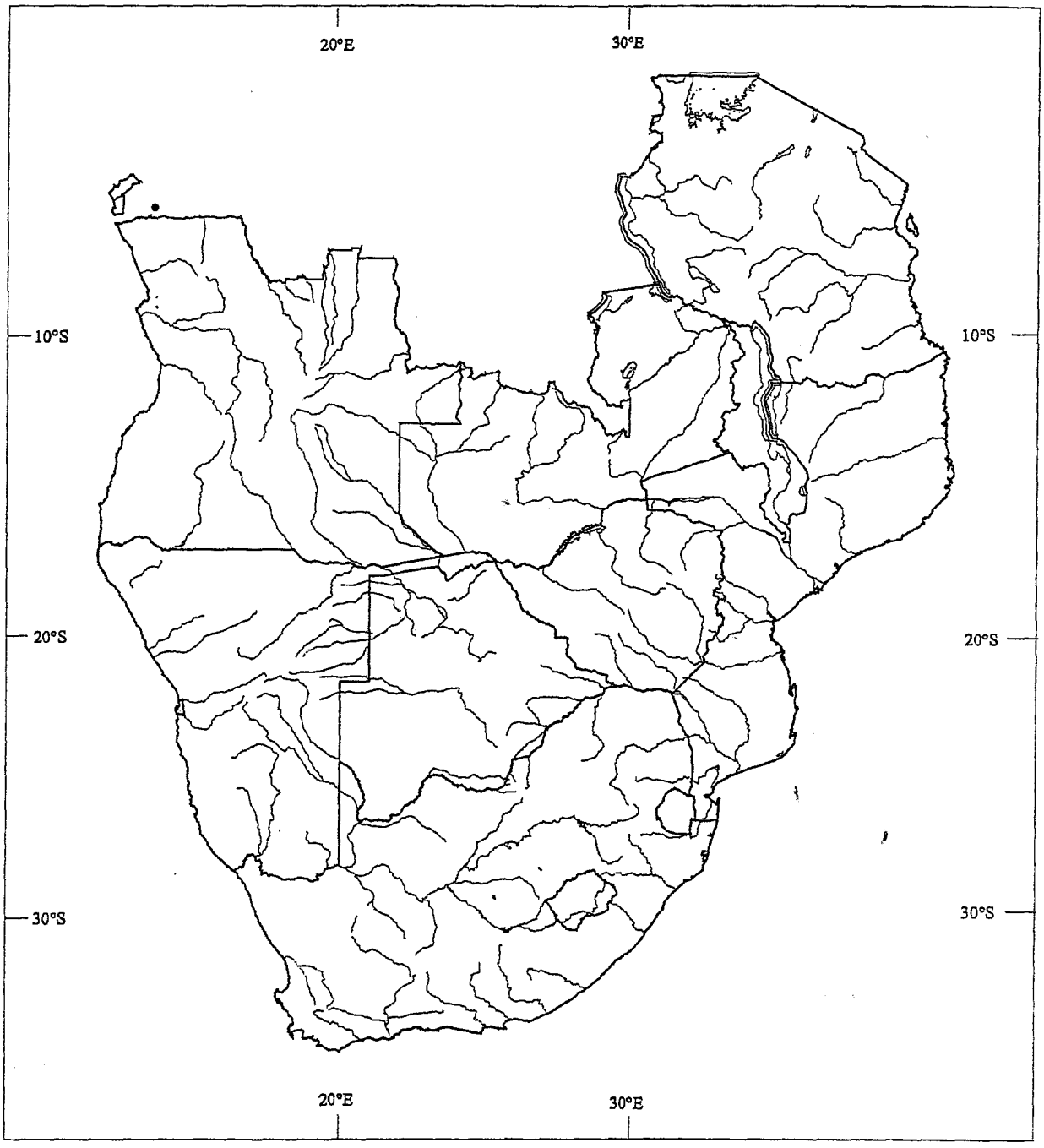


Figure F.558. Point distribution of *Phractura lindica*. Scale approximately 1:25 000 000

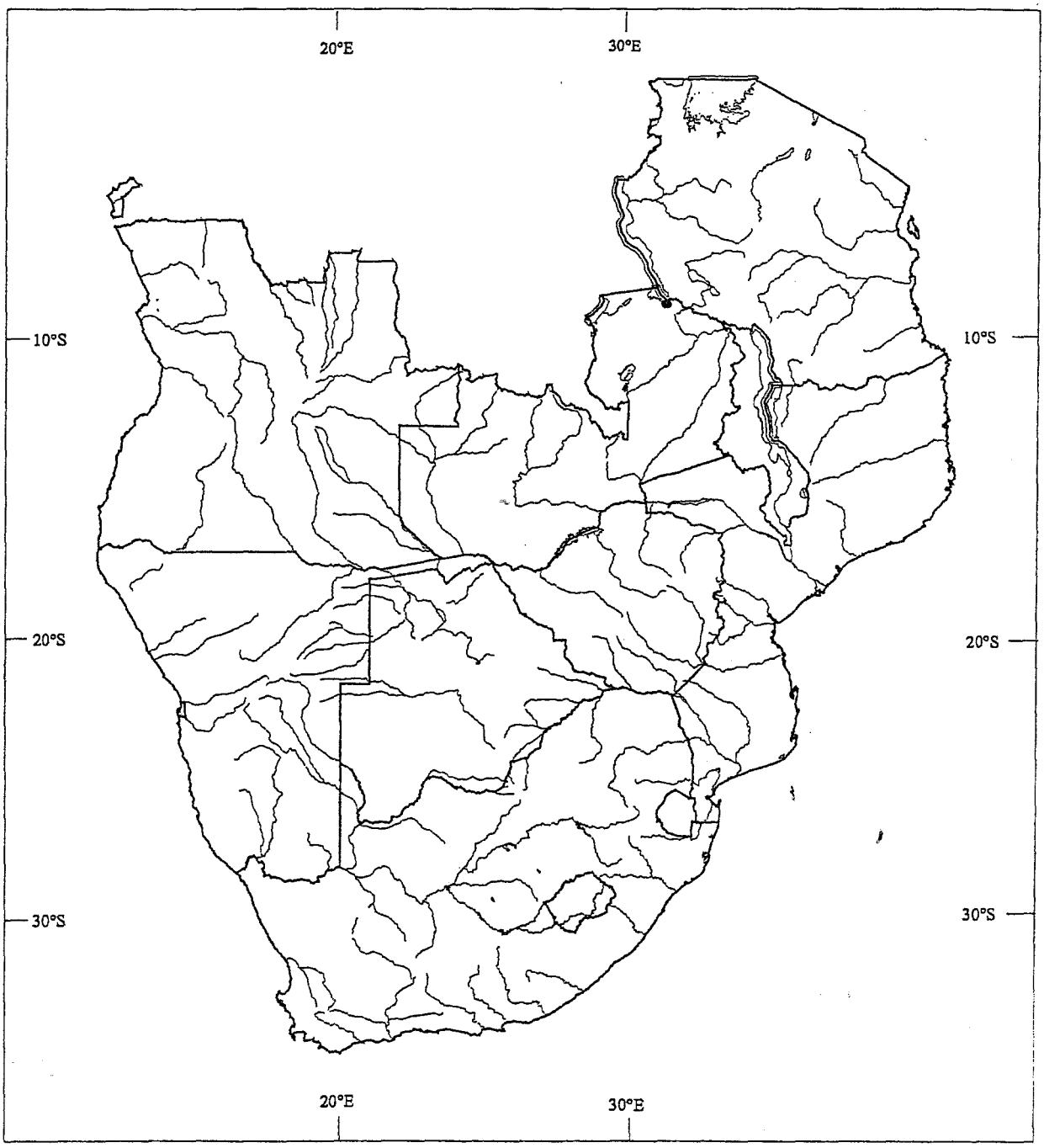


Figure F.559. Point distribution of *Phyllonemus typus*. Scale approximately 1:25 000 000

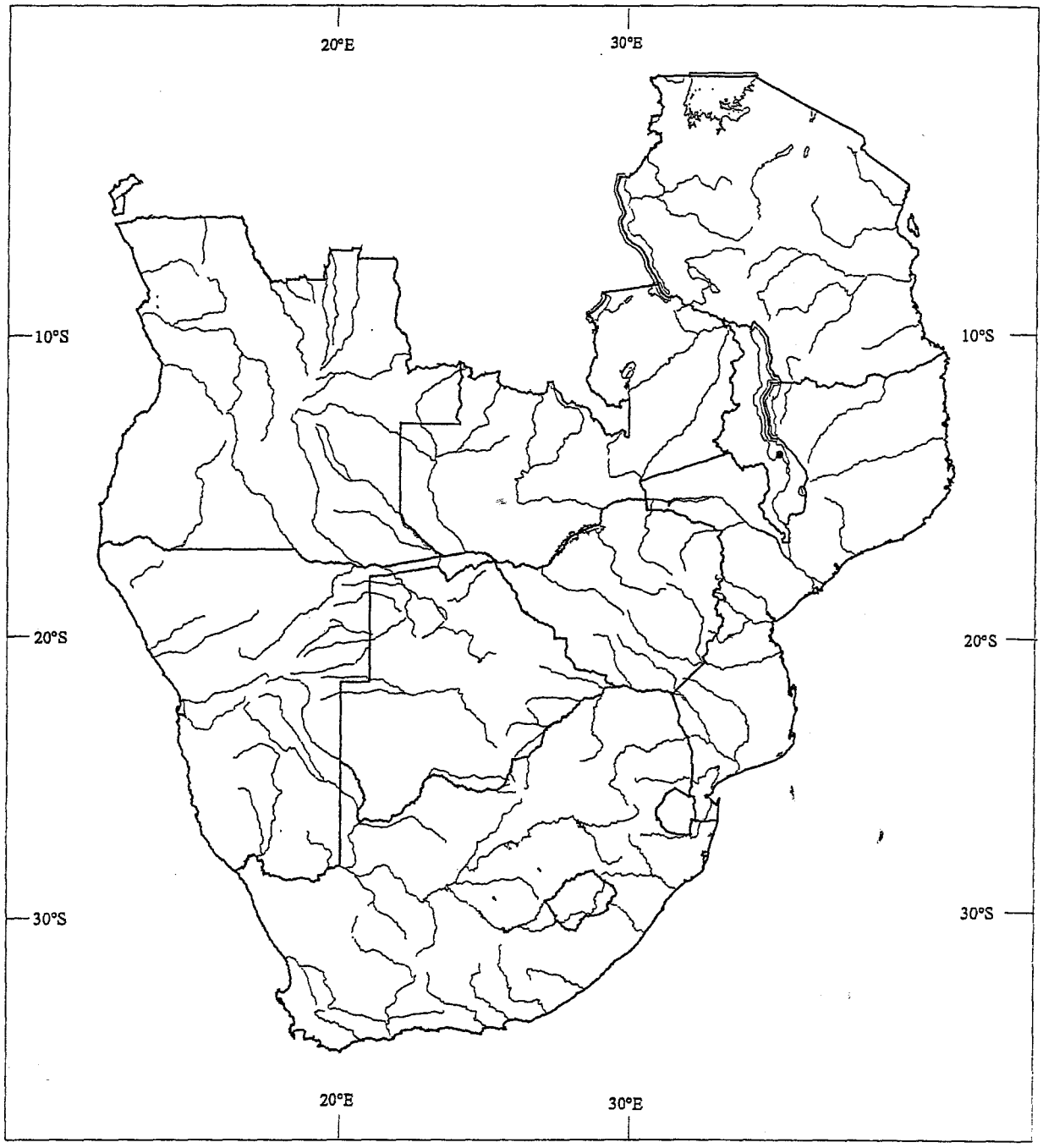


Figure F.560. Point distribution of *Placidochromis longimanus*. Scale approximately 1:25 000 000

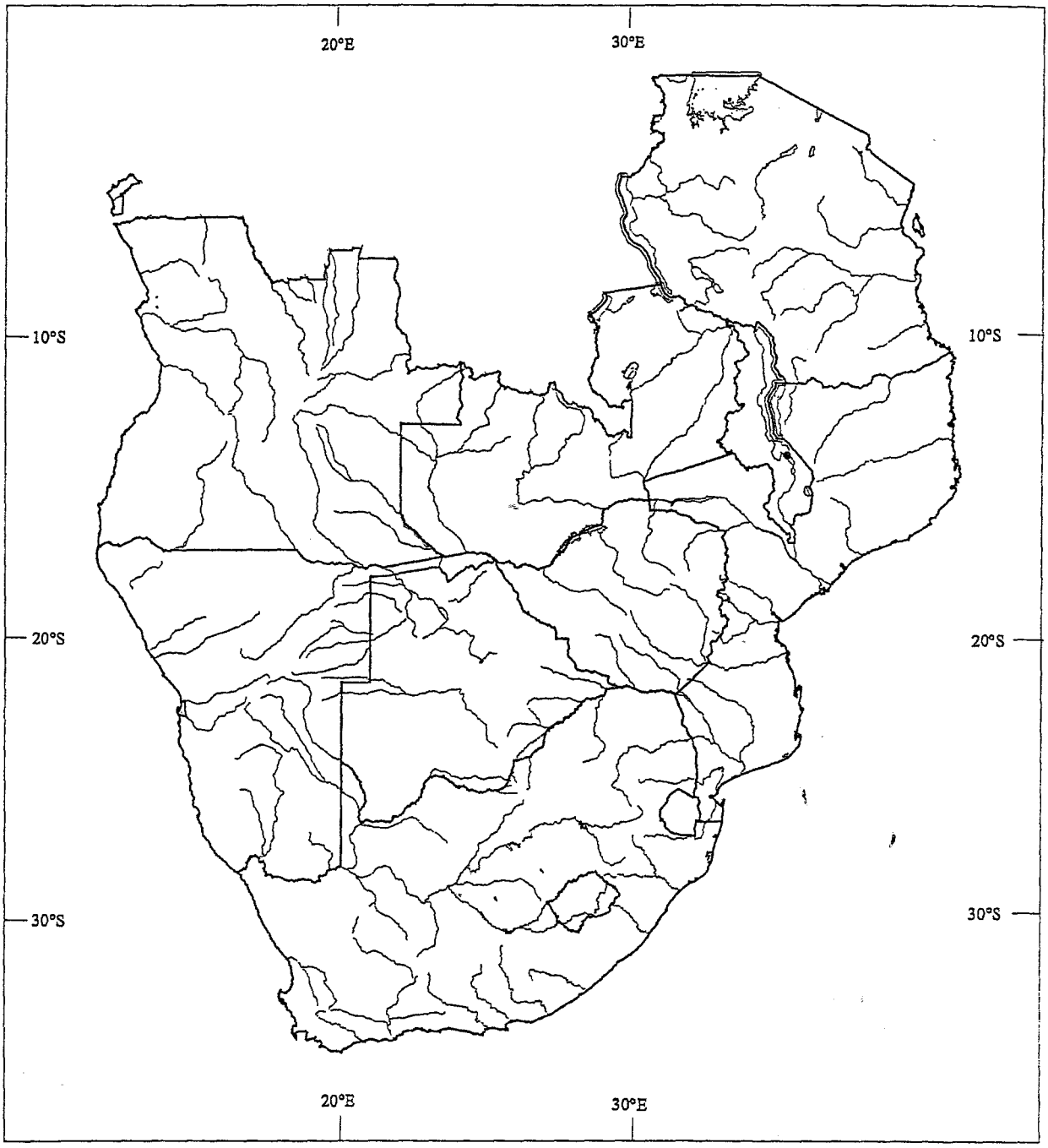


Figure F.561. Point distribution of *Placidochromis macrognathus*. Scale approximately 1:25 000 000

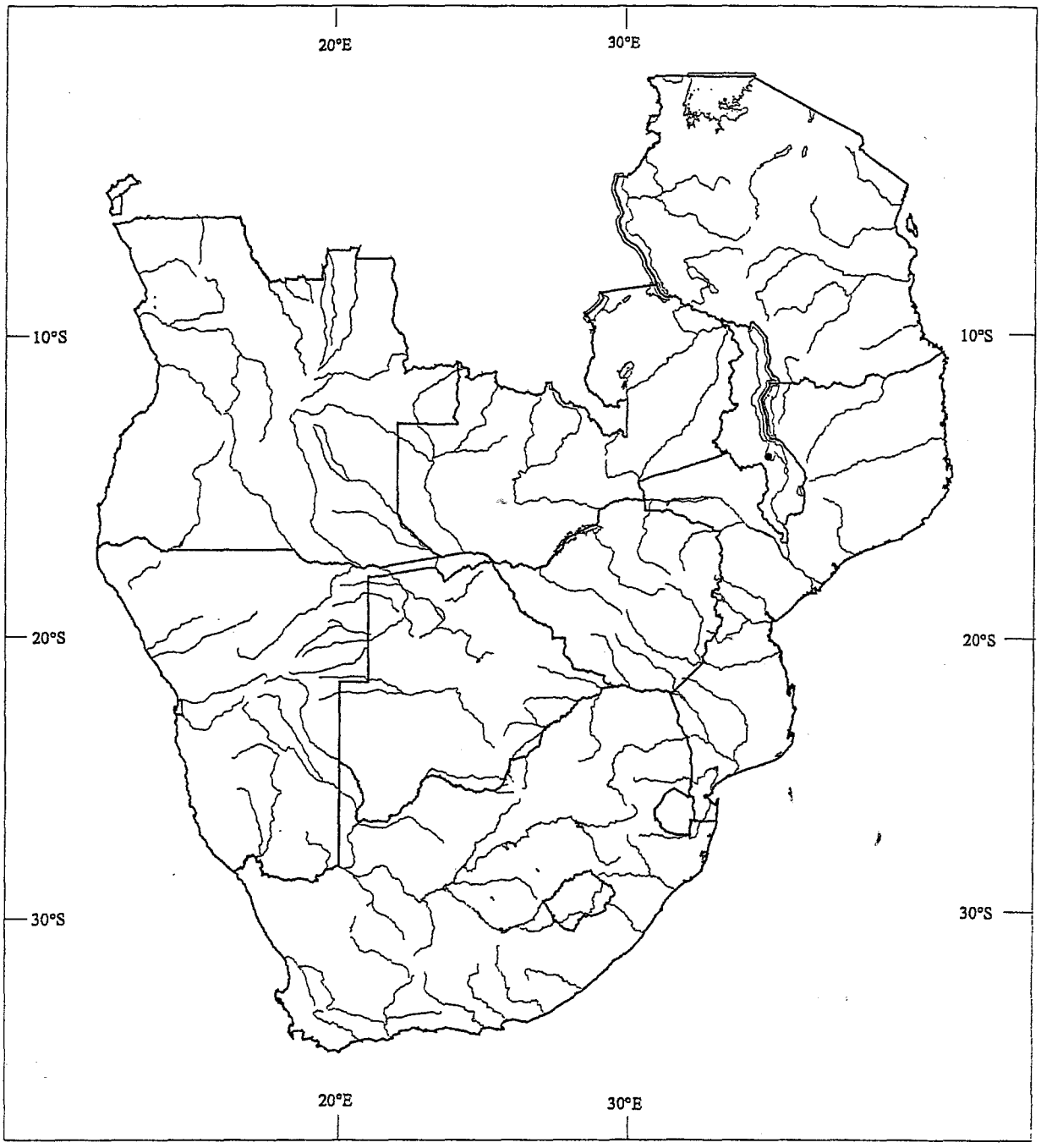


Figure F.562. Point distribution of *Placidochromis subocularis*. Scale approximately 1:25 000 000

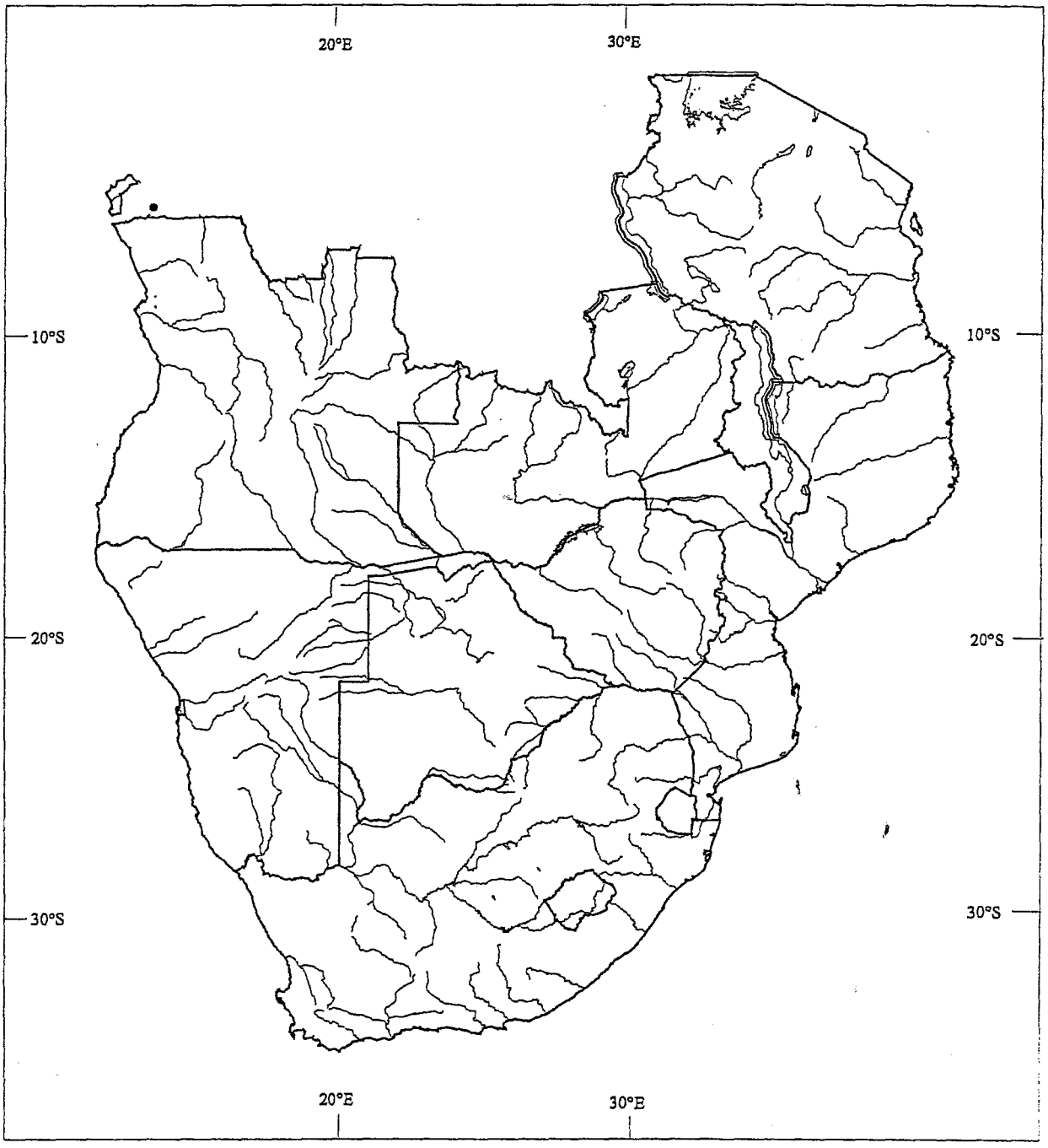


Figure F.563. Point distribution of *Platyallabes tihoni*. Scale approximately 1:25 000 000

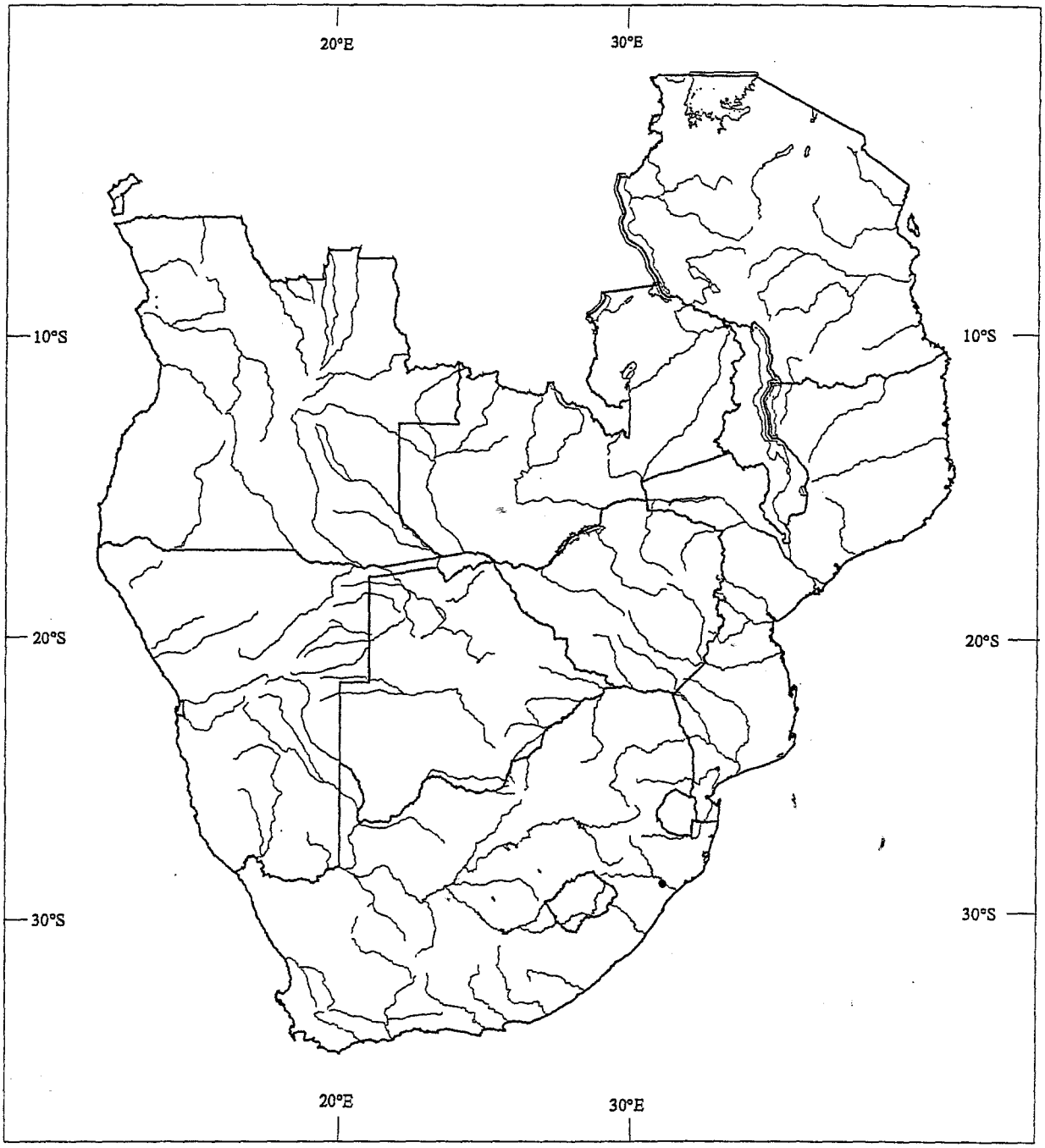


Figure F.564. Point distribution of *Platycephalus indicus*. Scale approximately 1:25 000 000

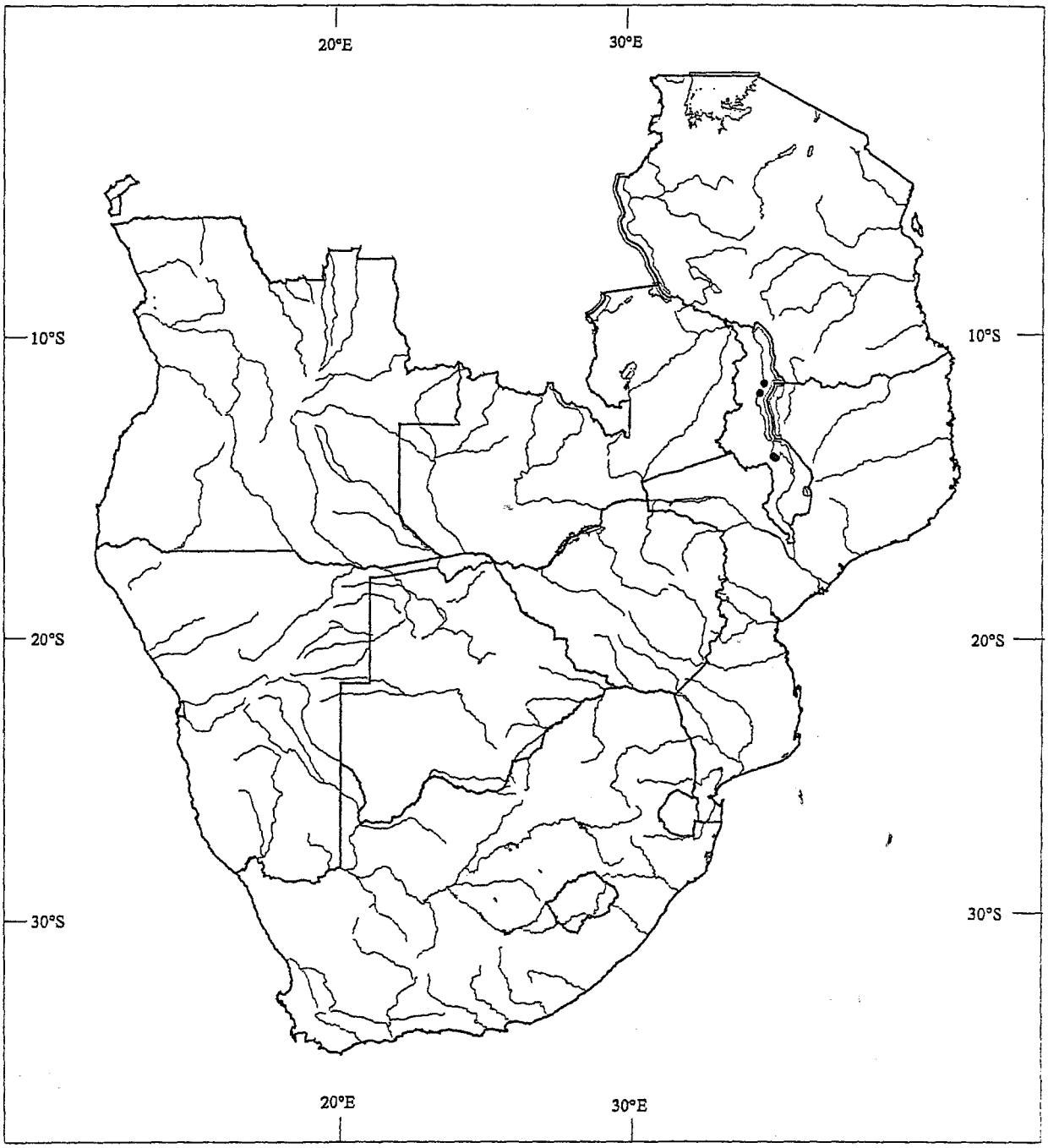


Figure F.565. Point distribution of *Platygnathochromis melanonotus*. Scale approximately 1:25 000 000

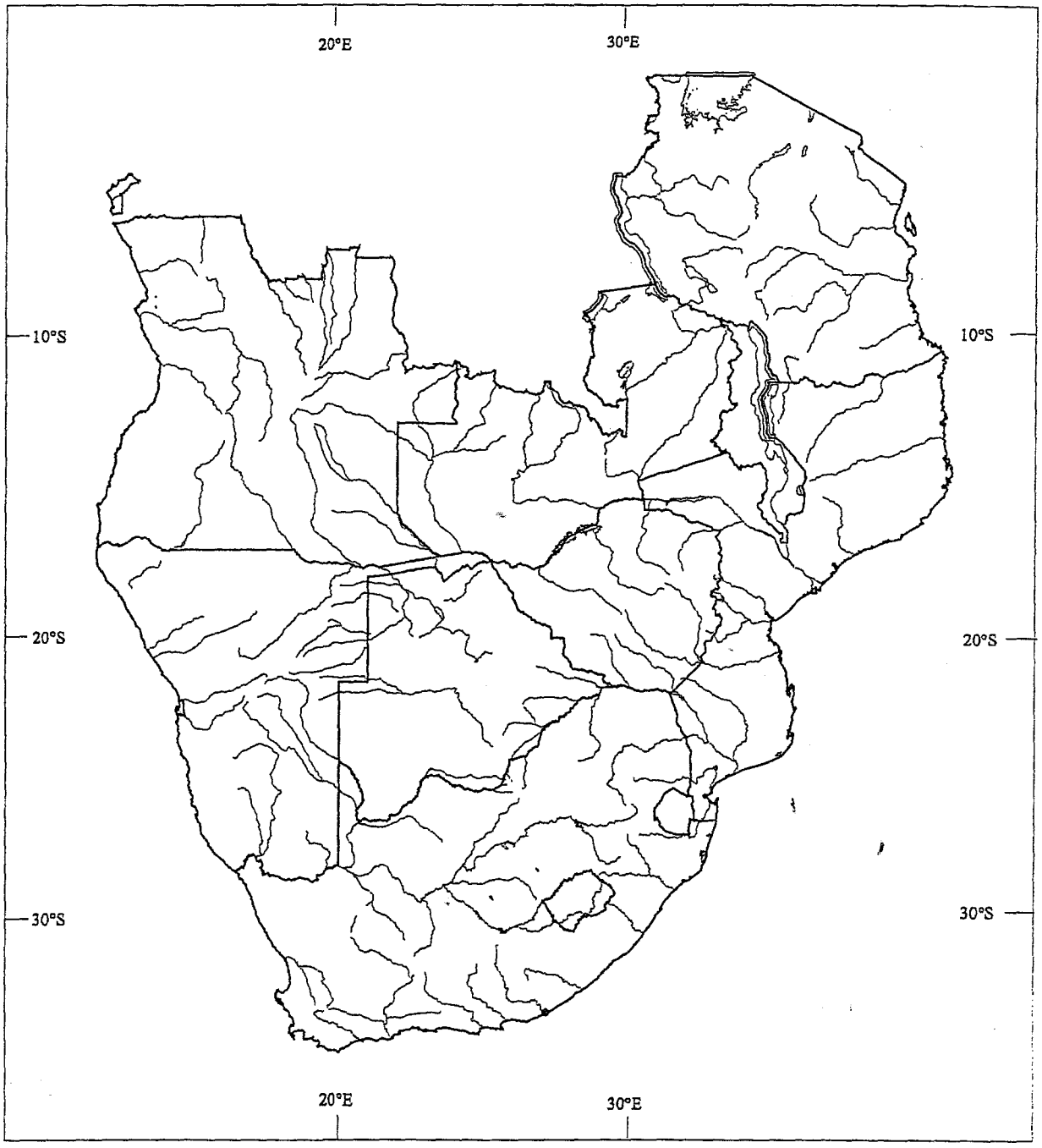


Figure F.566. Point distribution of *Plotosus anguillaris*. Scale approximately 1:25 000 000

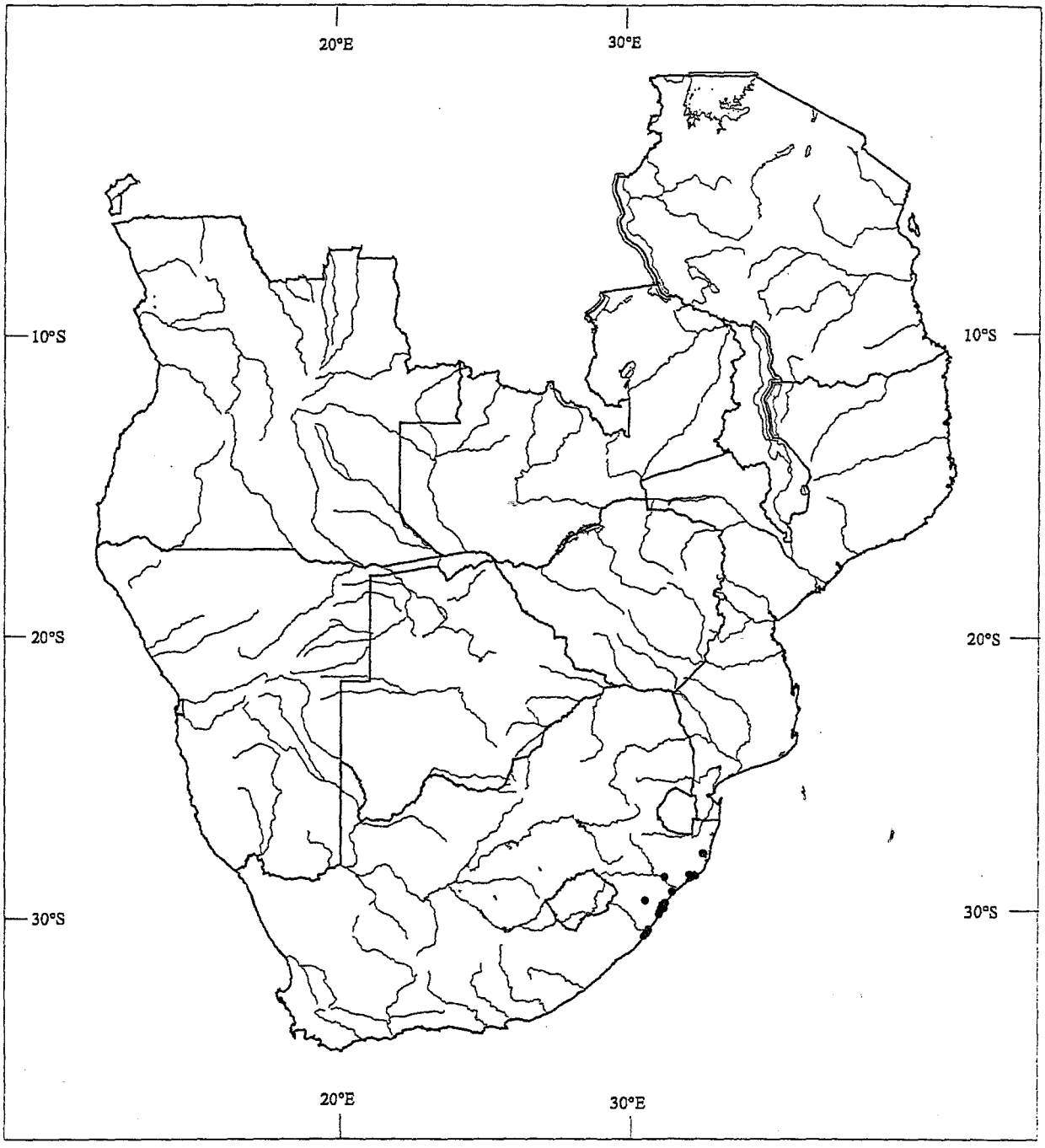


Figure F.567. Point distribution of *Poecilia reticulata*. Scale approximately 1:25 000 000

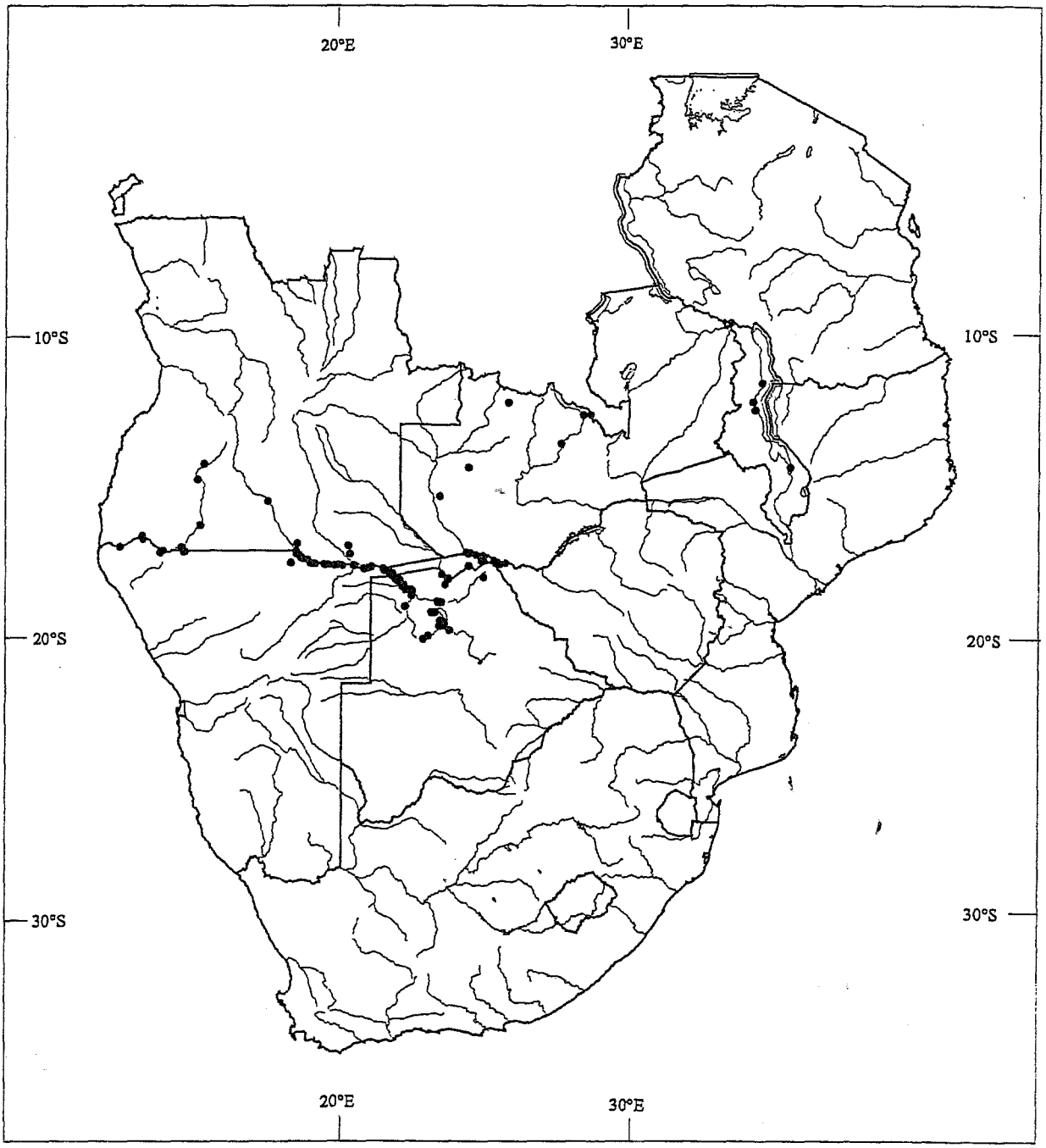


Figure F.568. Point distribution of *Pollimyrus castelnaui*. Scale approximately 1:25 000 000

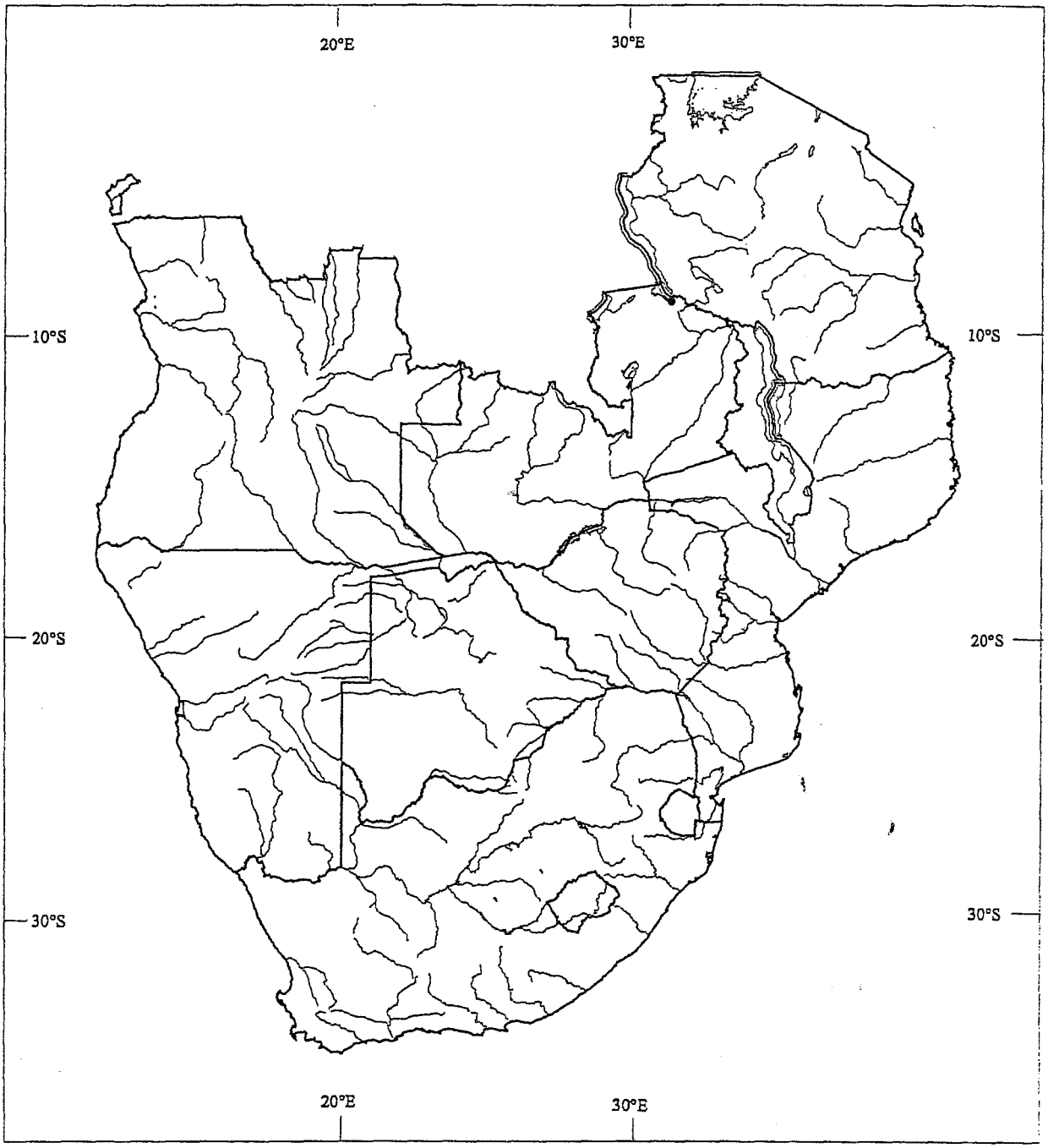


Figure F.569. Point distribution of *Polypterus endlicheri*. Scale approximately 1:25 000 000

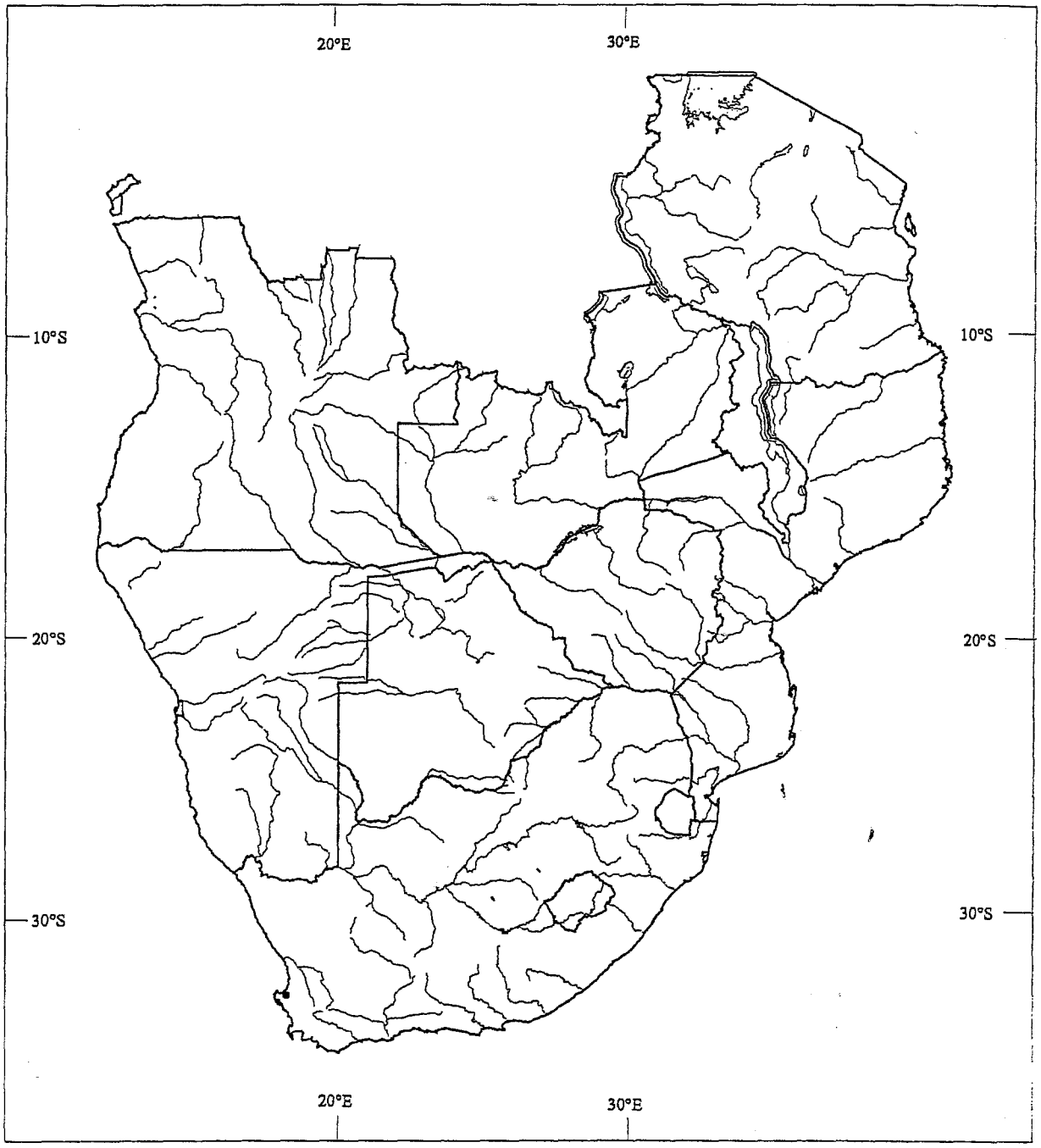


Figure F.570. Point distribution of *Pomatomus saltator*. Scale approximately 1:25 000 000

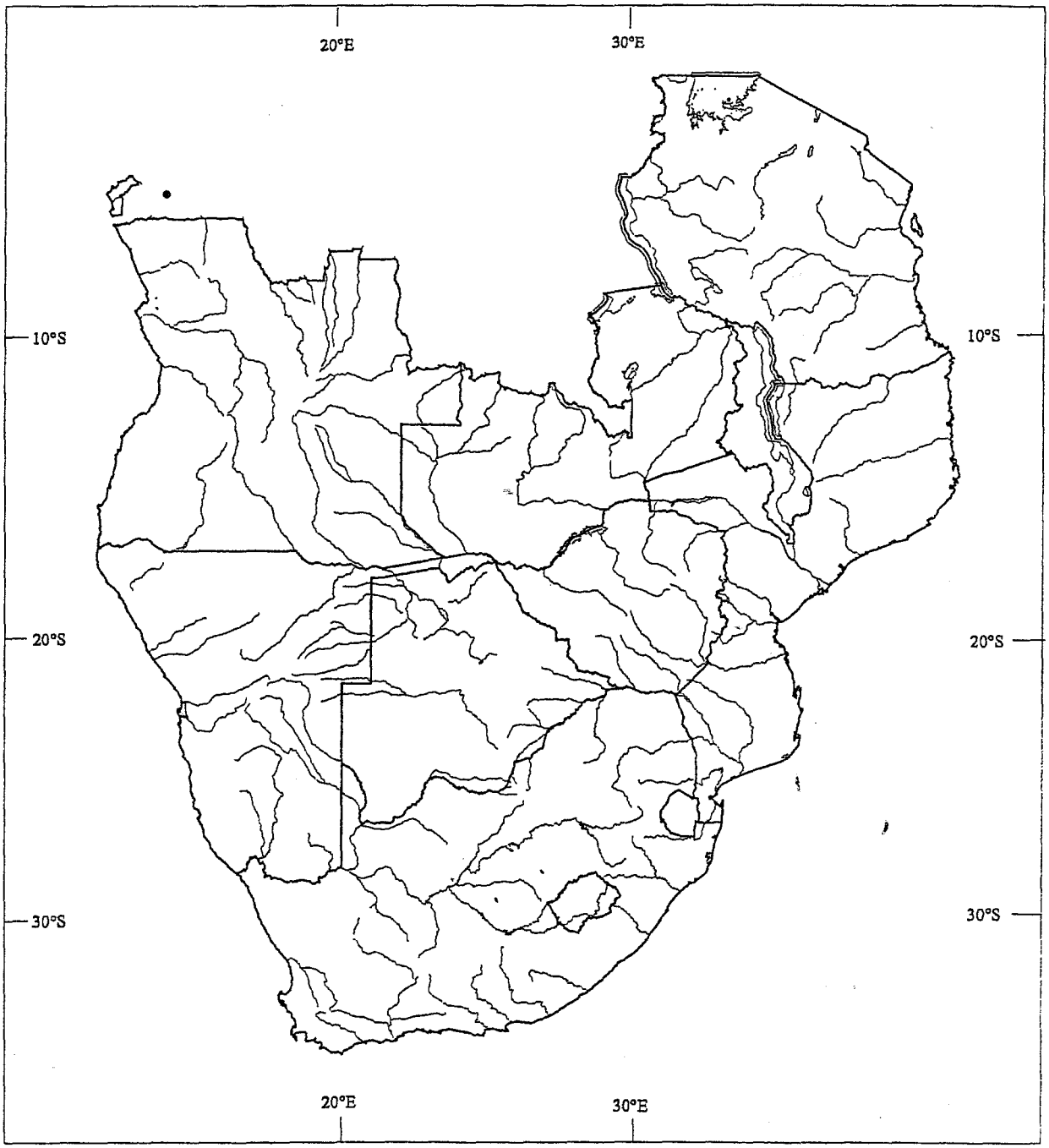


Figure F.571. Point distribution of *Potamothrissa obtusi rostris*. Scale approximately 1:25 000 000

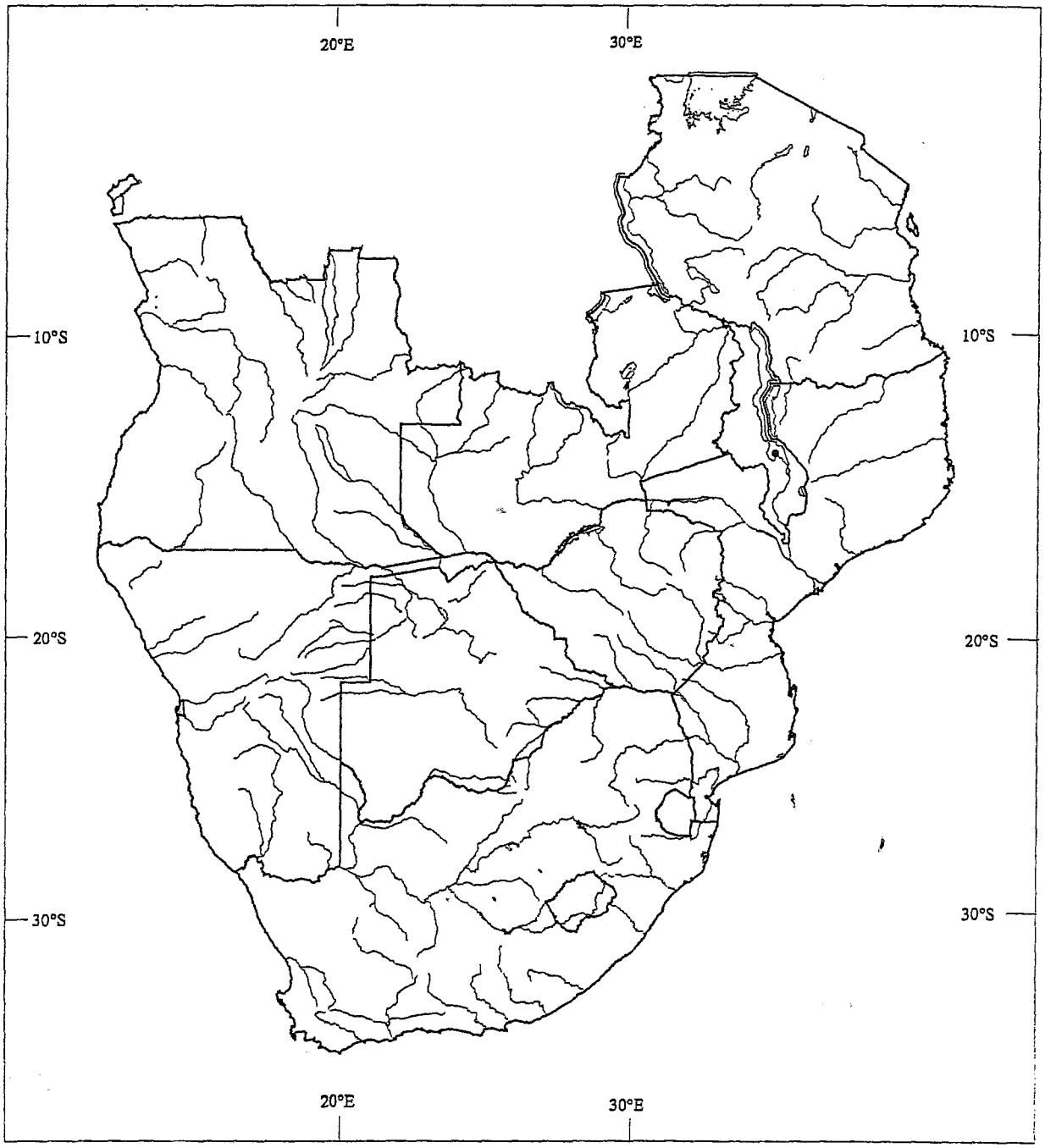


Figure F.572. Point distribution of *Protomelas annectens*. Scale approximately 1:25 000 000

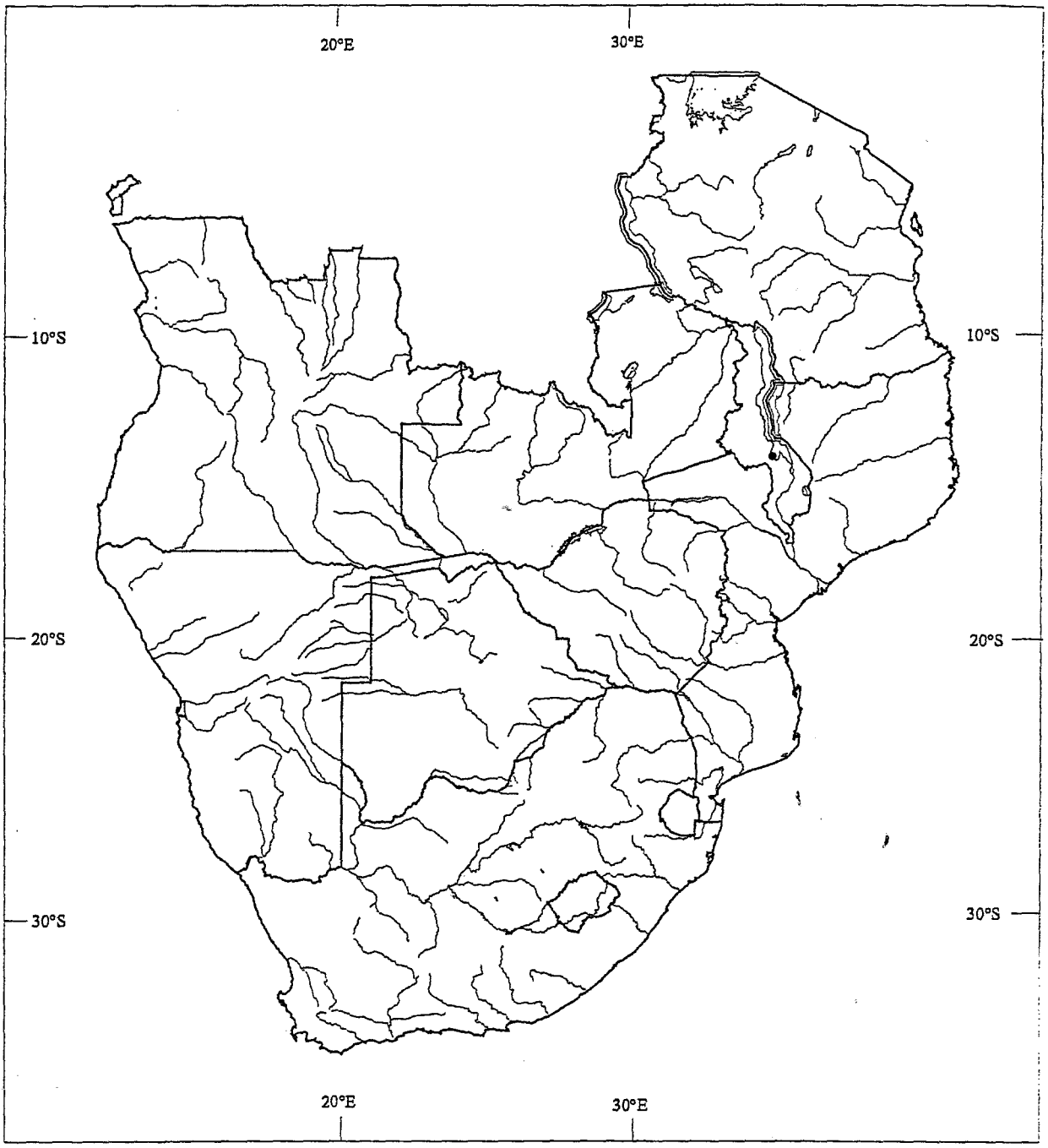


Figure F.573. Point distribution of *Protomelas kirkii*. Scale approximately 1:25 000 000

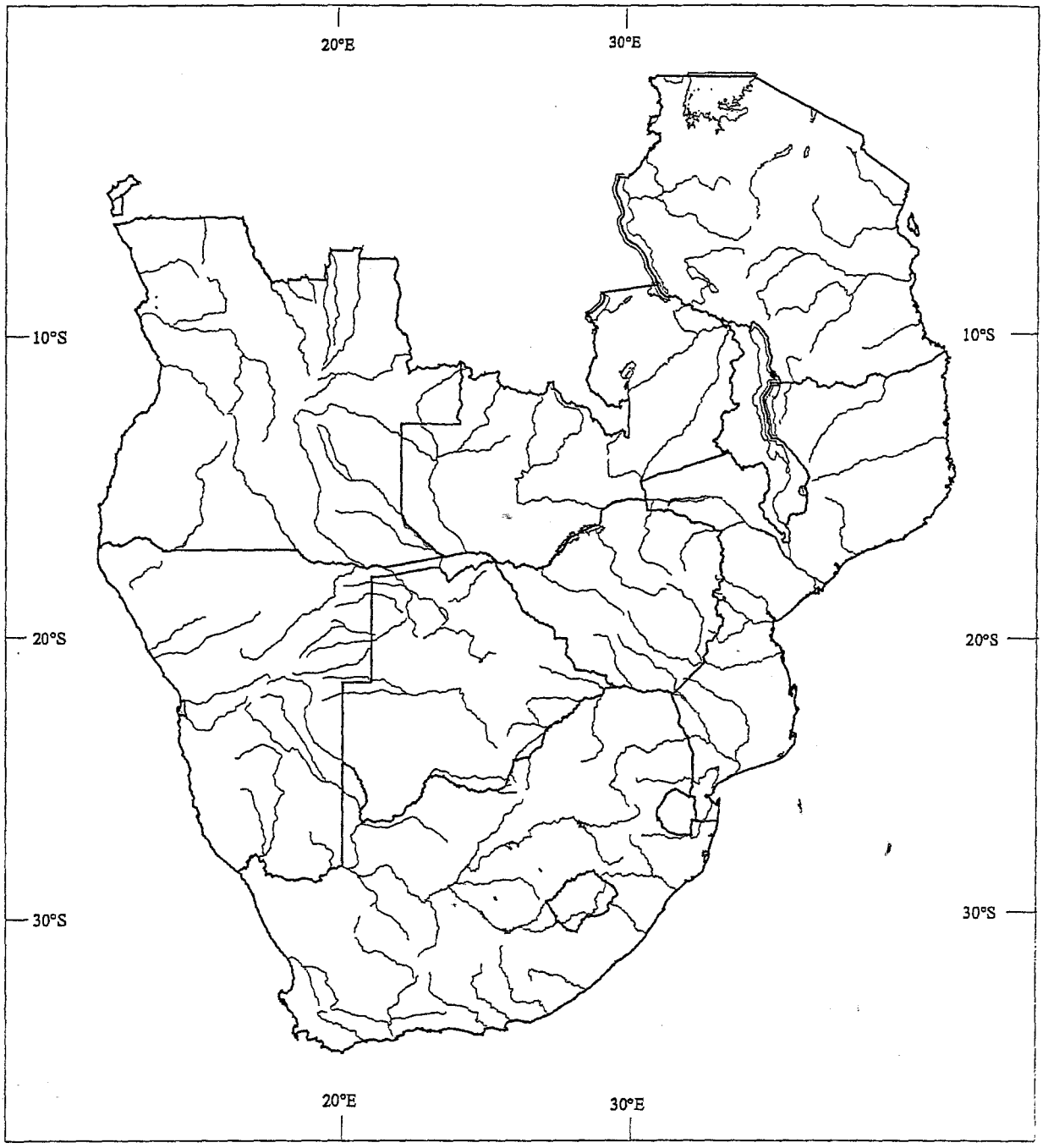


Figure F.574. Point distribution of *Protomelas labridens*. Scale approximately 1:25 000 000

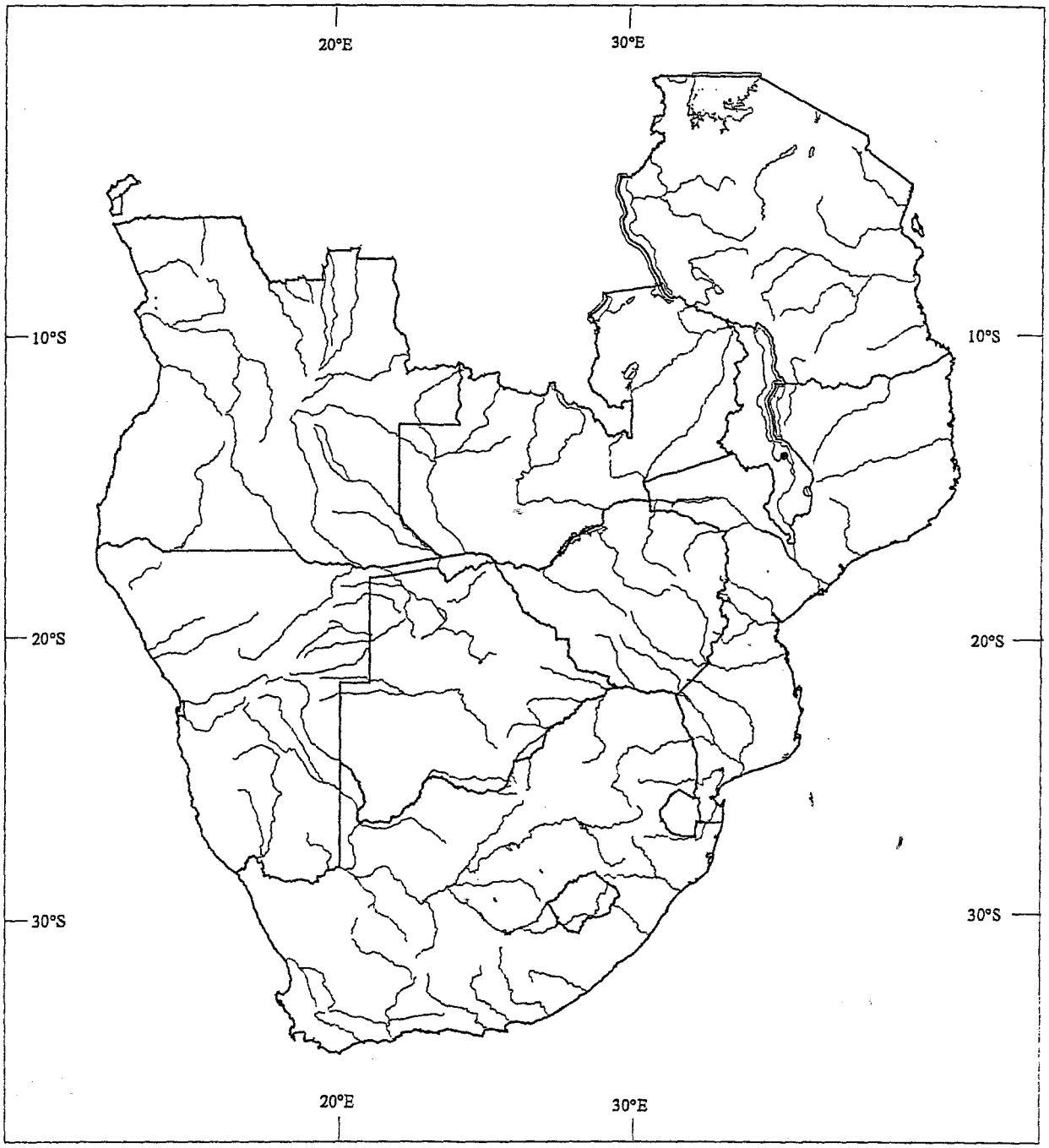


Figure F.575. Point distribution of *Protomelas marginatus*. Scale approximately 1:25 000 000

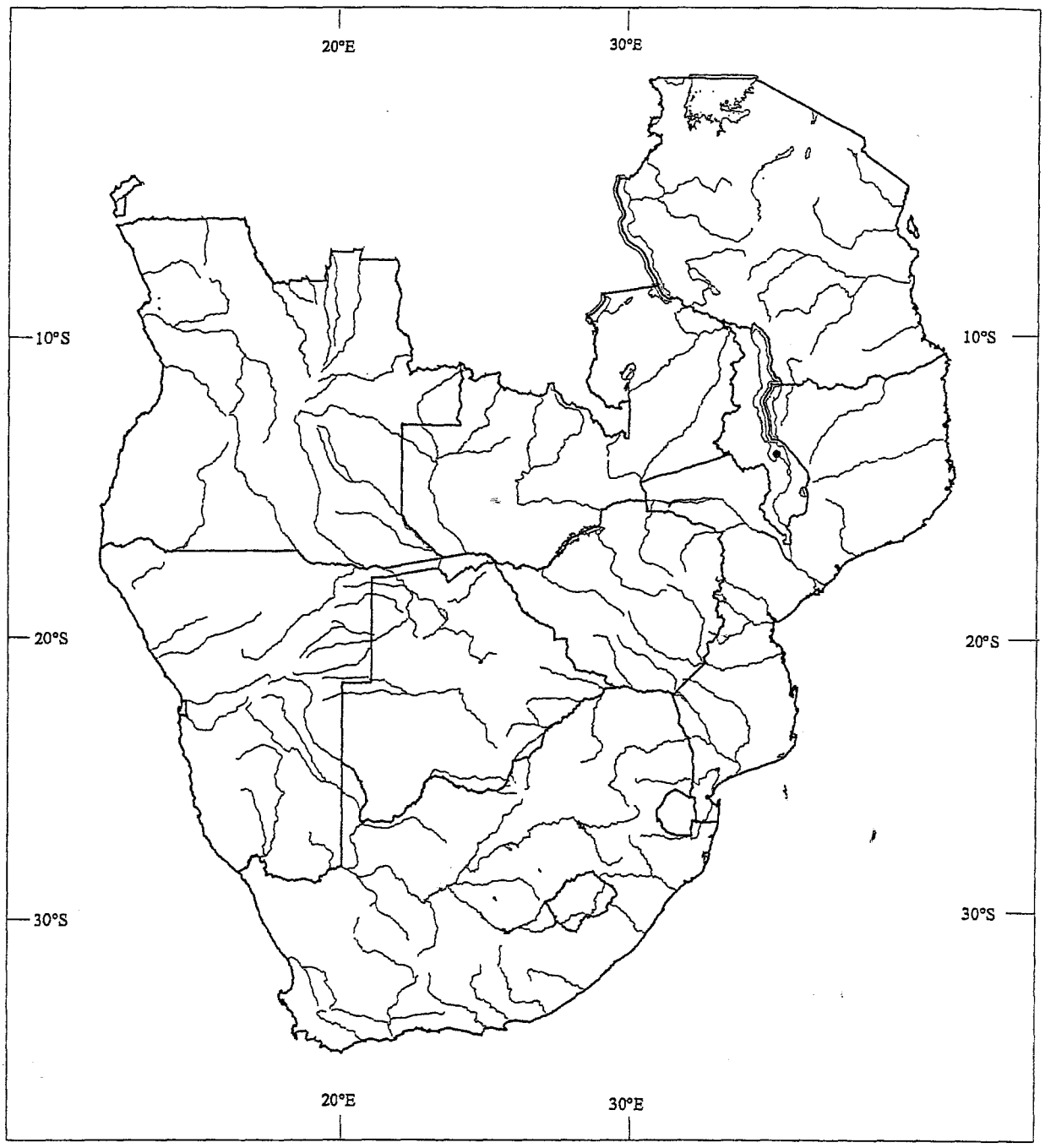


Figure F.576. Point distribution of *Protomelas similis*. Scale approximately 1:25 000 000

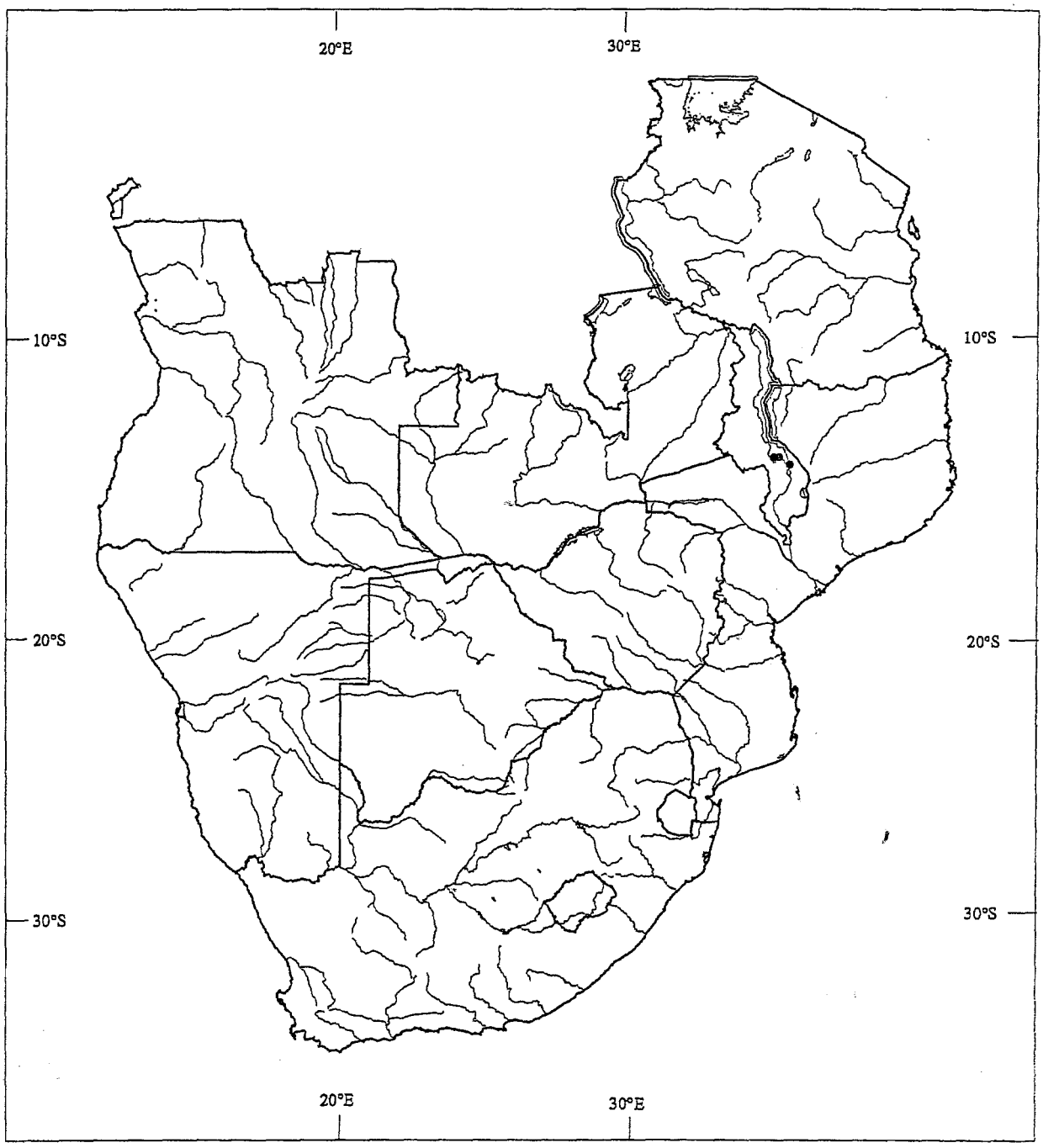


Figure F.577. Point distribution of *Protomelas spilopterus*. Scale approximately 1:25 000 000

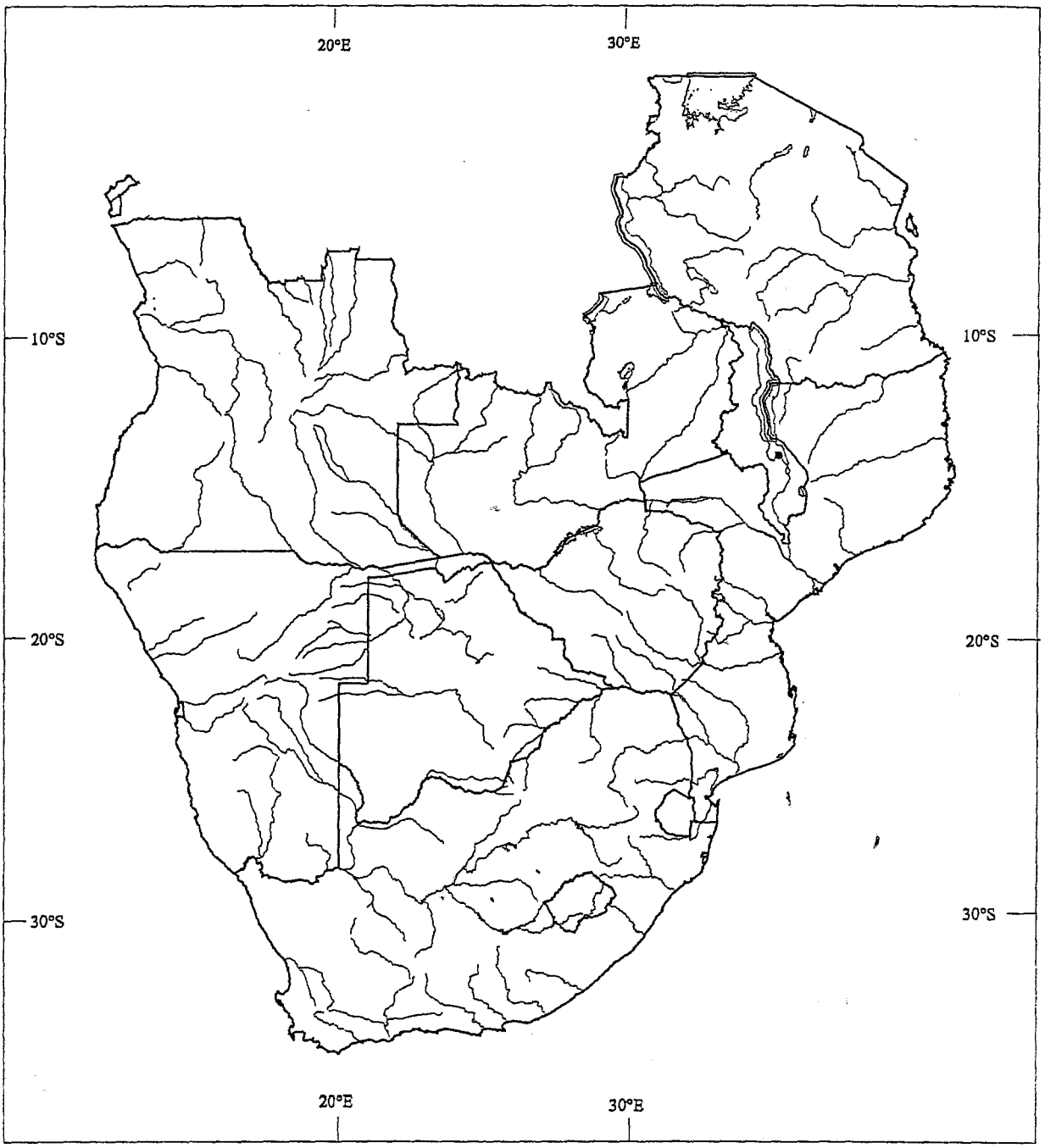


Figure F.578. Point distribution of *Protomelas taeniolatus*. Scale approximately 1:25 000 000

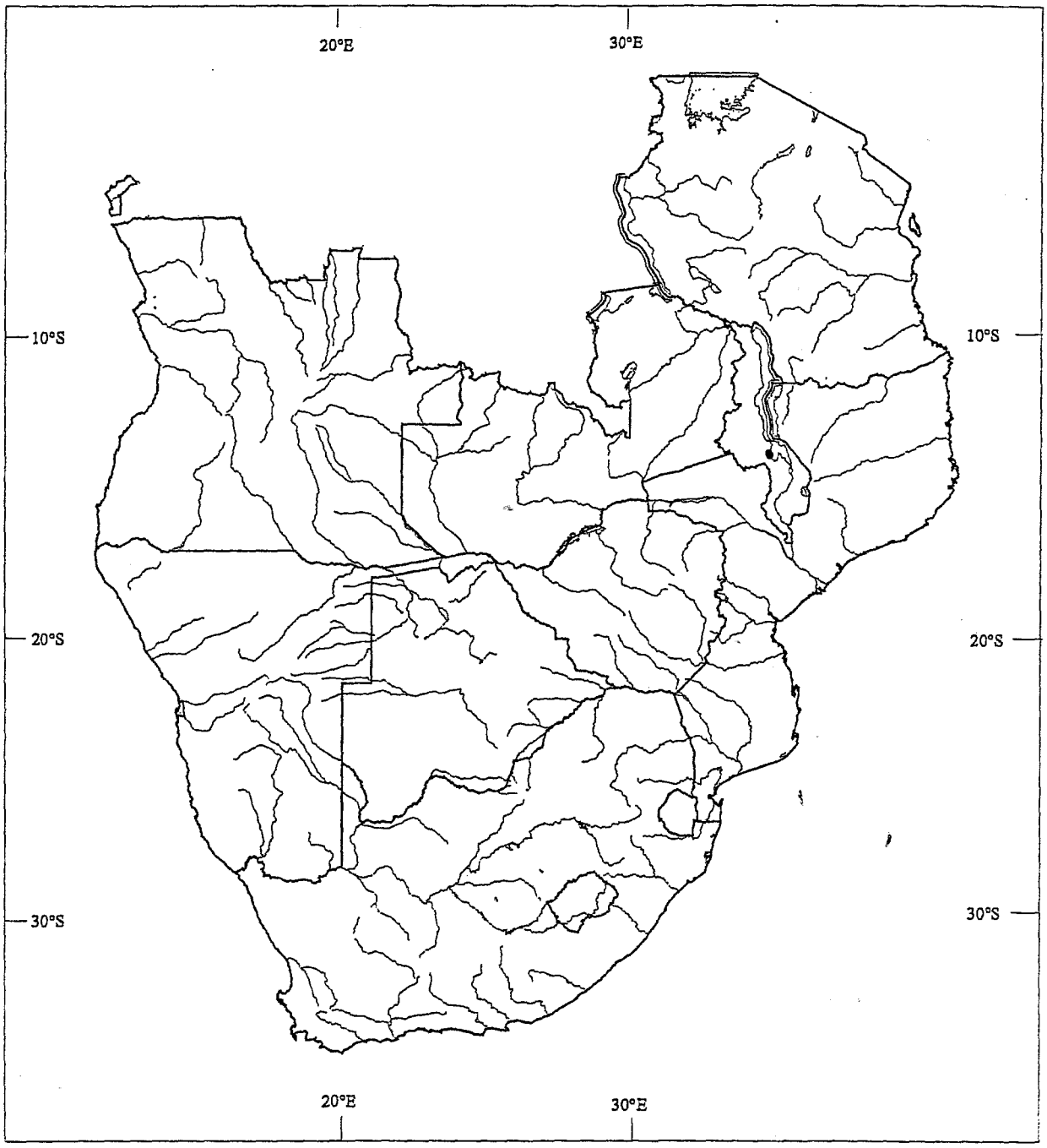


Figure F.579. Point distribution of *Protomelas triaenodon*. Scale approximately 1:25 000 000

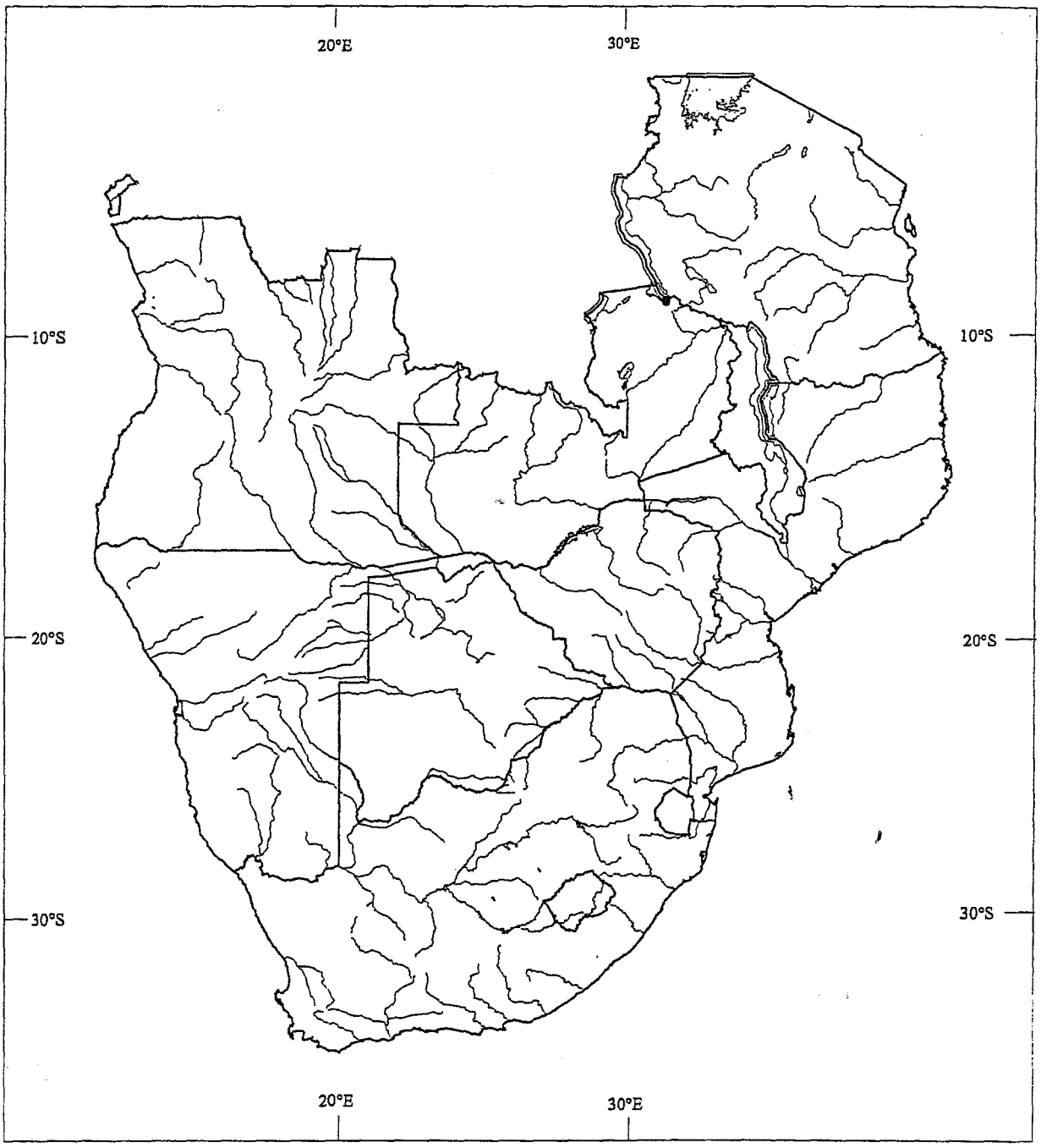


Figure F.580. Point distribution of *Protopterus aethiopicus*. Scale approximately 1:25 000 000

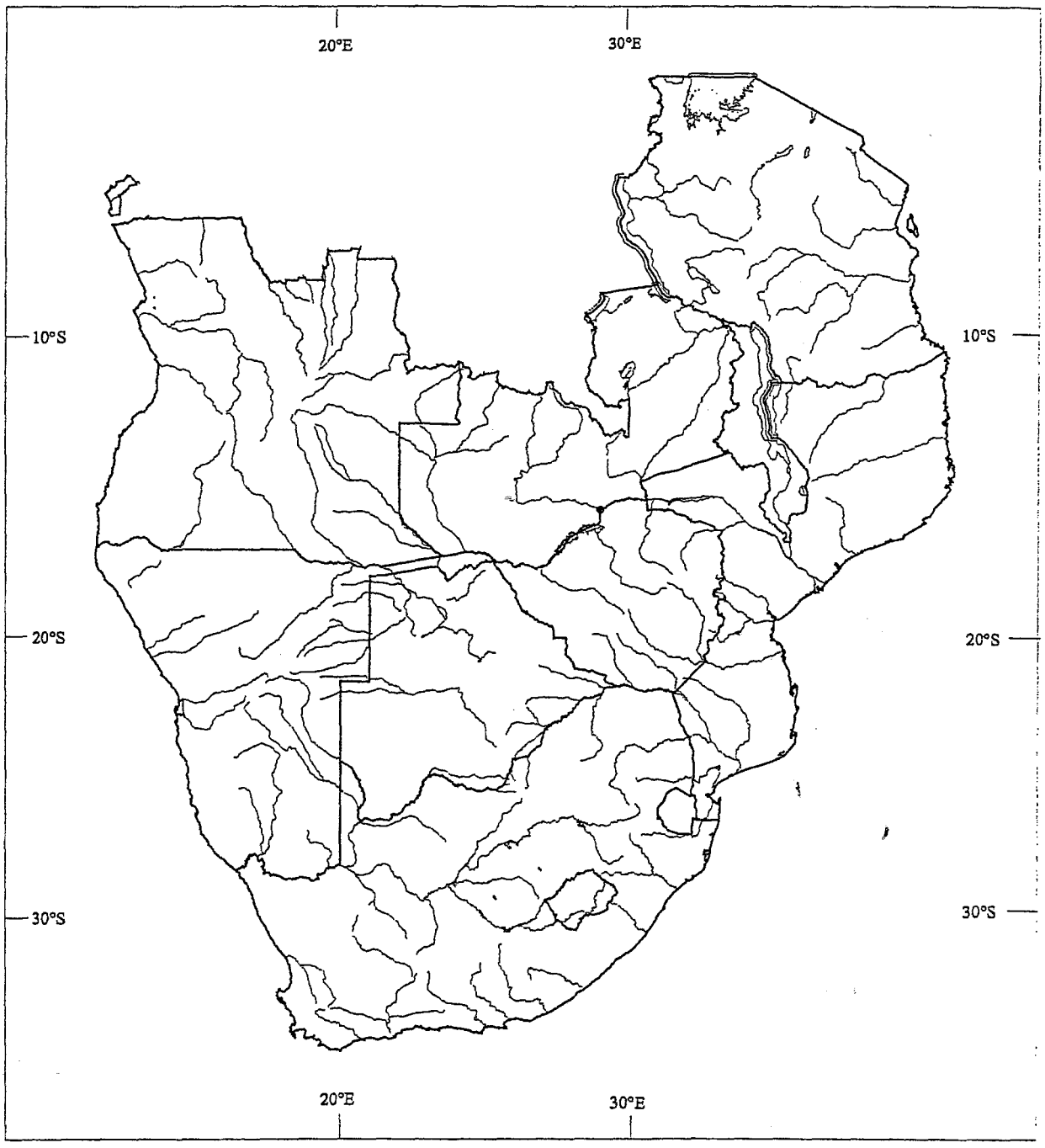


Figure F.581. Point distribution of *Protopterus annectens*. Scale approximately 1:25 000 000

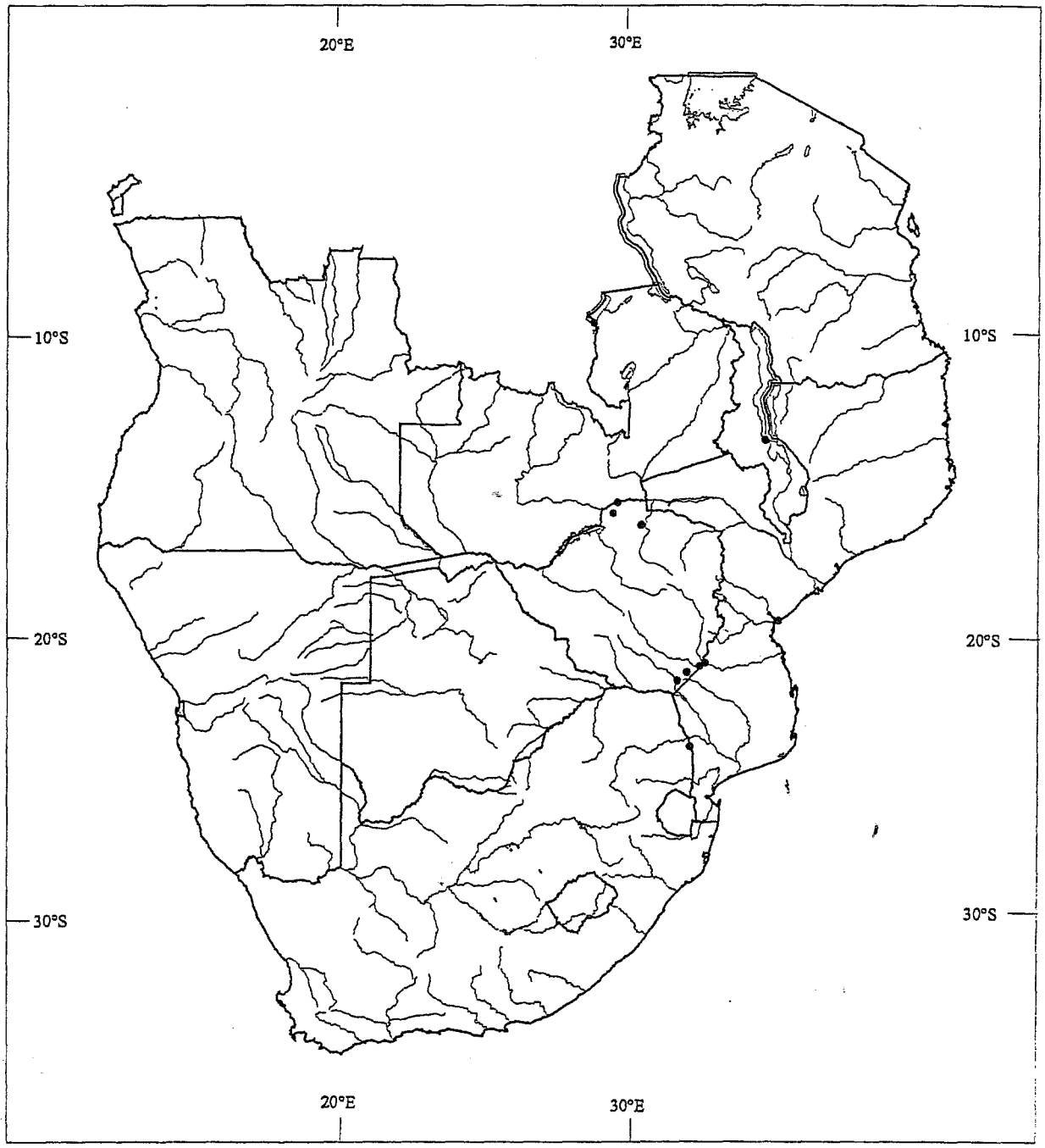


Figure F.582. Point distribution of *Protopterus annectens brieni*. Scale approximately 1:25 000 000

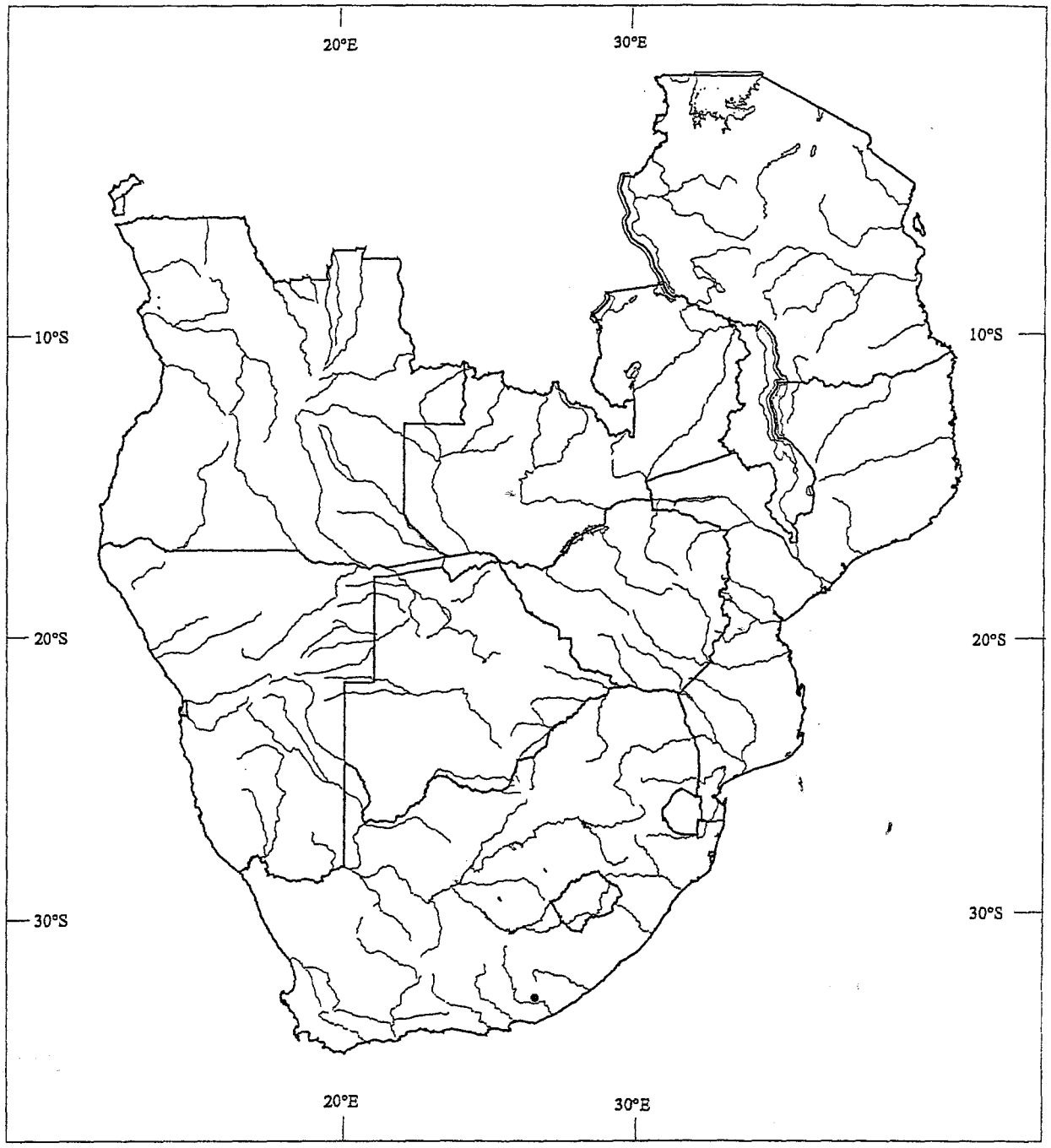


Figure F.583. Point distribution of *Psammogobius knysnaensis*. Scale approximately 1:25 000 000

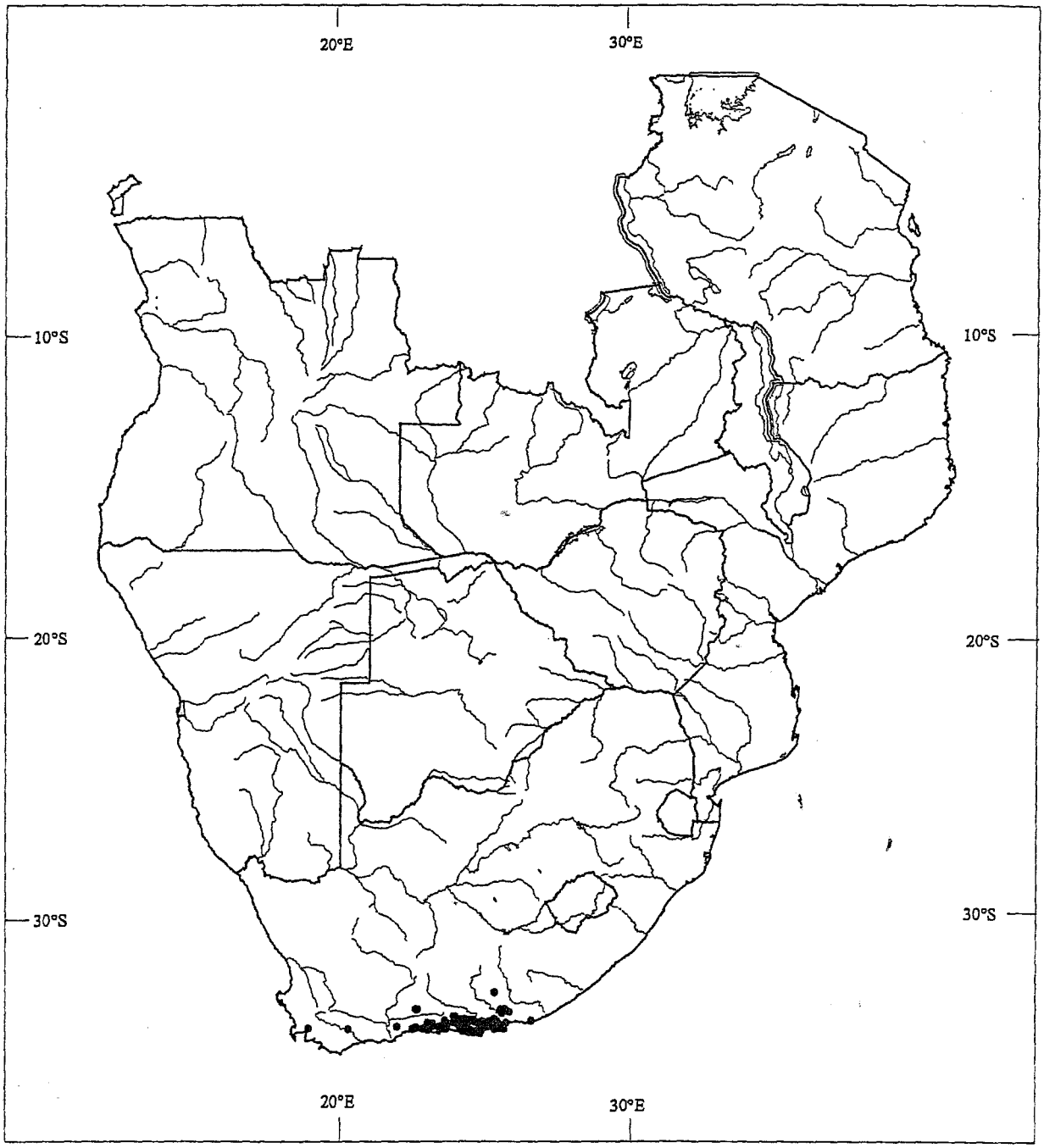


Figure F.584. Point distribution of *Pseudobarbus afer*. Scale approximately 1:25 000 000

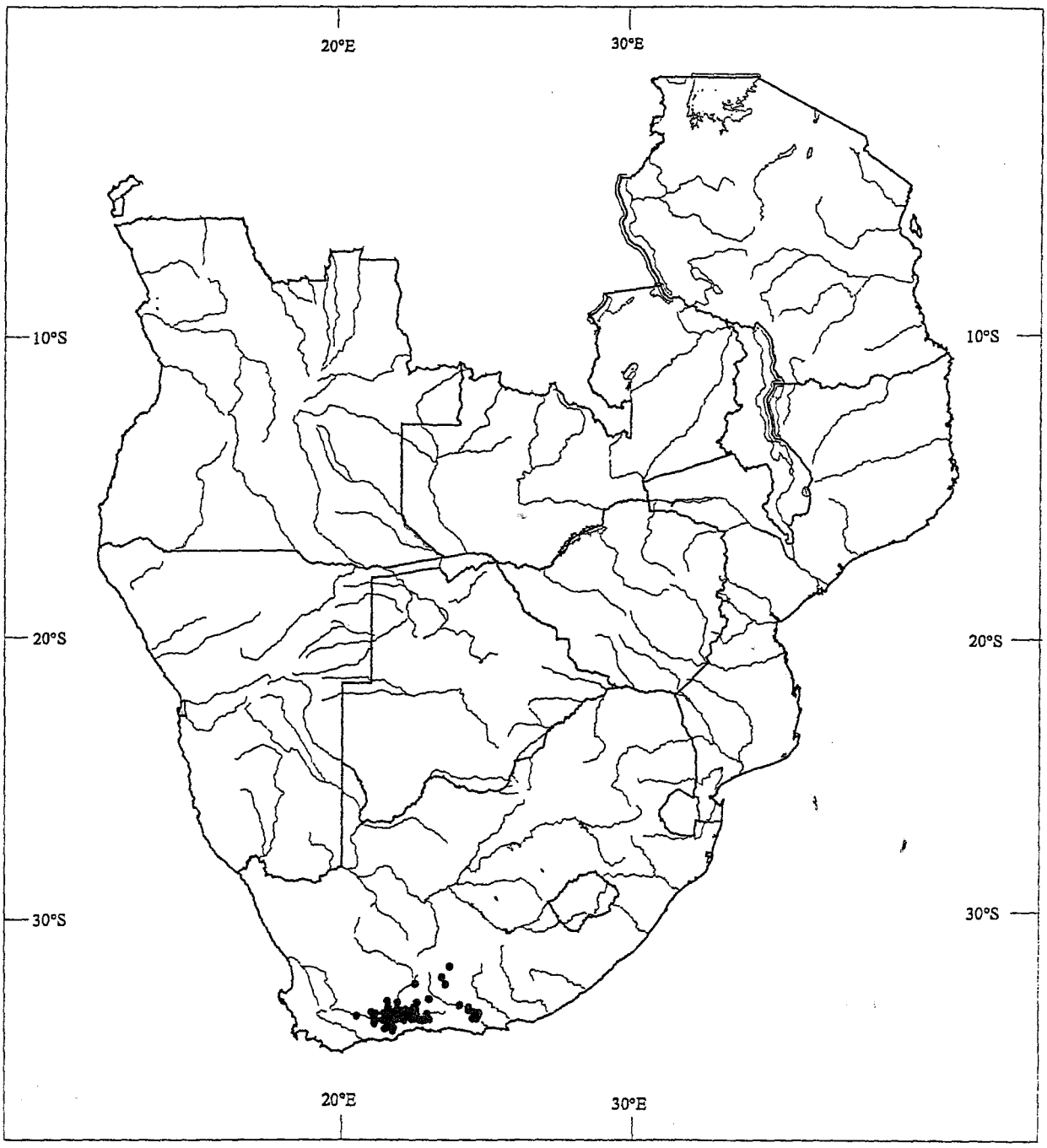


Figure F.585. Point distribution of *Pseudobarbus asper*. Scale approximately 1:25 000 000

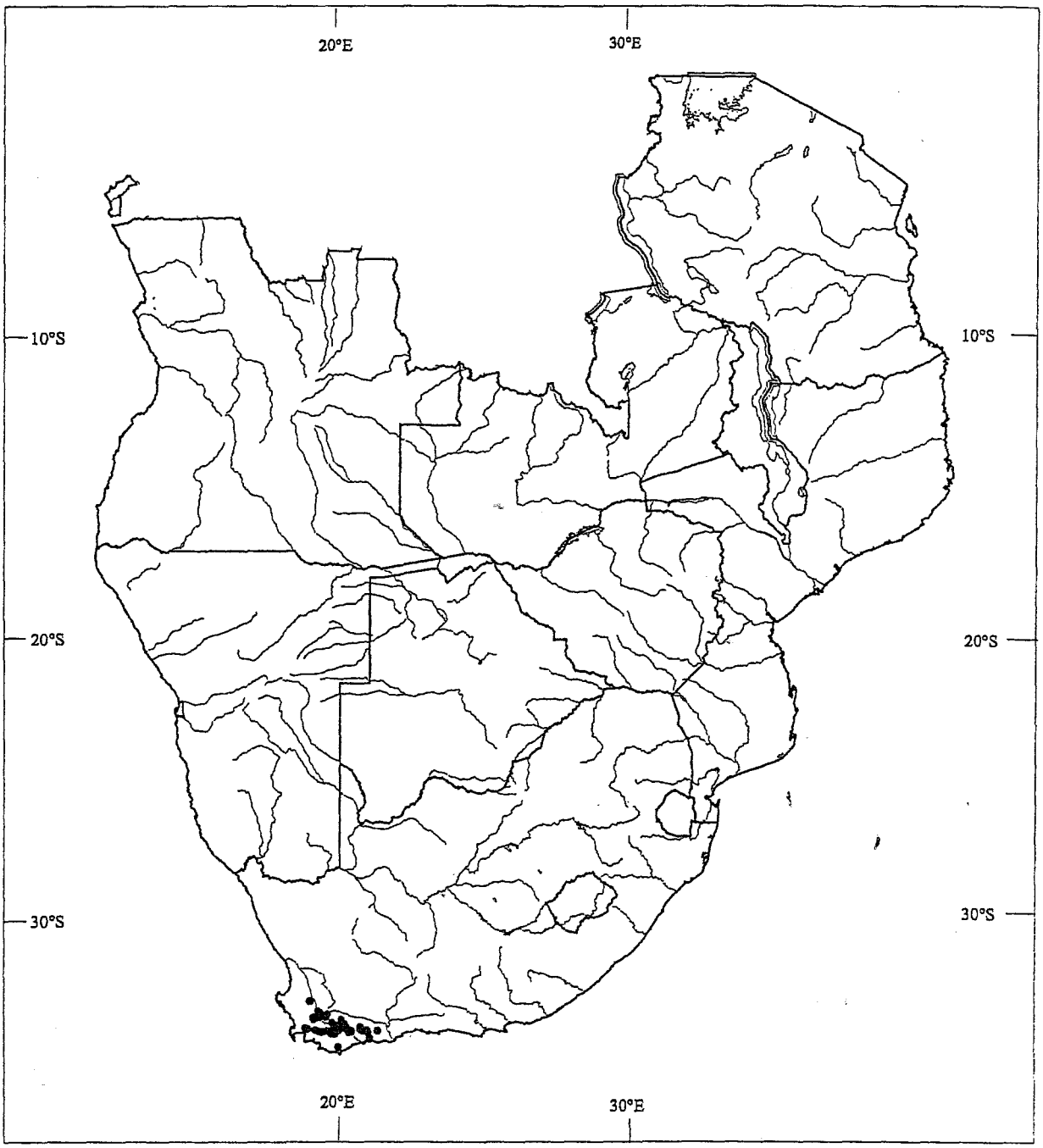


Figure F.586. Point distribution of *Pseudobarbus burchelli*. Scale approximately 1:25 000 000

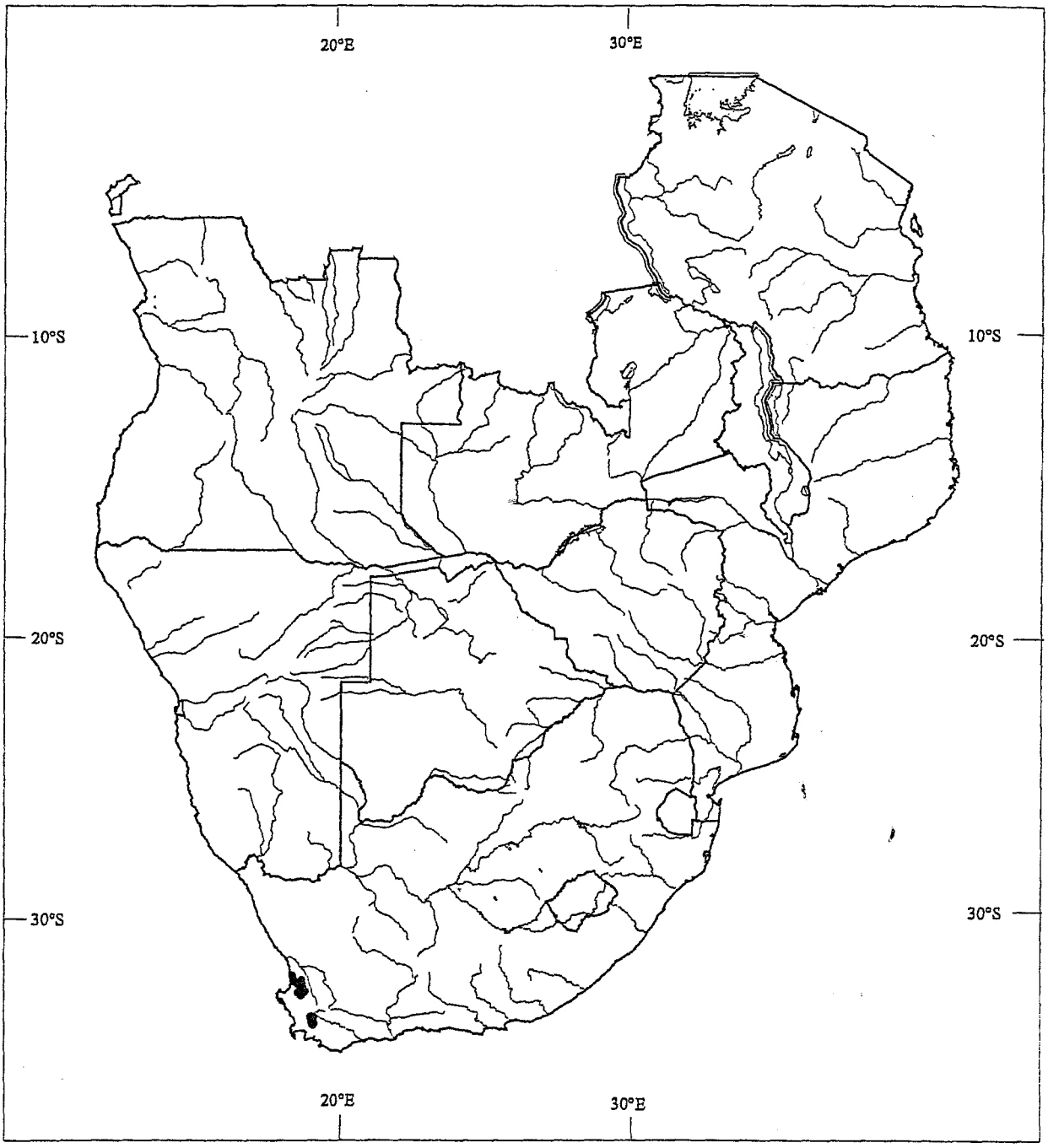


Figure F.587. Point distribution of *Pseudobarbus burgi*. Scale approximately 1:25 000 000

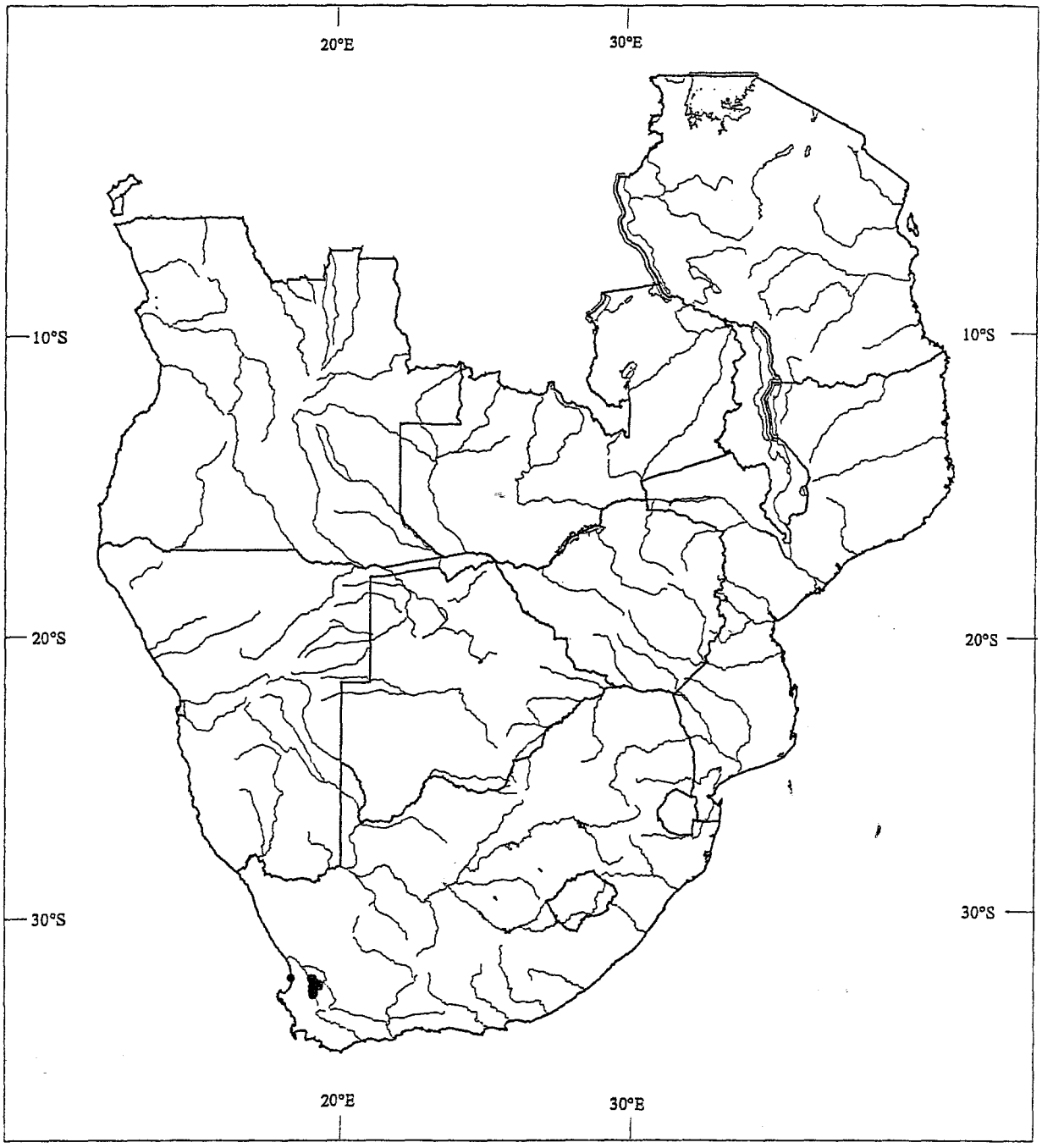


Figure F.588. Point distribution of *Pseudobarbus phlegethon*. Scale approximately 1:25 000 000

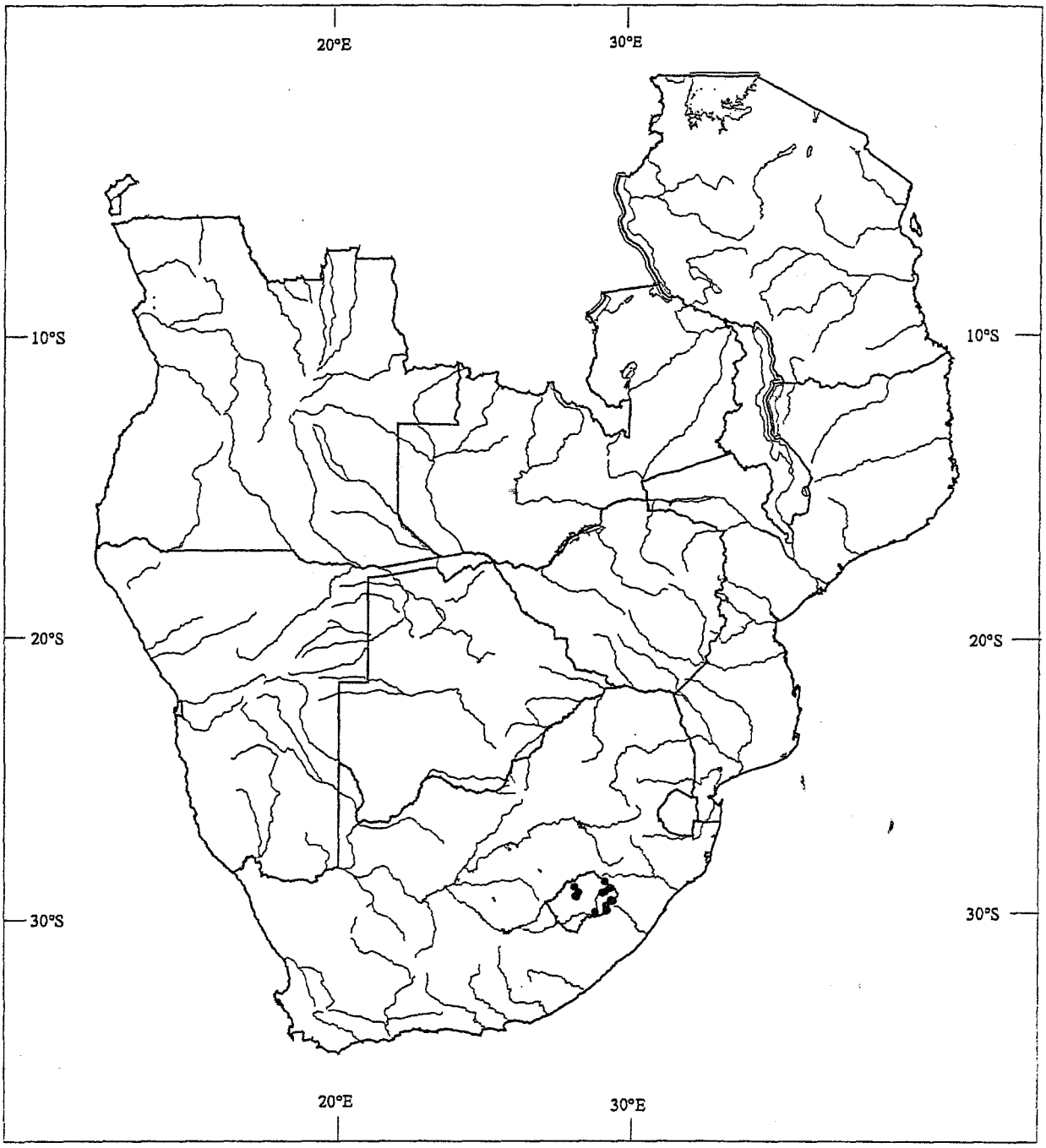


Figure F.589. Point distribution of *Pseudobarbus quathlambae*. Scale approximately 1:25 000 000

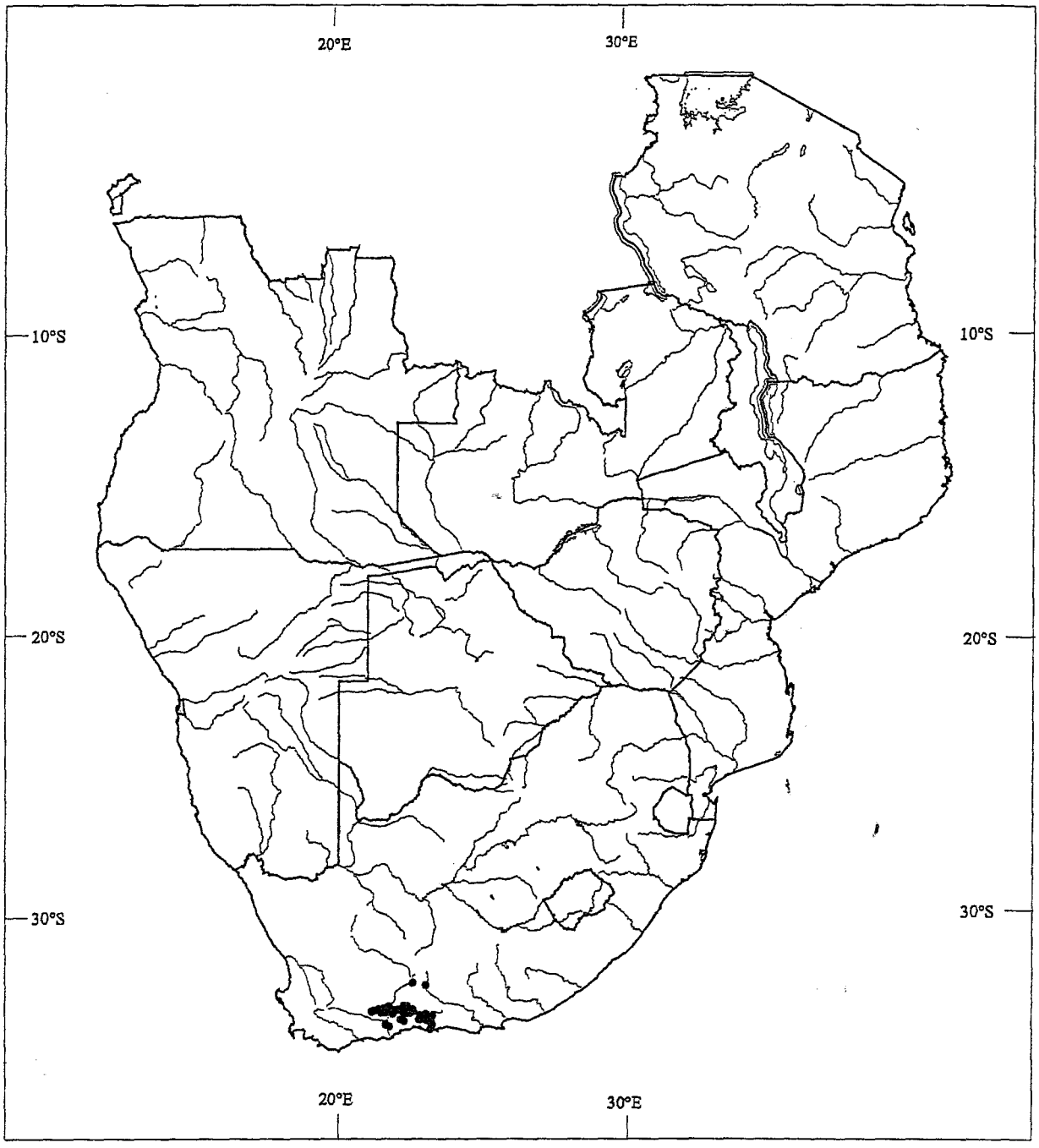


Figure F.590. Point distribution of *Pseudobarbus tenuis*. Scale approximately 1:25 000 000

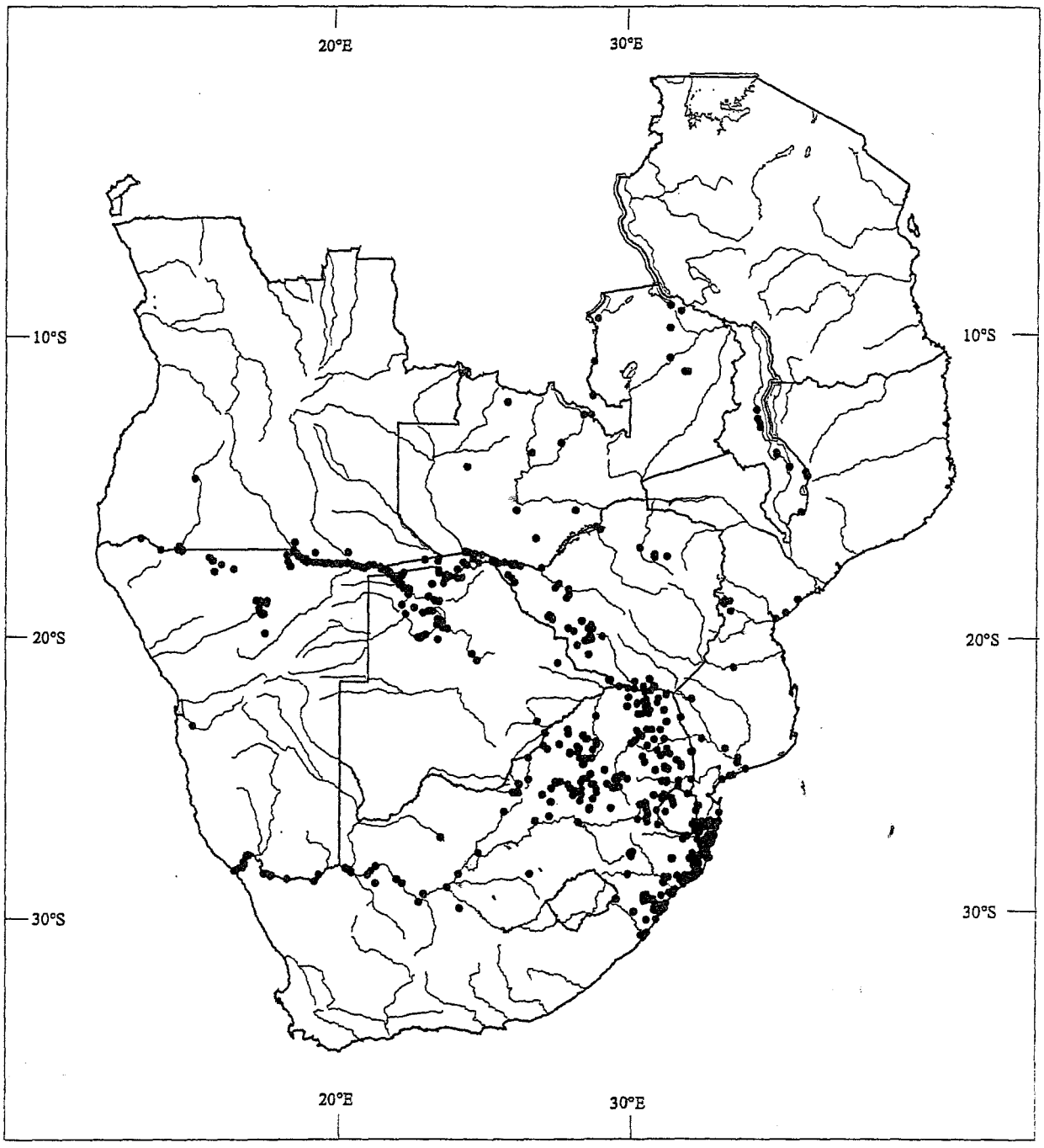


Figure F.591. Point distribution of *Pseudocrenilabrus philander*. Scale approximately 1:25 000 000

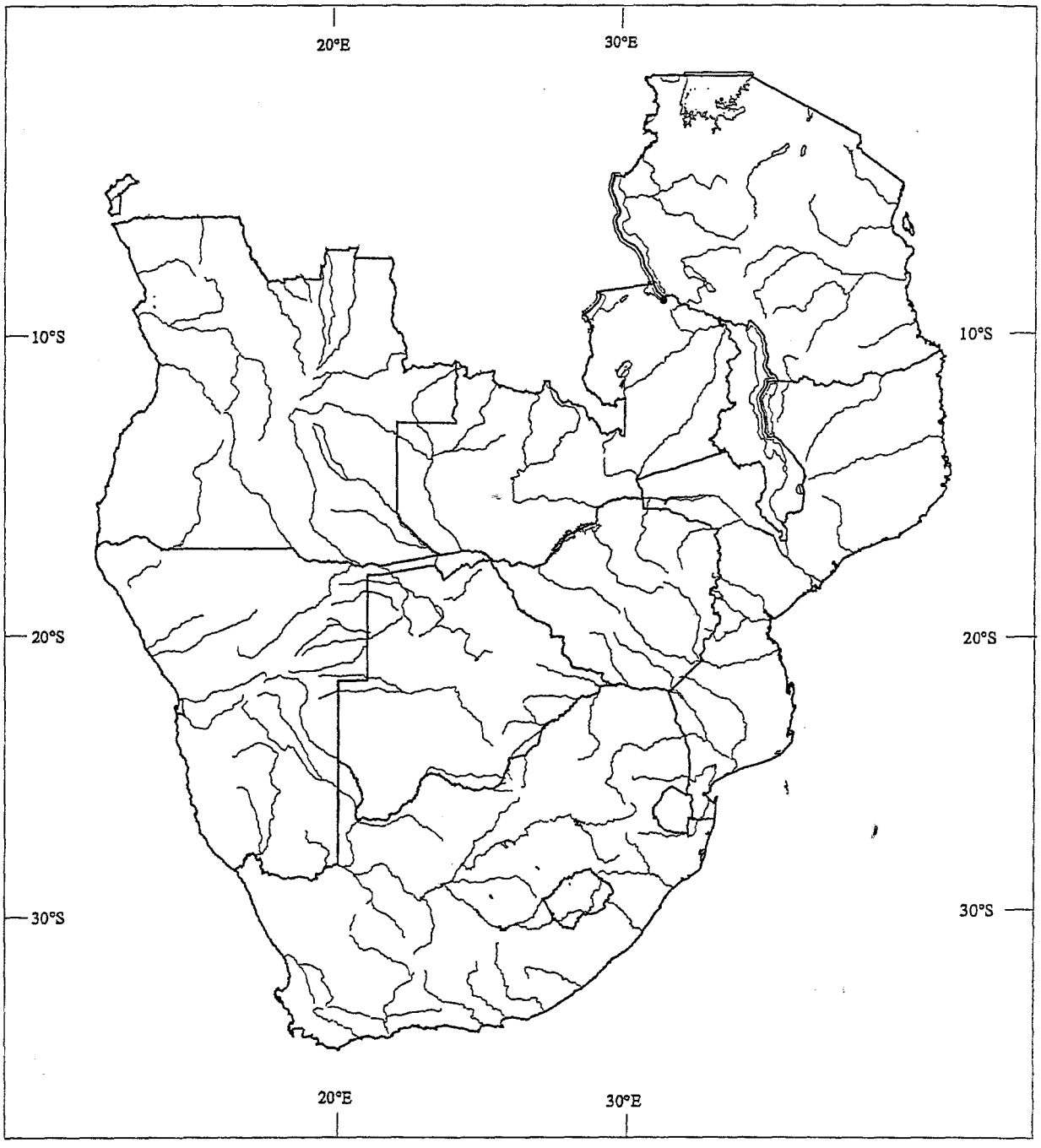


Figure F.592. Point distribution of *Pseudosimochromis curvifrons*. Scale approximately 1:25 000 000

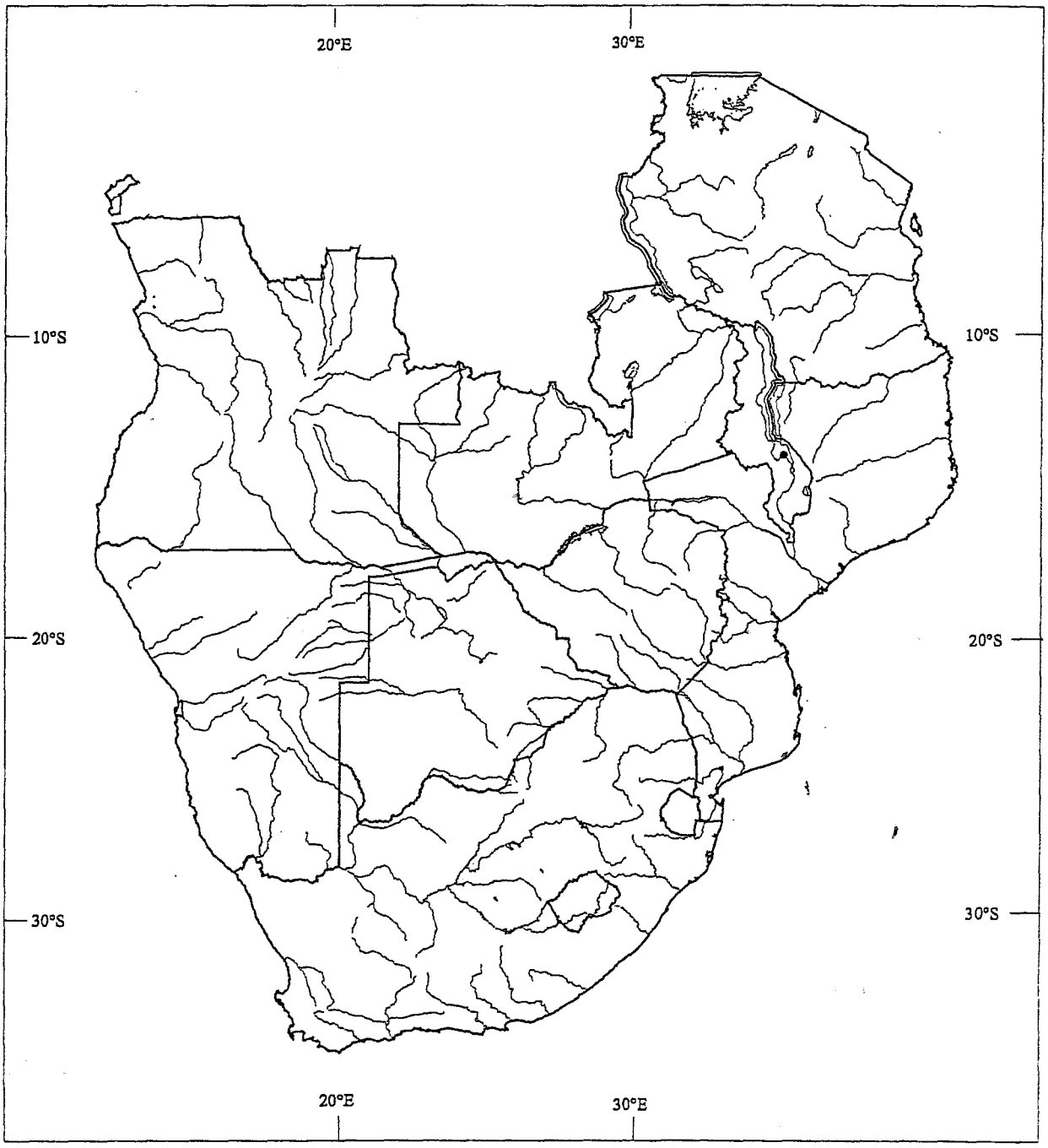


Figure F.593. Point distribution of *Pseudotropheus auratus*. Scale approximately 1:25 000 000

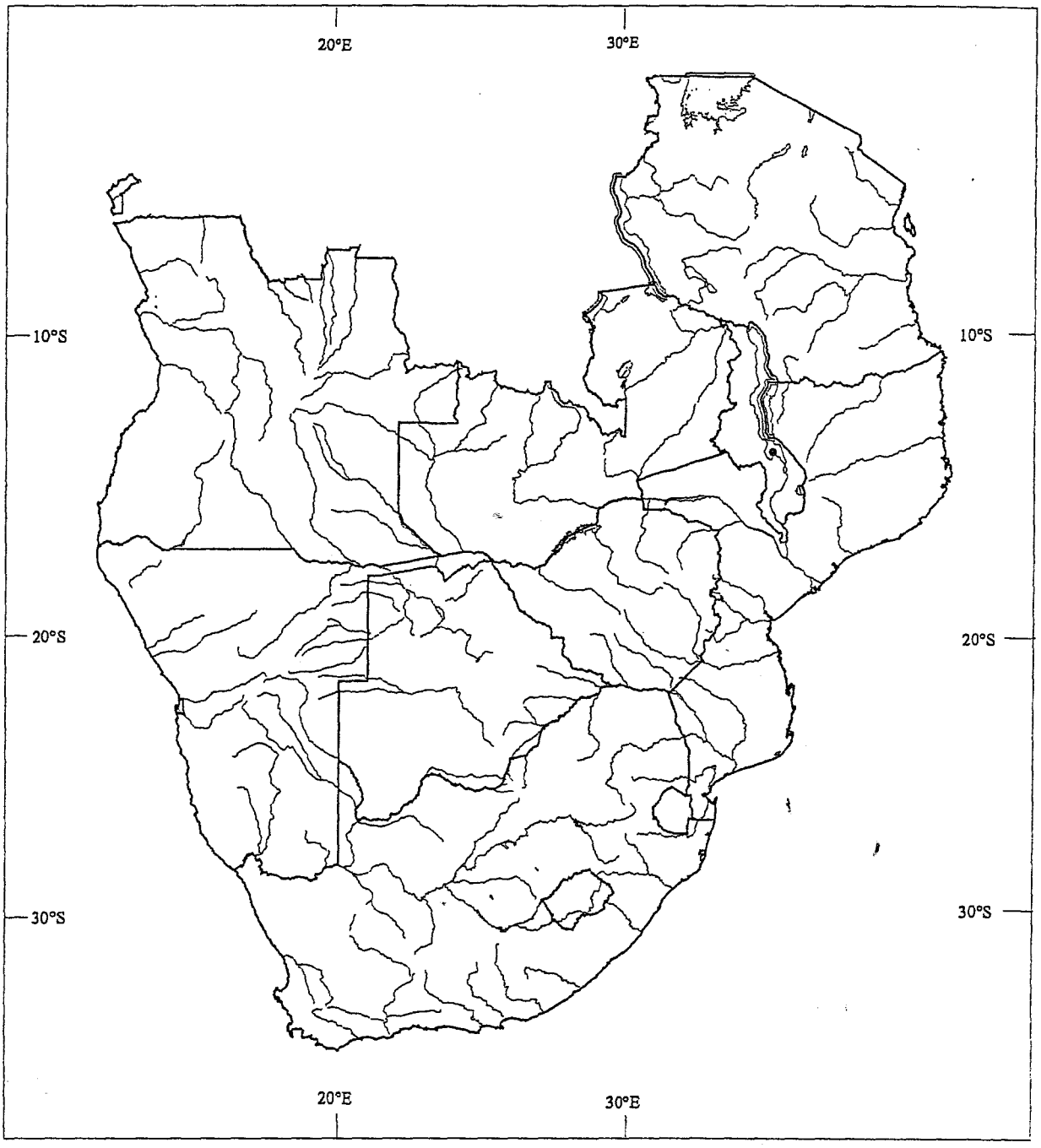


Figure F.594. Point distribution of *Pseudotropheus aurora*. Scale approximately 1:25 000 000

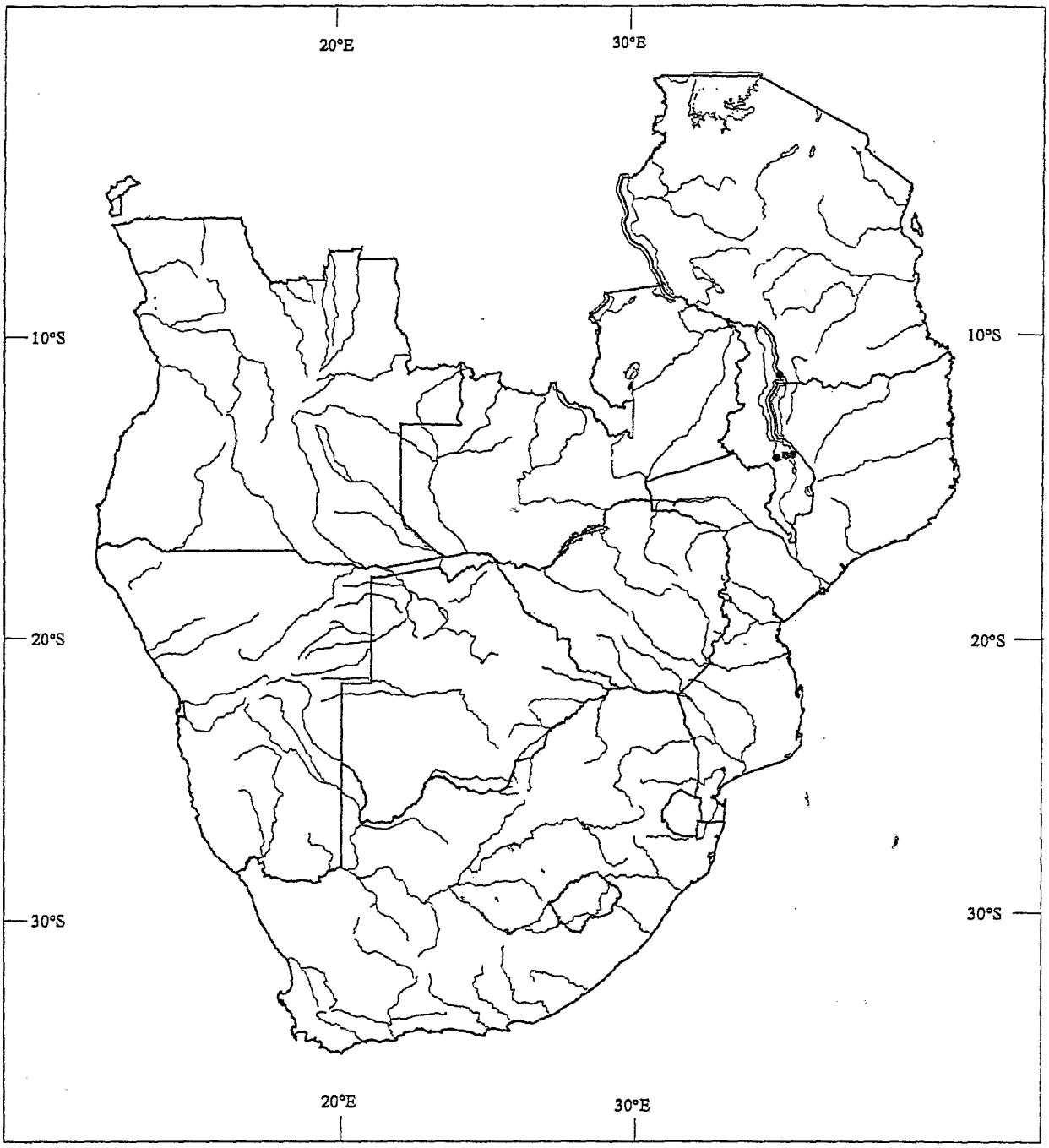


Figure F.595. Point distribution of *Pseudotropheus elegans*. Scale approximately 1:25 000 000

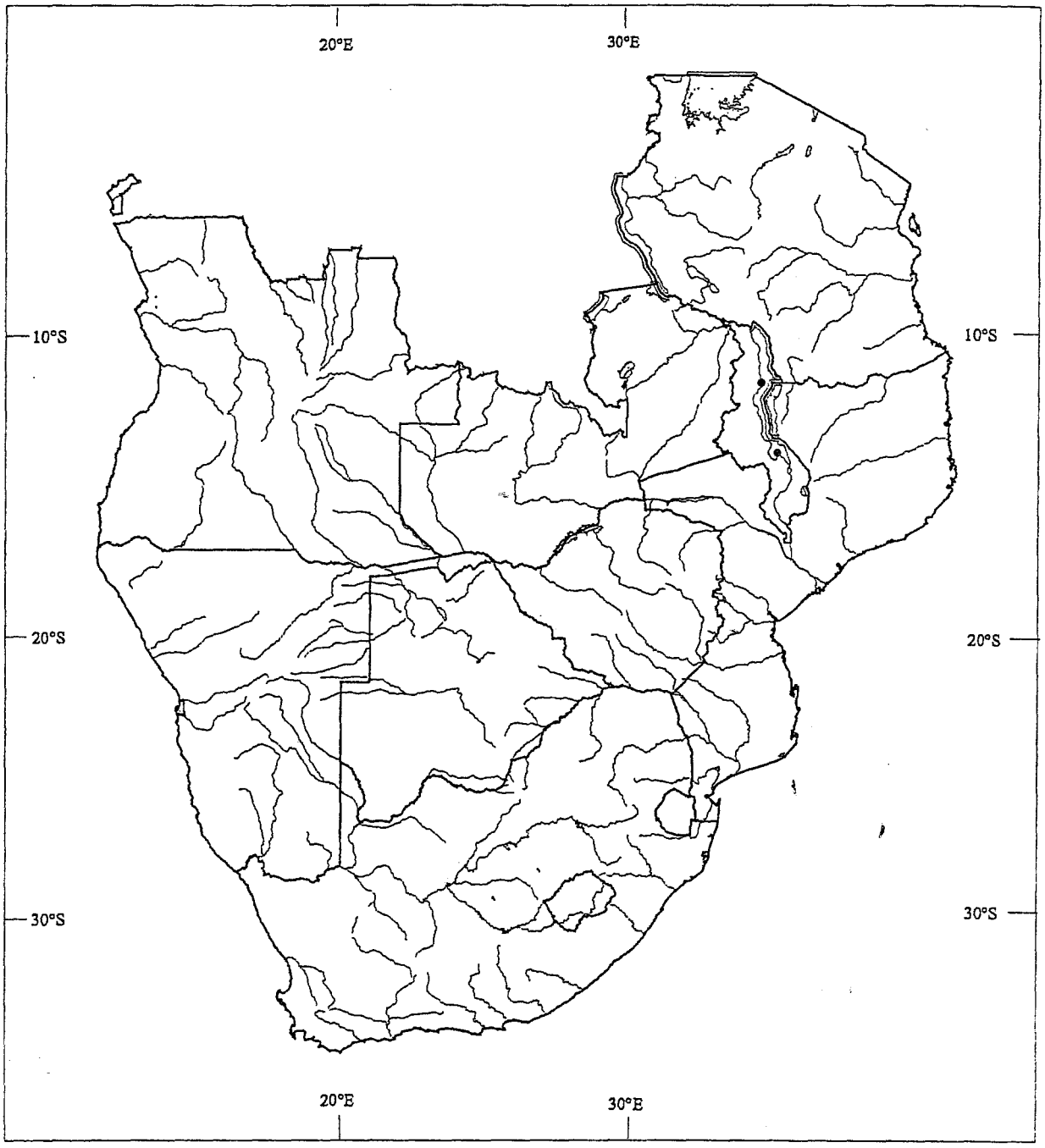


Figure F.596. Point distribution of *Pseudotropheus elongatus*. Scale approximately 1:25 000 000

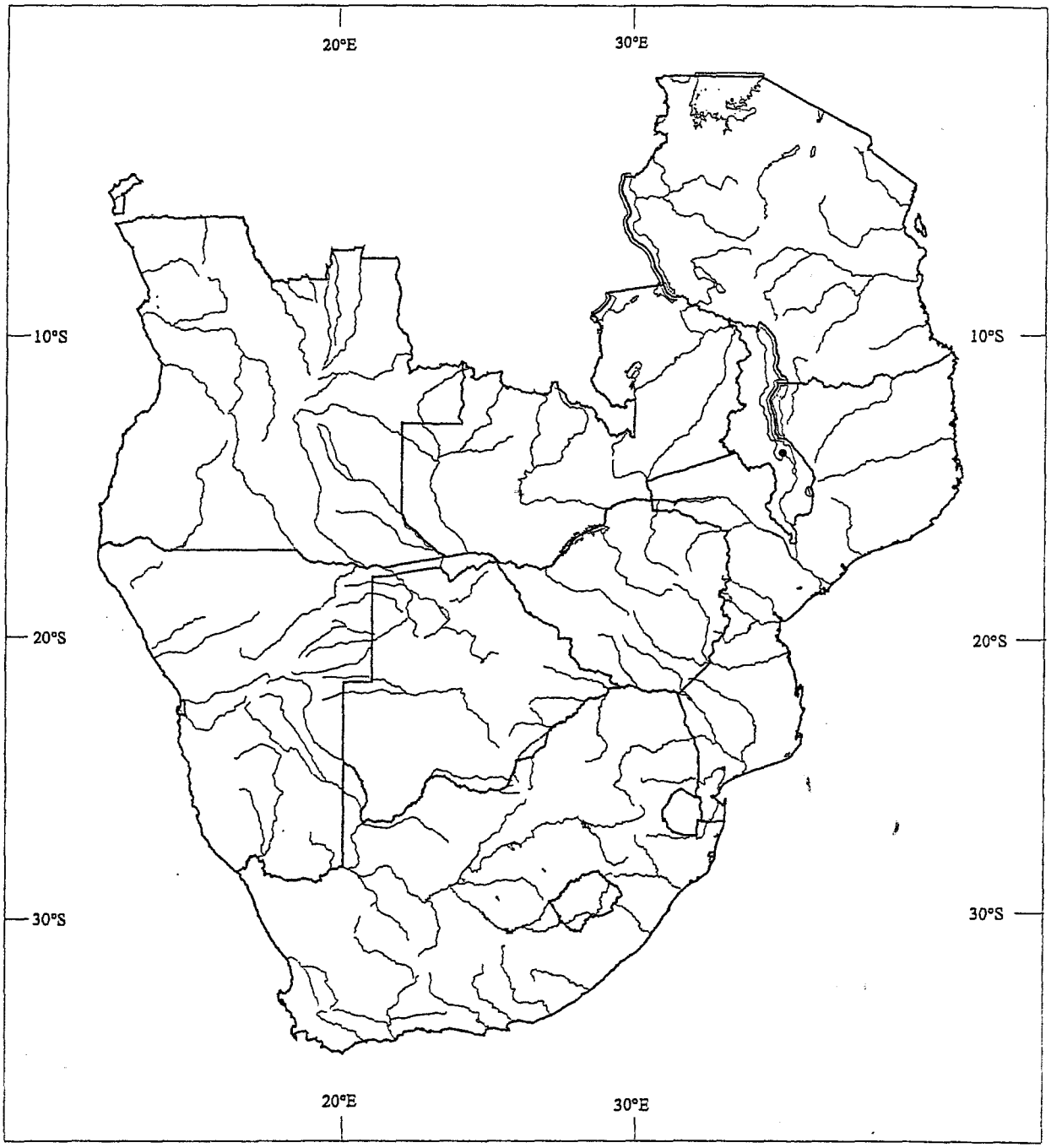


Figure F.597. Point distribution of *Pseudotropheus gracilior*. Scale approximately 1:25 000 000

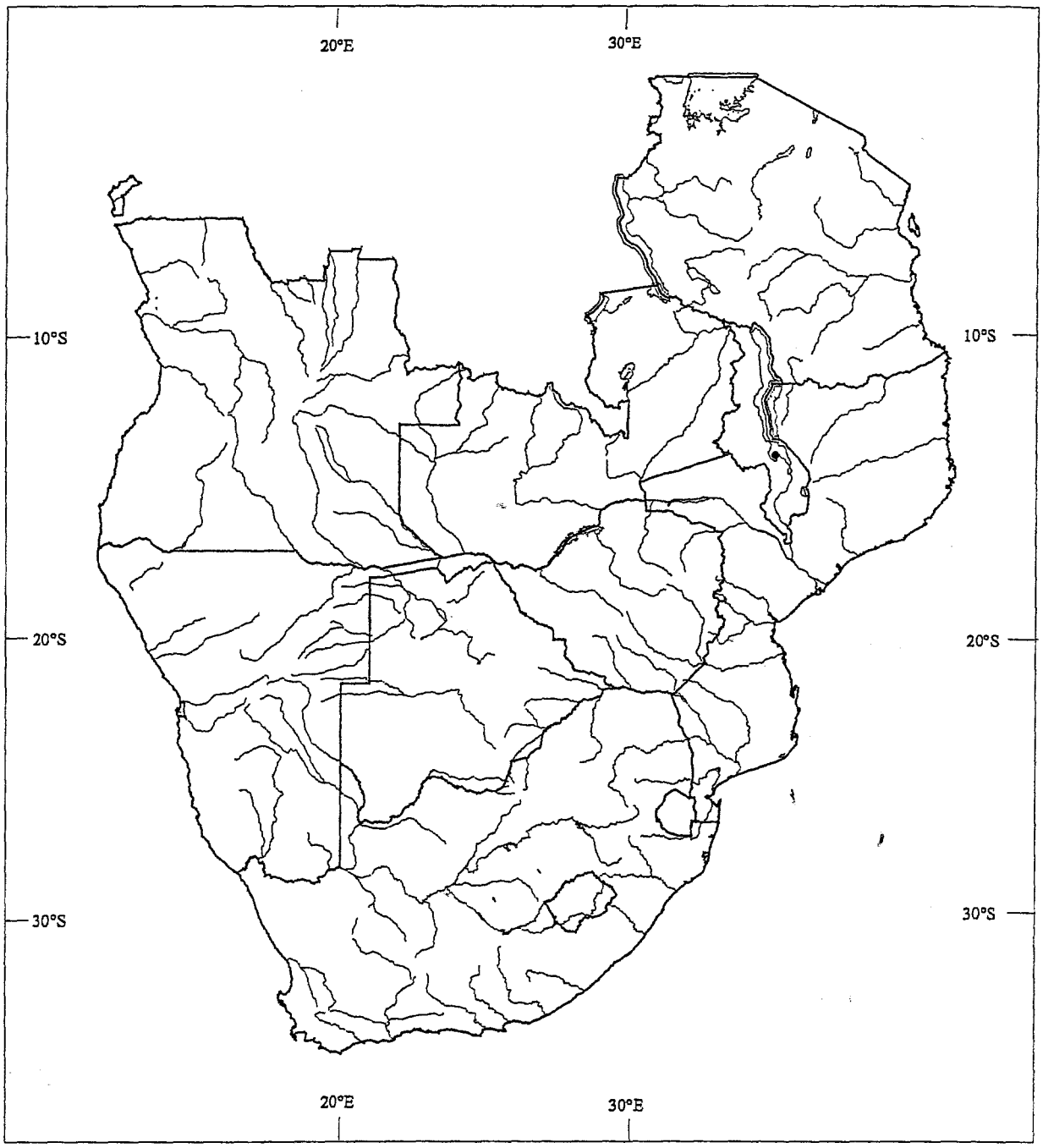


Figure F.598. Point distribution of *Pseudotropheus johanni*. Scale approximately 1:25 000 000

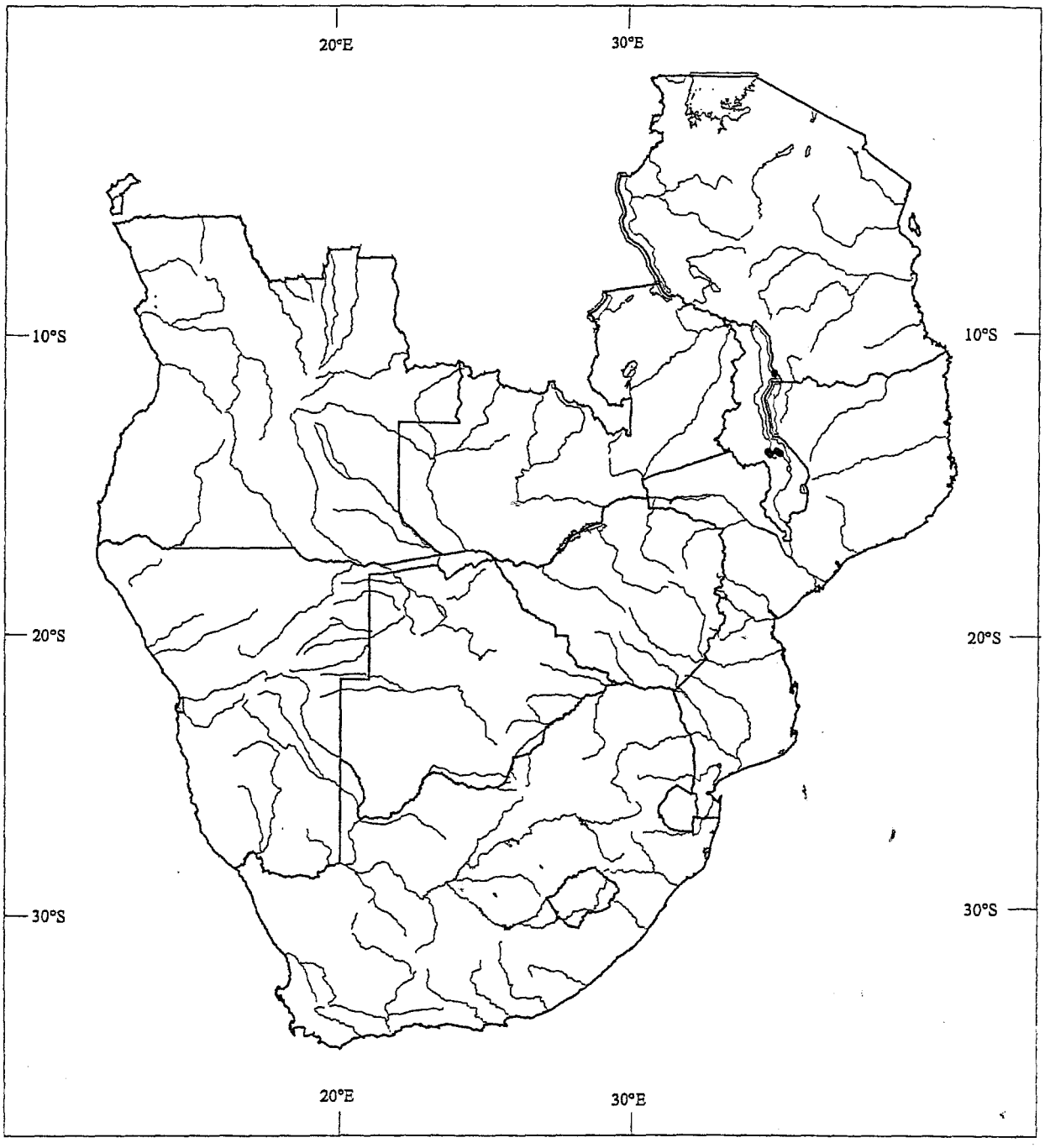


Figure F.599. Point distribution of *Pseudotropheus livingstonii*. Scale approximately 1:25 000 000

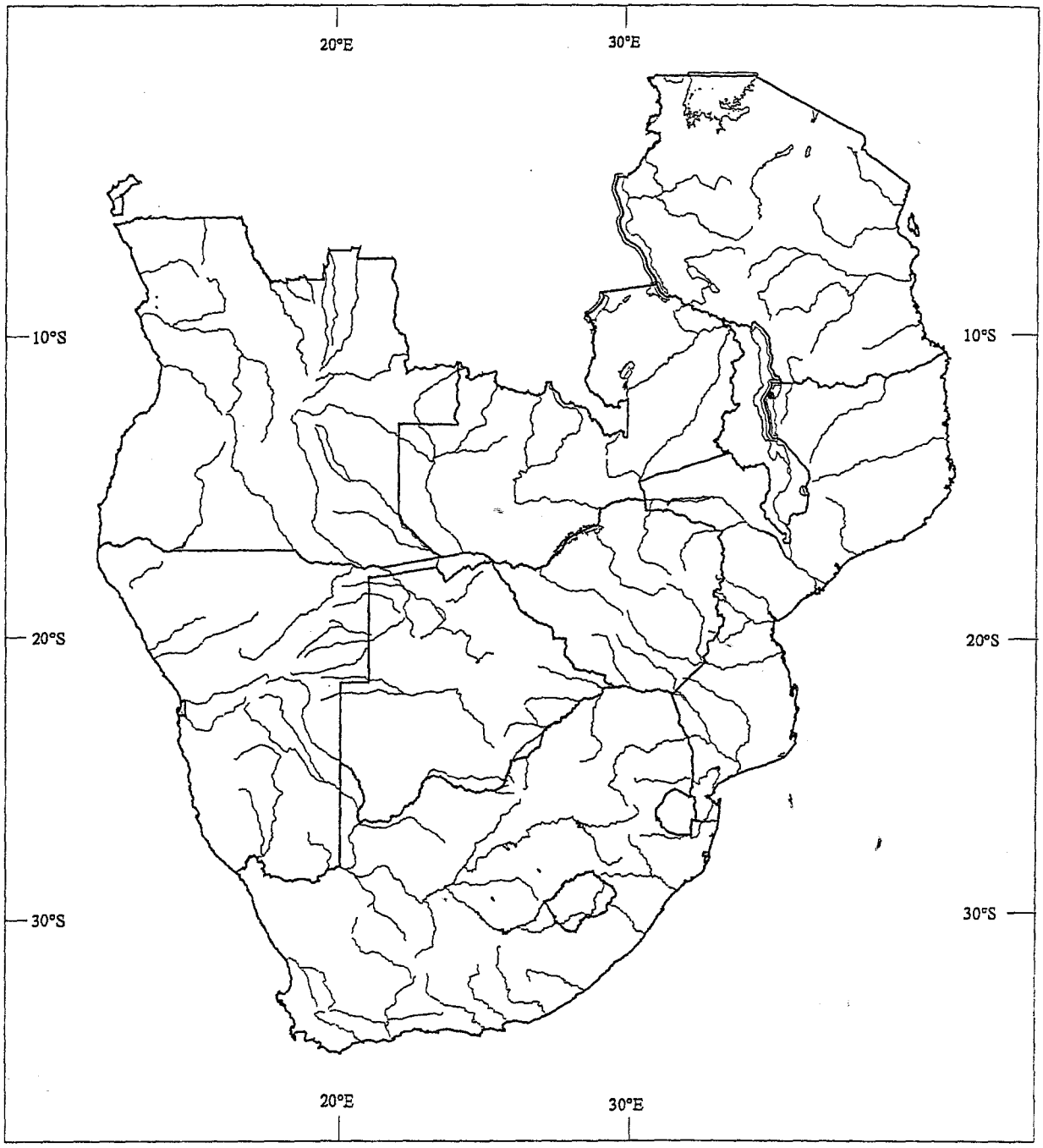


Figure F.600. Point distribution of *Pseudotropheus lombardai*. Scale approximately 1:25 000 000

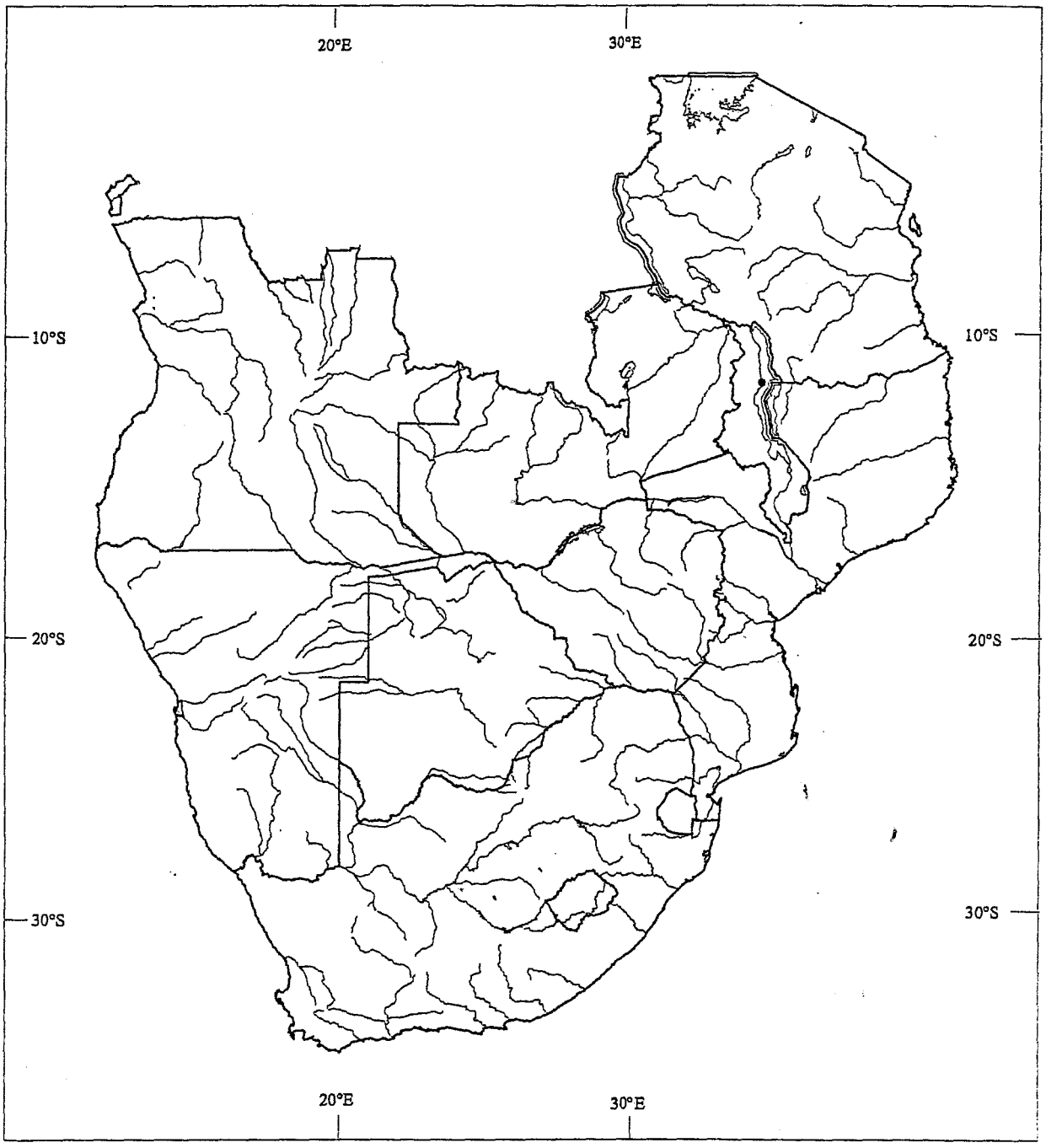


Figure F.601. Point distribution of *Pseudotropheus lucerna*. Scale approximately 1:25 000 000

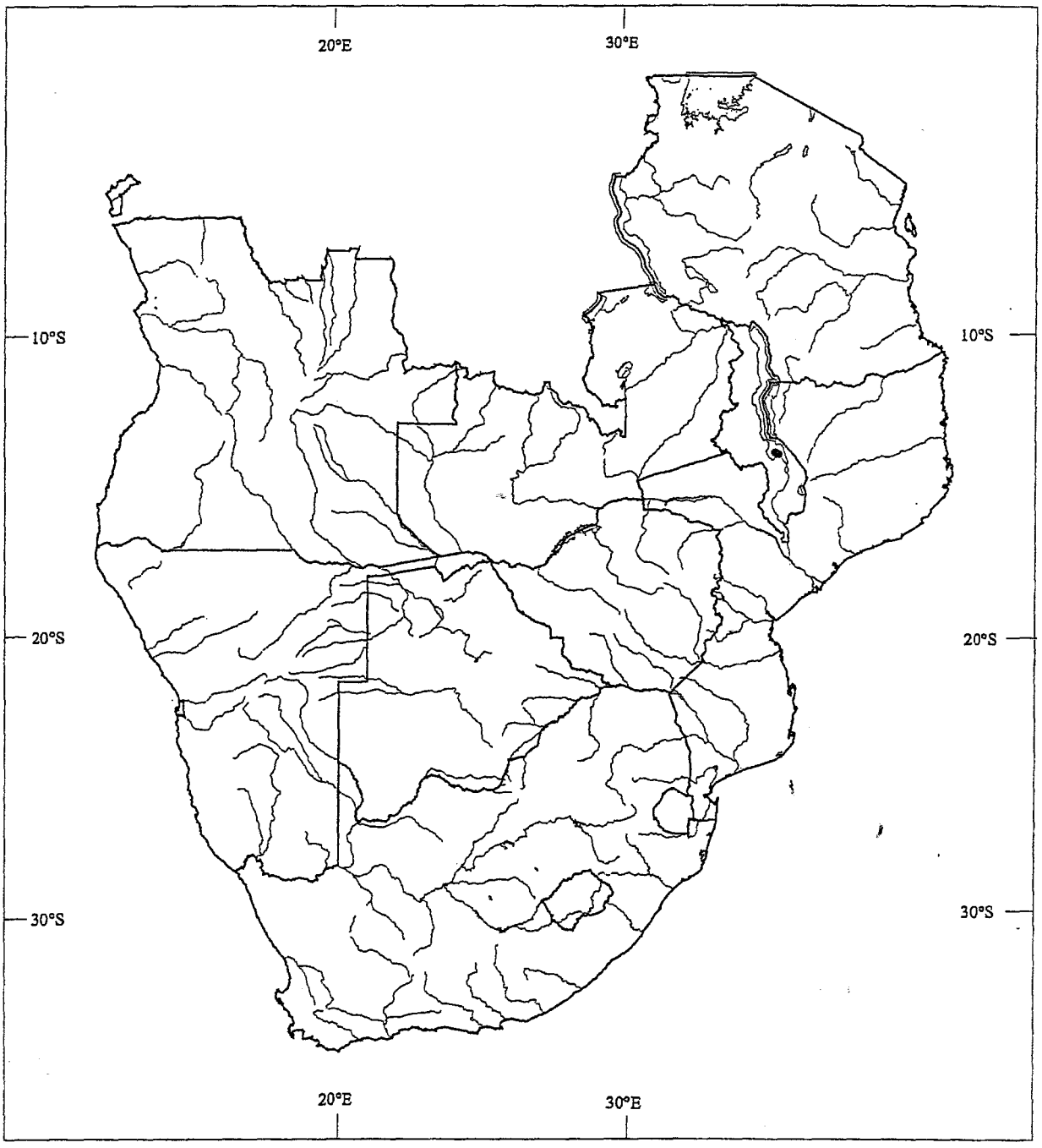


Figure F.602. Point distribution of *Pseudotropheus microstoma*. Scale approximately 1:25 000 000

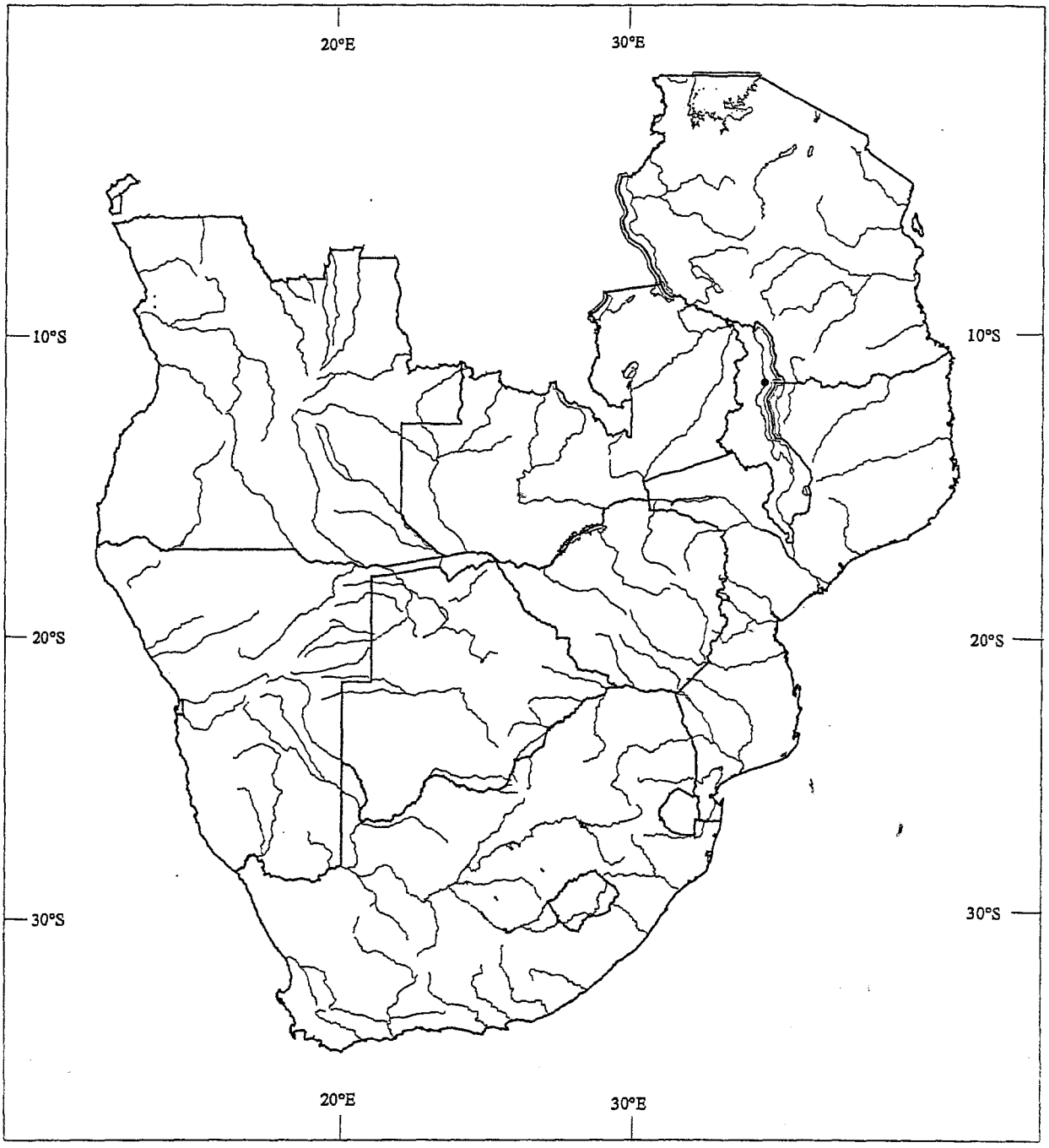


Figure F.603. Point distribution of *Pseudotropheus minutus*. Scale approximately 1:25 000 000

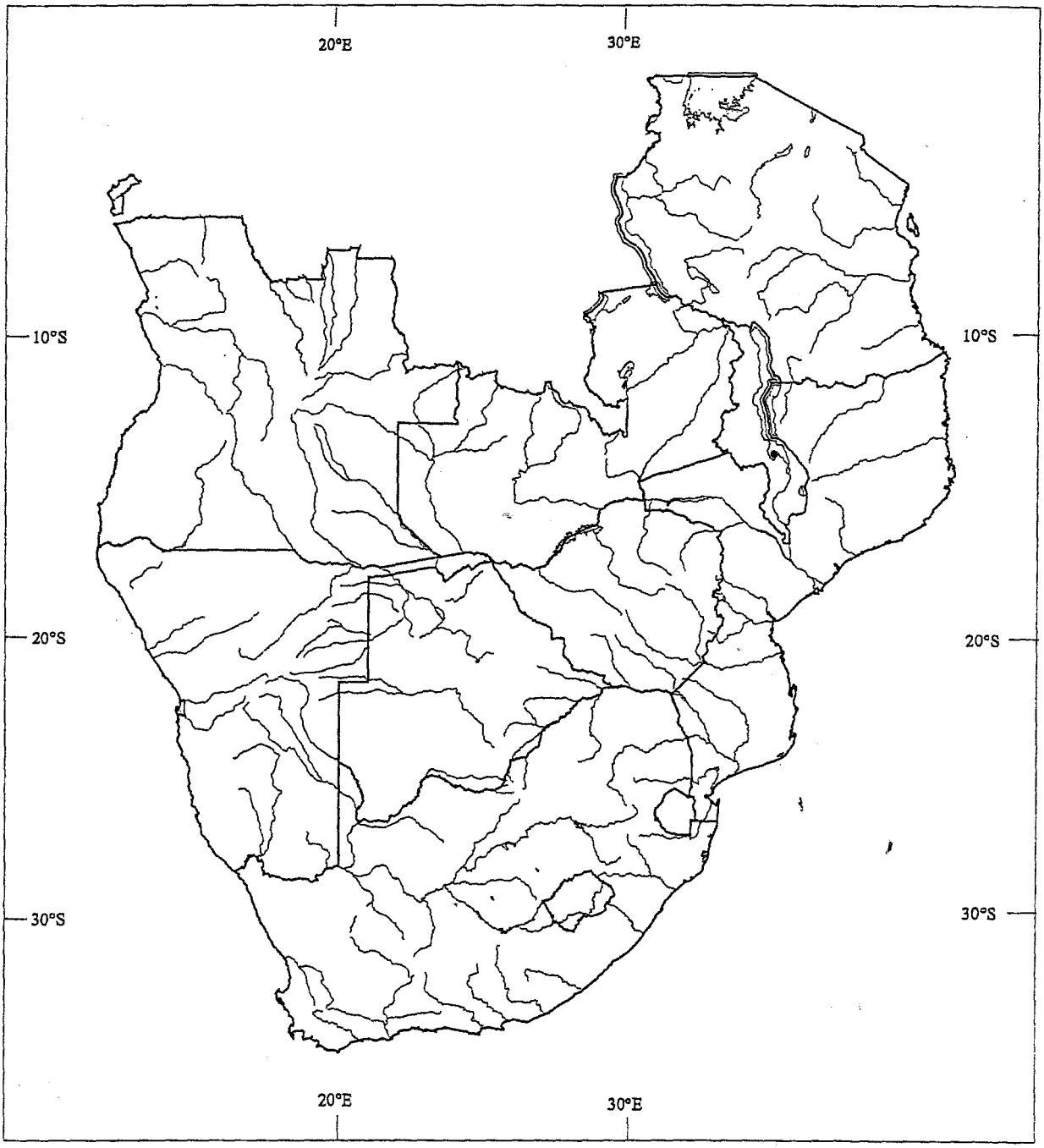


Figure F.604. Point distribution of *Pseudotropheus tropheops*. Scale approximately 1:25 000 000

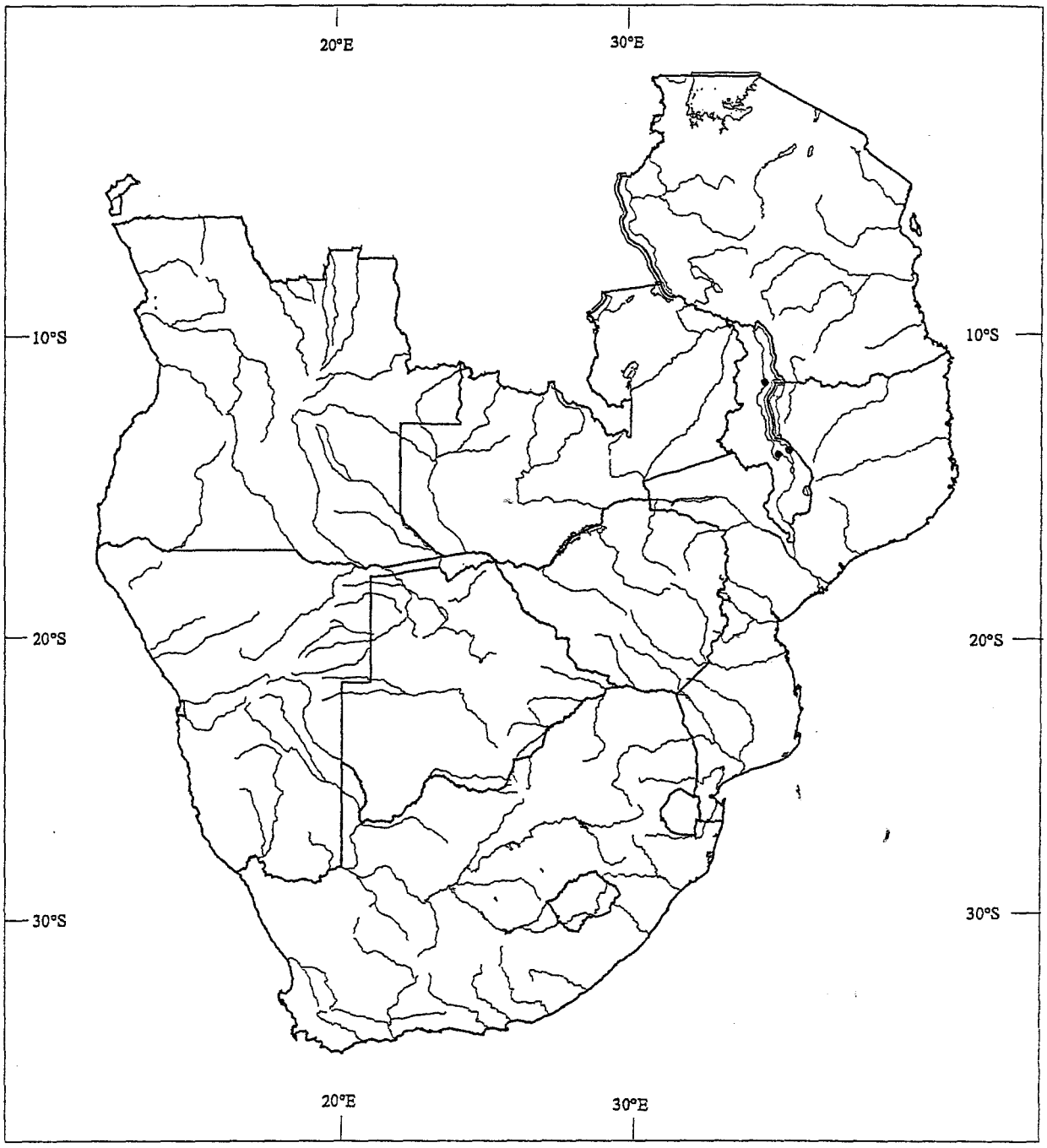


Figure F.605. Point distribution of *Pseudotropheus williamsi*. Scale approximately 1:25 000 000

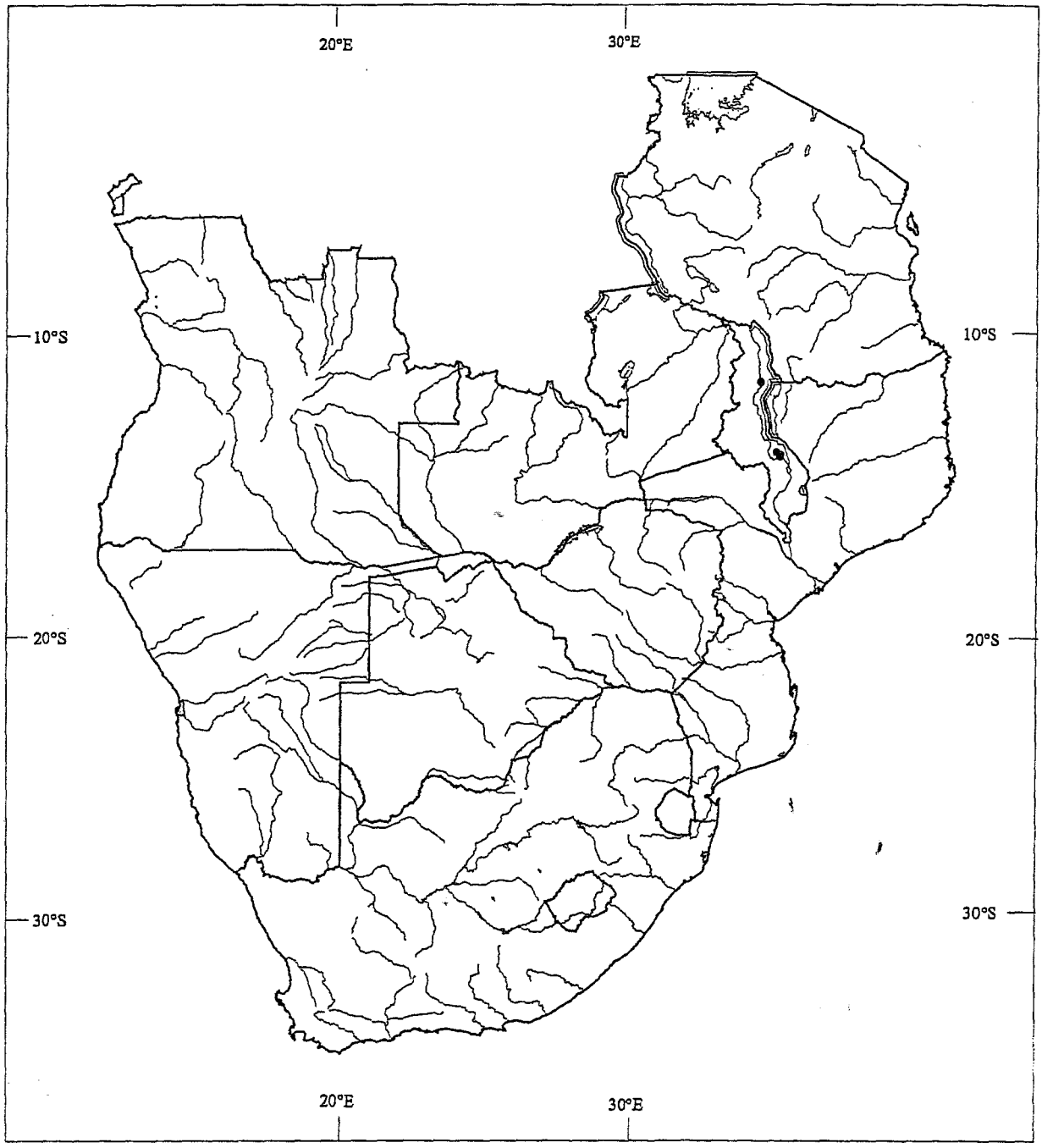


Figure F.606. Point distribution of *Pseudotropheus zebra*. Scale approximately 1:25 000 000

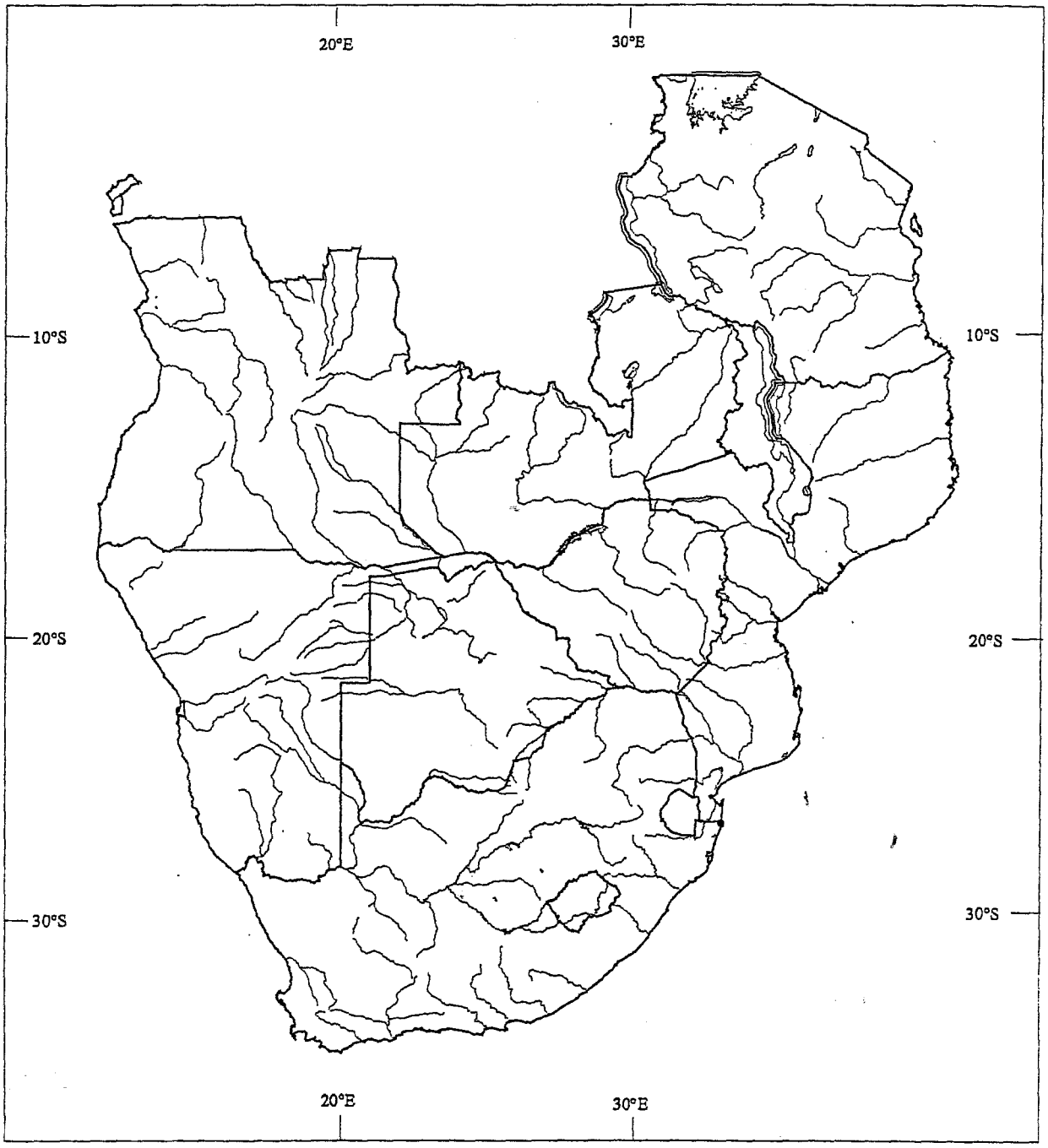


Figure F.607. Point distribution of *Pterois volitans*. Scale approximately 1:25 000 000

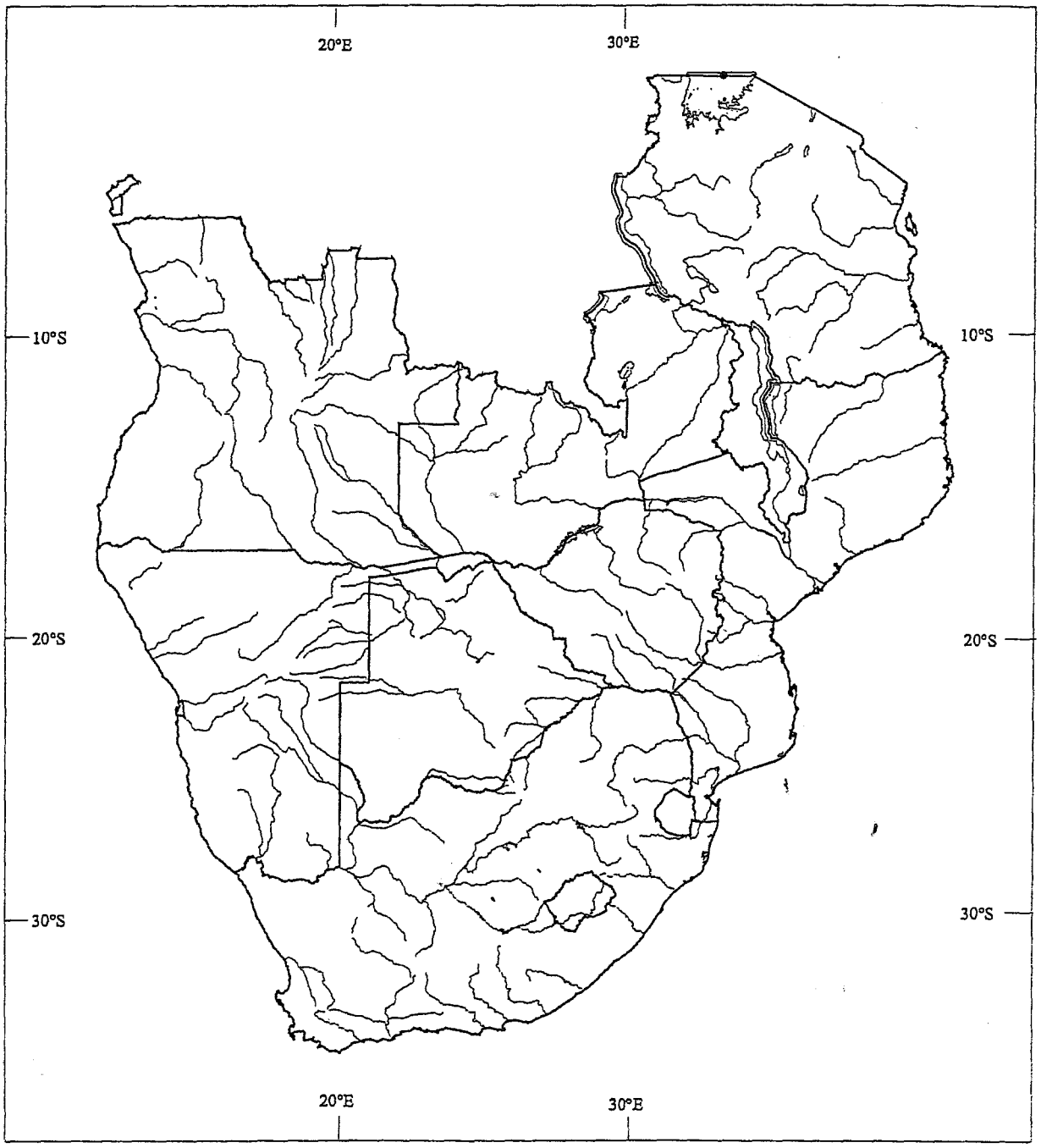


Figure F.608. Point distribution of *Ptyochromis annectens*. Scale approximately 1:25 000 000

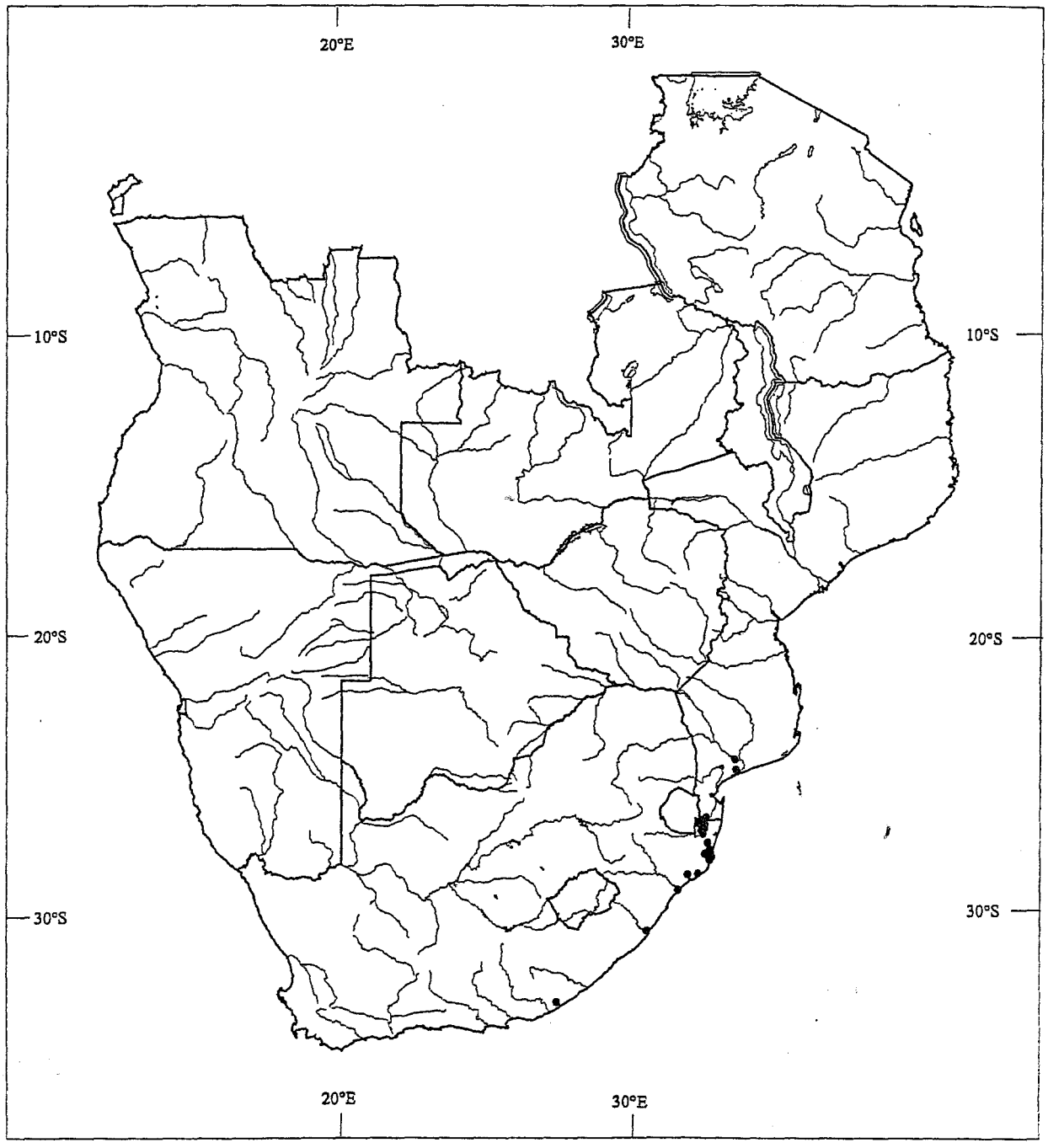


Figure F.609. Point distribution of *Redigobius dewaali*. Scale approximately 1:25 000 000

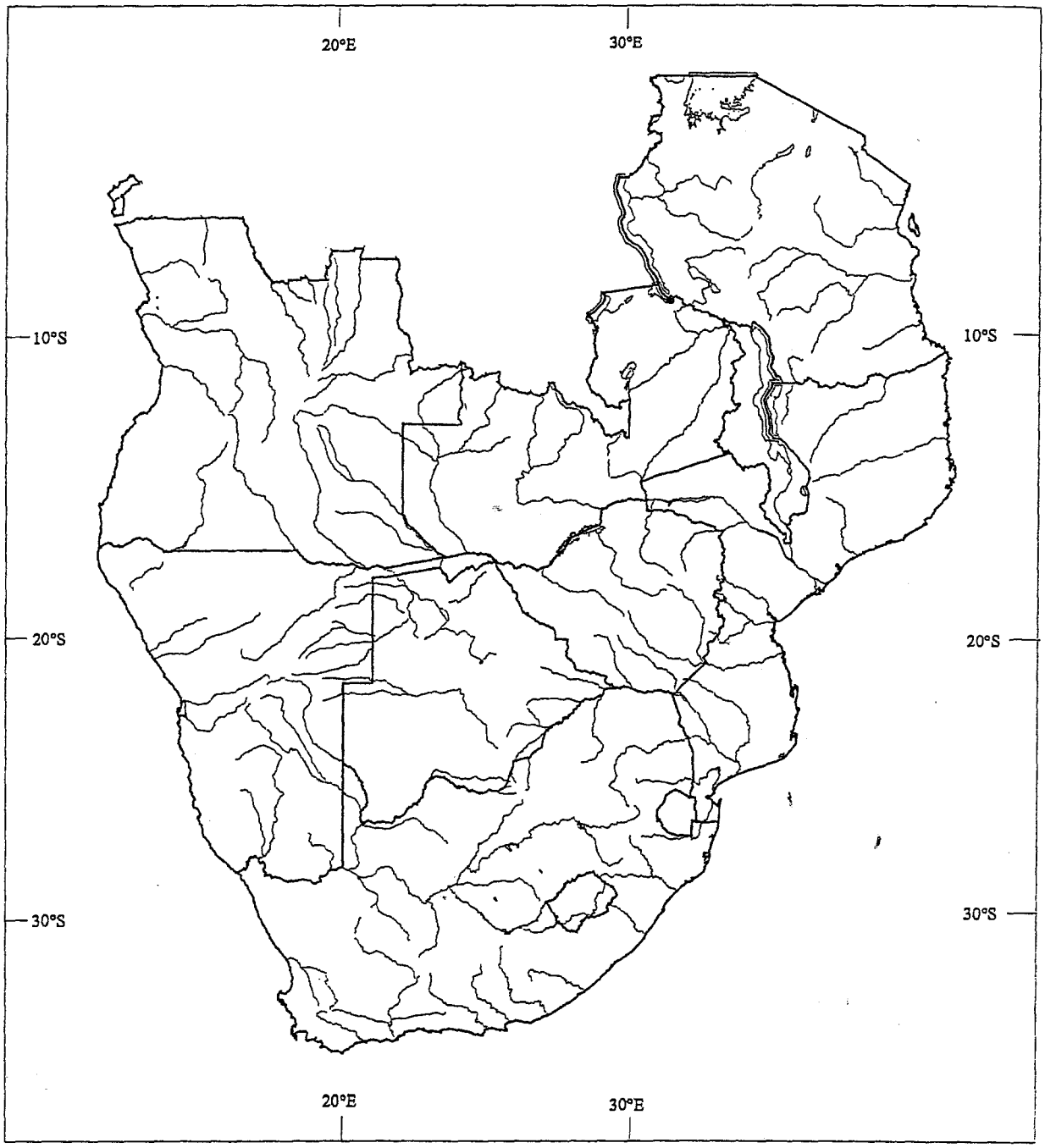


Figure F.610. Point distribution of *Reganochromis calliurus*. Scale approximately 1:25 000 000

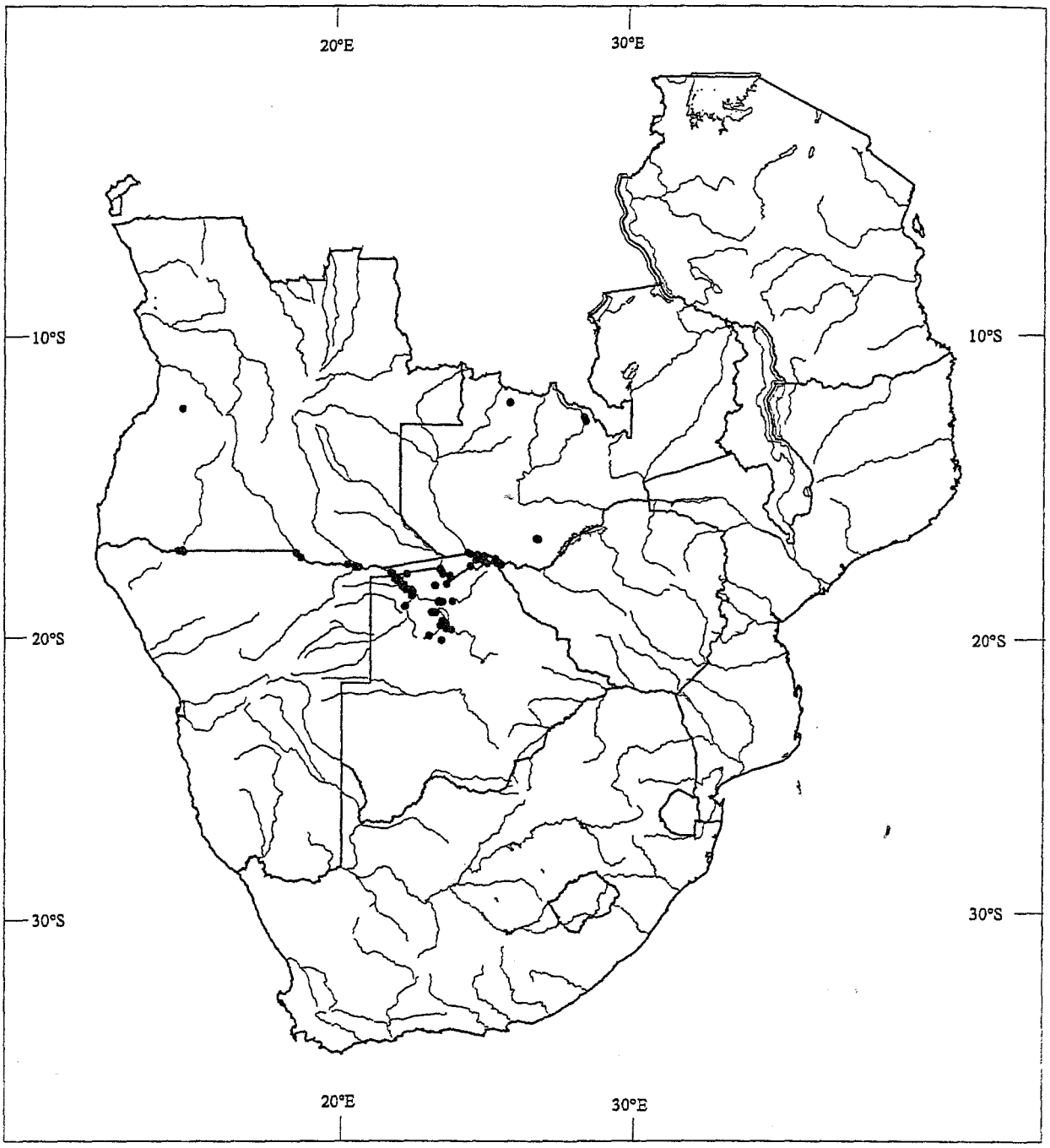


Figure F.611. Point distribution of *Rhabdalestes maunensis*. Scale approximately 1:25 000 000

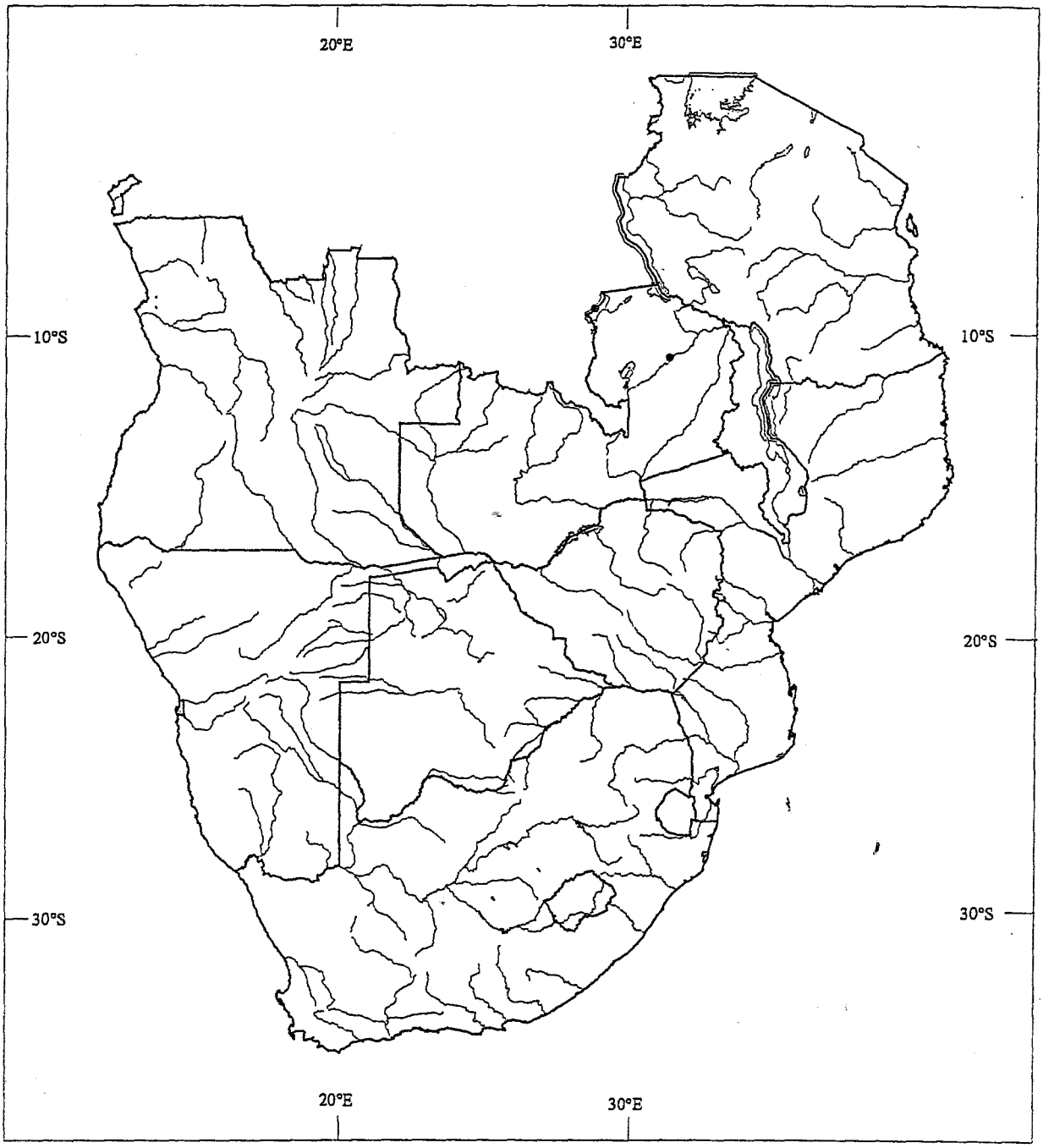


Figure F.612. Point distribution of *Rhabdalestes rhodesiensis*. Scale approximately 1:25 000 000

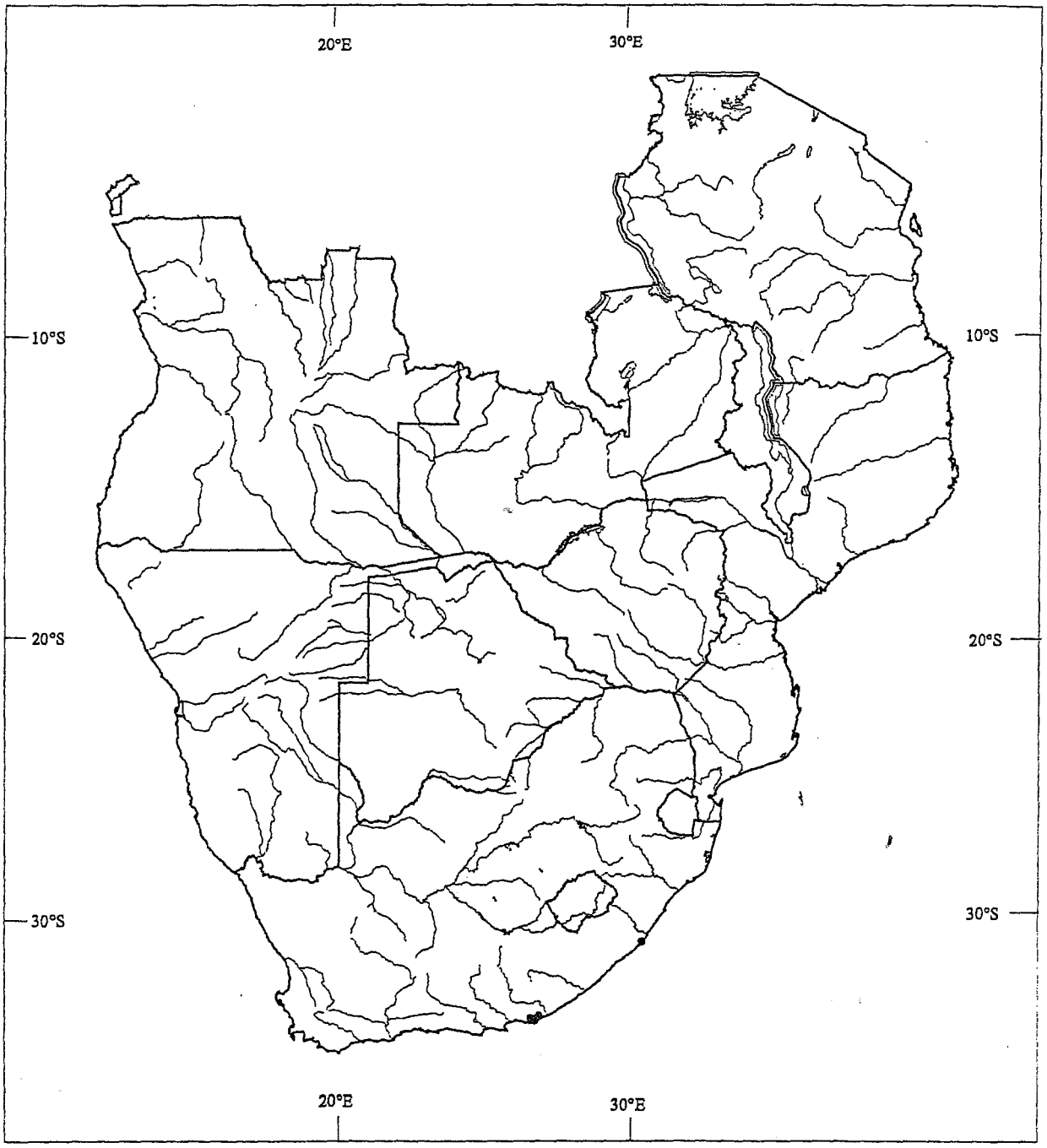


Figure F.613. Point distribution of *Rhabdosargus holubi*. Scale approximately 1:25 000 000

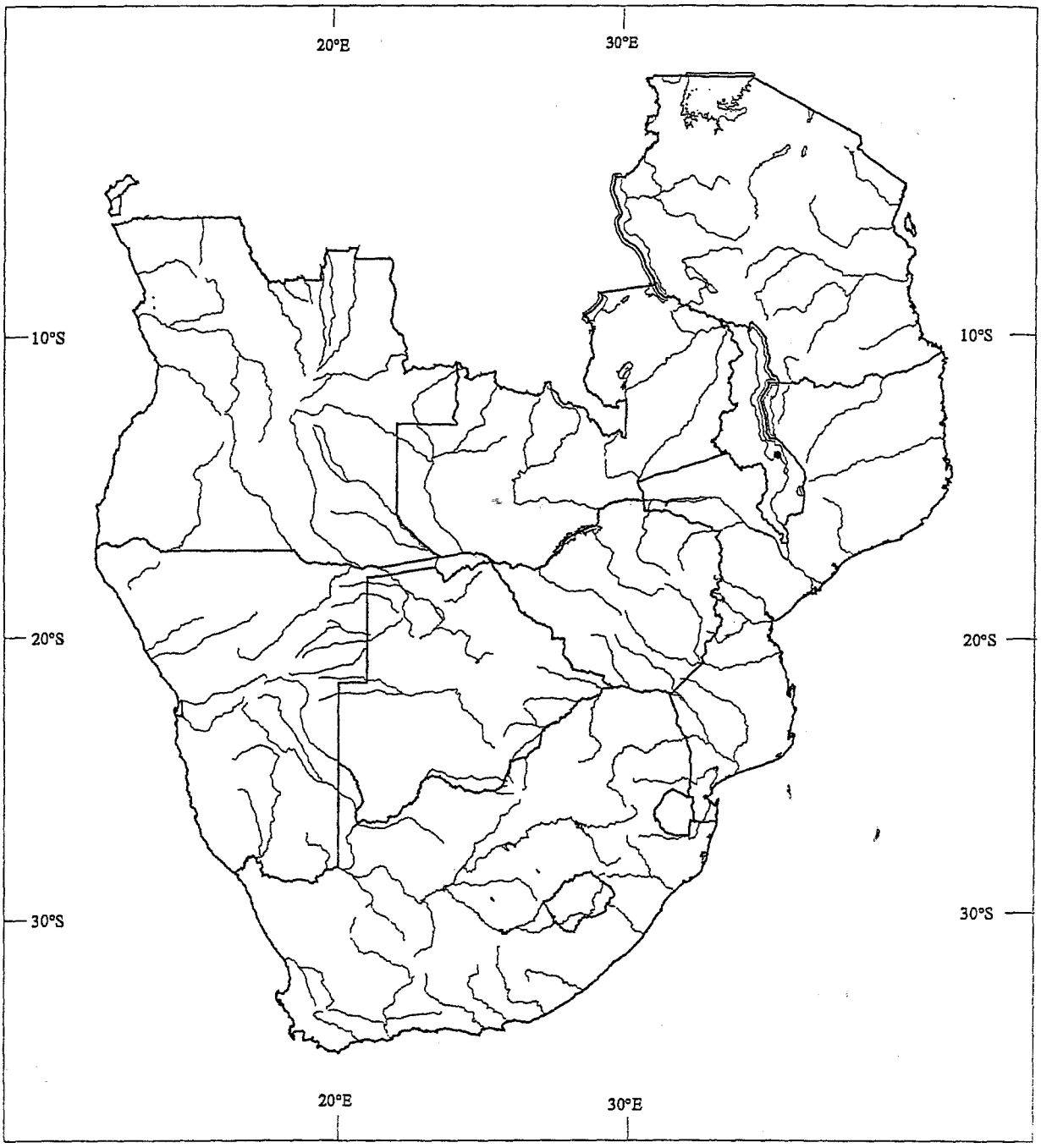


Figure F.614. Point distribution of *Rhamphochromis esox*. Scale approximately 1:25 000 000

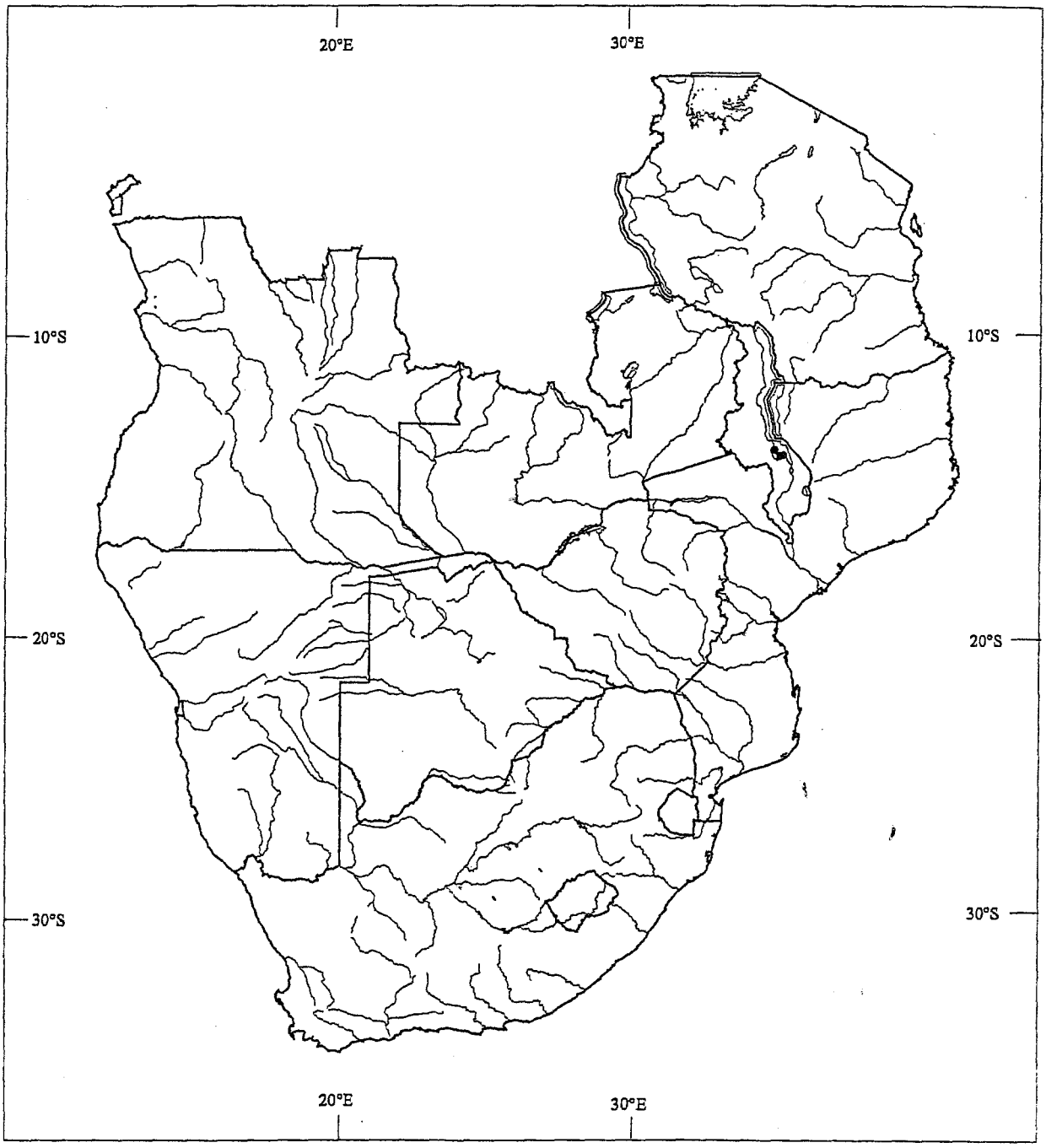


Figure F.615. Point distribution of *Rhamphochromis longiceps*. Scale approximately 1:25 000 000

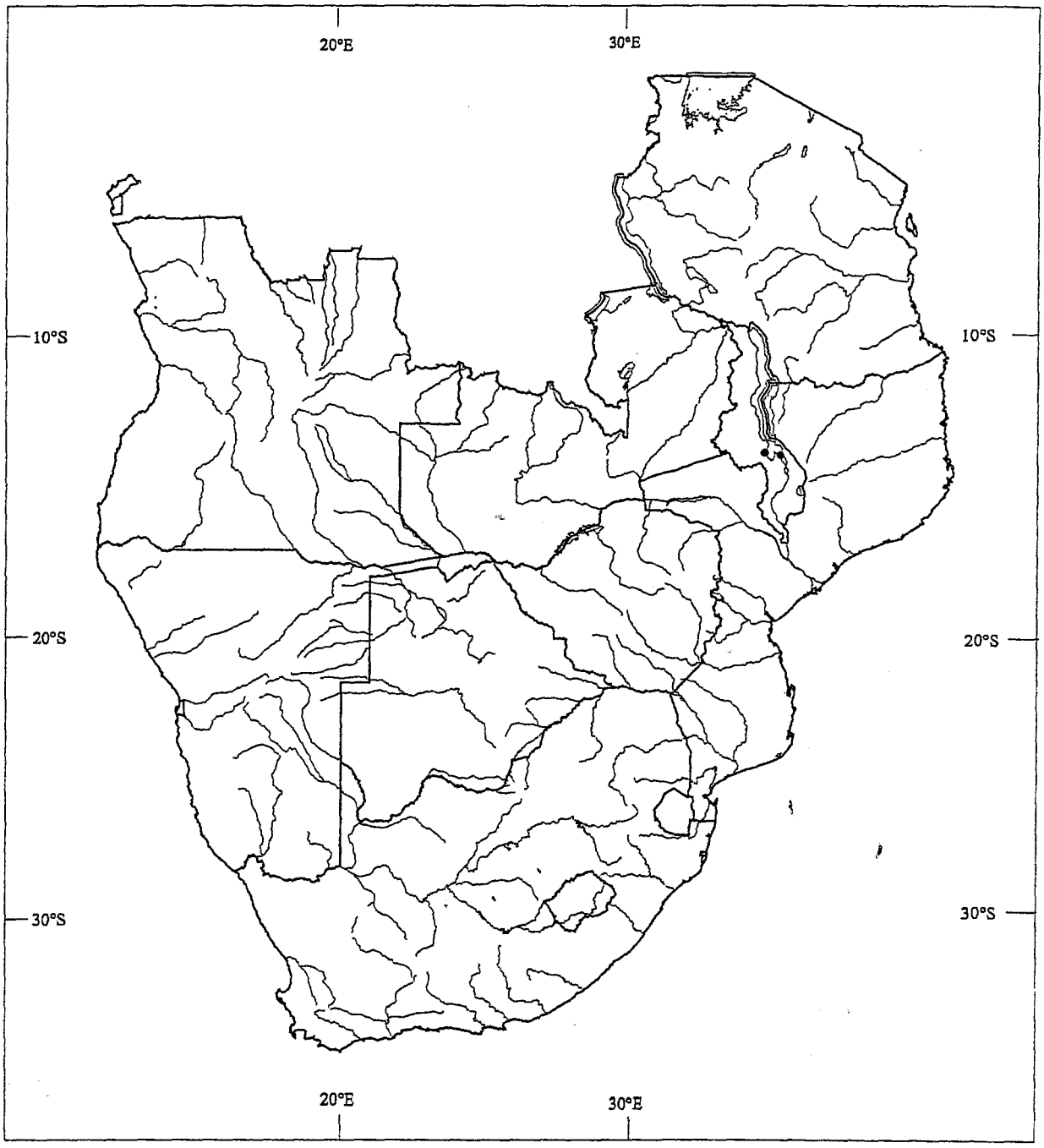


Figure F.616. Point distribution of *Rhamphochromis macrophthalmus*. Scale approximately 1:25 000 000

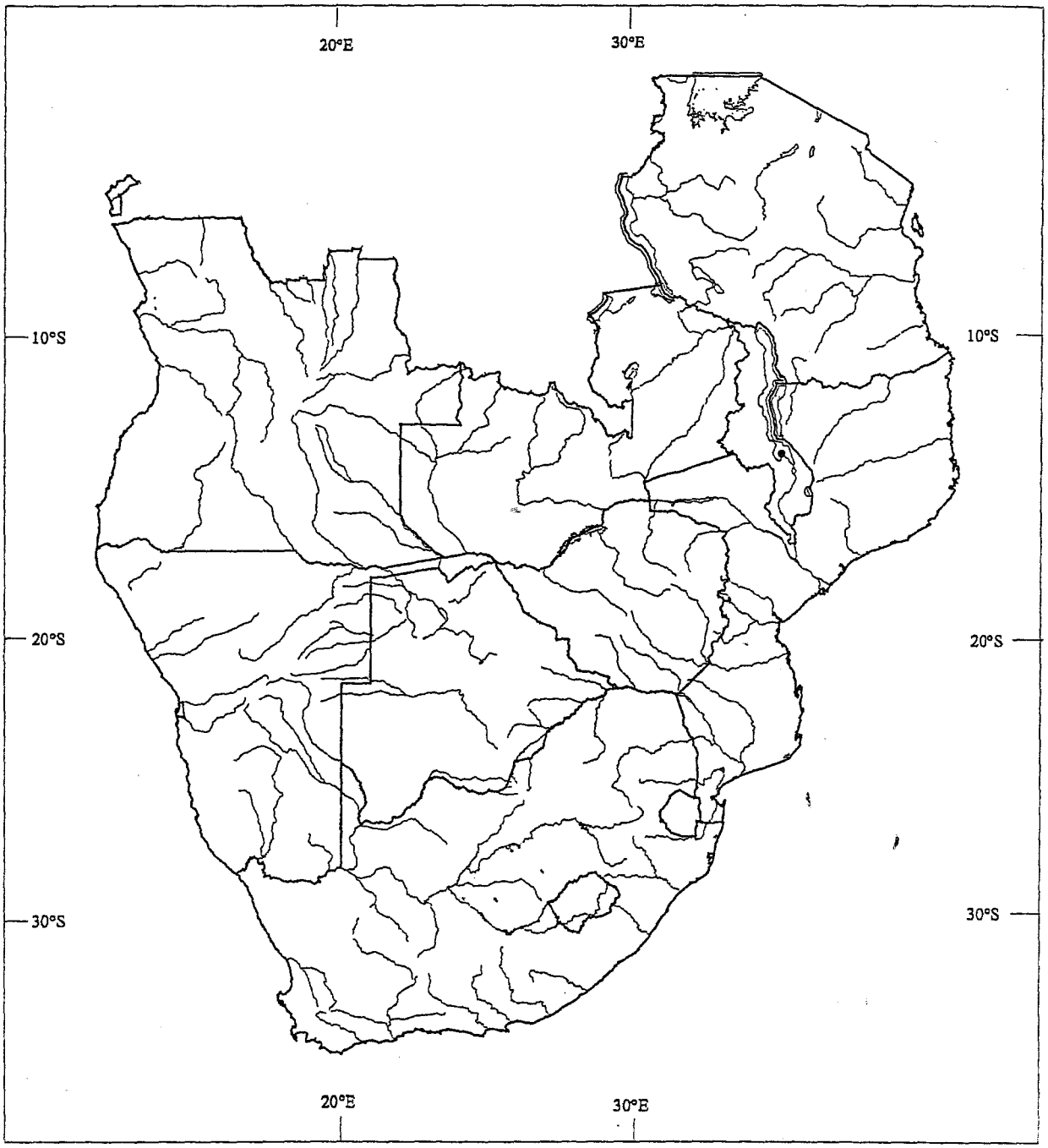


Figure F.617. Point distribution of *Rhamphochromis sox*. Scale approximately 1:25 000 000

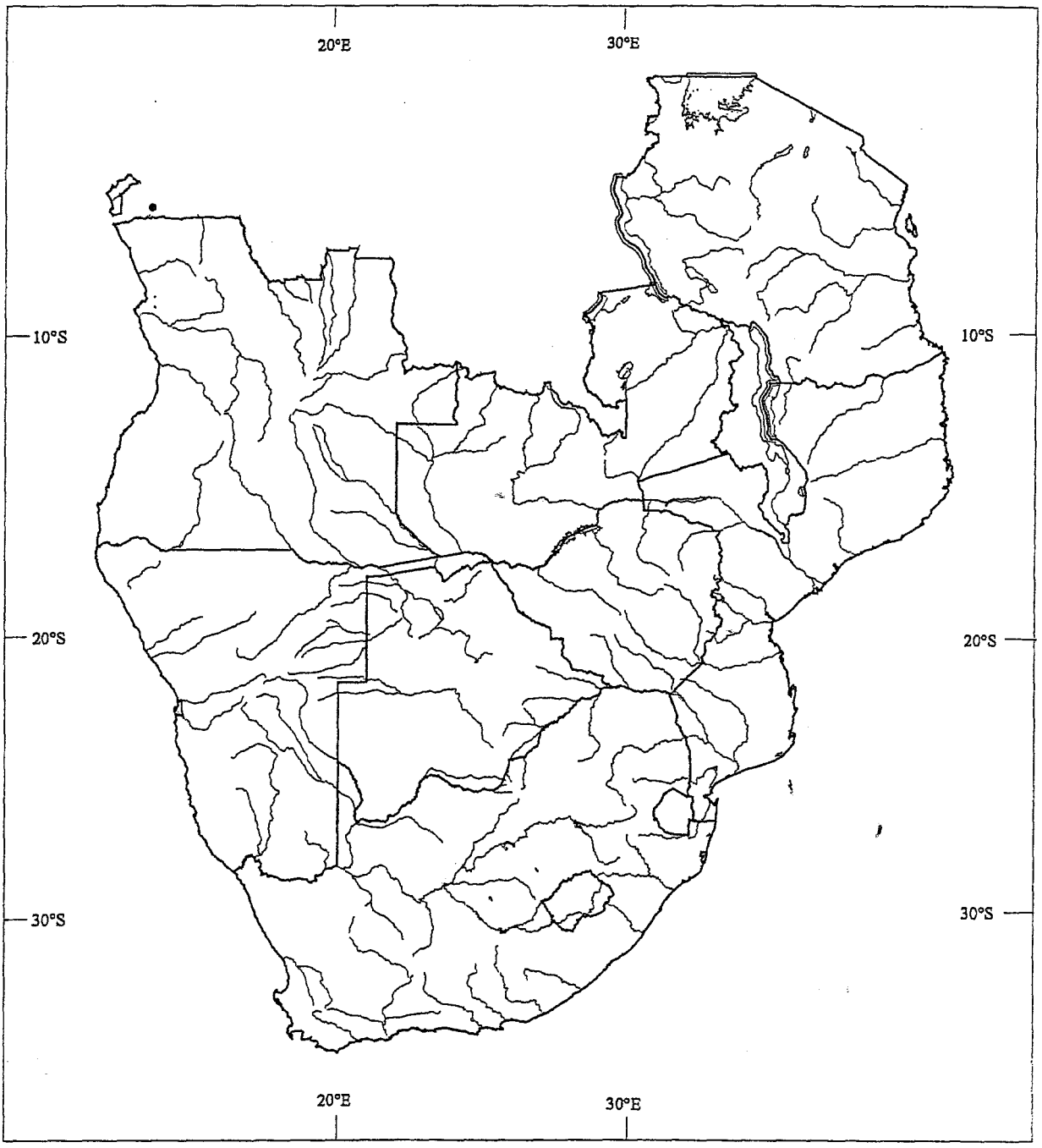


Figure F.618. Point distribution of *Rheoglanis dendrophorus*. Scale approximately 1:25 000 000

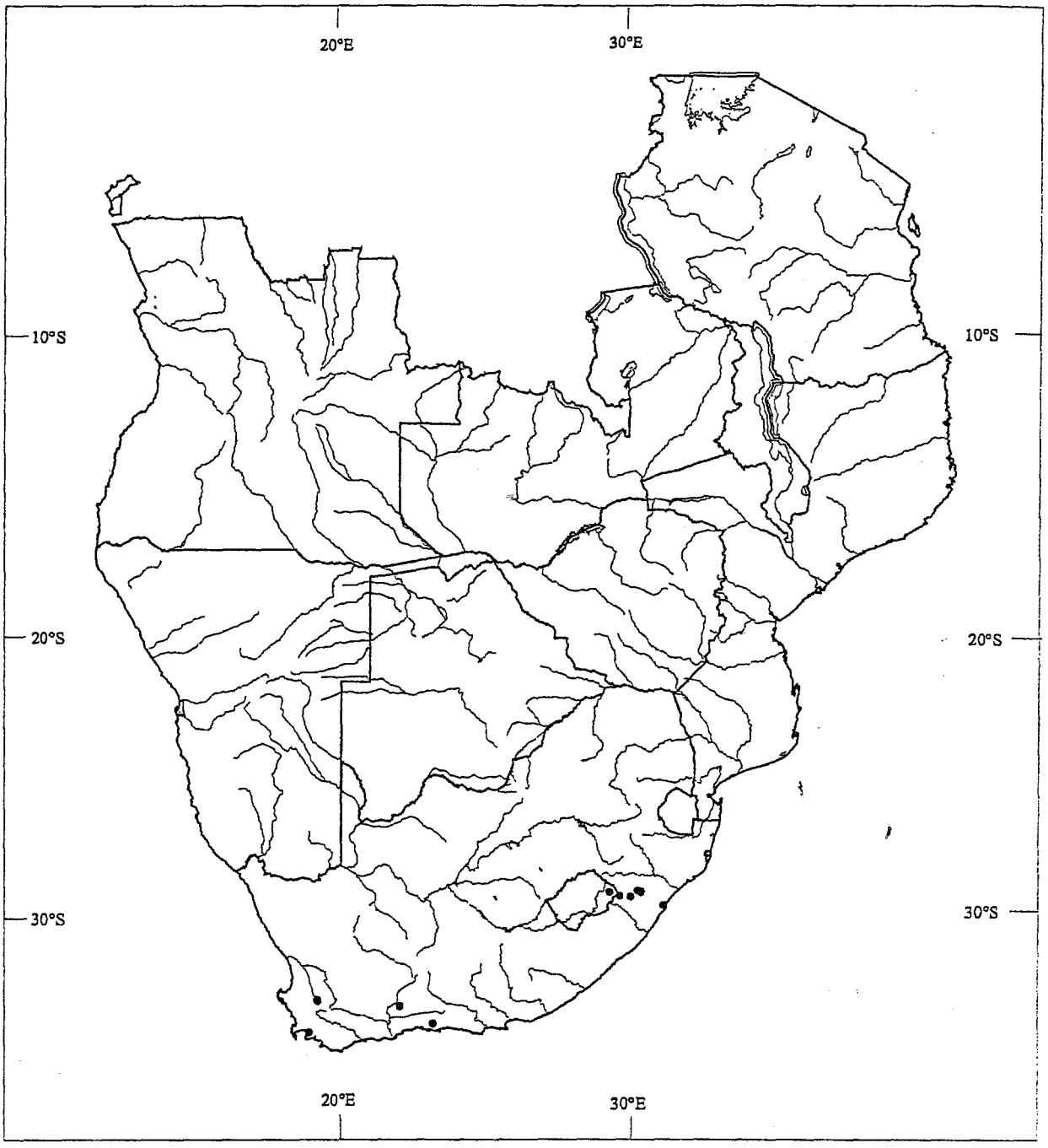


Figure F.619. Point distribution of *Salmo trutta*. Scale approximately 1:25 000 000

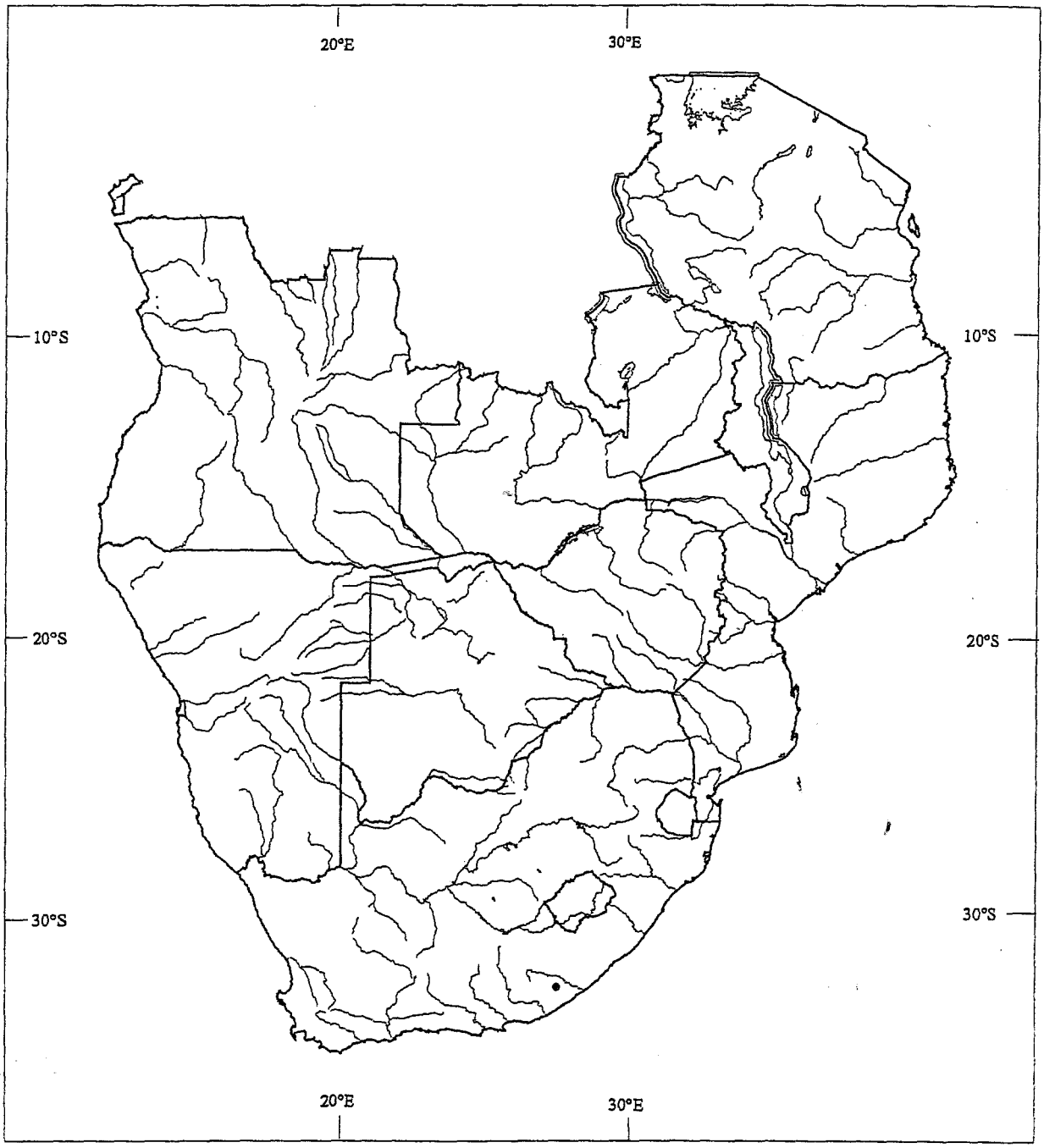


Figure F.620. Point distribution of *Salvelinus fontinalis*. Scale approximately 1:25 000 000

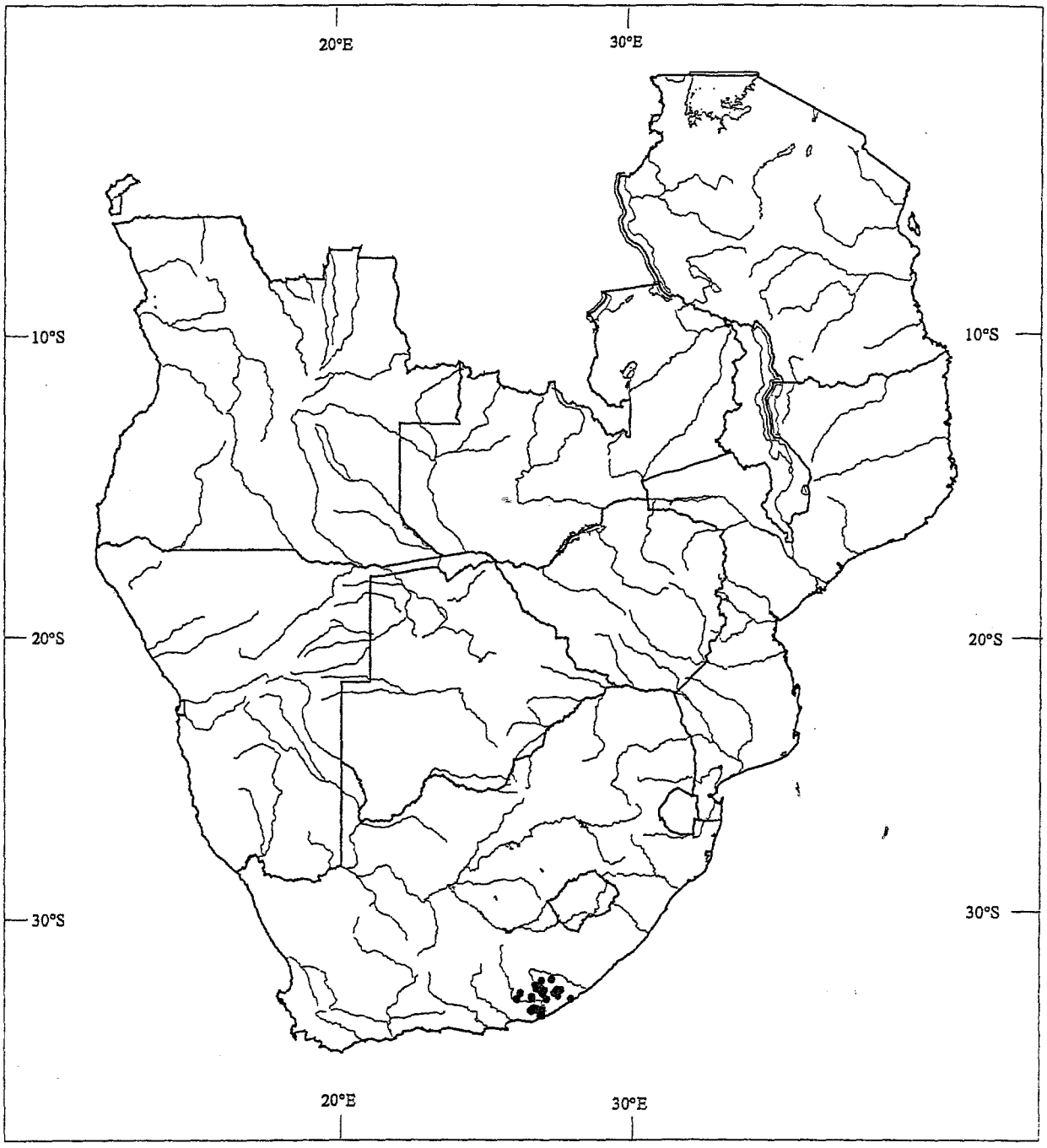


Figure F.621. Point distribution of *Sandelia bainsii*. Scale approximately 1:25 000 000

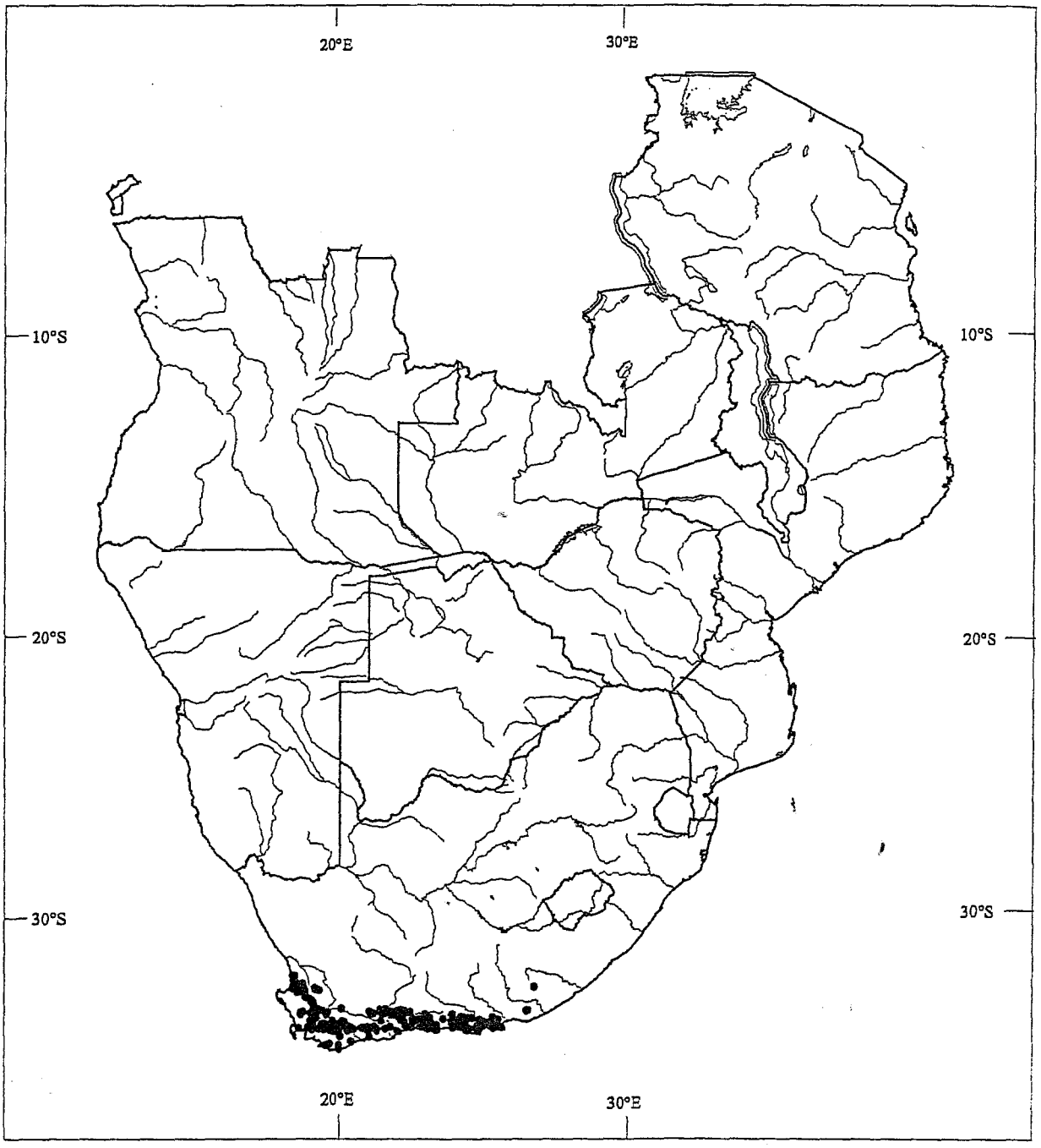


Figure F.622. Point distribution of *Sandelia capensis*. Scale approximately 1:25 000 000

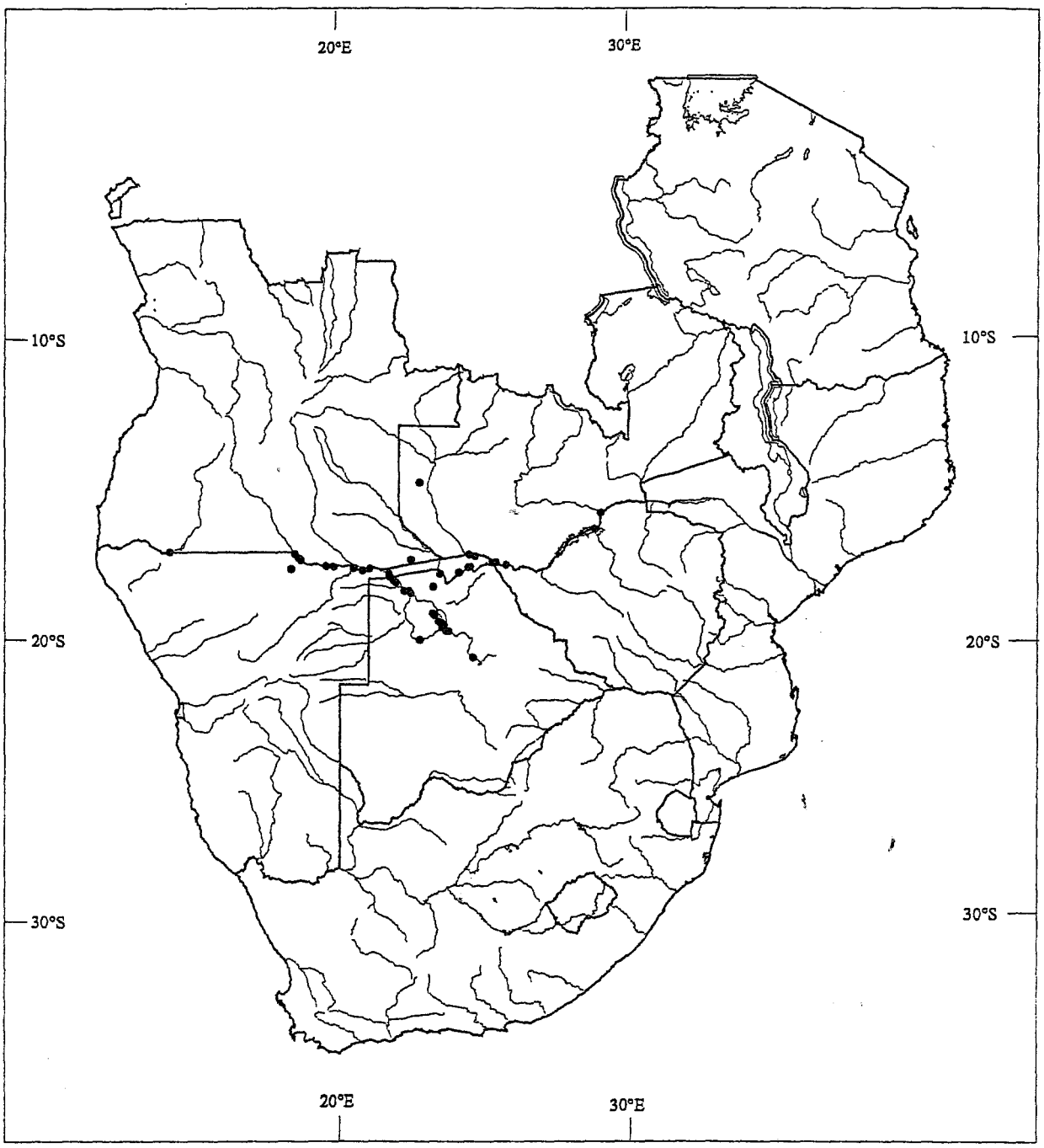


Figure F.623. Point distribution of *Sargochromis carlottae*. Scale approximately 1:25 000 000

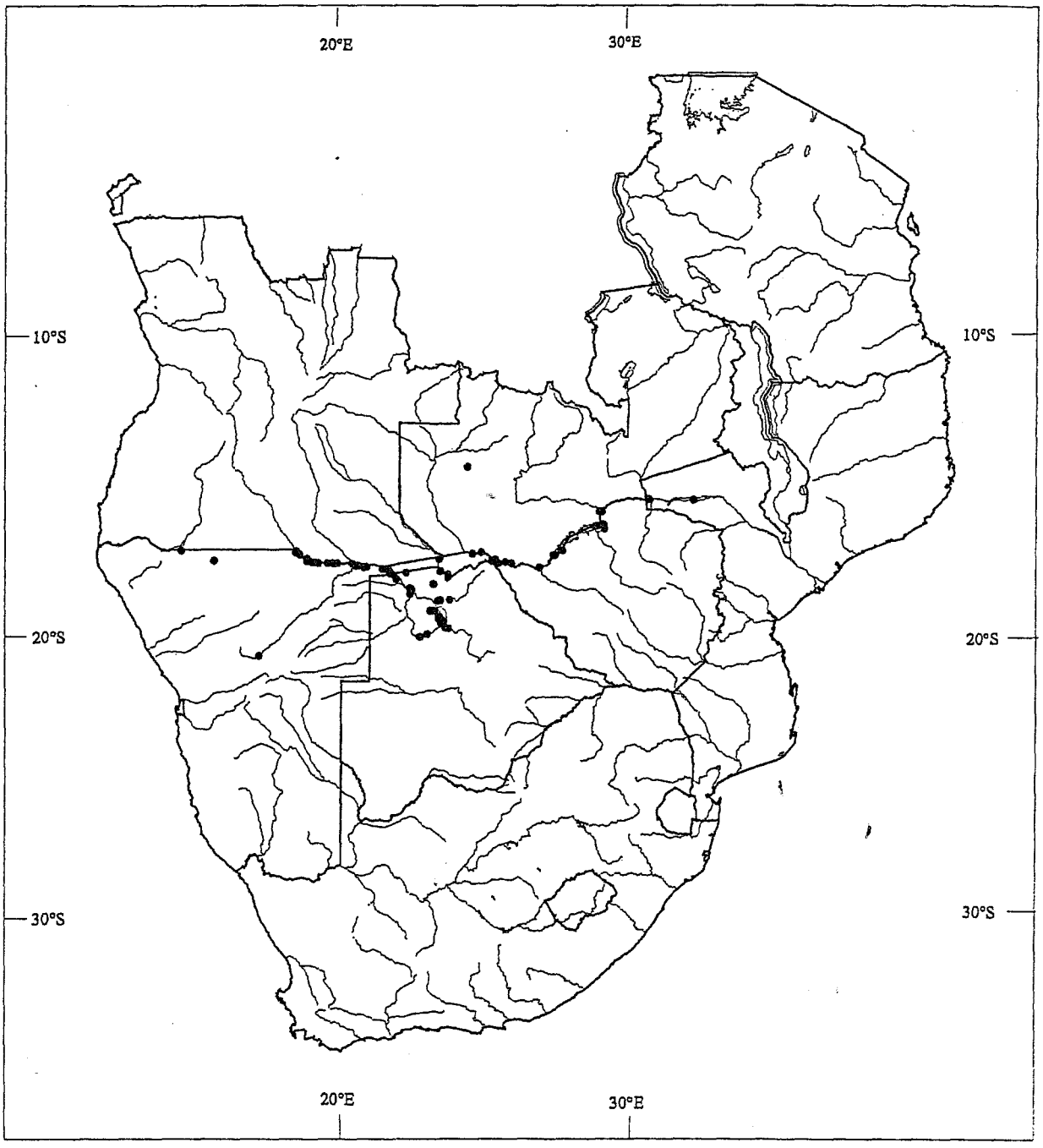


Figure F.624. Point distribution of *Sargochromis codringtonii*. Scale approximately 1:25 000 000

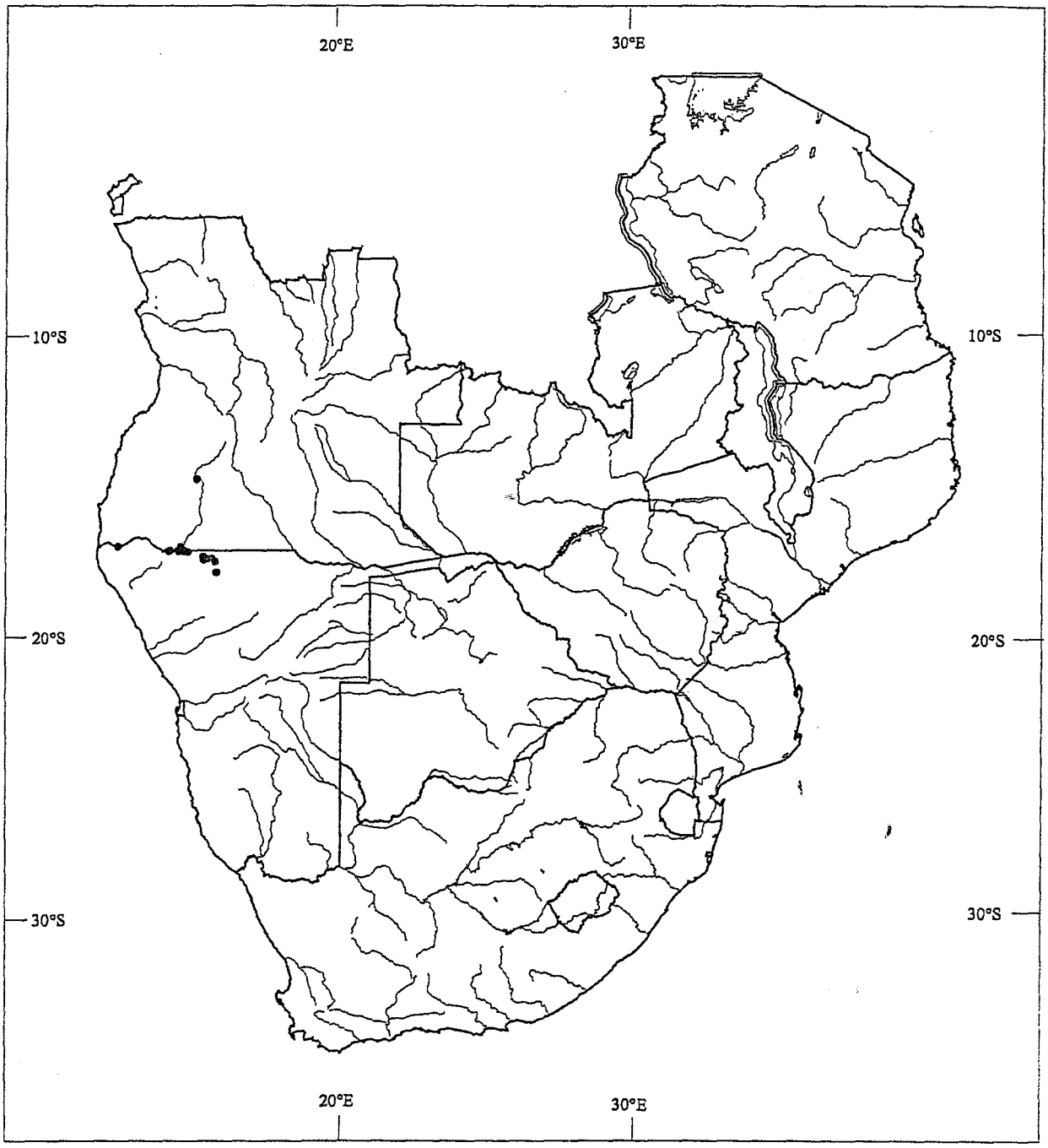


Figure F.625. Point distribution of *Sargochromis coulteri*. Scale approximately 1:25 000 000

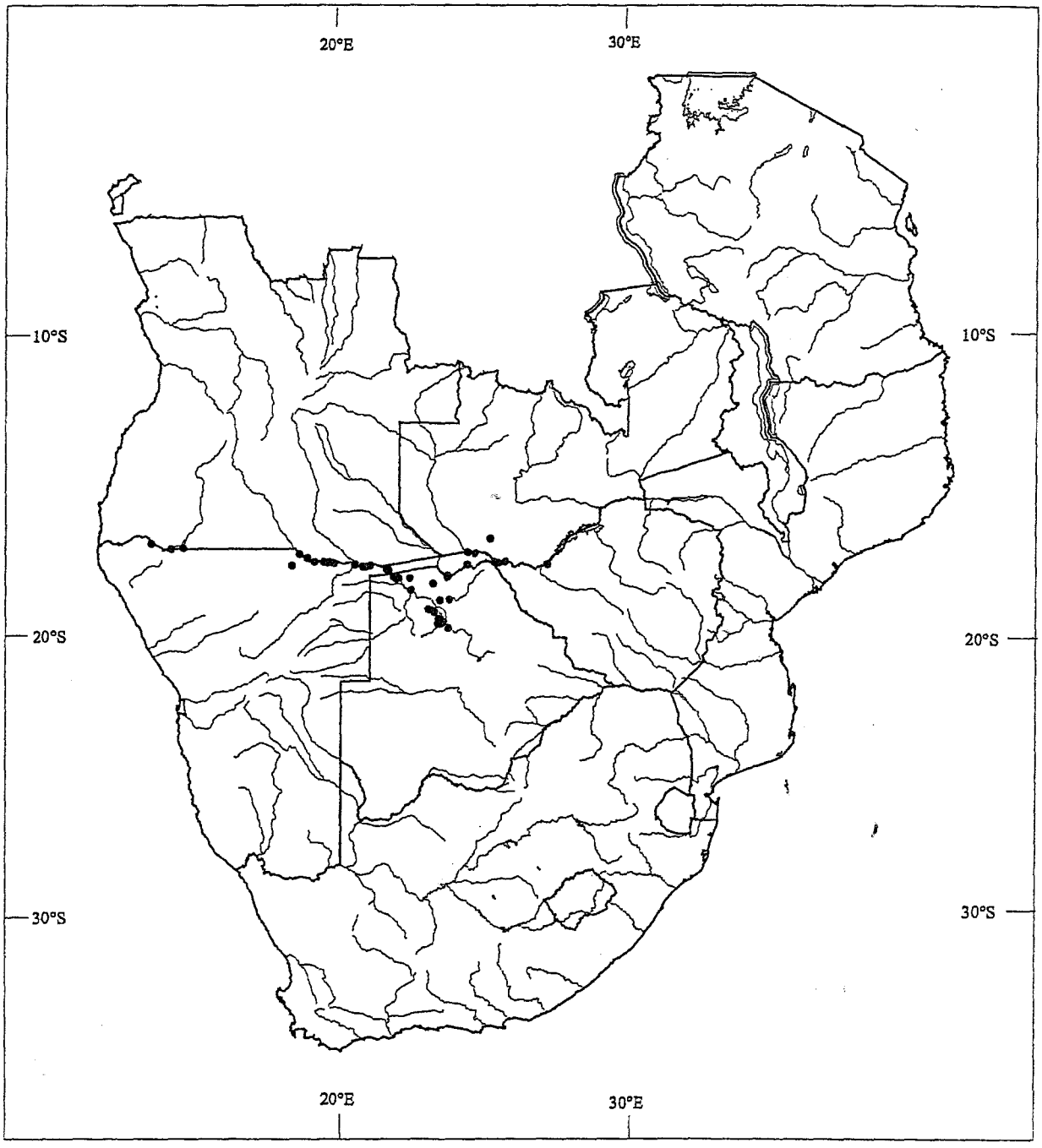


Figure F.626. Point distribution of *Sargochromis giardi*. Scale approximately 1:25 000 000

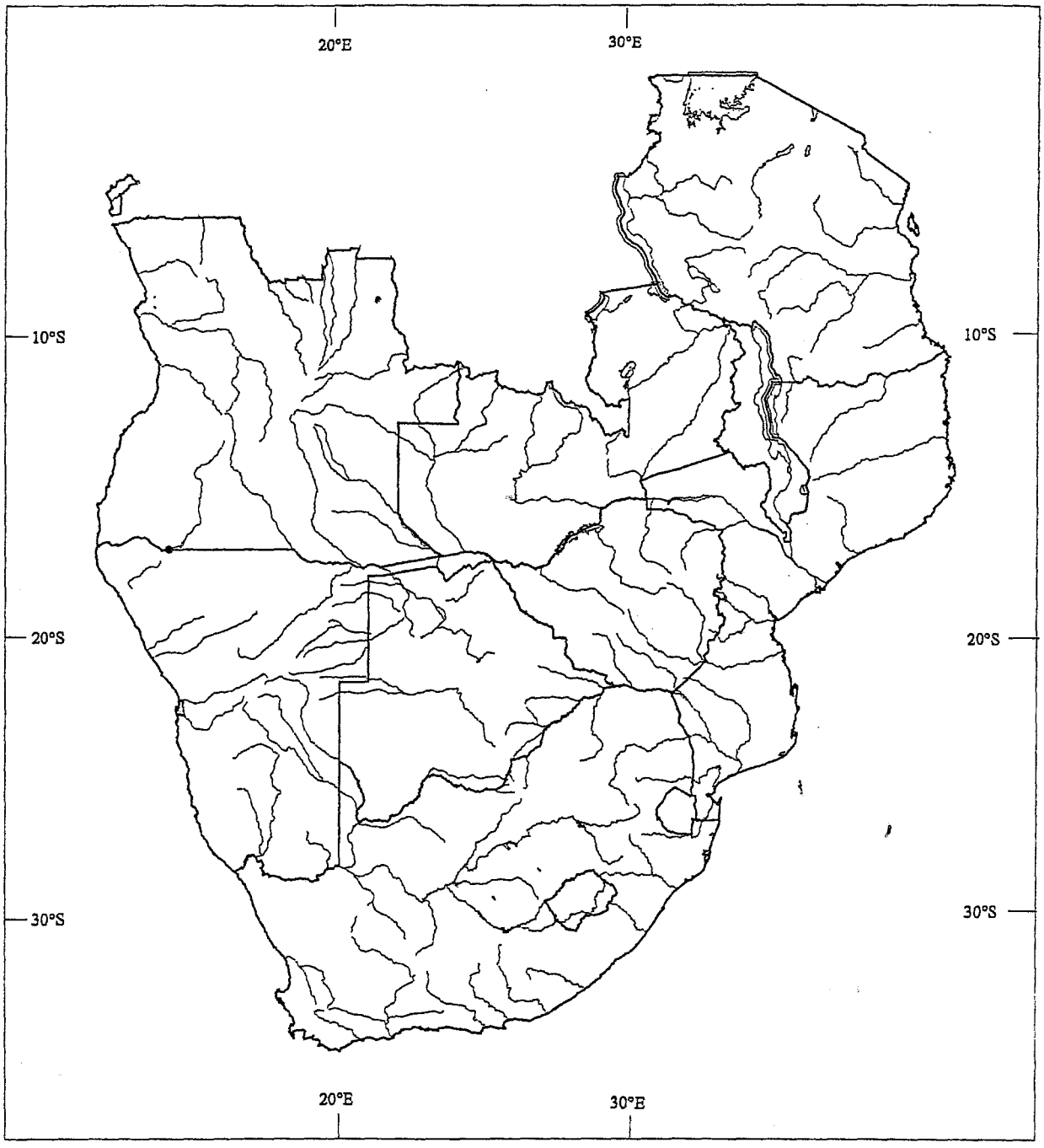


Figure F.627. Point distribution of *Sargochromis gracilis*. Scale approximately 1:25 000 000

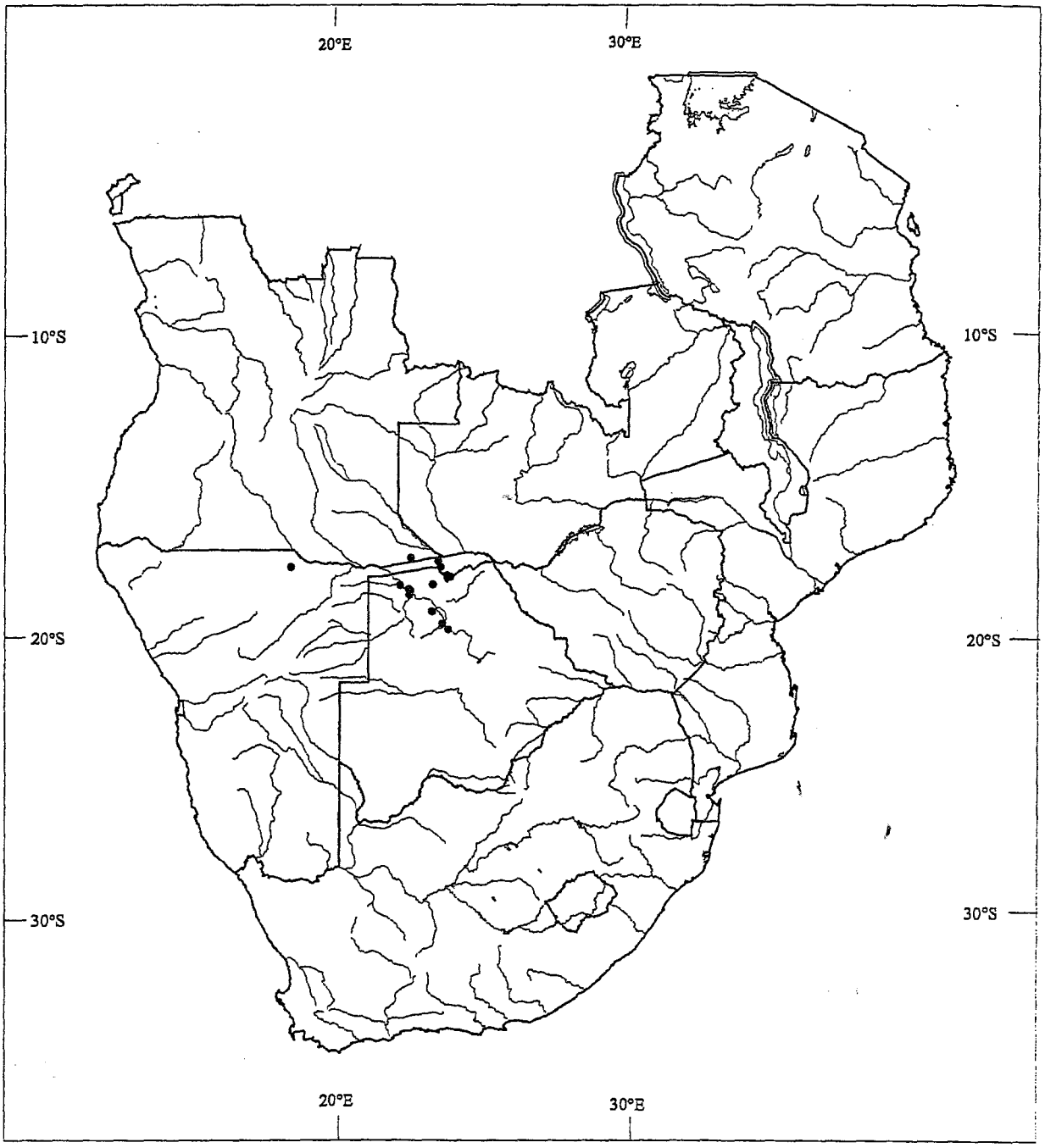


Figure F.628. Point distribution of *Sargochromis greenwoodi*. Scale approximately 1:25 000 000

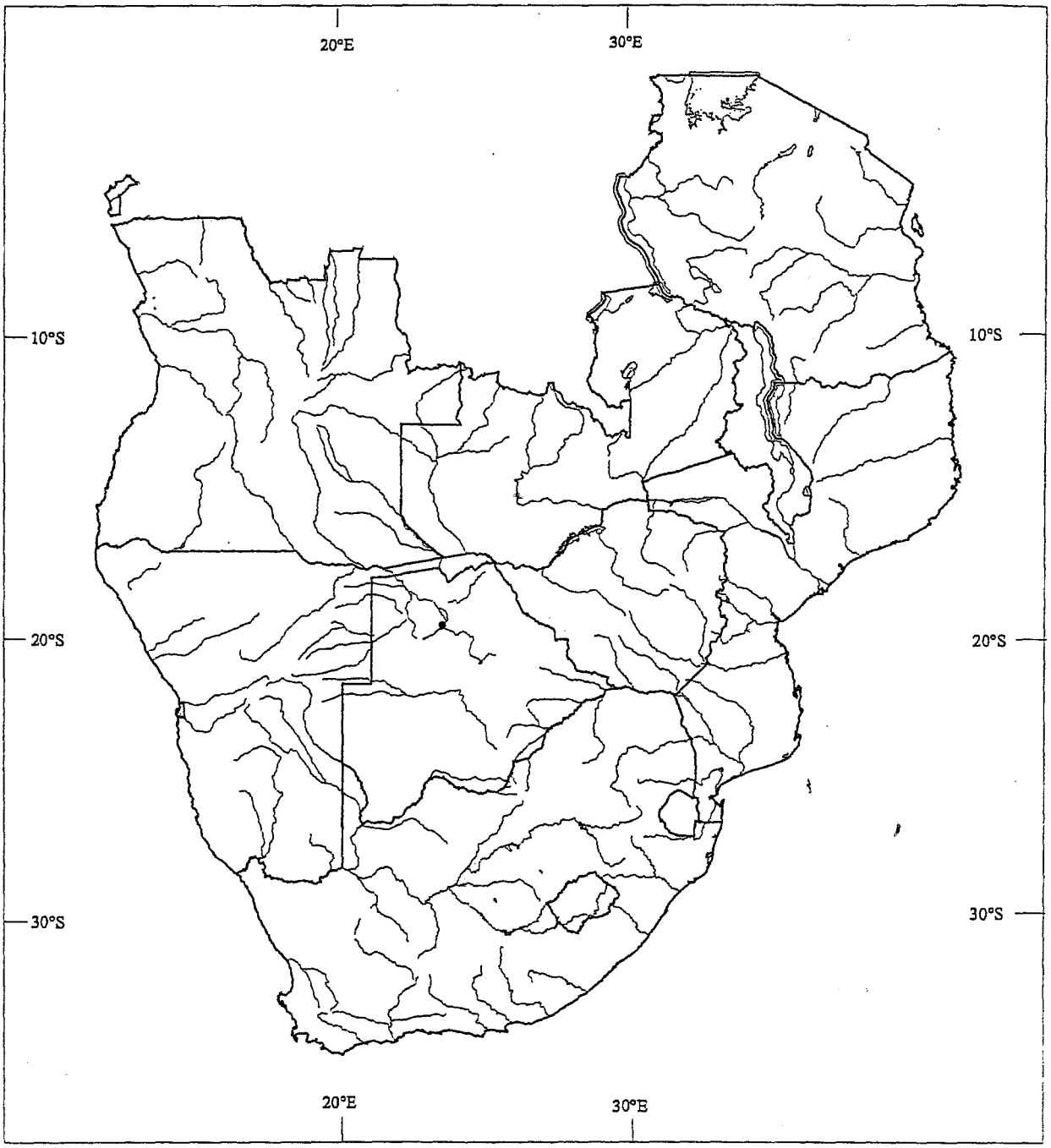


Figure F.629. Point distribution of *Sargochromis mellandi*. Scale approximately 1:25 000 000

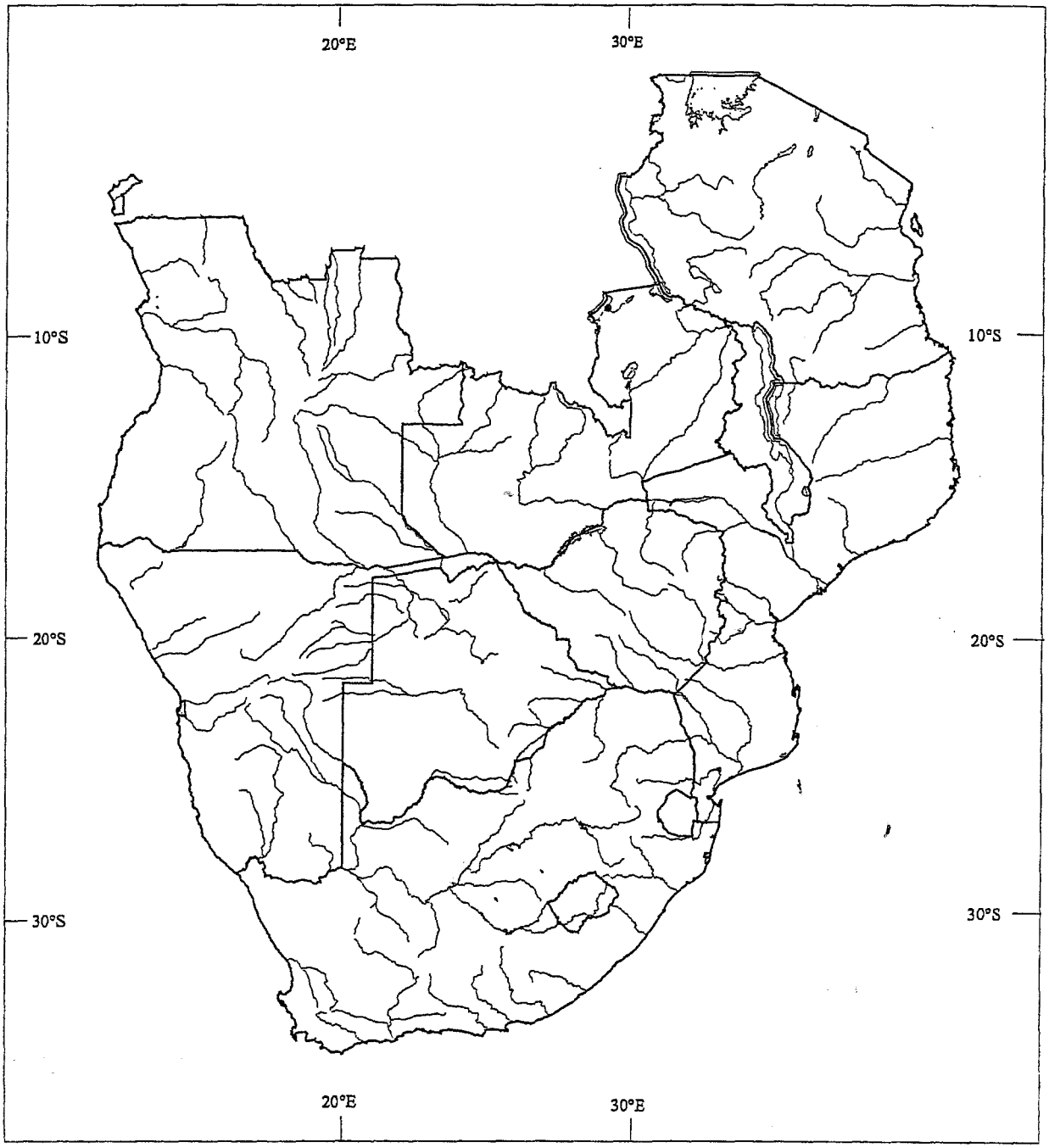


Figure F.630. Point distribution of *Schilbe banguelensis*. Scale approximately 1:25 000 000

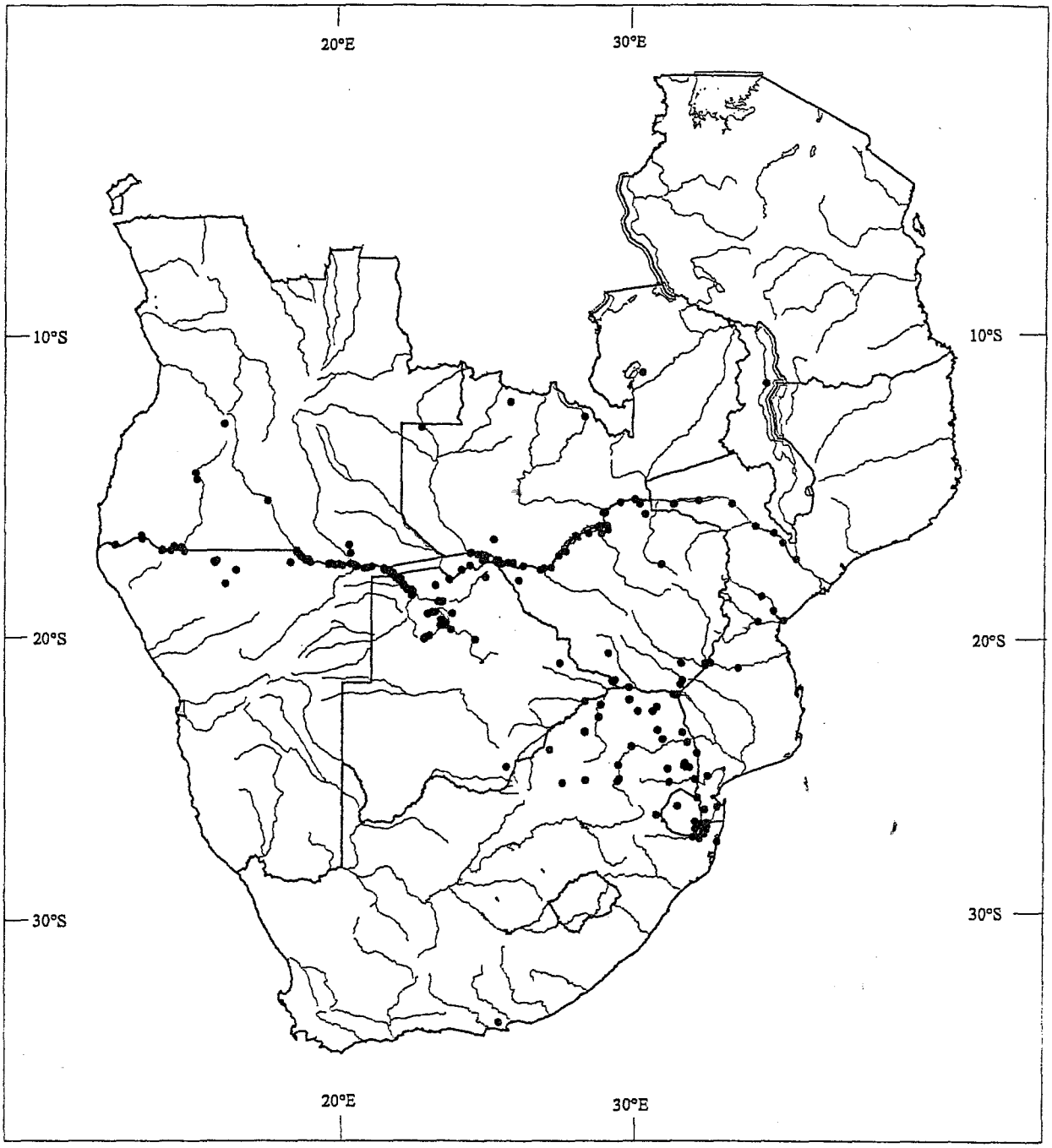


Figure F.631. Point distribution of *Schilbe intermedius*. Scale approximately 1:25 000 000

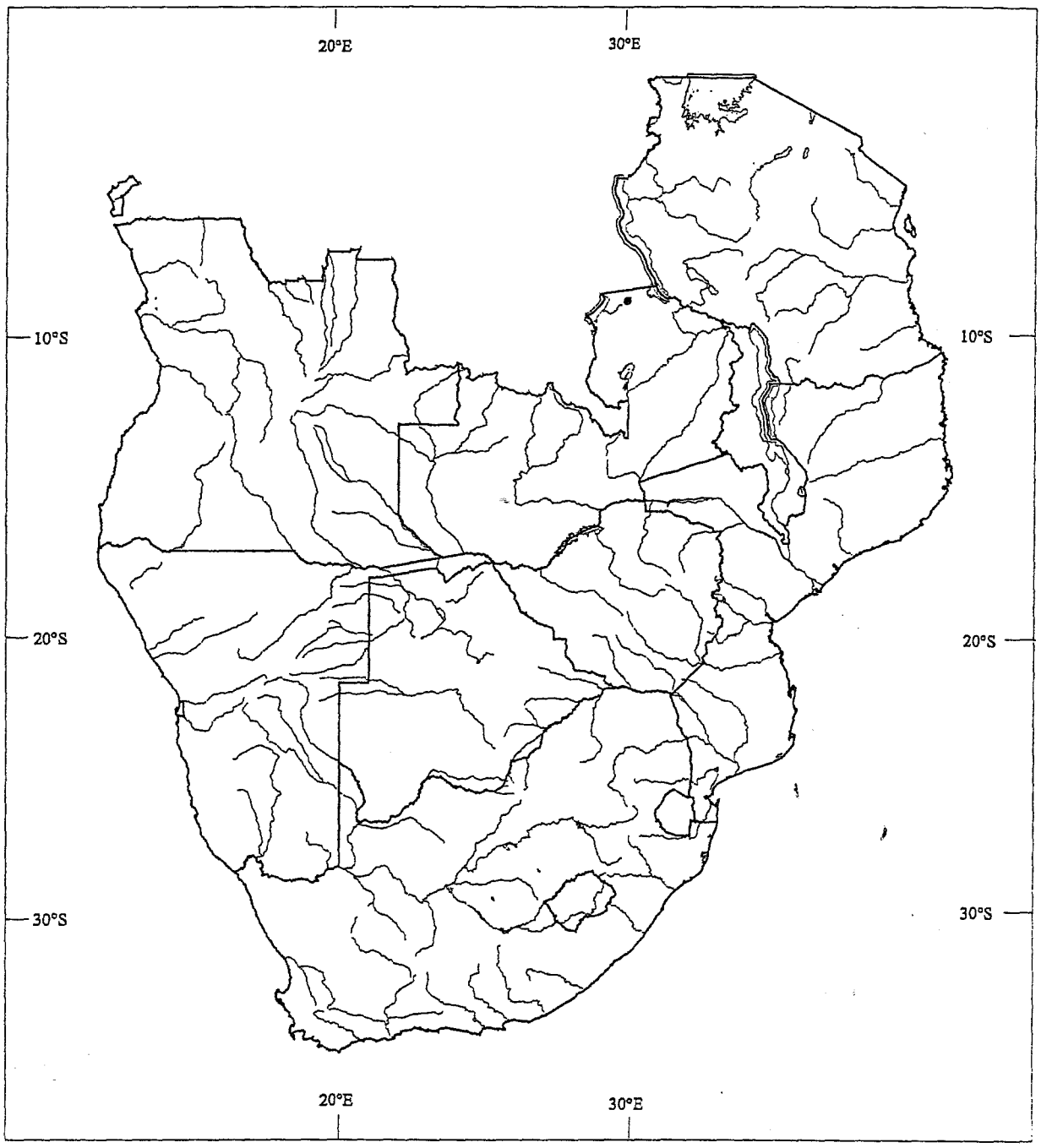


Figure F.632. Point distribution of *Schilbe nasalis*. Scale approximately 1:25 000 000

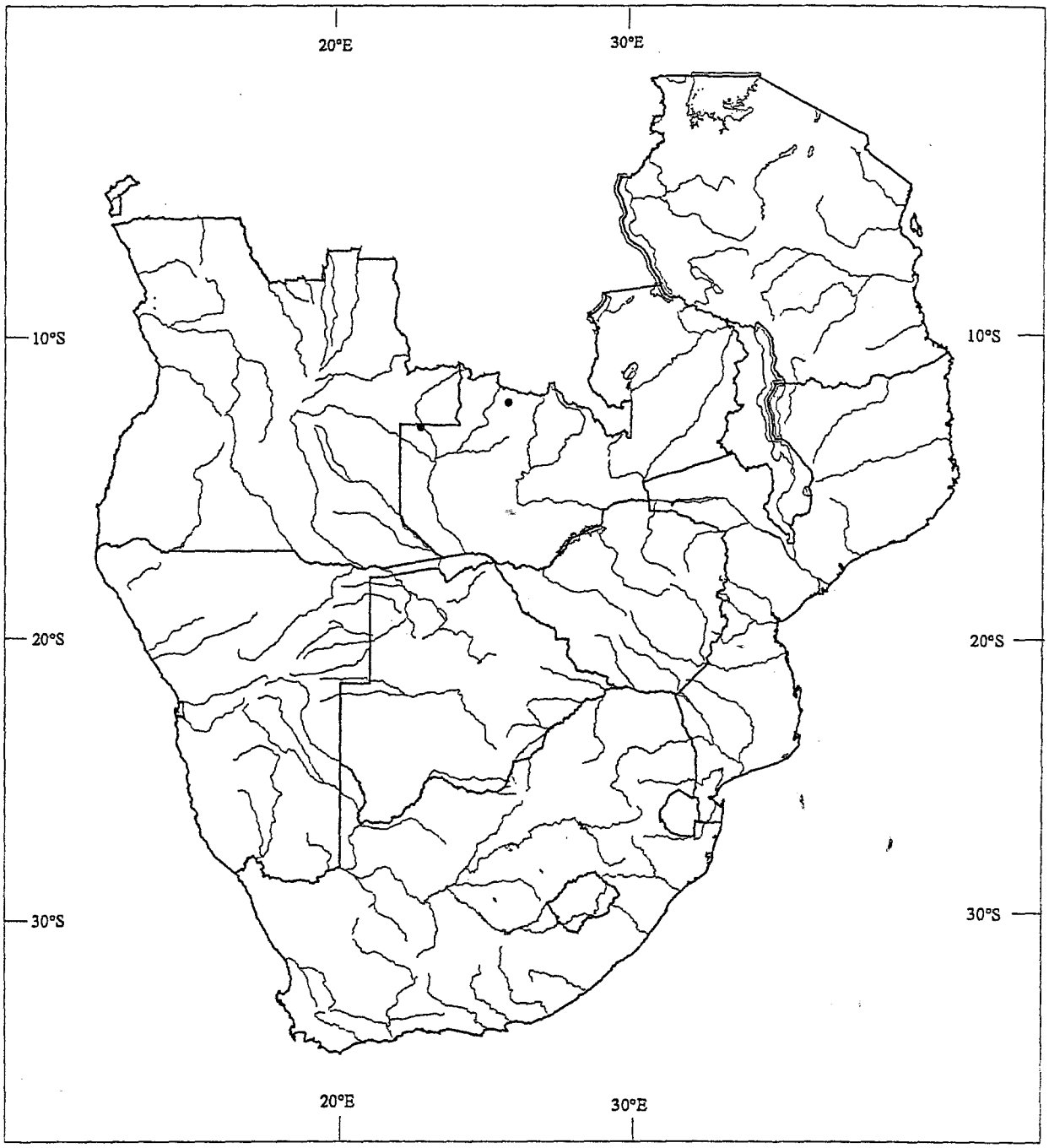


Figure F.633. Point distribution of *Schilbe yangambianus*. Scale approximately 1:25 000 000

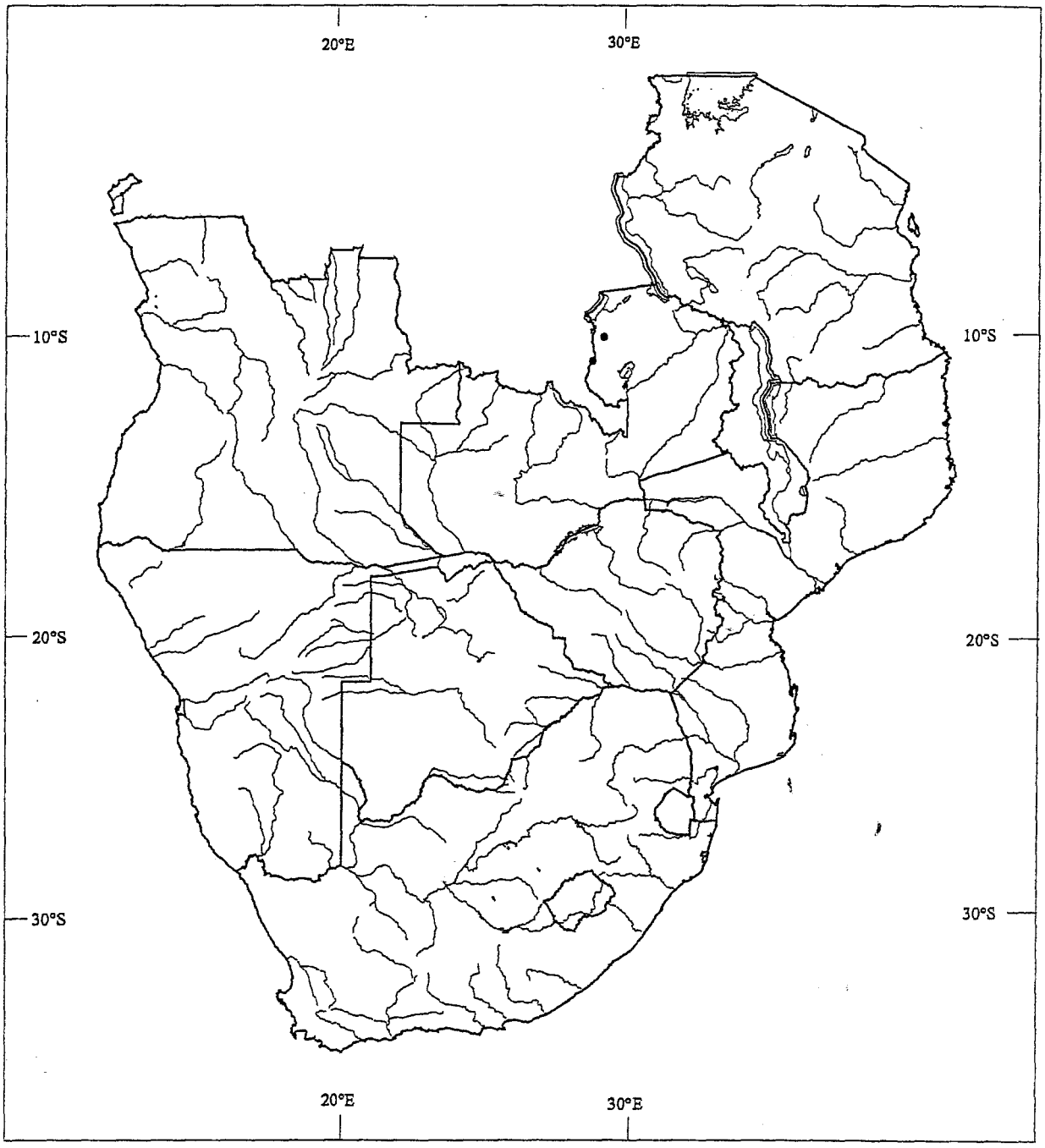


Figure F.634. Point distribution of *Schwetzochromis luongoensis*. Scale approximately 1:25 000 000

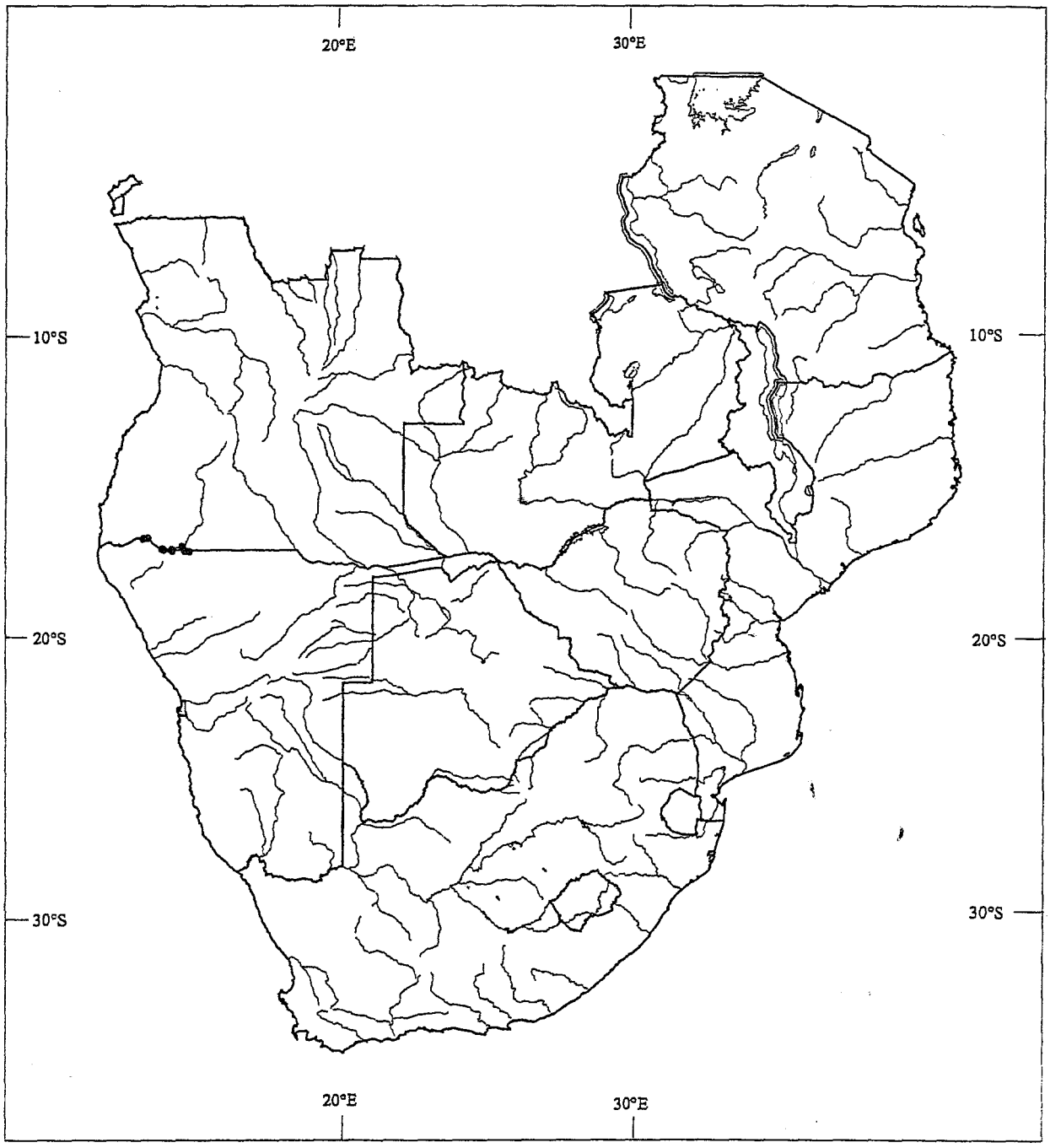


Figure F.635. Point distribution of *Schwetzochromis machadoi*. Scale approximately 1:25 000 000

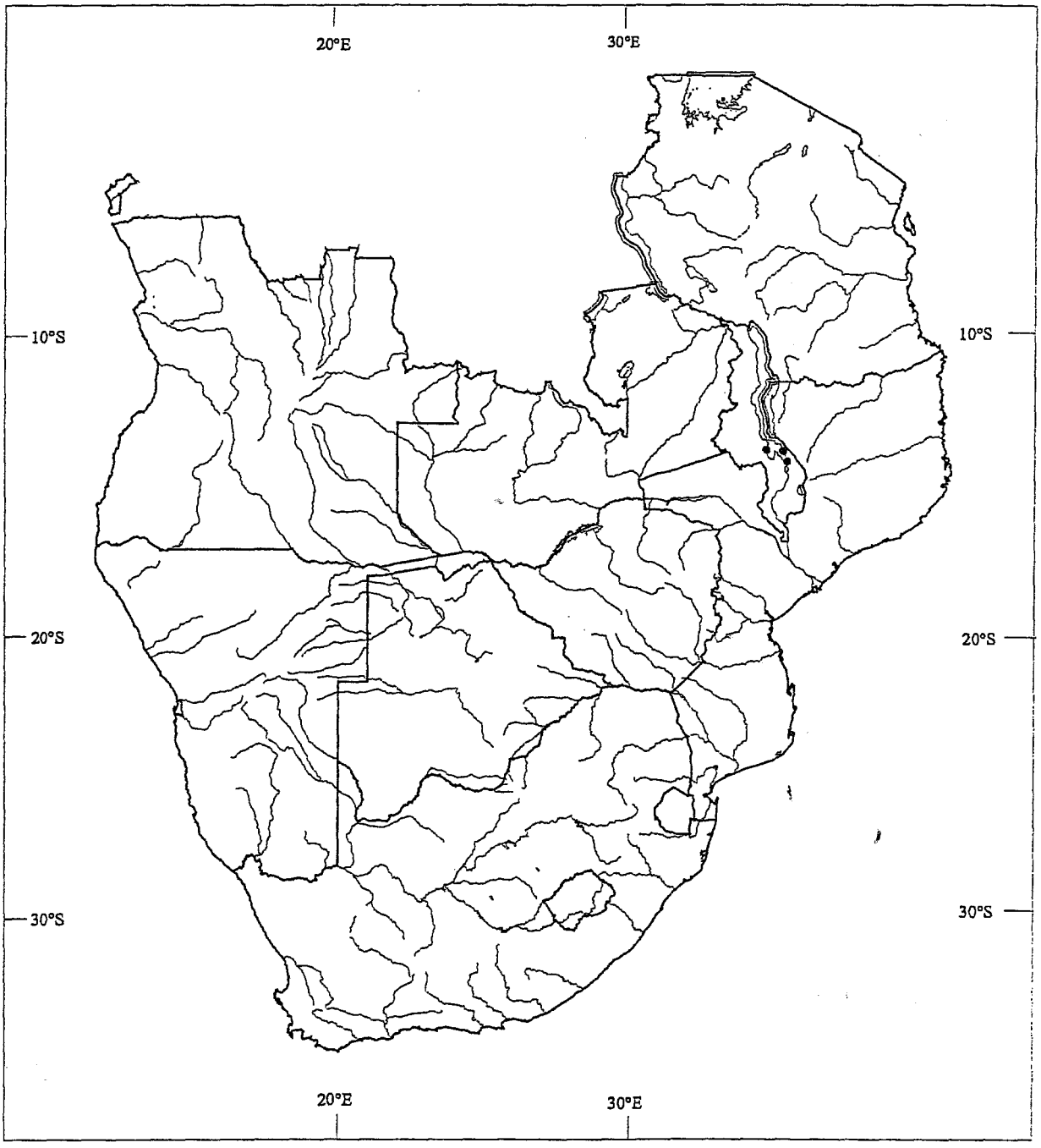


Figure F.636. Point distribution of *Sciaenochromis ahli*. Scale approximately 1:25 000 000

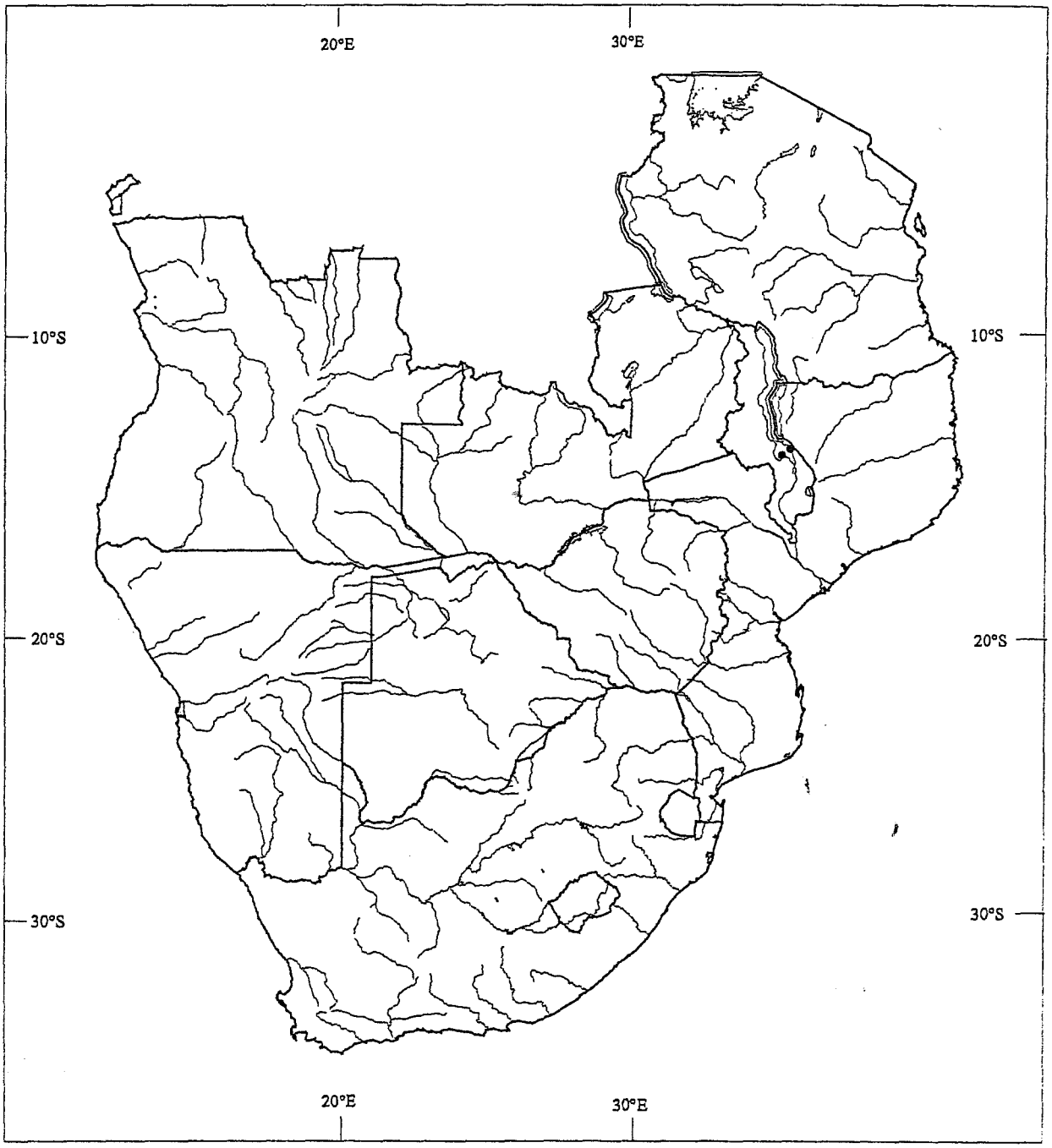


Figure F.637. Point distribution of *Sciaenochromis gracilis*. Scale approximately 1:25 000 000

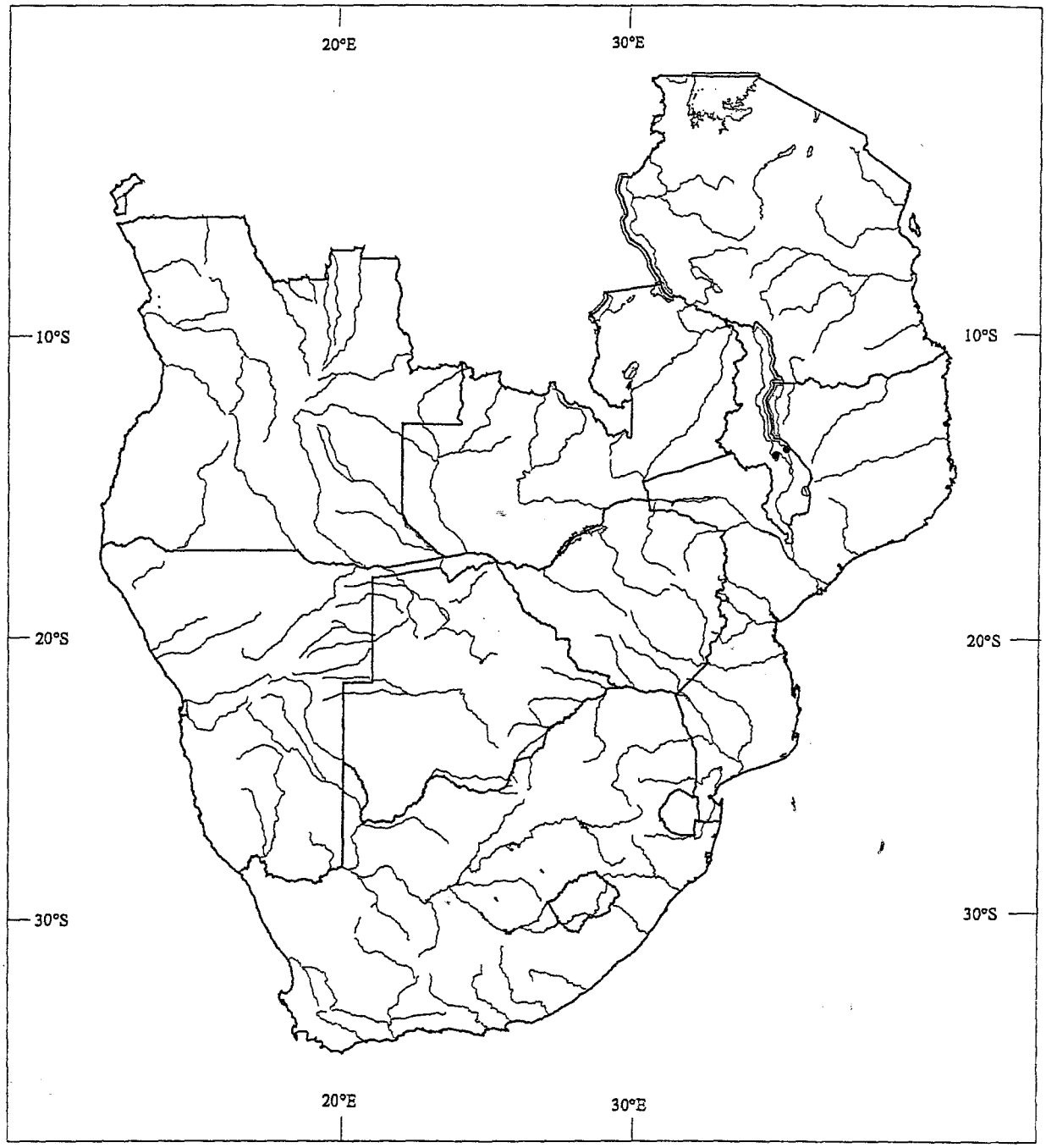


Figure F.638. Point distribution of *Sciaenochromis spiloticus*. Scale approximately 1:25 000 000

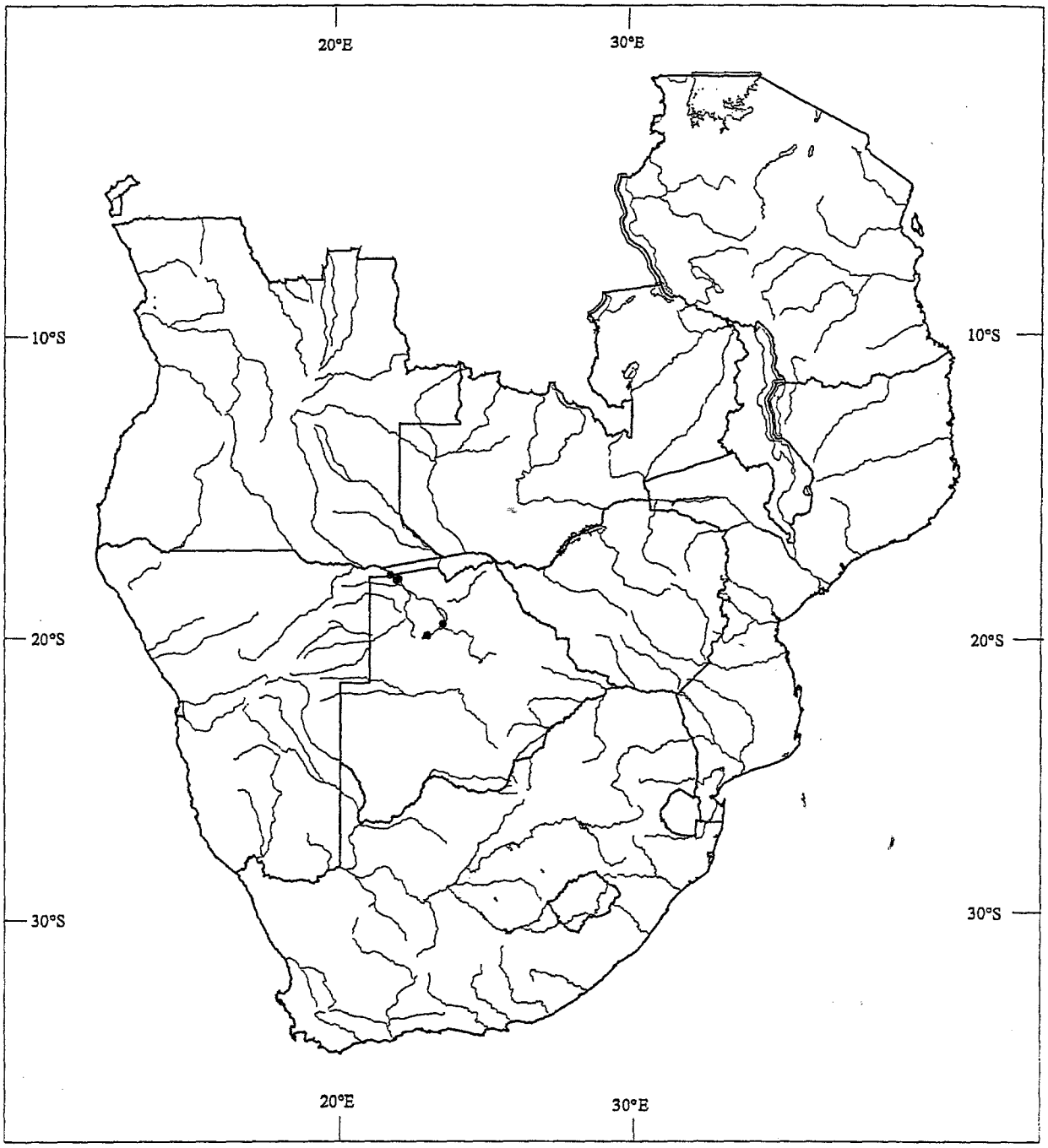


Figure F.639. Point distribution of *Serranochromis altus*. Scale approximately 1:25 000 000

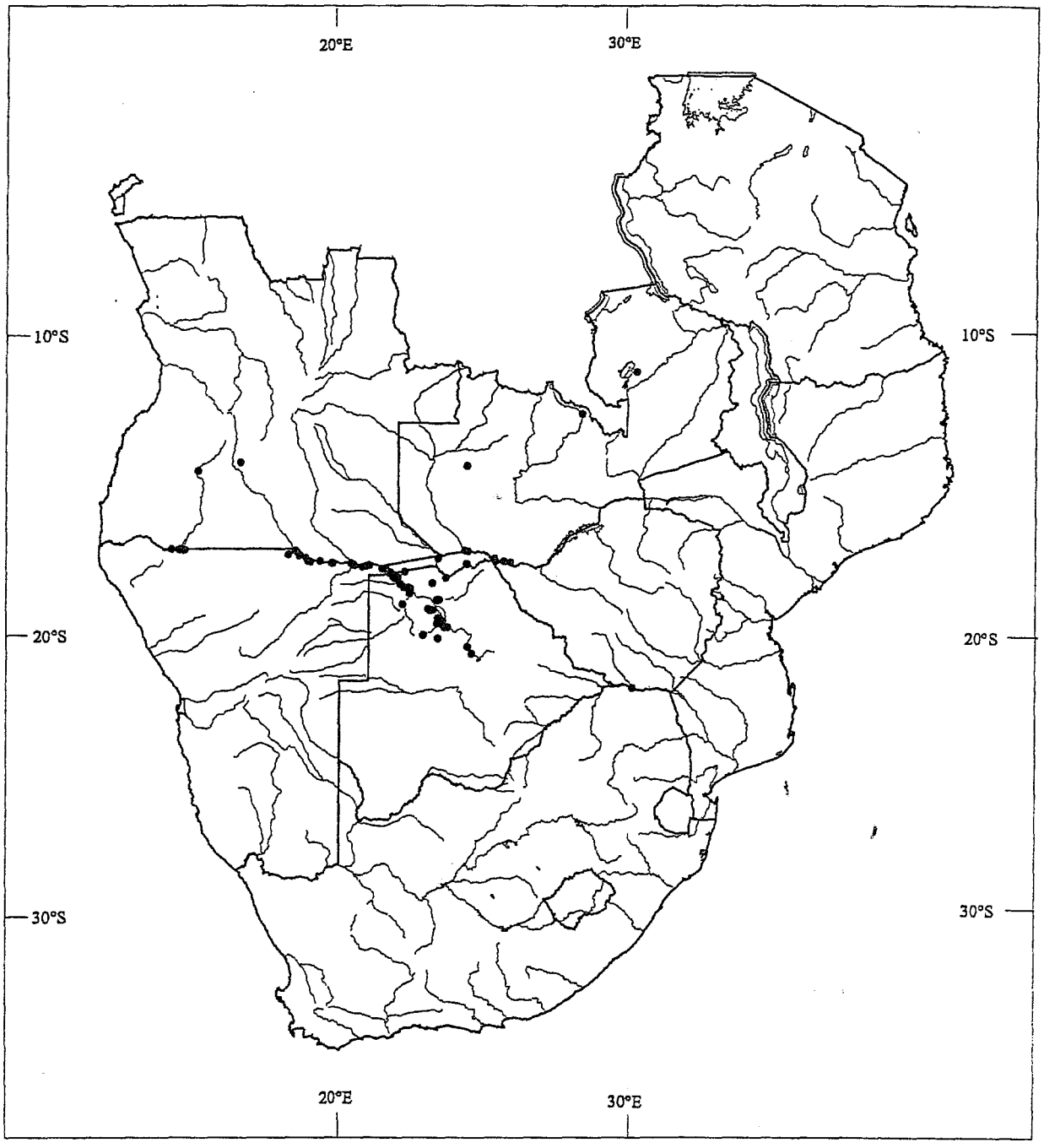


Figure F.640. Point distribution of *Serranochromis angusticeps*. Scale approximately 1:25 000 000

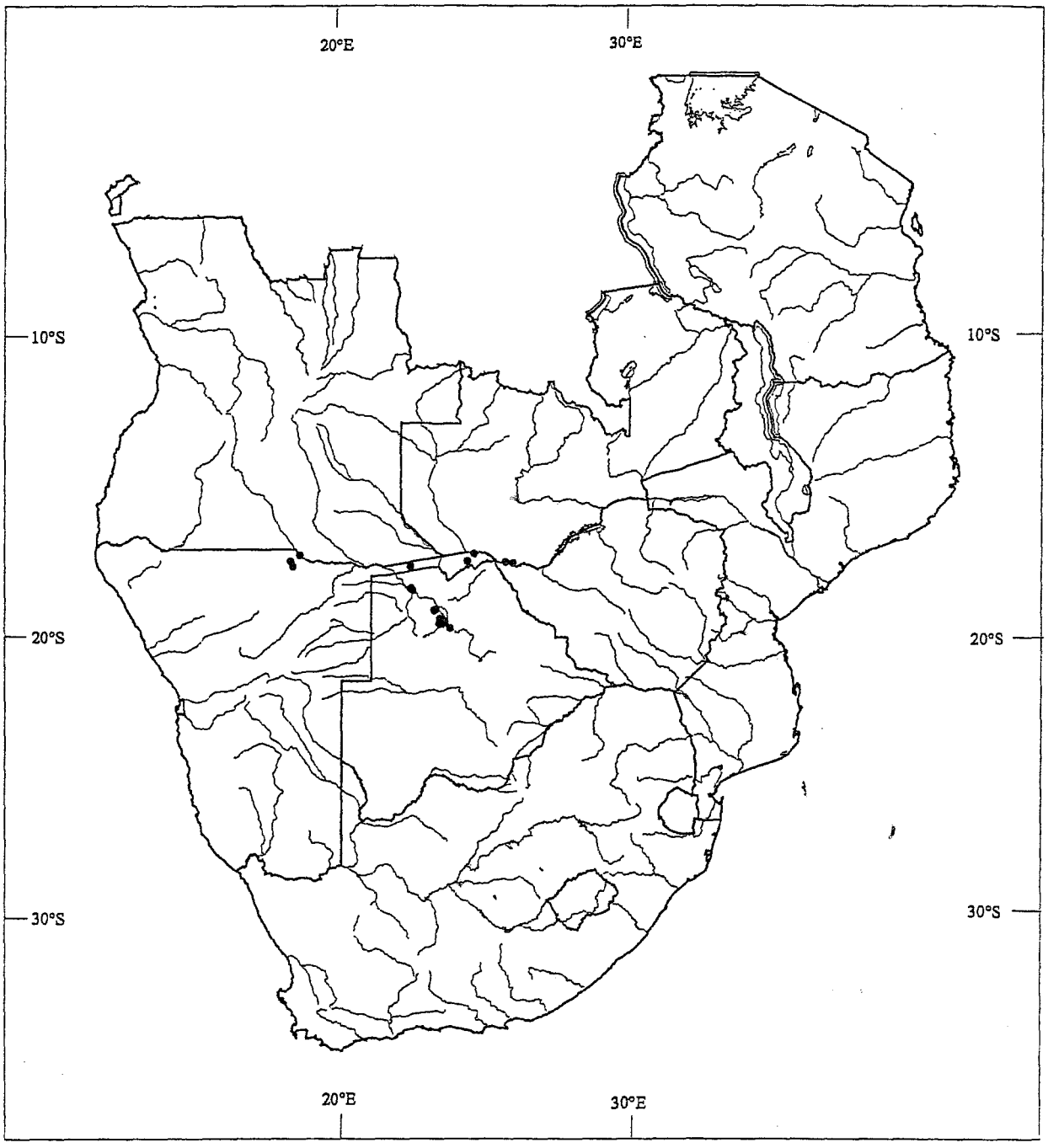


Figure F.641. Point distribution of *Serranochromis longimanus*. Scale approximately 1:25 000 000

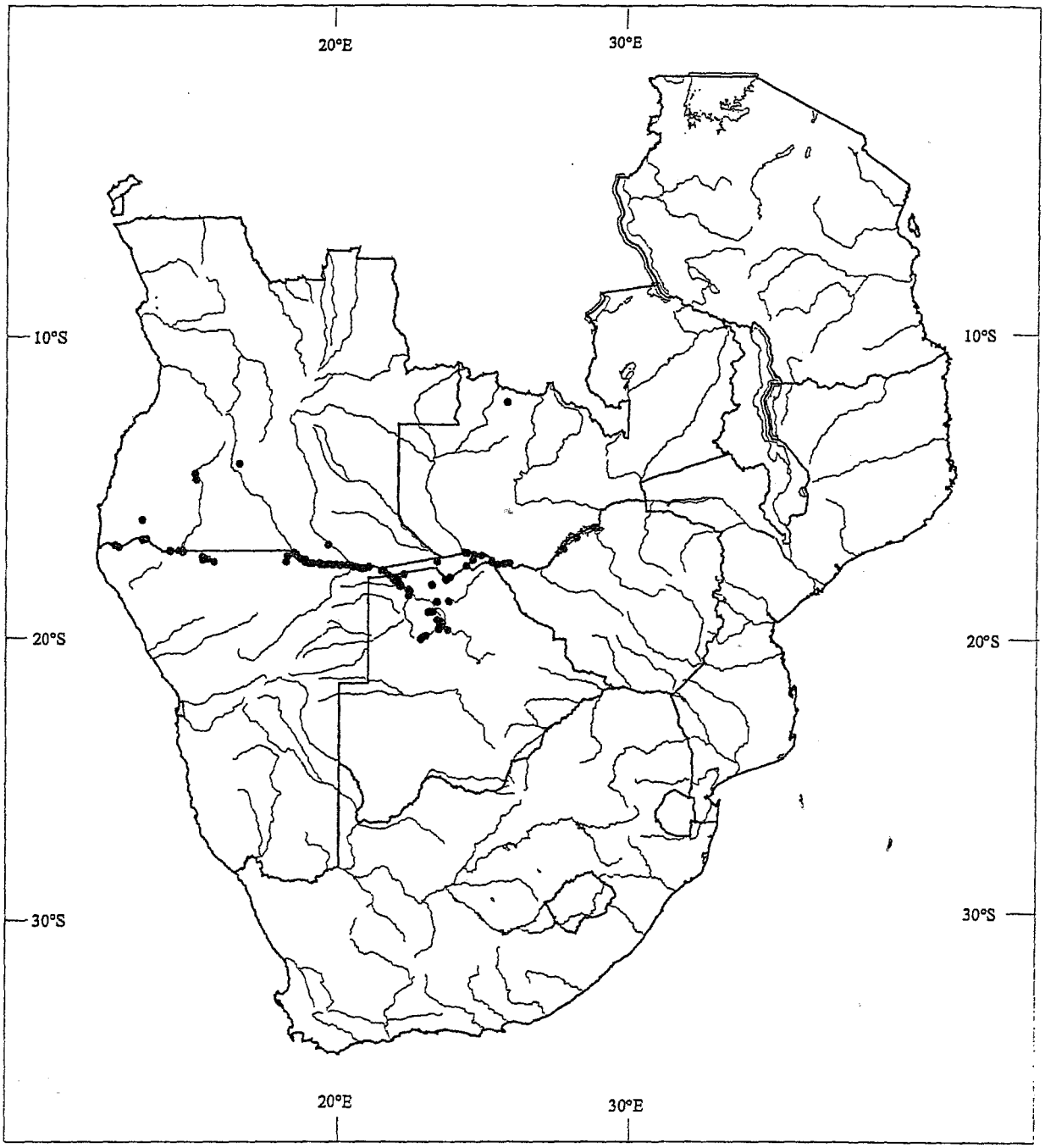


Figure F.642. Point distribution of *Serranochromis macrocephalus*. Scale approximately 1:25 000 000

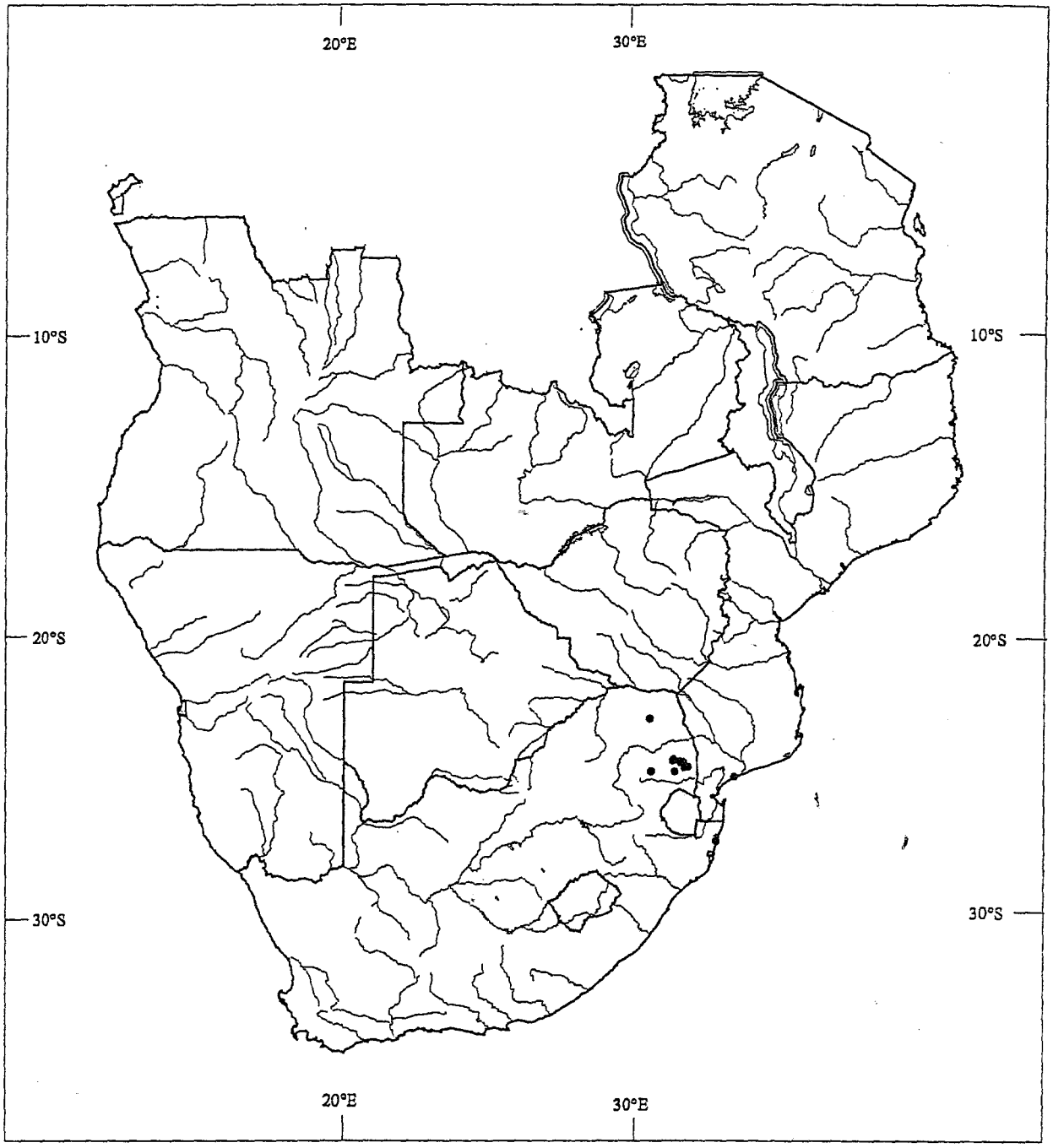


Figure F.643. Point distribution of *Serranochromis meridianus*. Scale approximately 1:25 000 000

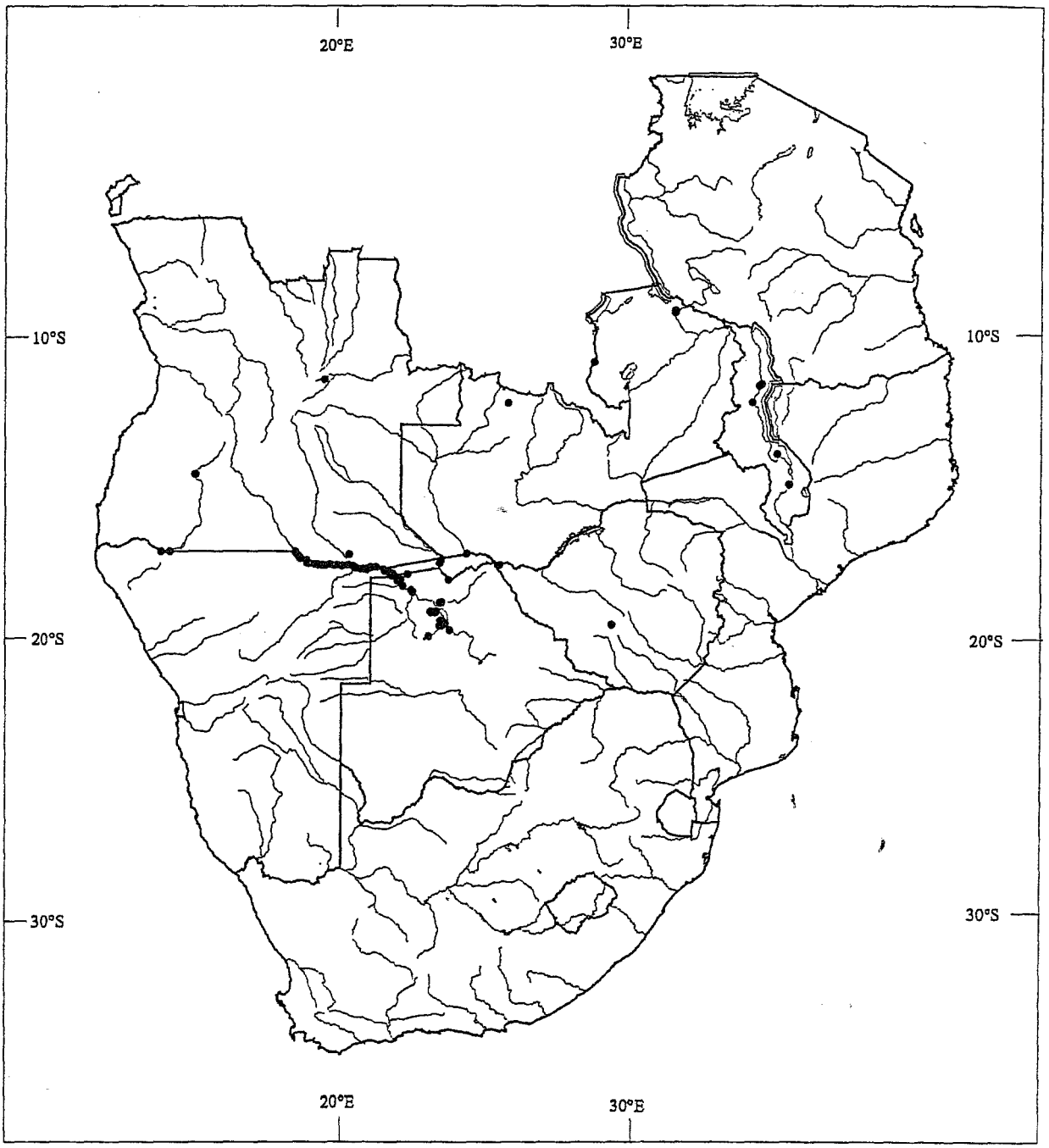


Figure F.644. Point distribution of *Serranochromis robustus*. Scale approximately 1:25 000 000

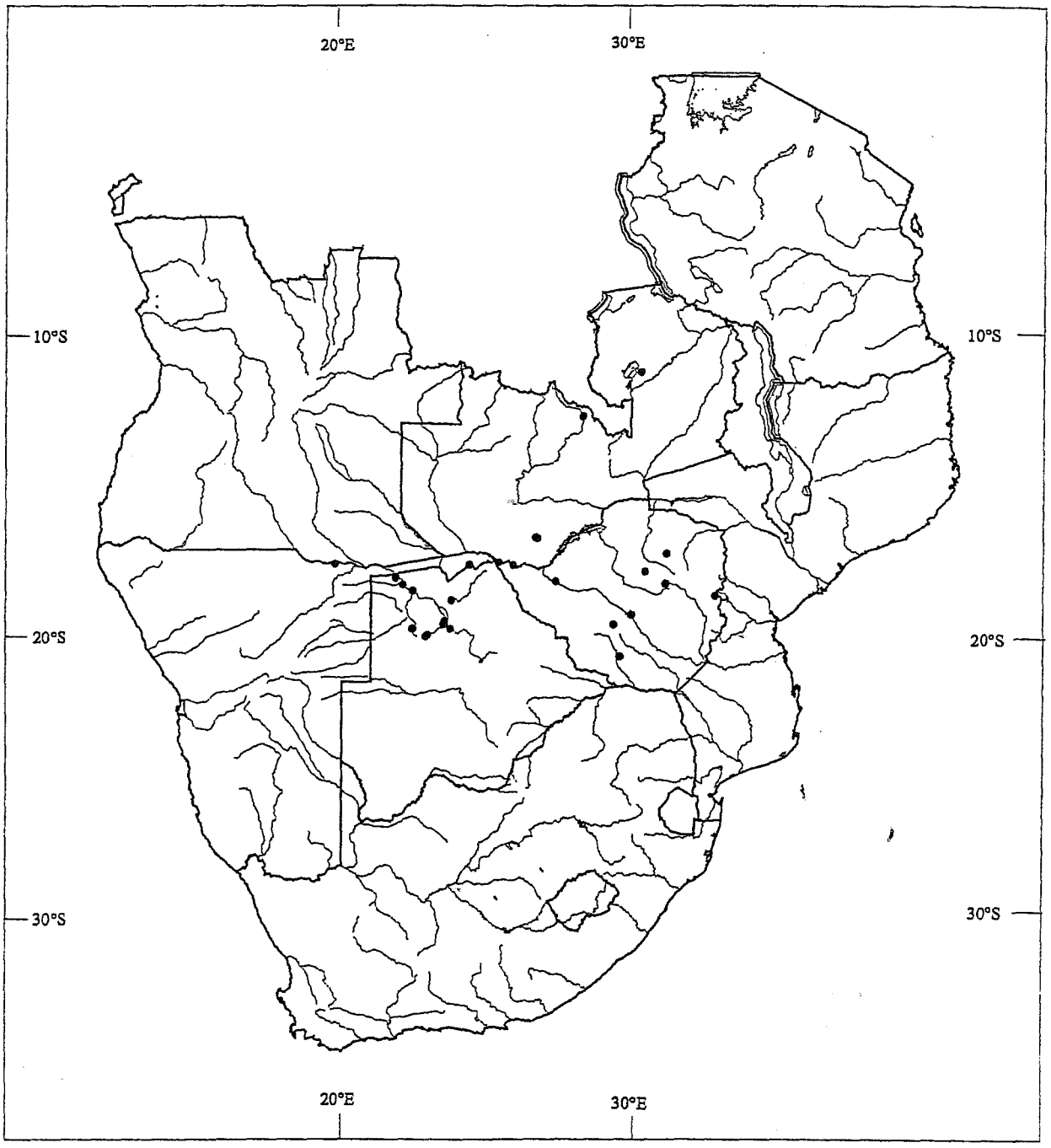


Figure F.645. Point distribution of *Serranochromis robustus jallae*. Scale approximately 1:25 000 000

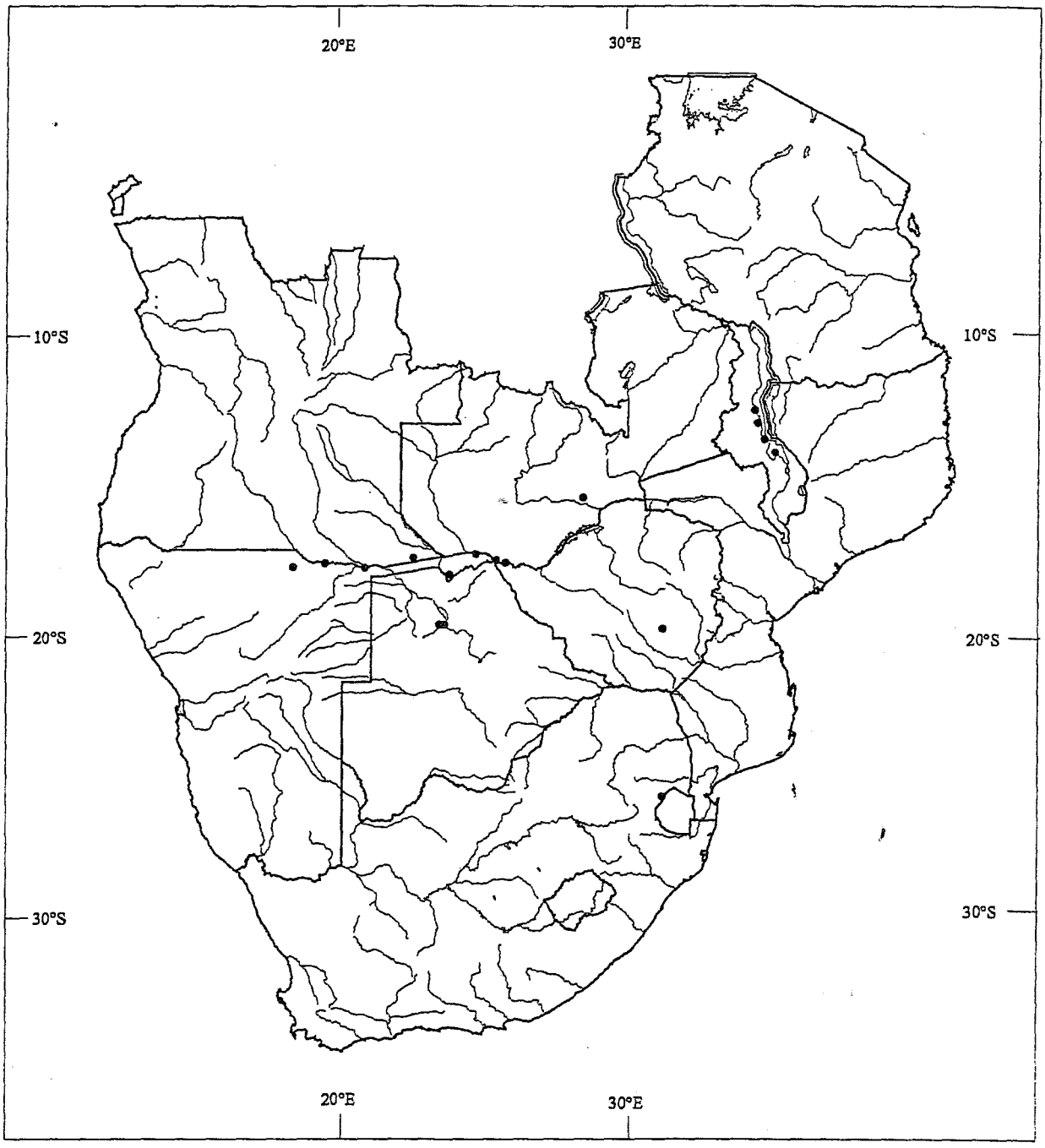


Figure F.646. Point distribution of *Serranochromis robustus robustus*. Scale approximately 1:25 000 000

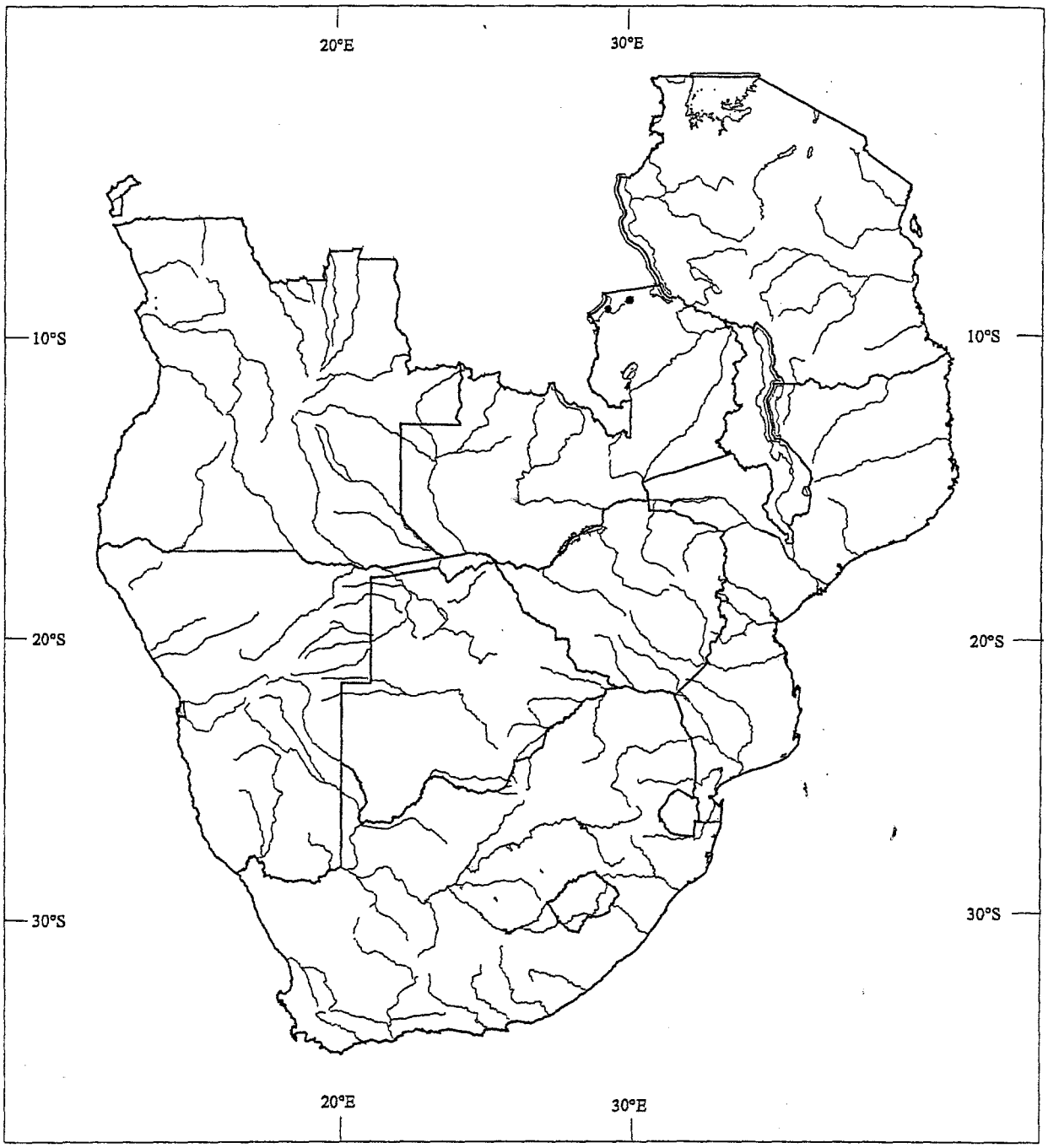


Figure F.647. Point distribution of *Serranochromis stappersi*. Scale approximately 1:25 000 000

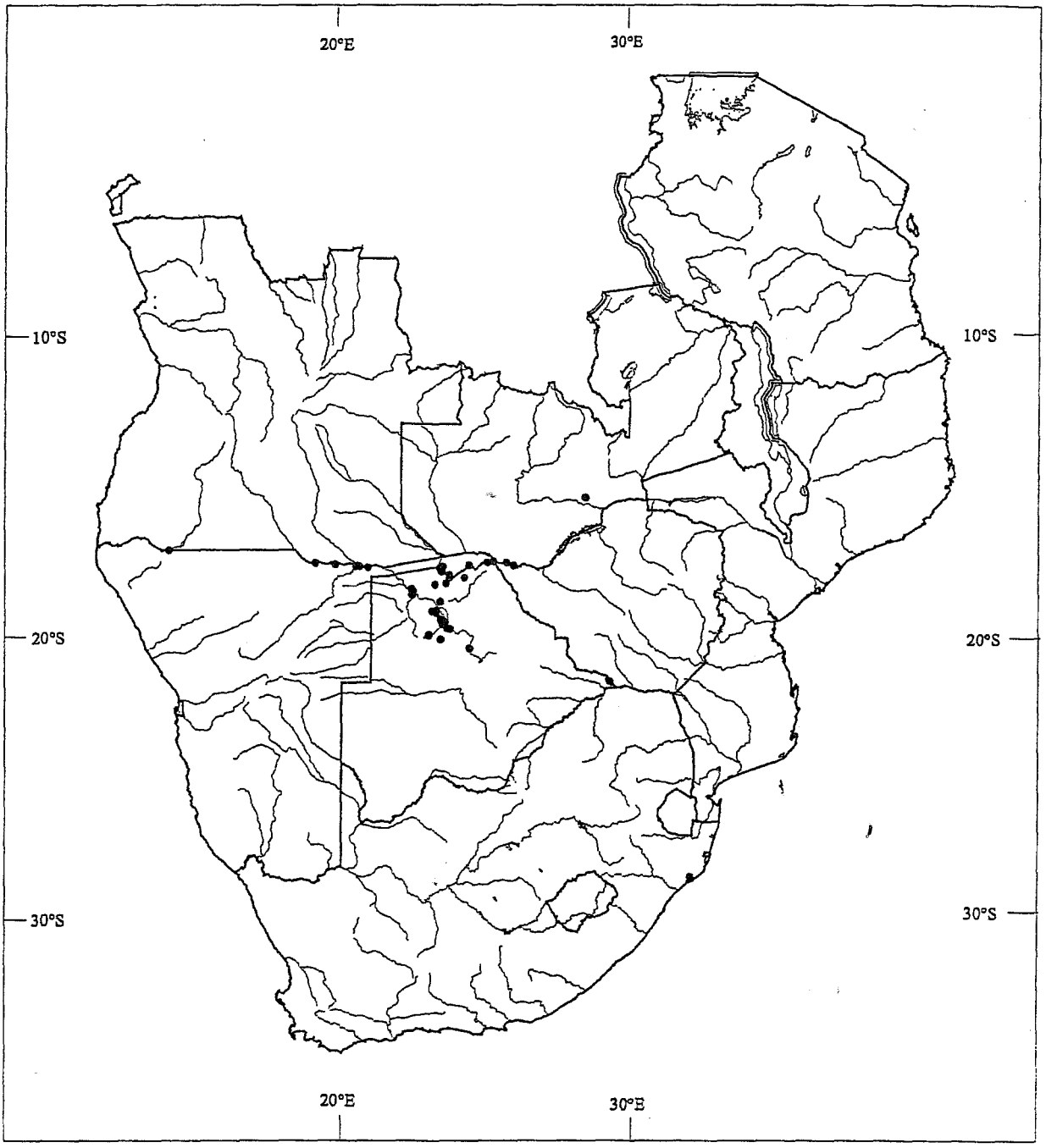


Figure F.648. Point distribution of *Serranochromis thumbergi*. Scale approximately 1:25 000 000

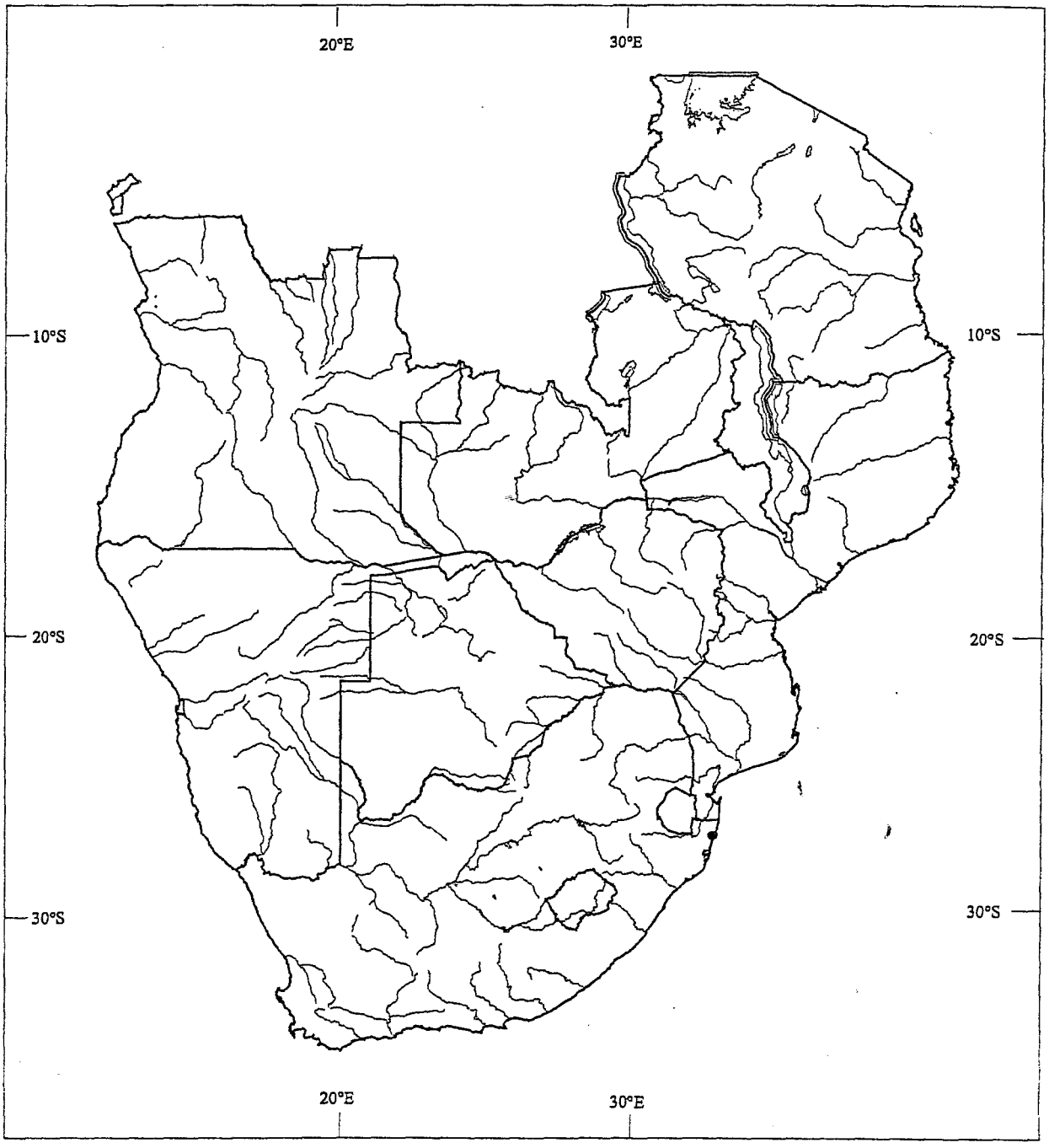


Figure F.649. Point distribution of *Silhouettea sibayi*. Scale approximately 1:25 000 000

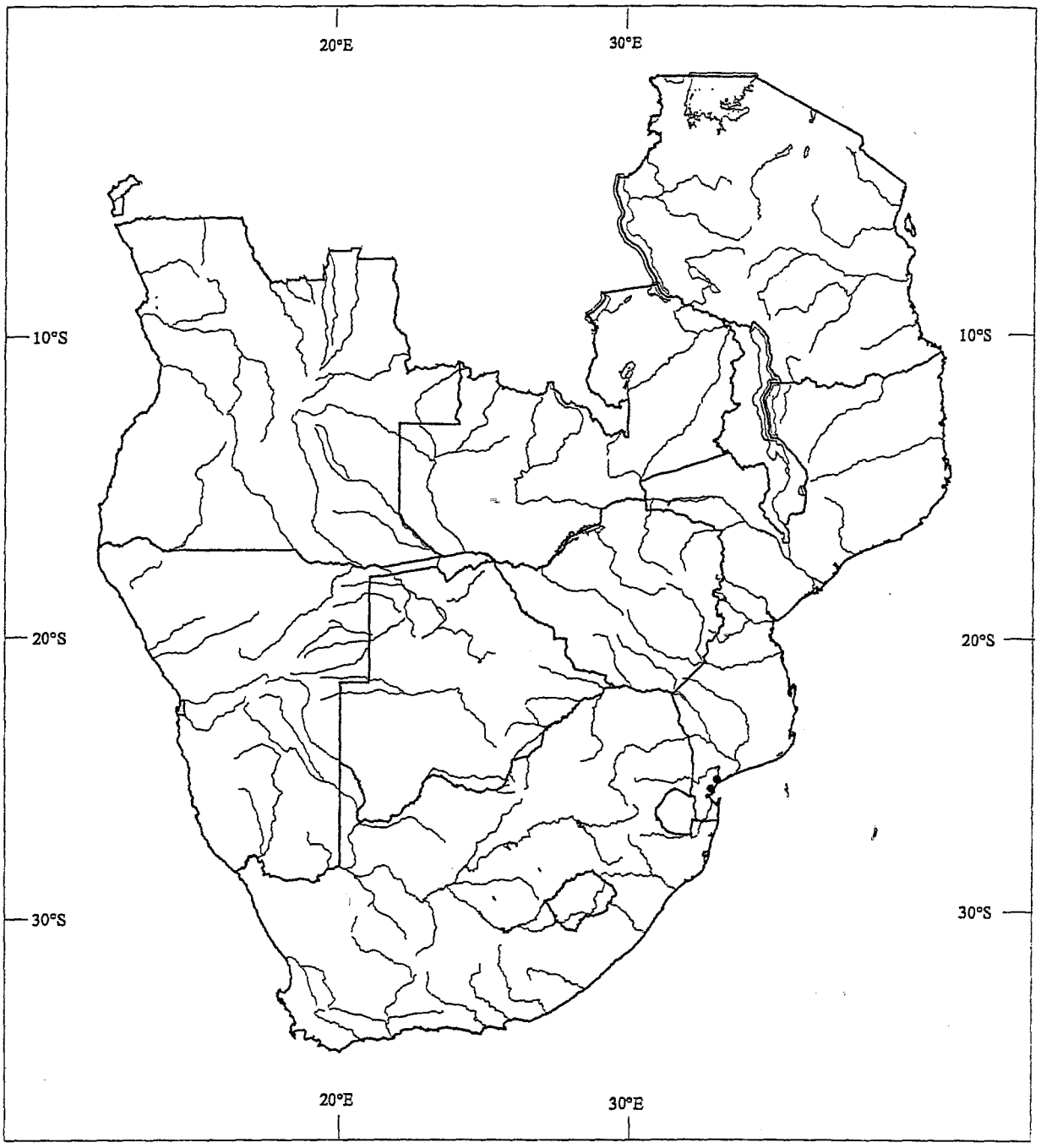


Figure F.650. Point distribution of *Sillago sihama*. Scale approximately 1:25 000 000

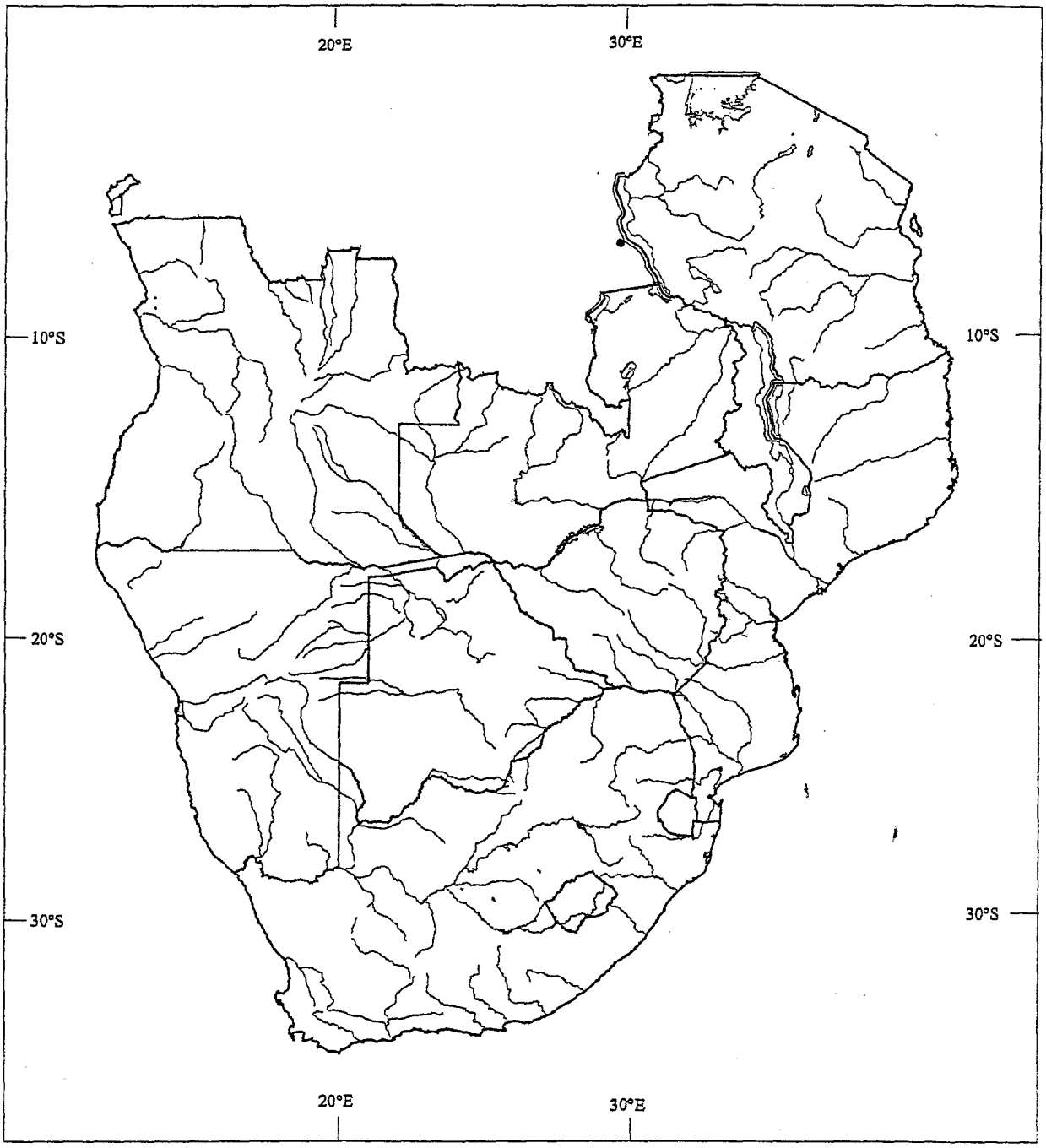


Figure F.651. Point distribution of *Simochromis diagramma*. Scale approximately 1:25 000 000

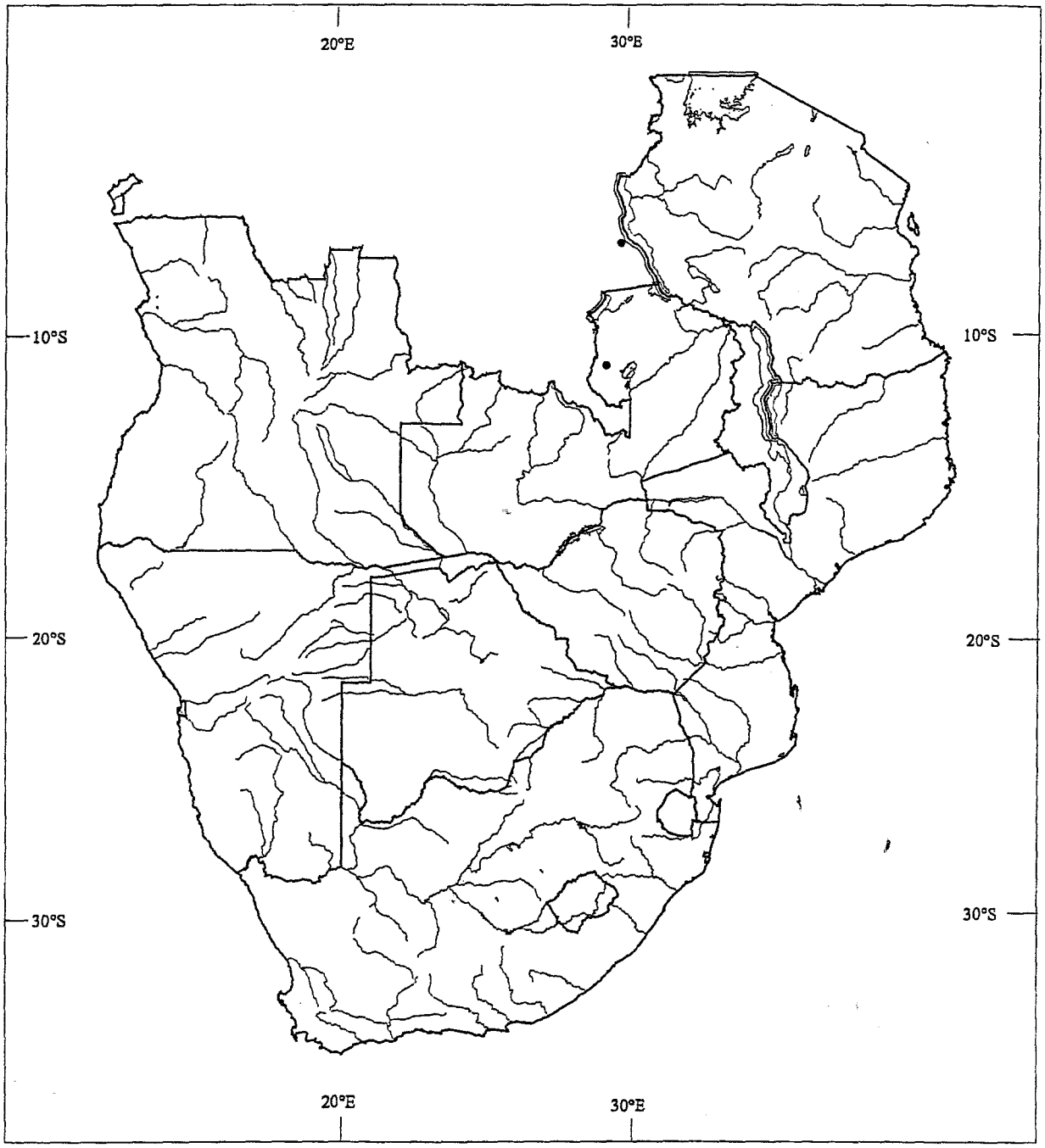


Figure F.652. Point distribution of *Simochromis loocki*. Scale approximately 1:25 000 000

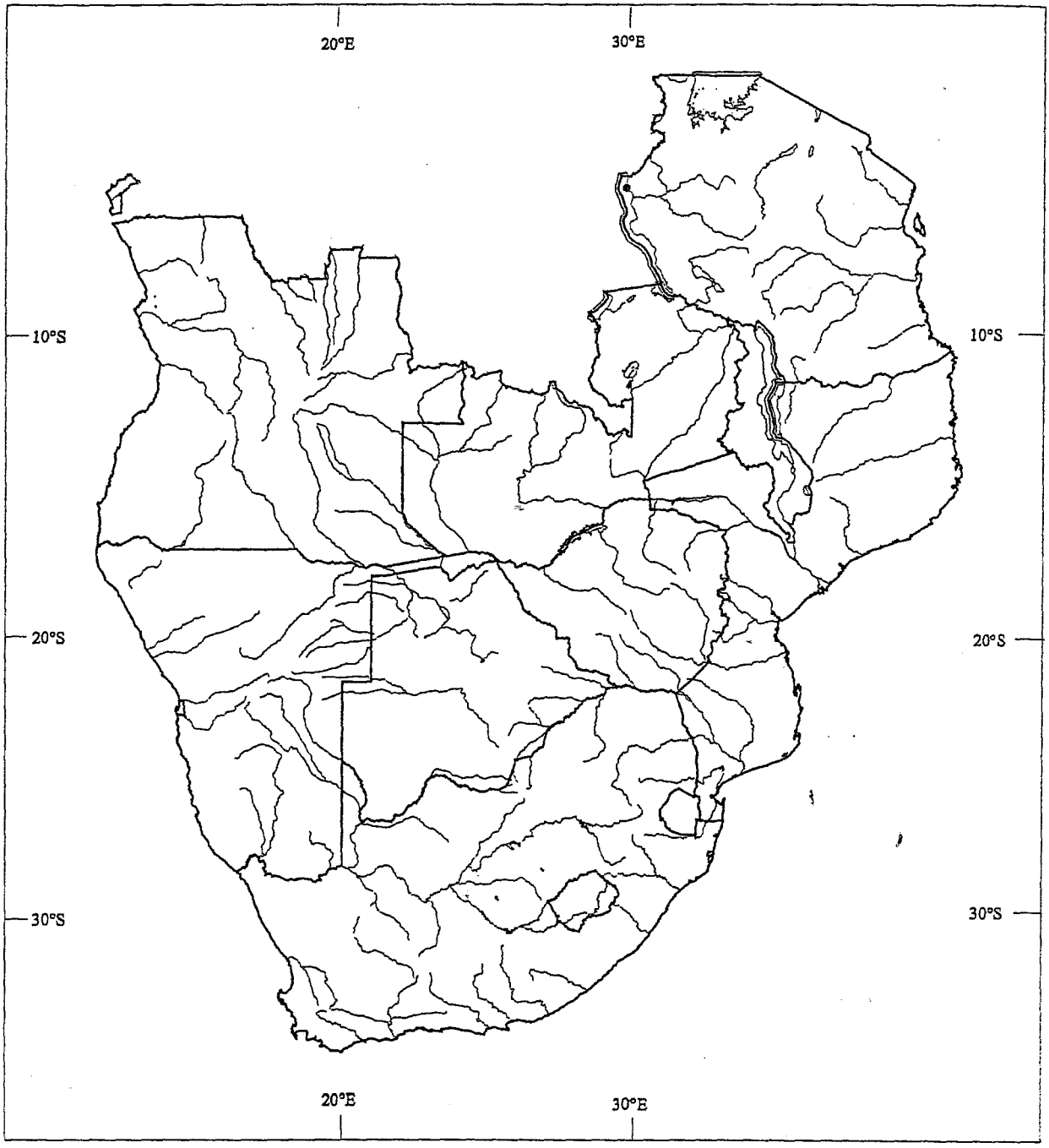


Figure F.653. Point distribution of *Simochromis margaretae*. Scale approximately 1:25 000 000

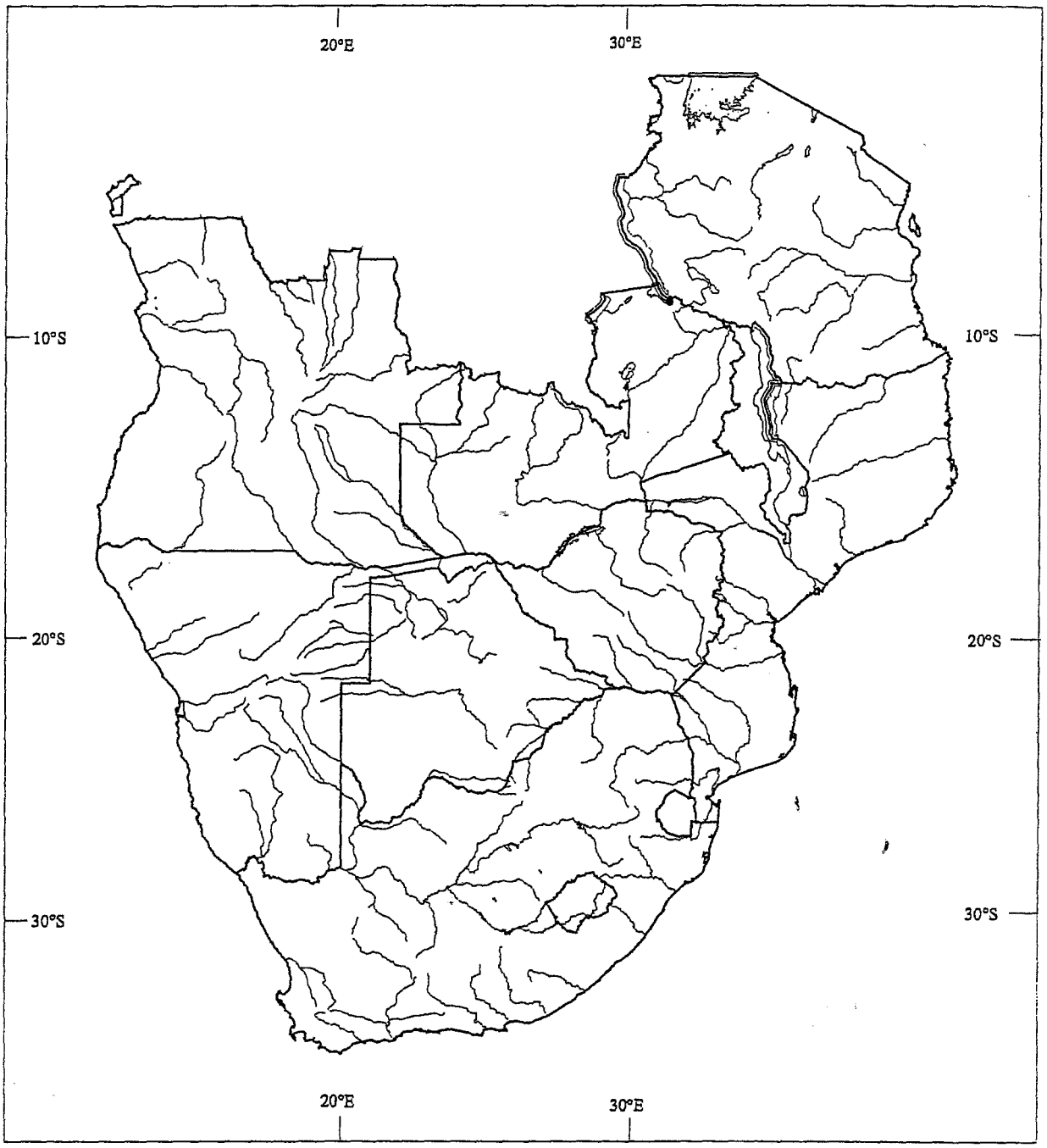


Figure F.654. Point distribution of *Simochromis marginatus*. Scale approximately 1:25 000 000

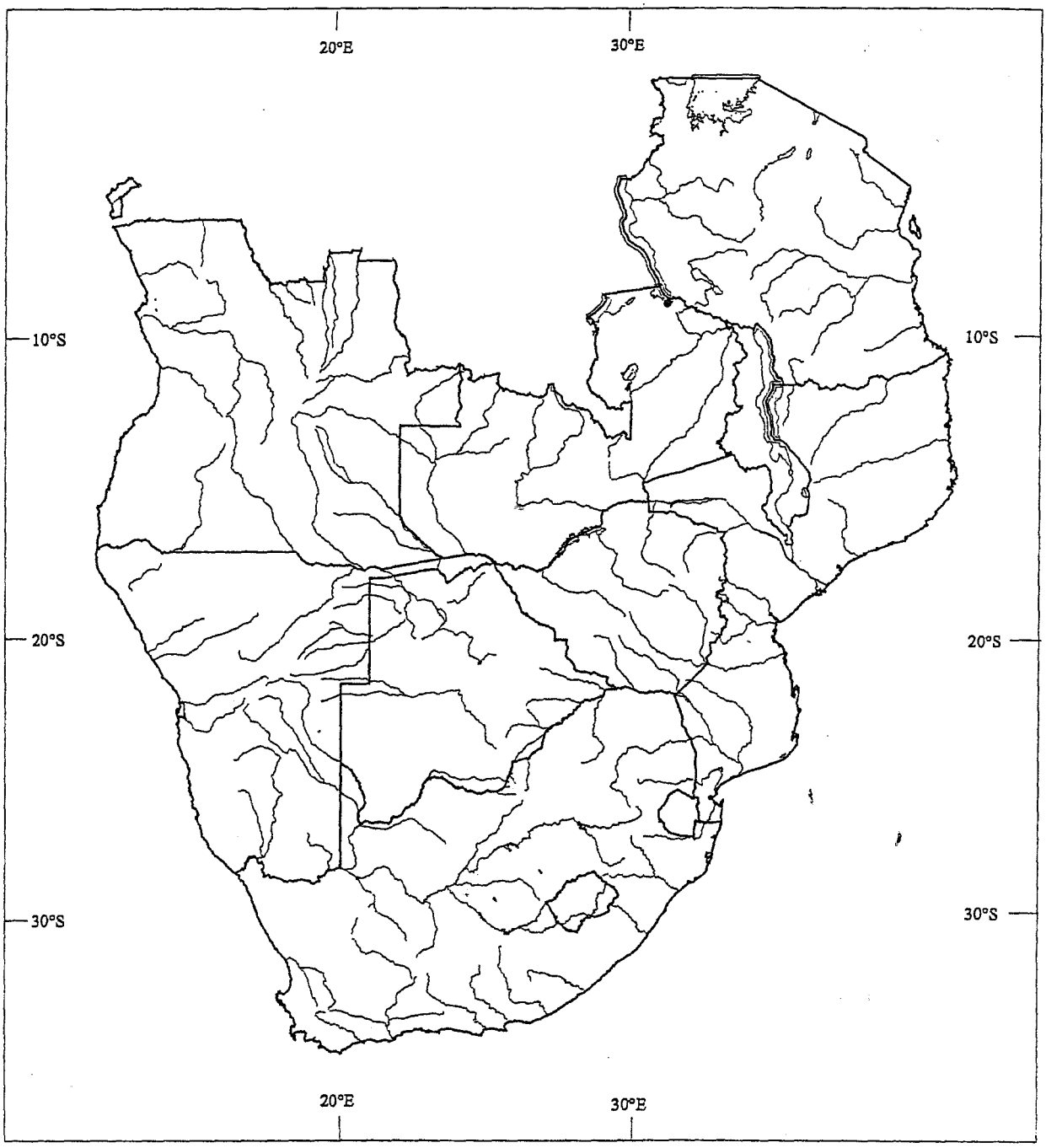


Figure F.655. Point distribution of *Simochromis pleurospilus*. Scale approximately 1:25 000 000

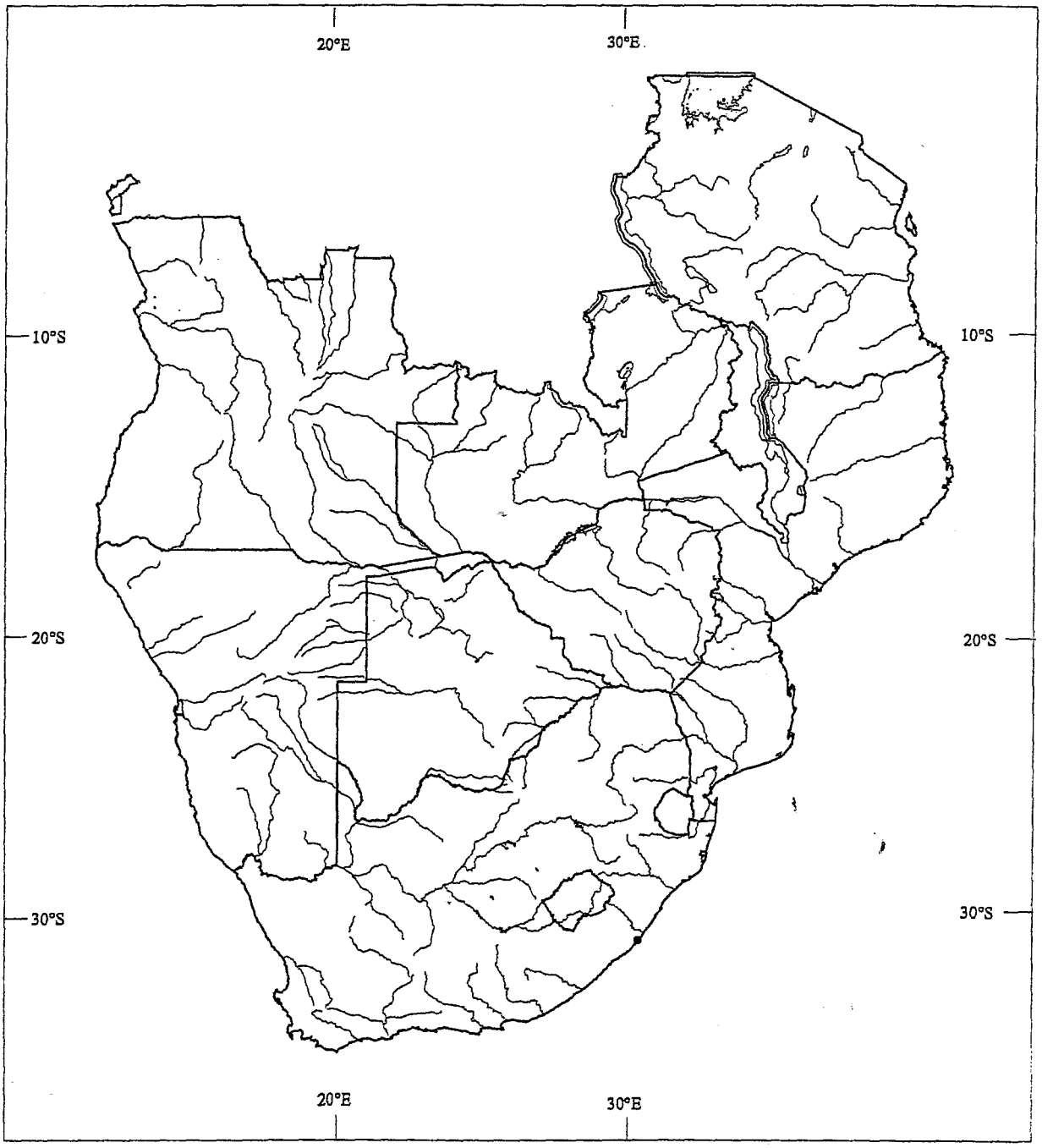


Figure F.656. Point distribution of *Solea bleekeri*. Scale approximately 1:25 000 000

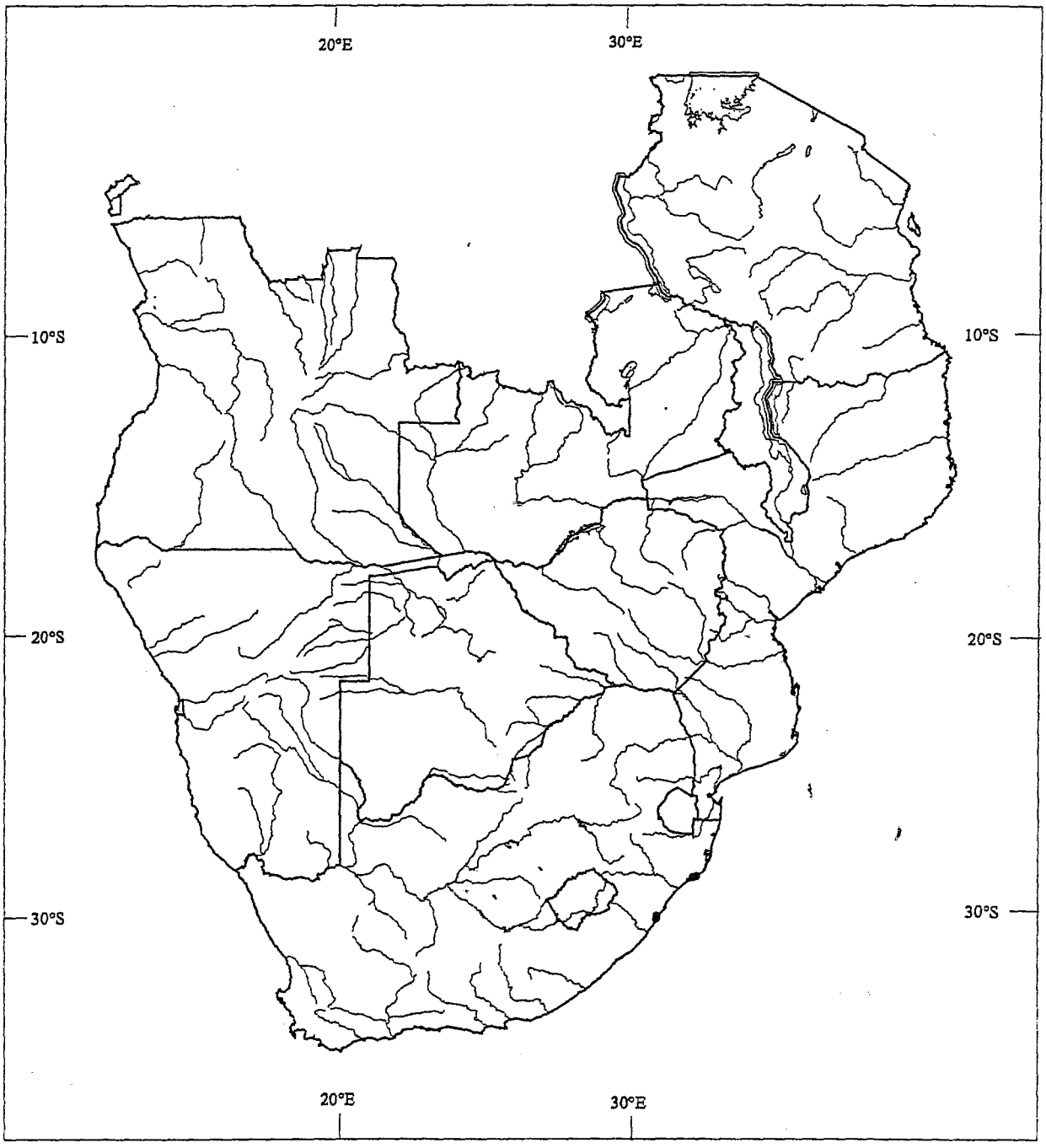


Figure F.657. Point distribution of *Stenogobius kenyae*. Scale approximately 1:25 000 000

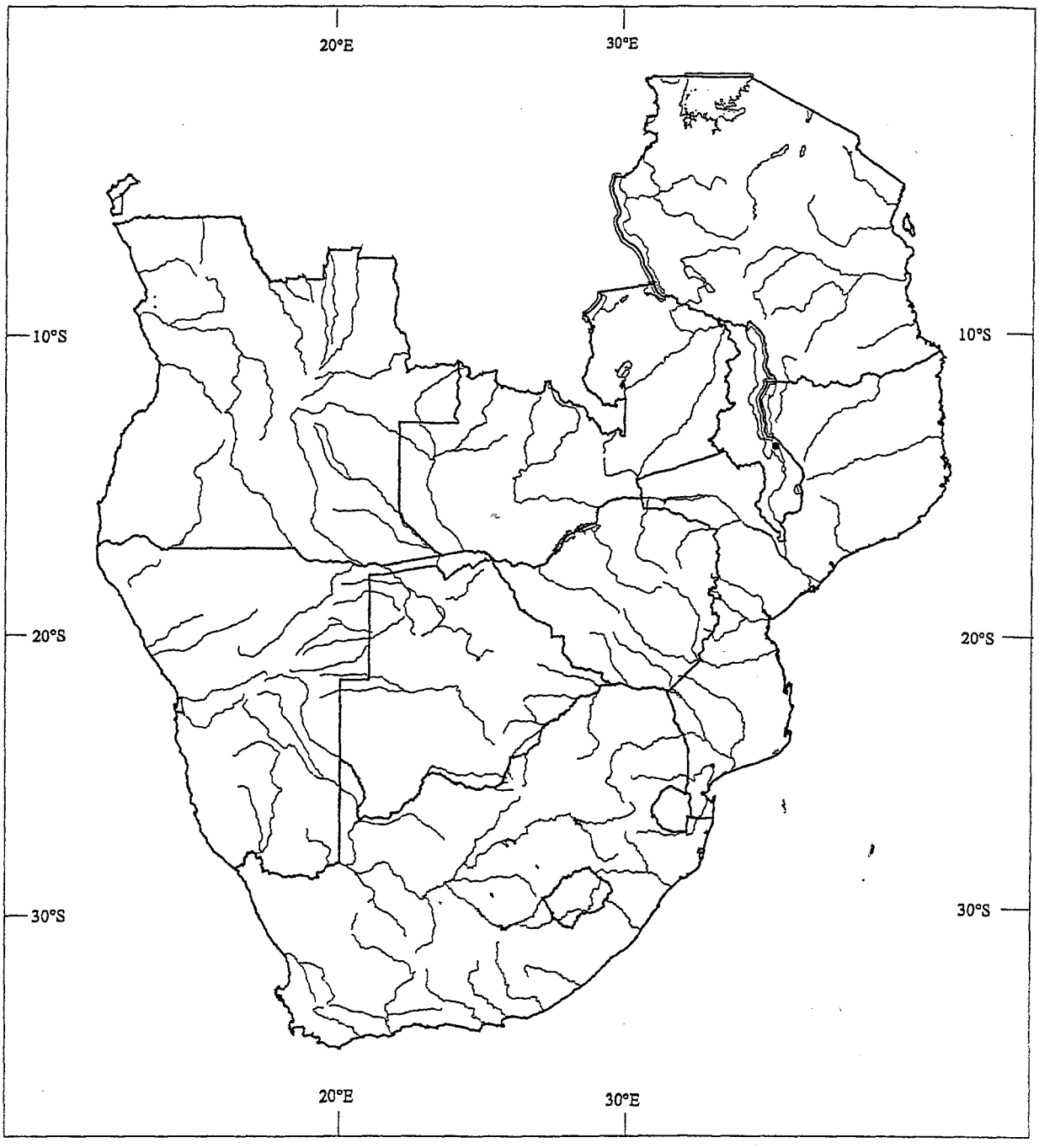


Figure F.658. Point distribution of *Stigmatochromis modestus*. Scale approximately 1:25 000 000

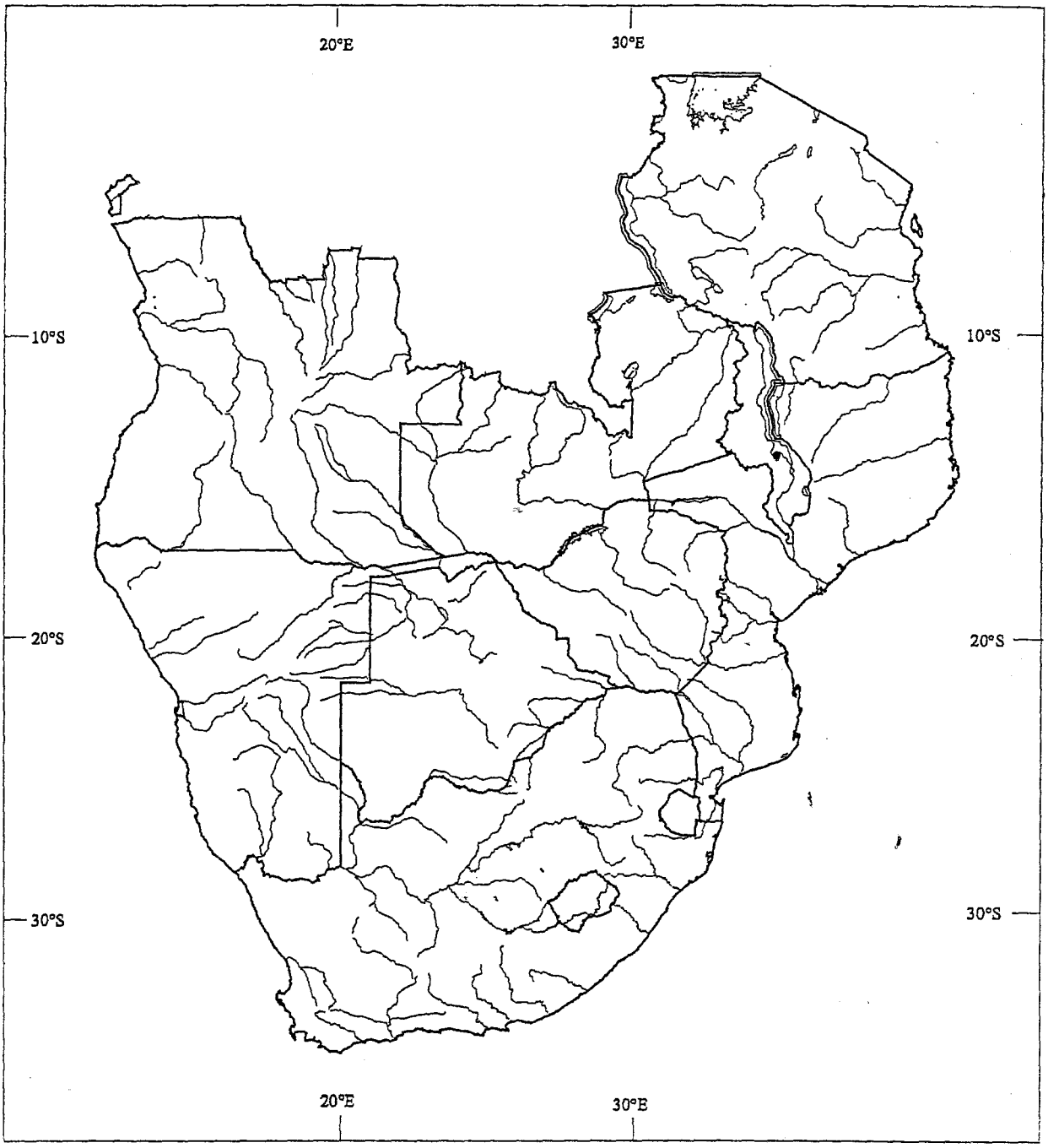


Figure F.659. Point distribution of *Stigmatochromis pholidophorus*. Scale approximately 1:25 000 000

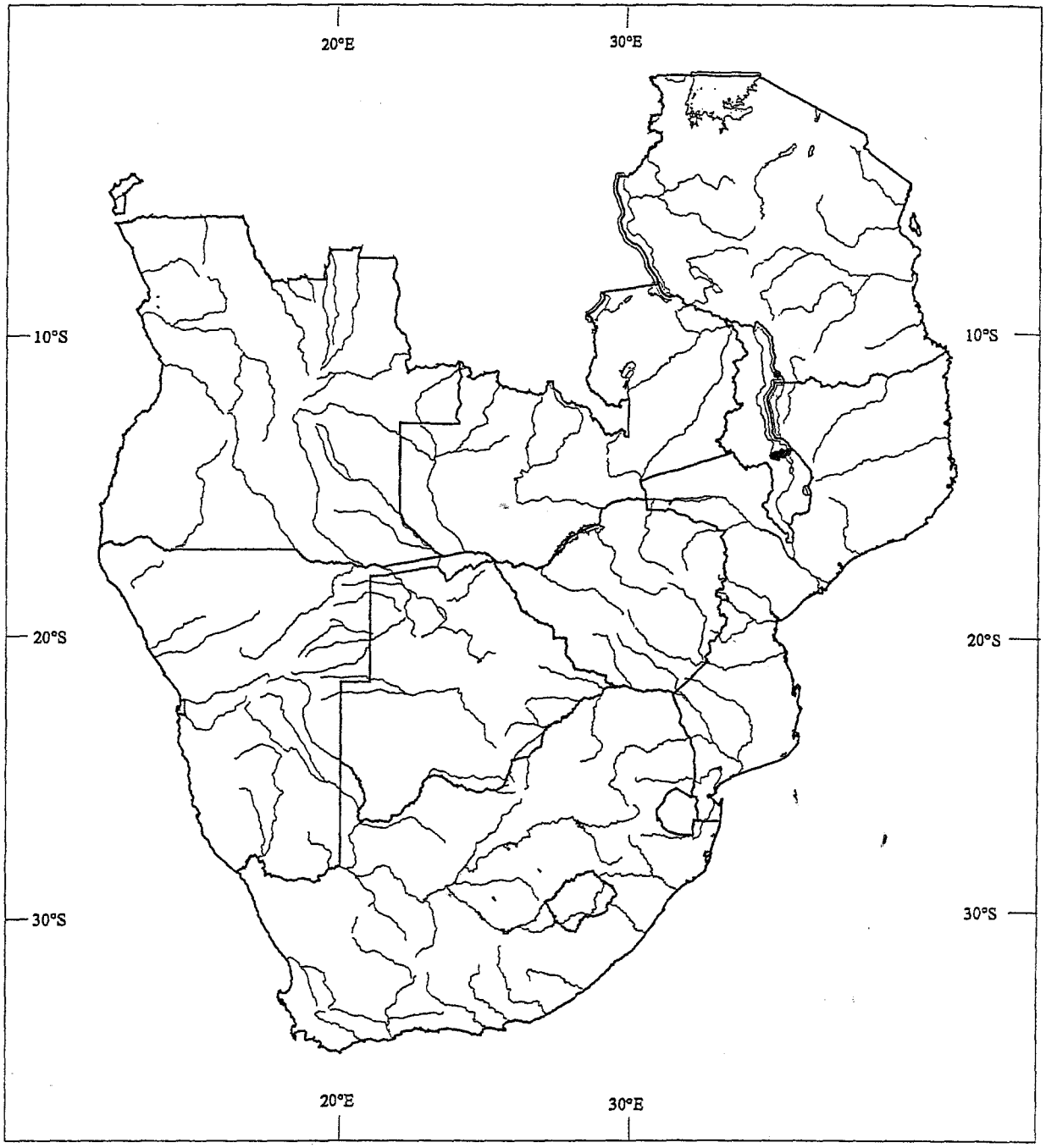


Figure F.660. Point distribution of *Stigmatochromis woodi*. Scale approximately 1:25 000 000

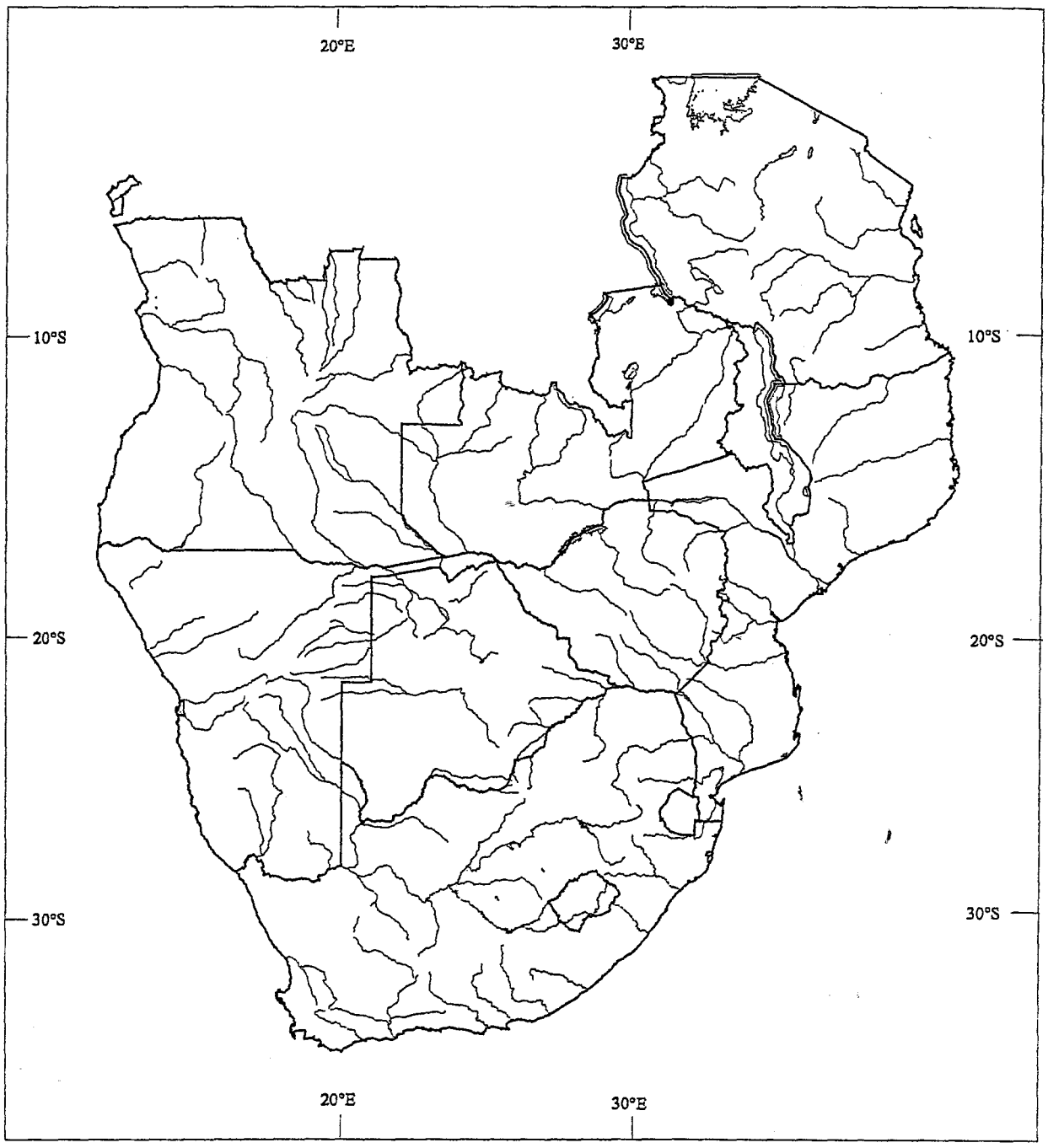


Figure F.661. Point distribution of *Stolothrissa tanganicae*. Scale approximately 1:25 000 000

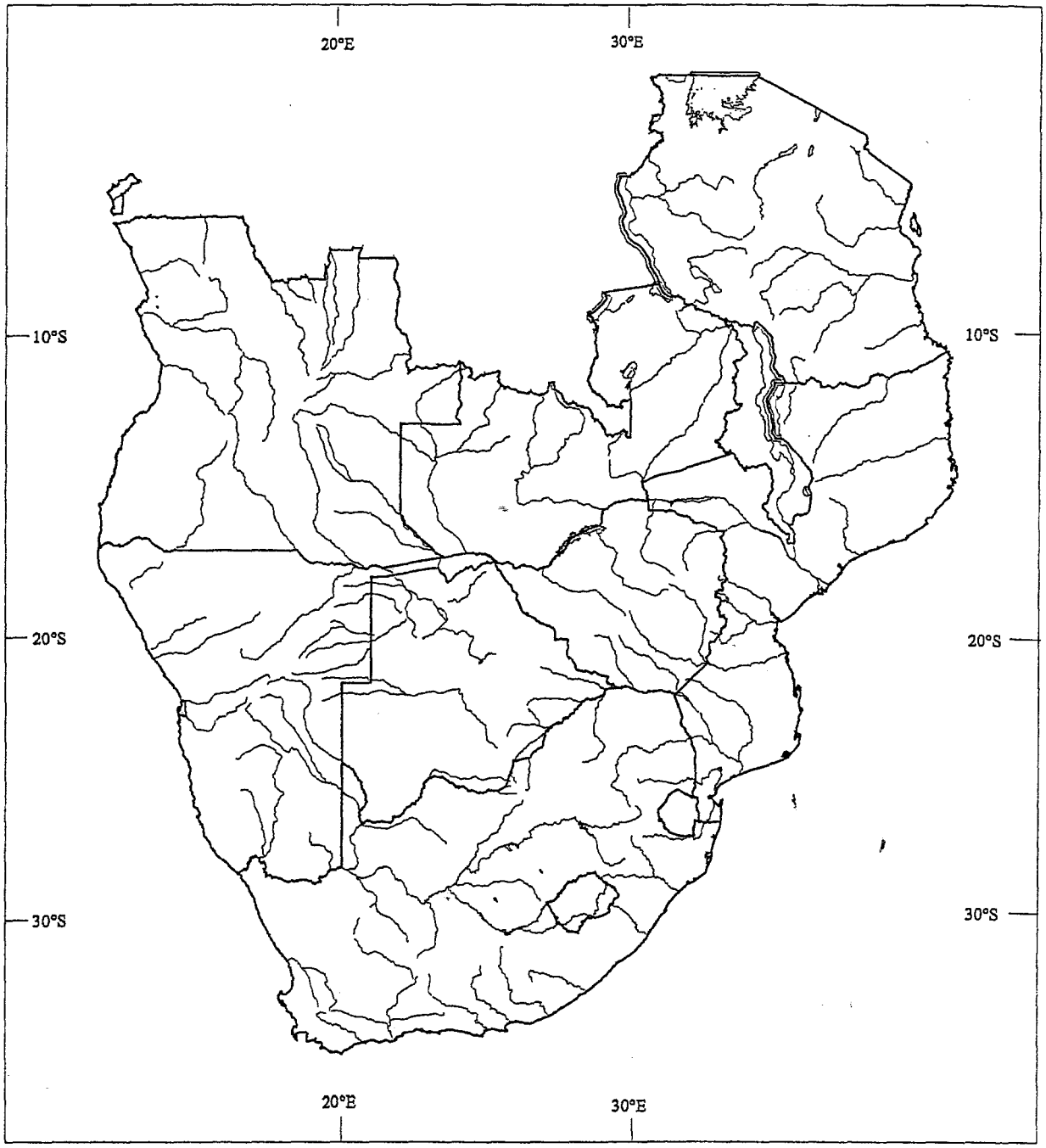


Figure F.662. Point distribution of *Strongylura leiura*. Scale approximately 1:25 000 000

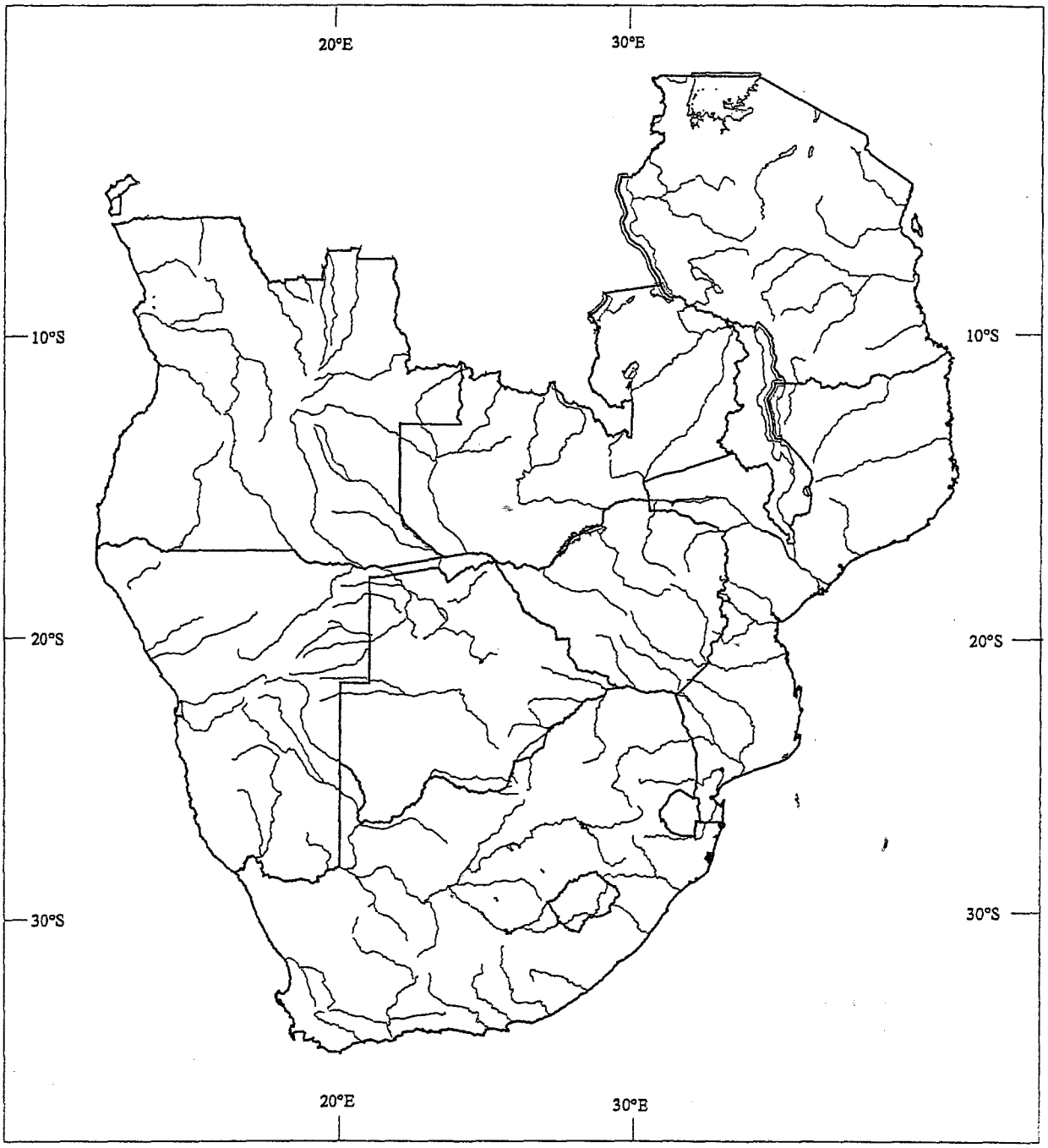


Figure F.663. Point distribution of *Syngnathus cyanospilus*. Scale approximately 1:25 000 000

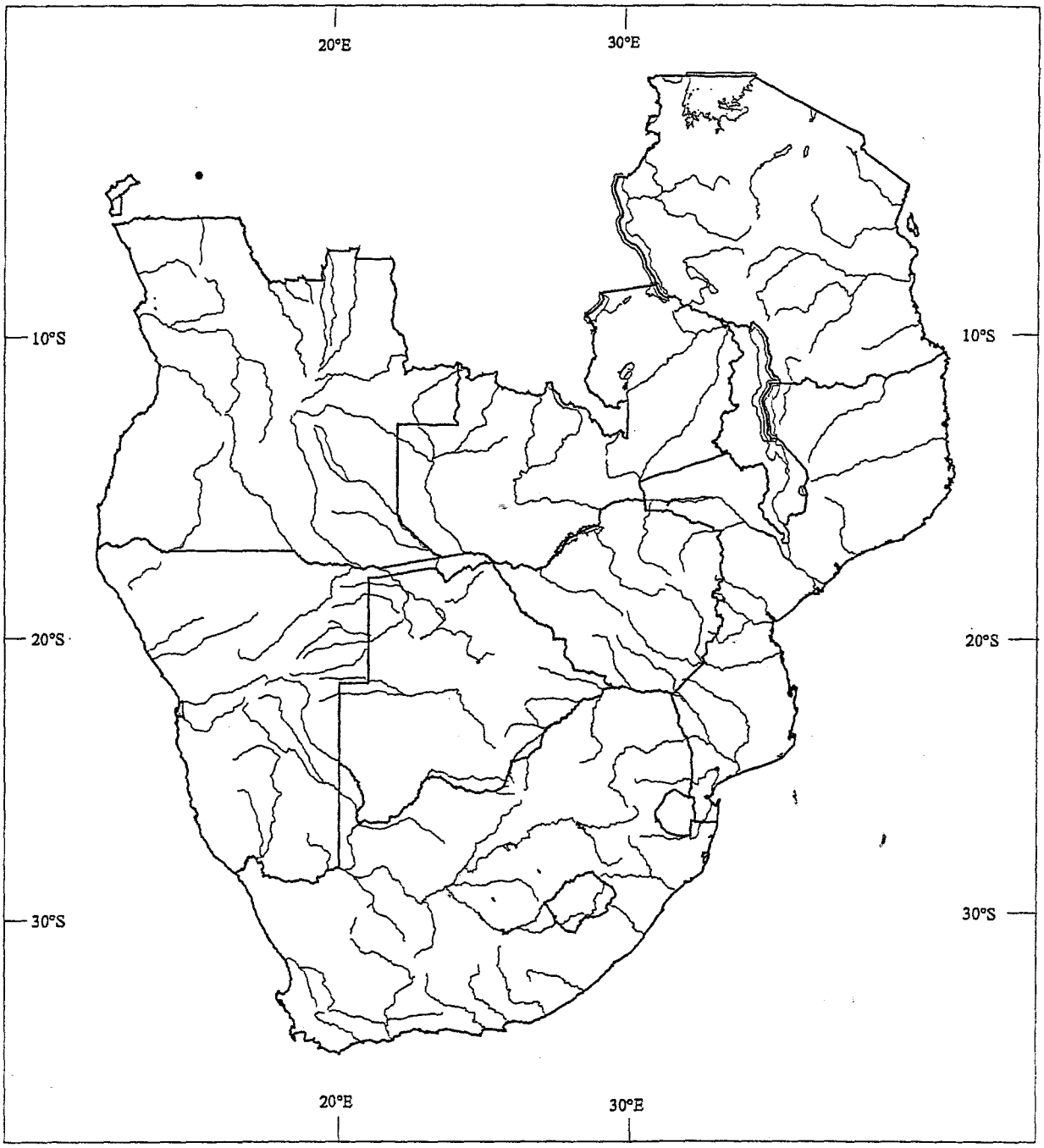


Figure F.664. Point distribution of *Synodontis acanthomias*. Scale approximately 1:25 000 000

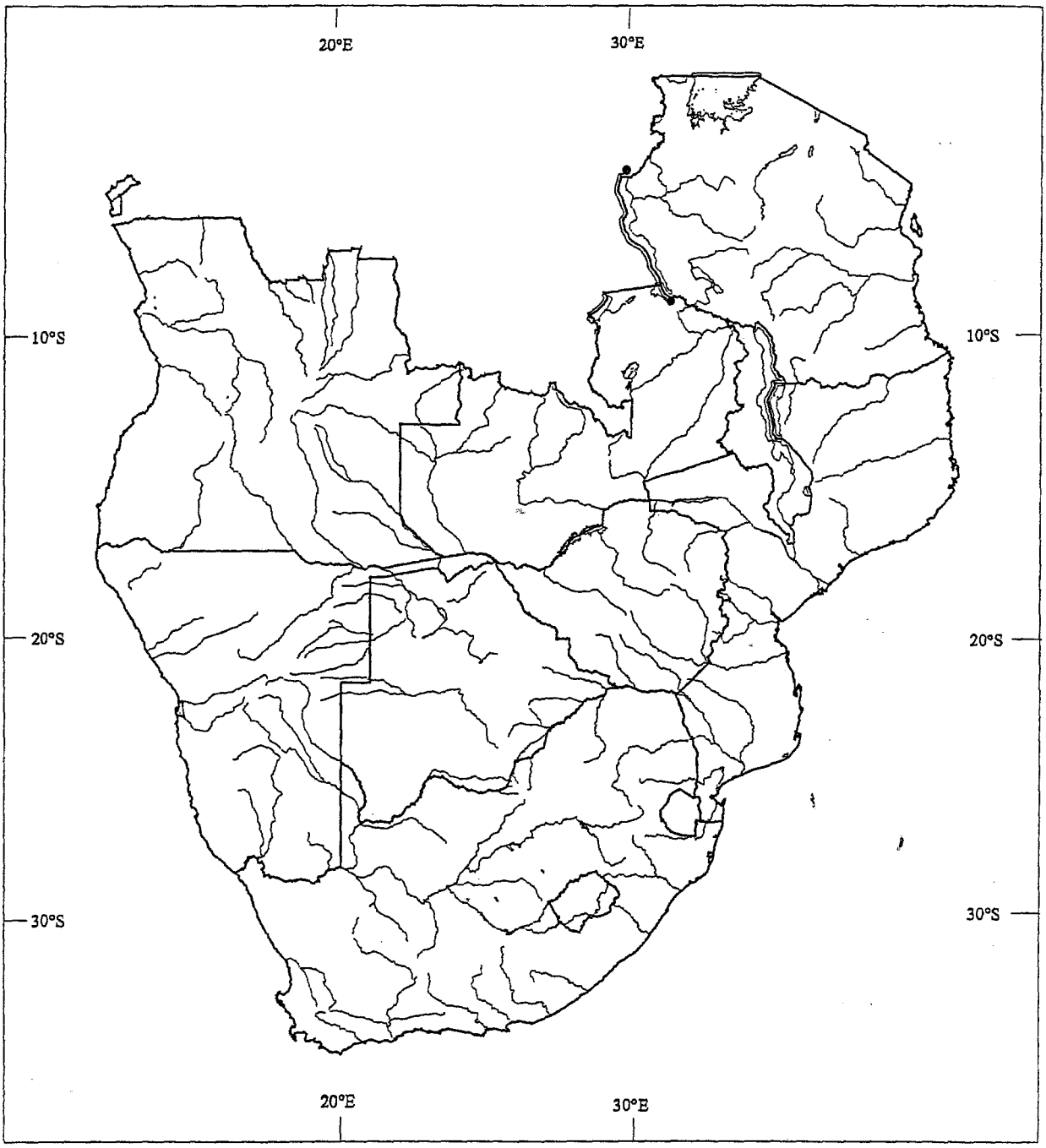


Figure F.665. Point distribution of *Synodontis dhonti*. Scale approximately 1:25 000 000

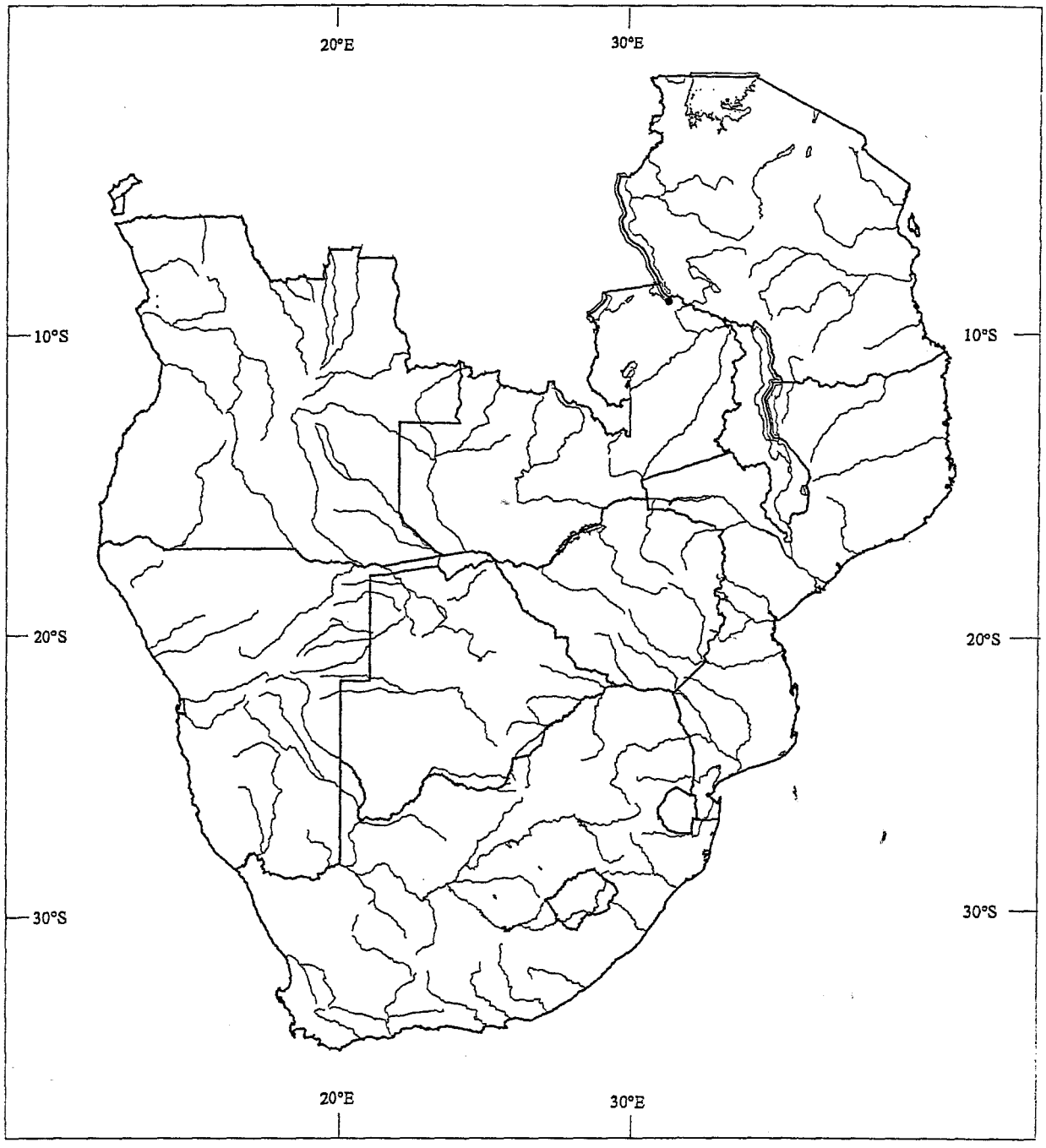


Figure F.666. Point distribution of *Synodontis eurystomus*. Scale approximately 1:25 000 000

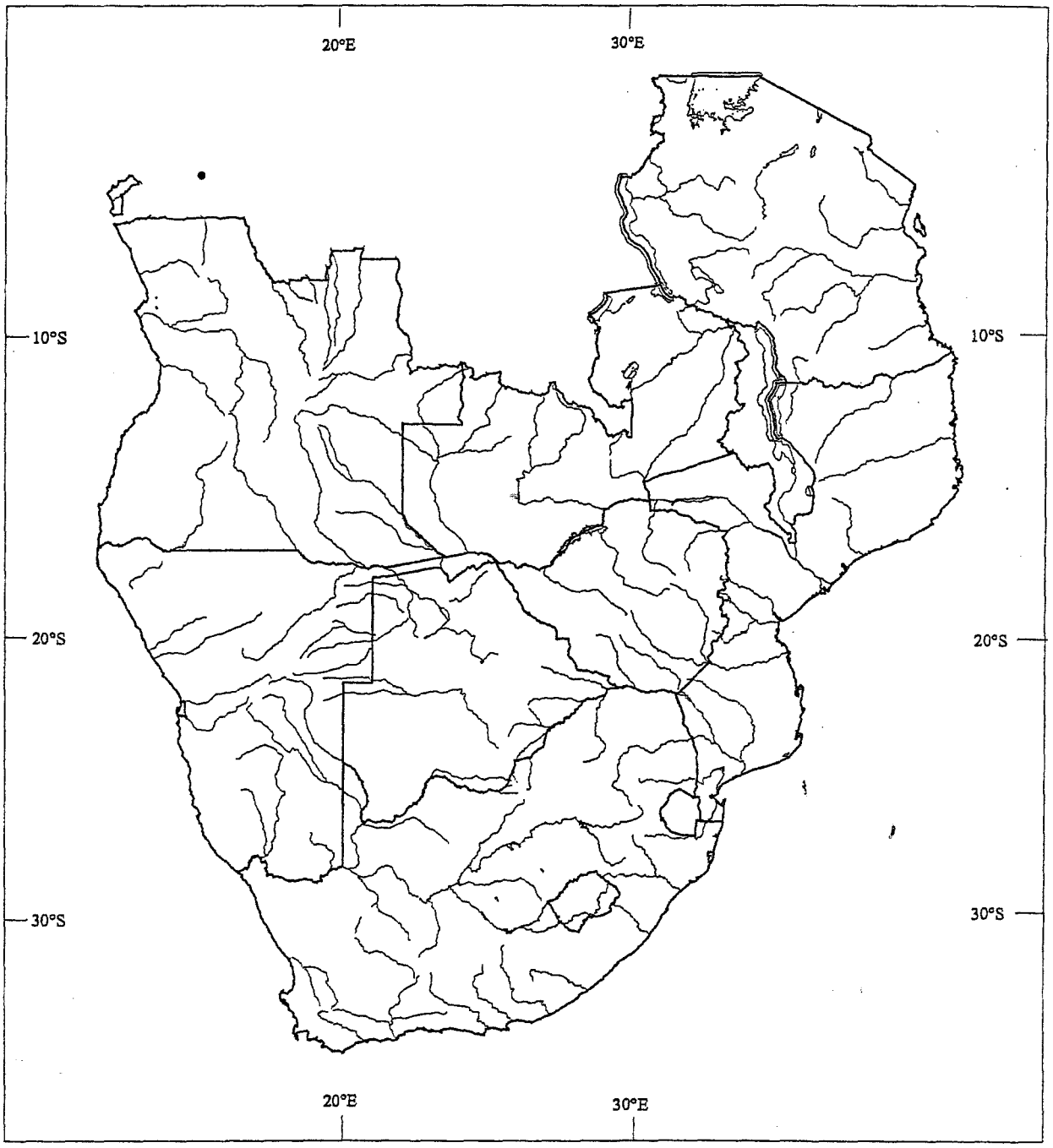


Figure F.667. Point distribution of *Synodontis greshoffi*. Scale approximately 1:25 000 000

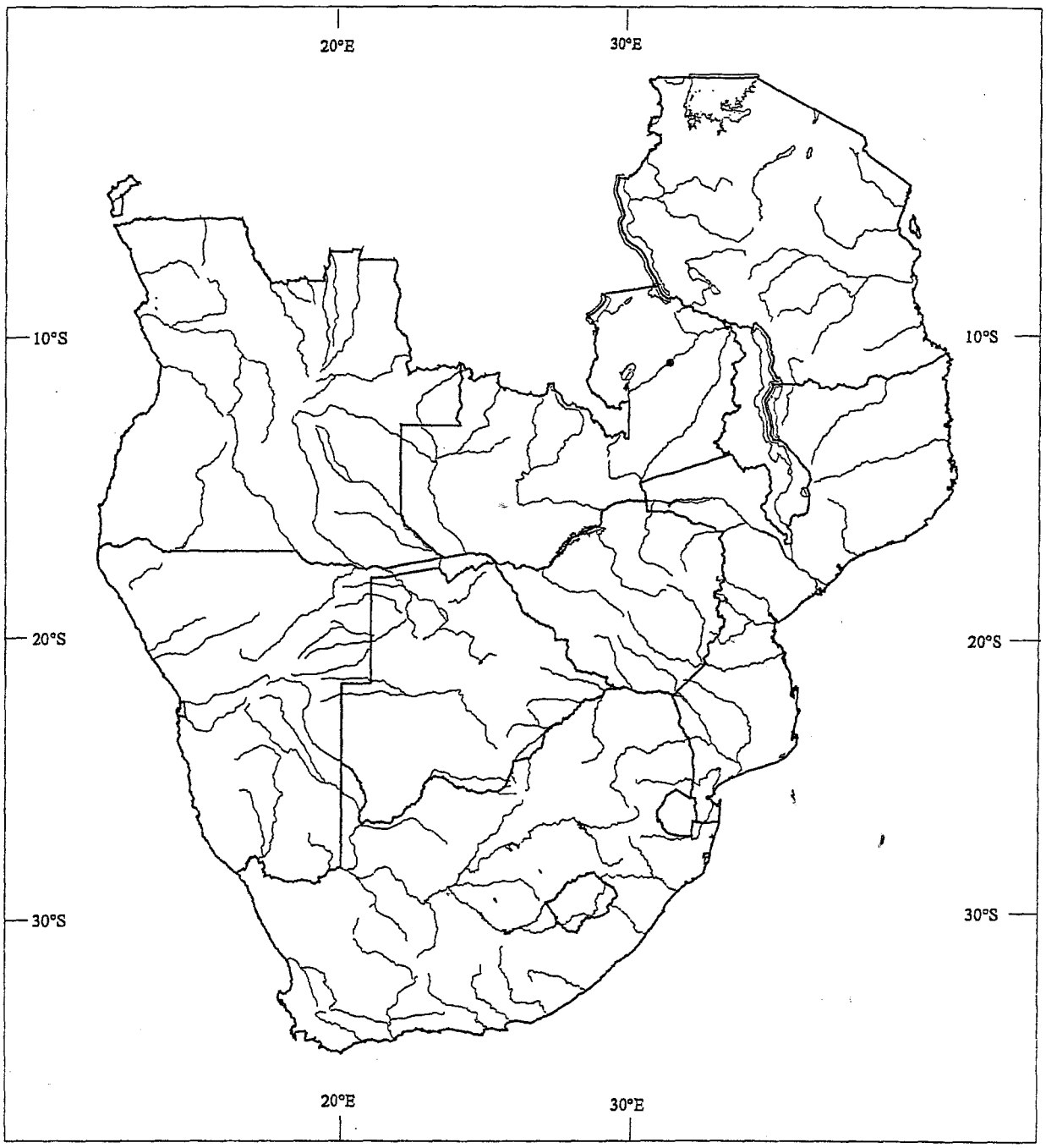


Figure F.668. Point distribution of *Synodontis katangae*. Scale approximately 1:25 000 000

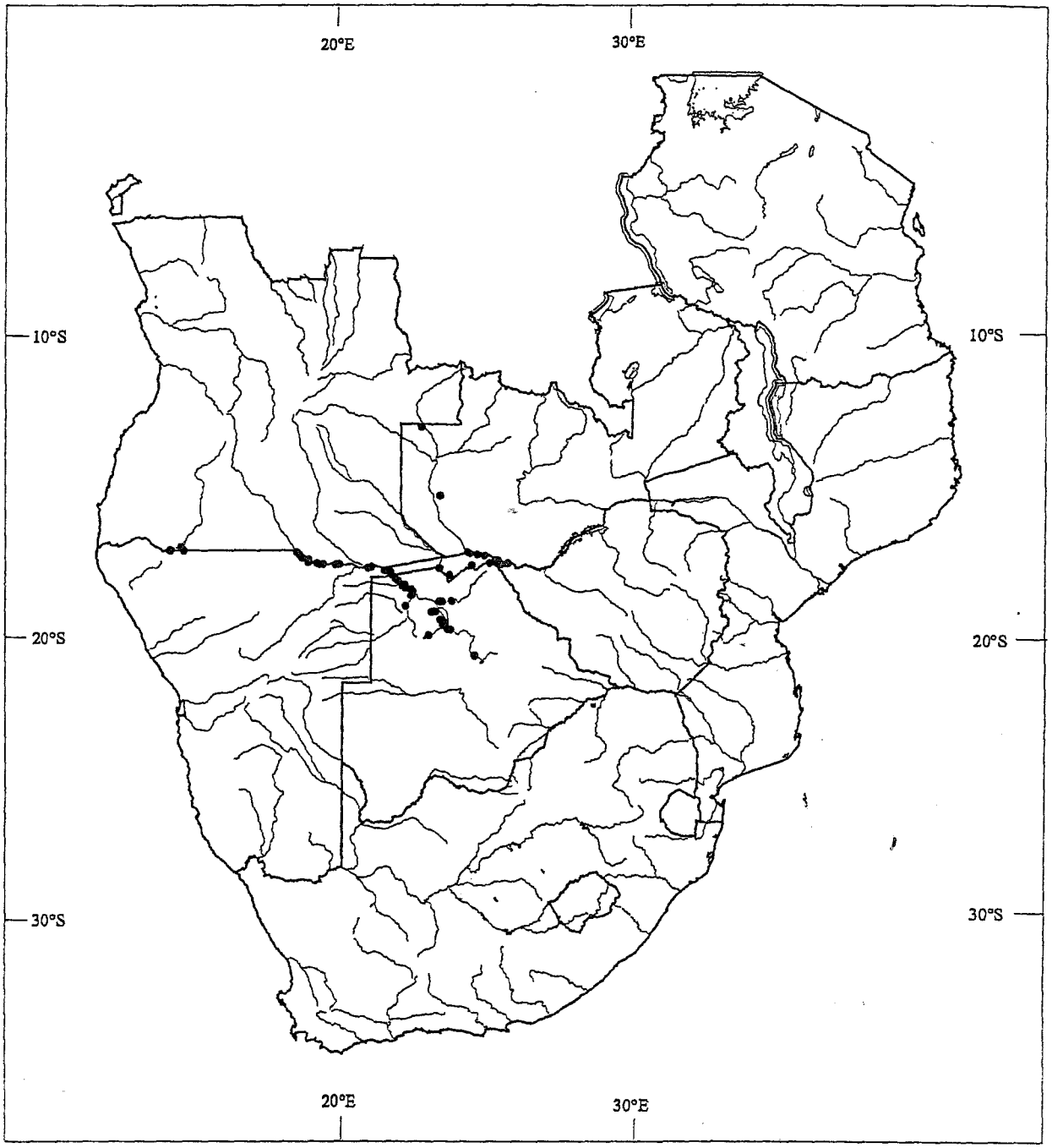


Figure F.669. Point distribution of *Synodontis leopardinus*. Scale approximately 1:25 000 000

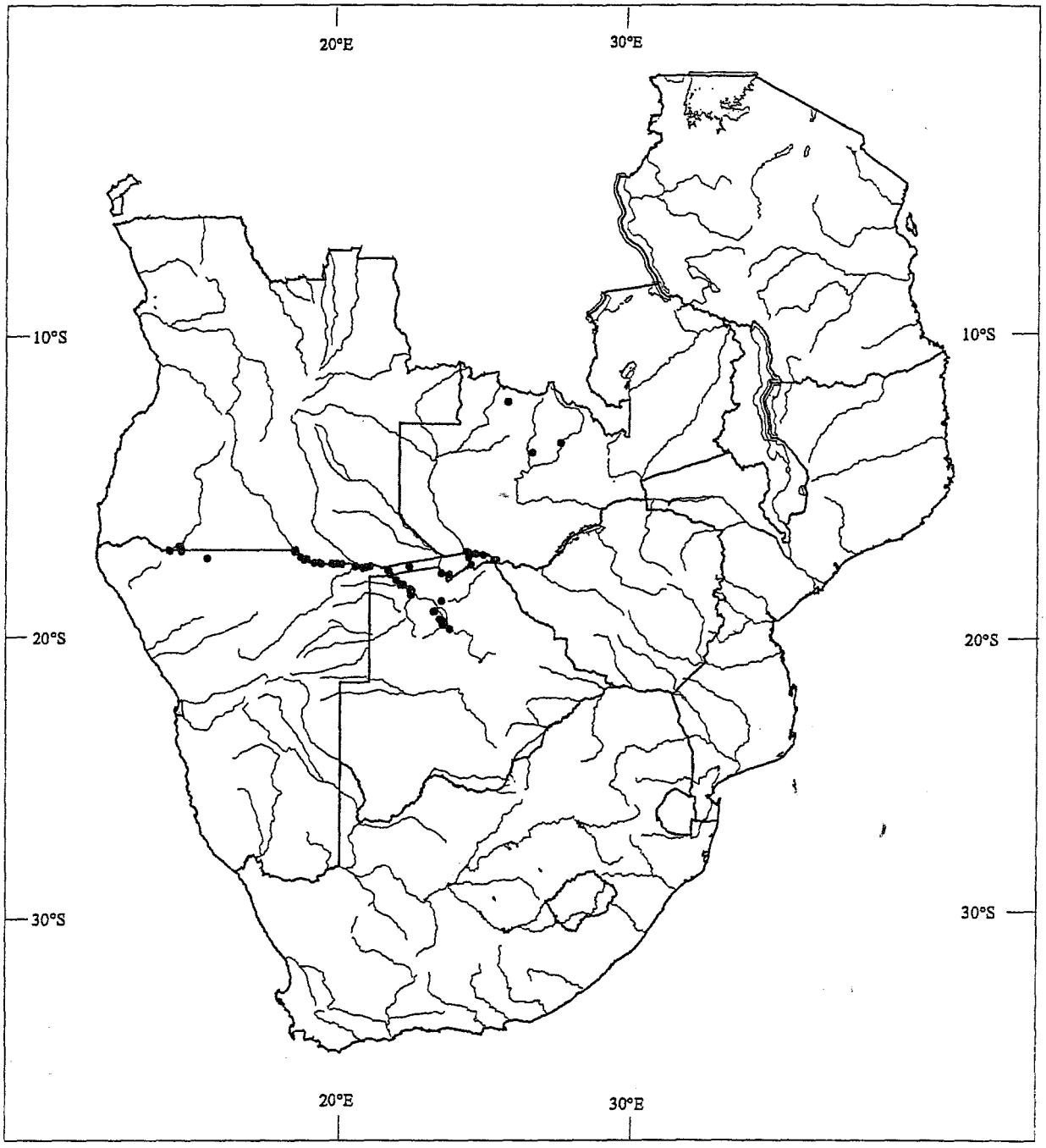


Figure F.670. Point distribution of *Synodontis macrostigma*. Scale approximately 1:25 000 000

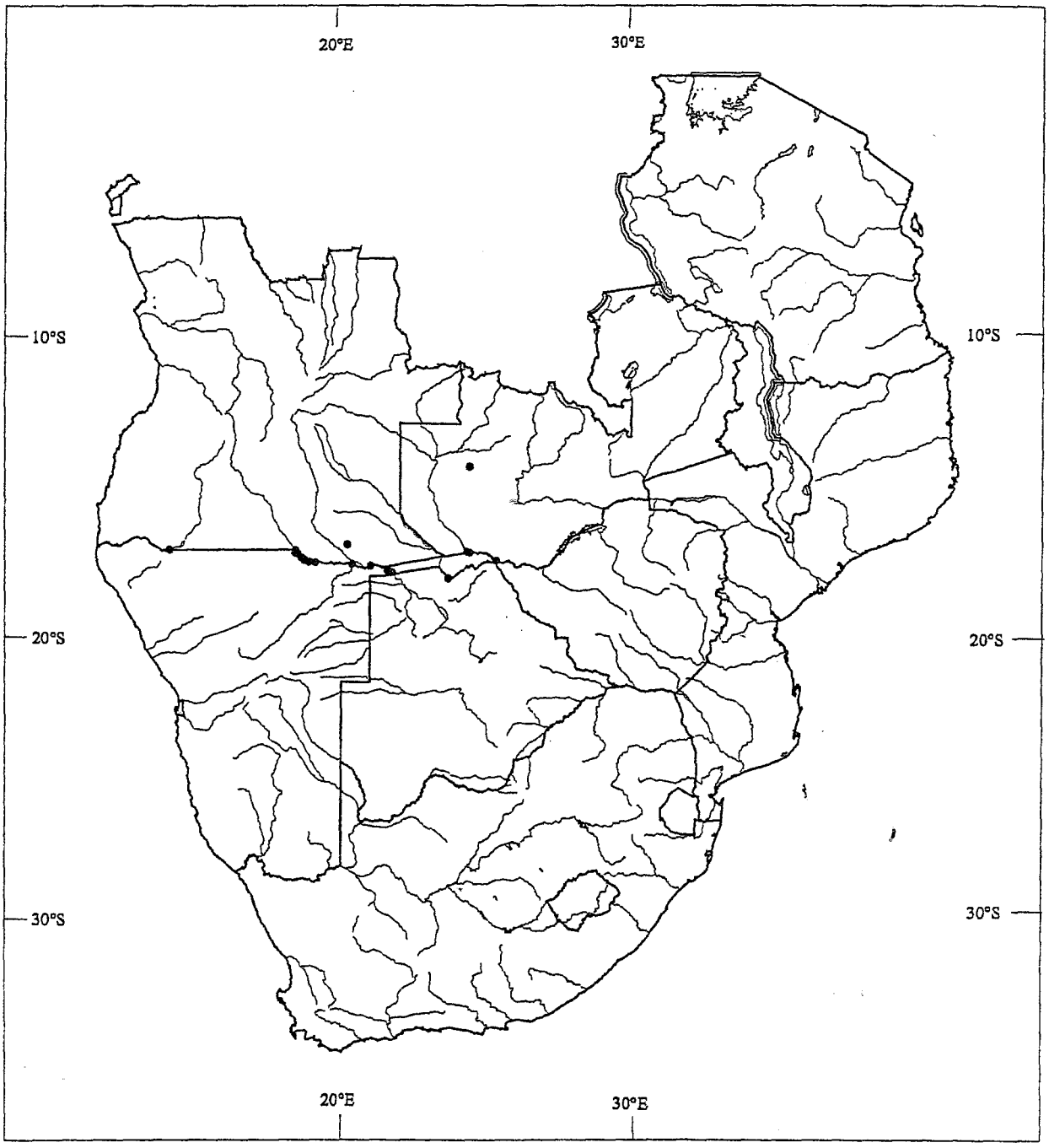


Figure F.671. Point distribution of *Synodontis macrostoma*. Scale approximately 1:25 000 000

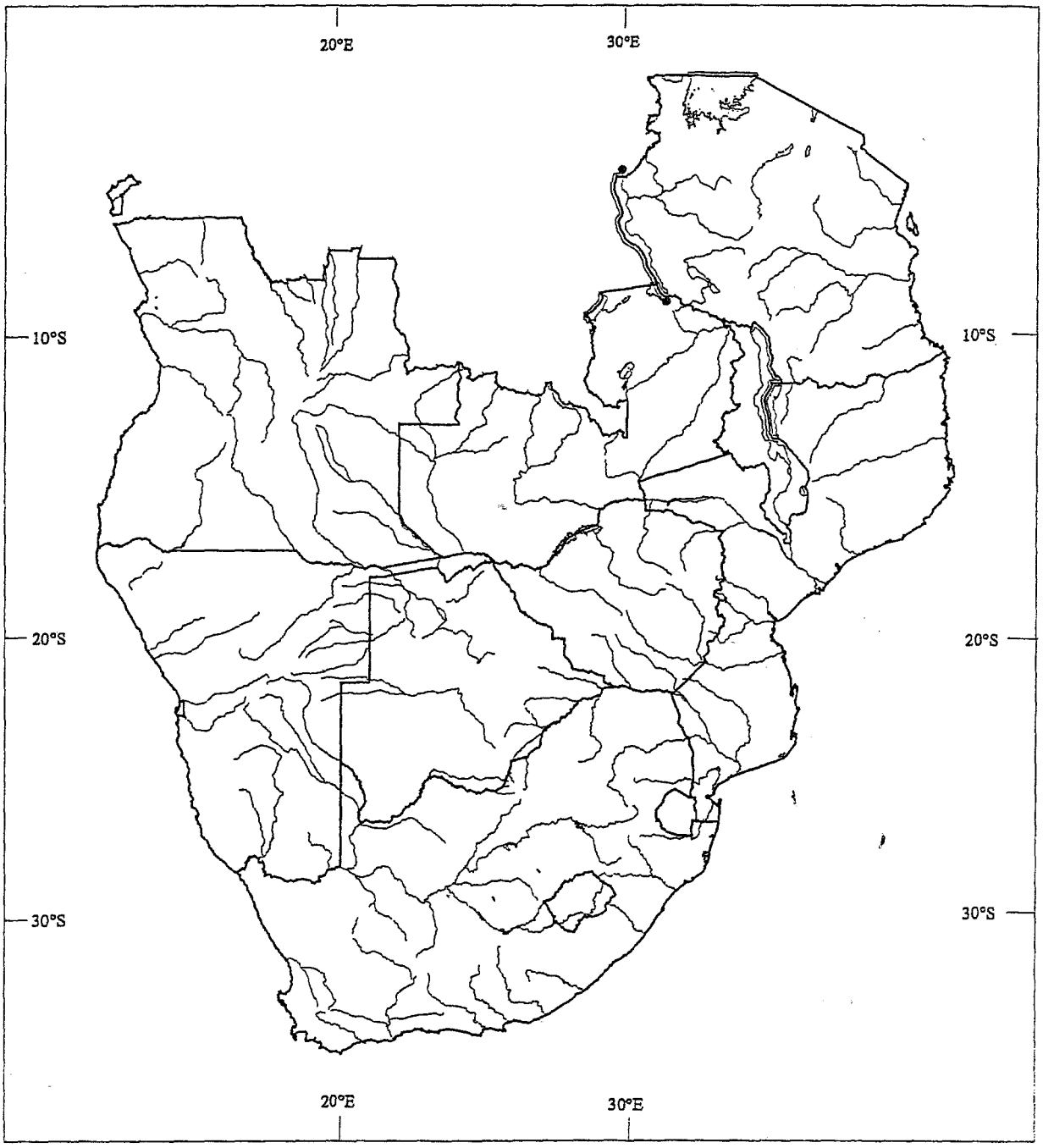


Figure F.672. Point distribution of *Synodontis multipunctatus*. Scale approximately 1:25 000 000

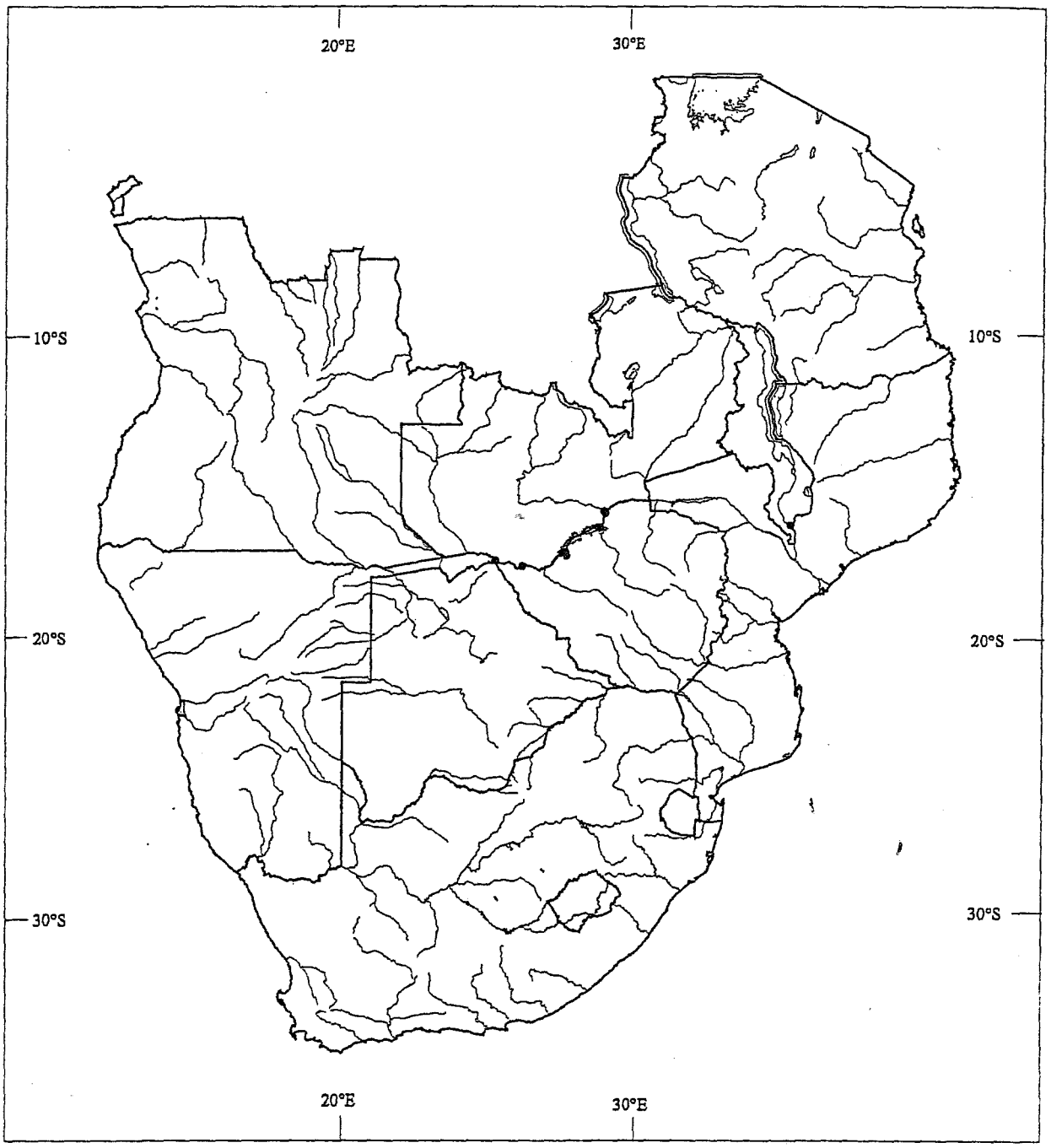


Figure F.673. Point distribution of *Synodontis nebulosus*. Scale approximately 1:25 000 000

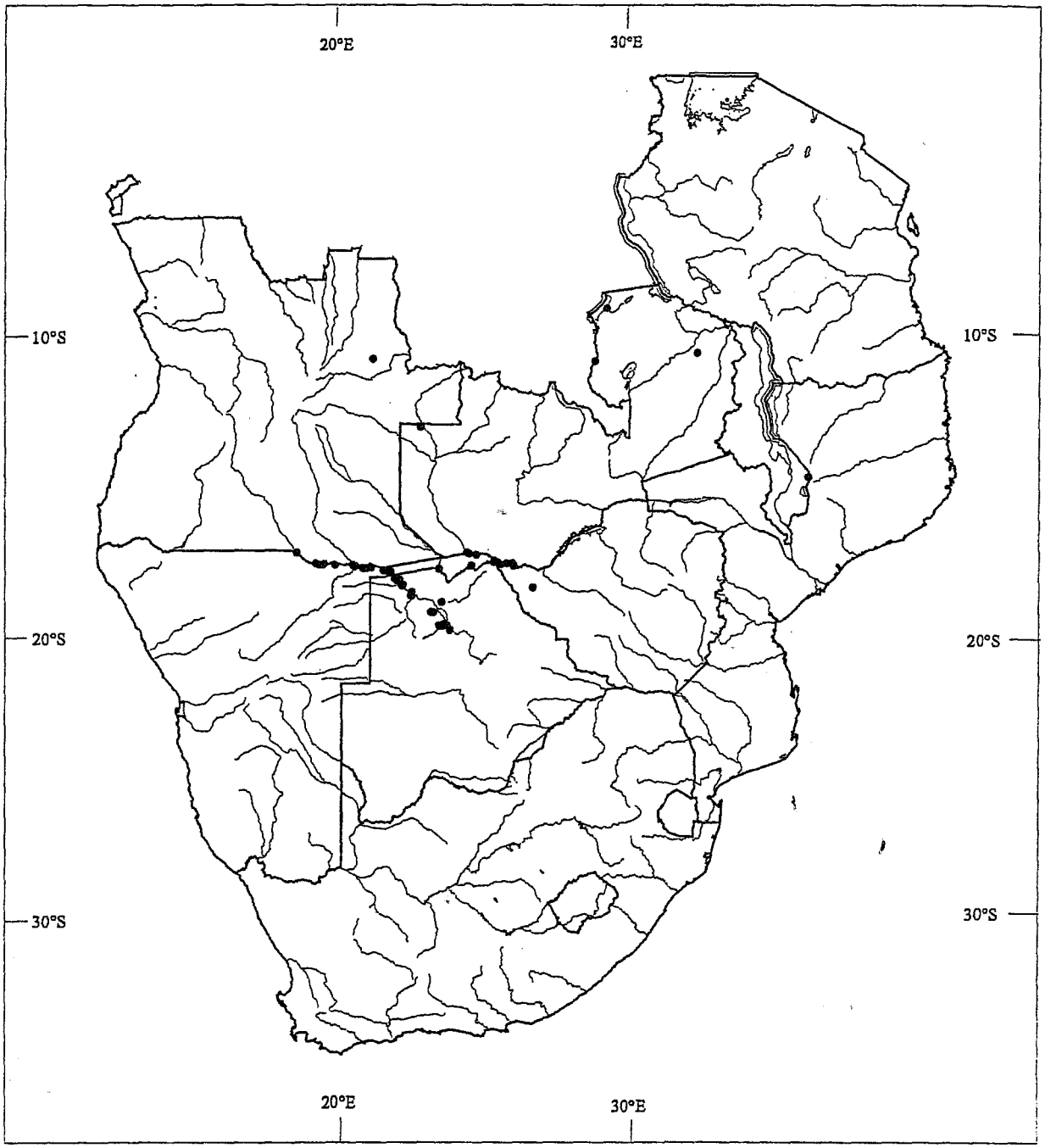


Figure F.674. Point distribution of *Synodontis nigromaculatus*. Scale approximately 1:25 000 000

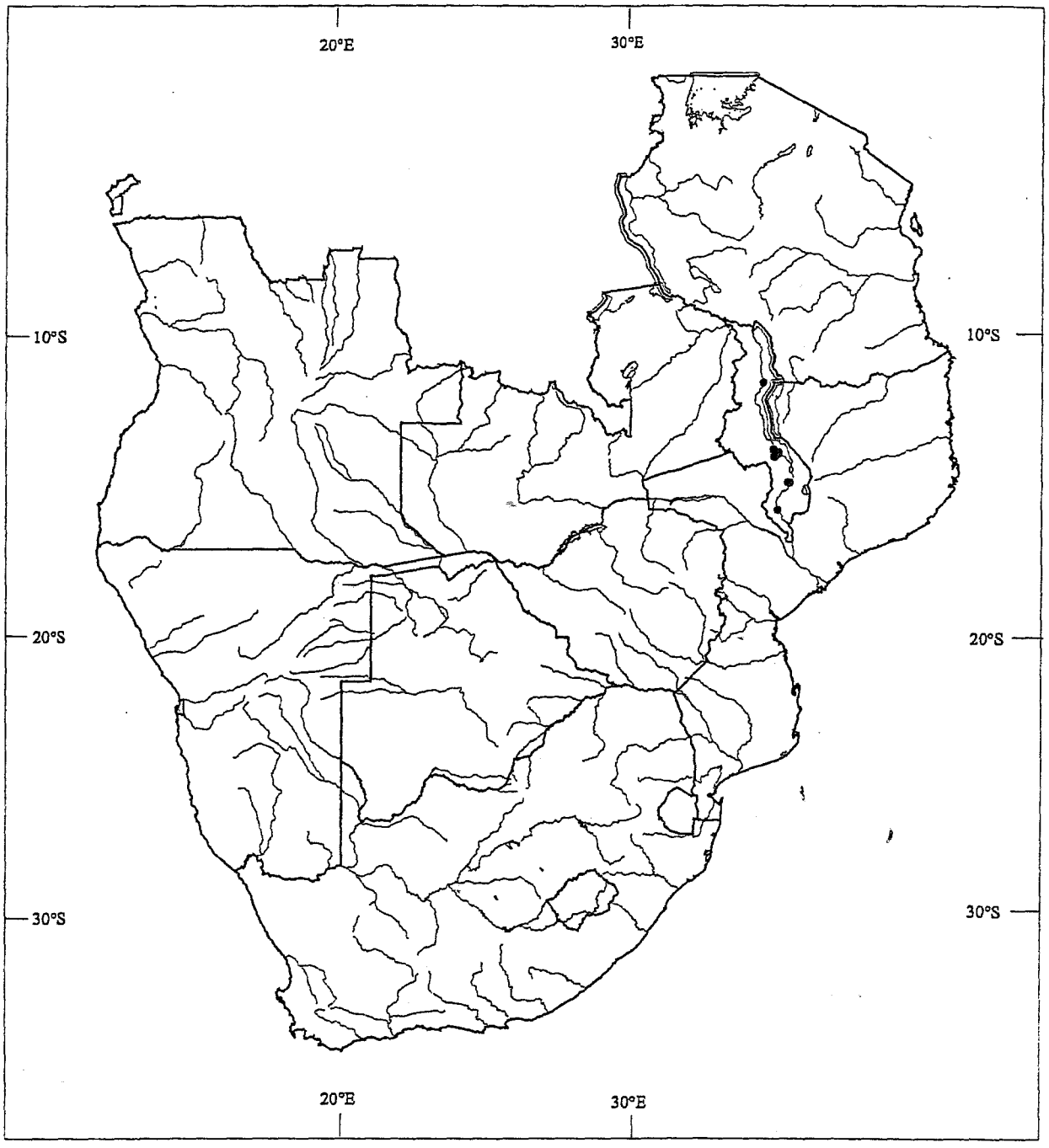


Figure F.675. Point distribution of *Synodontis nyassae*. Scale approximately 1:25 000 000

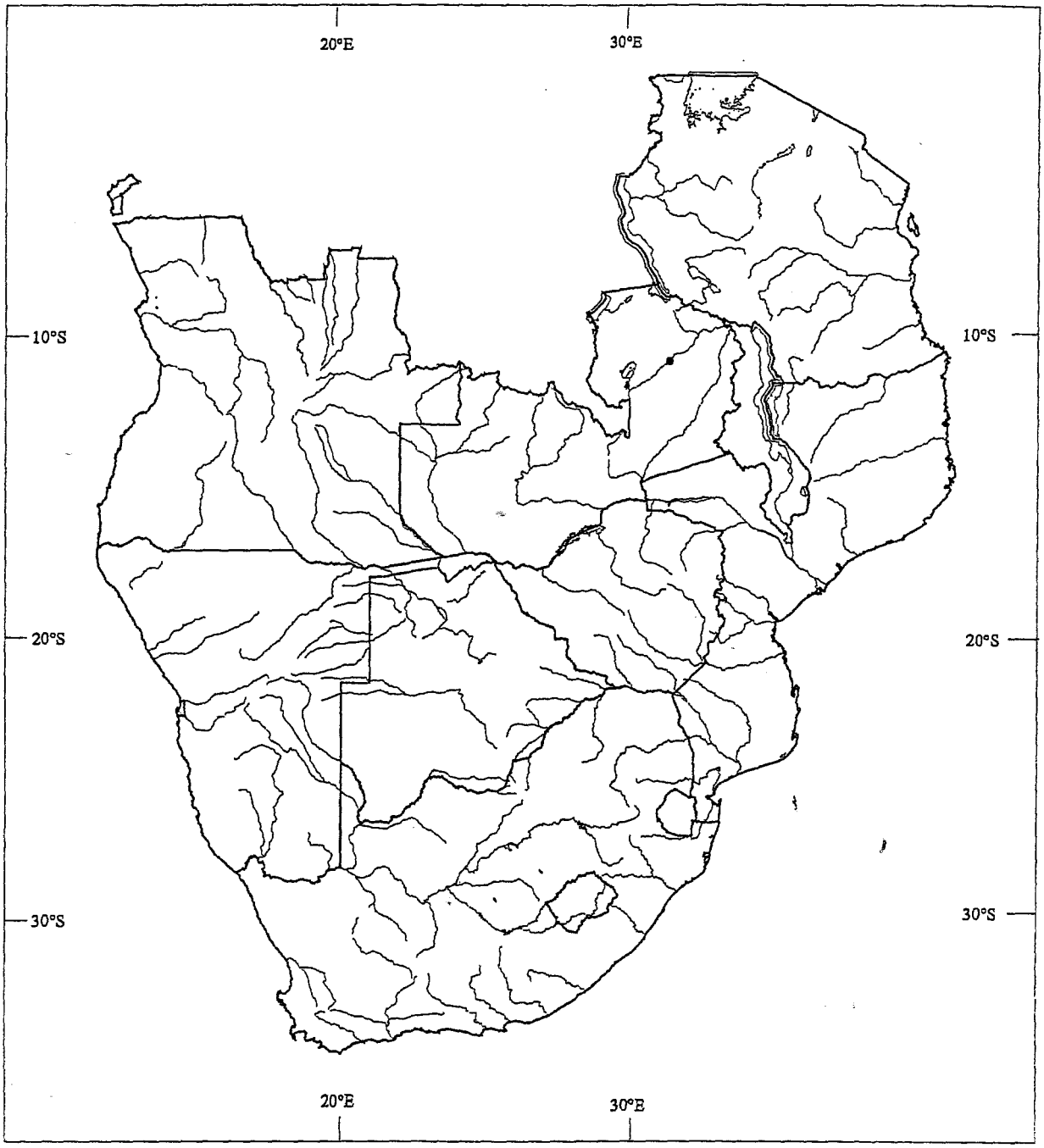


Figure F.676. Point distribution of *Synodontis ornatipinnis*. Scale approximately 1:25 000 000

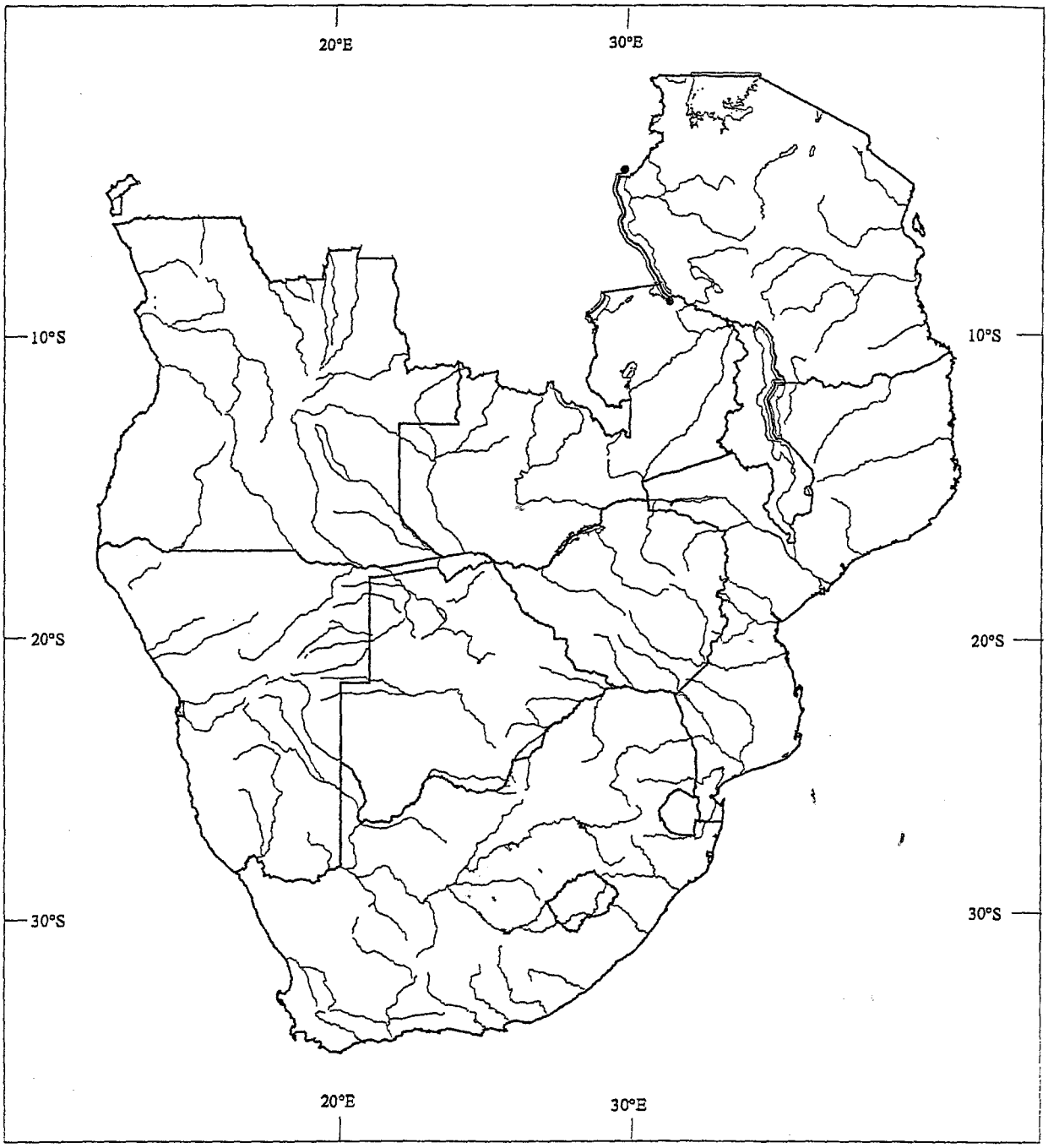


Figure F.677. Point distribution of *Synodontis petricola*. Scale approximately 1:25 000 000

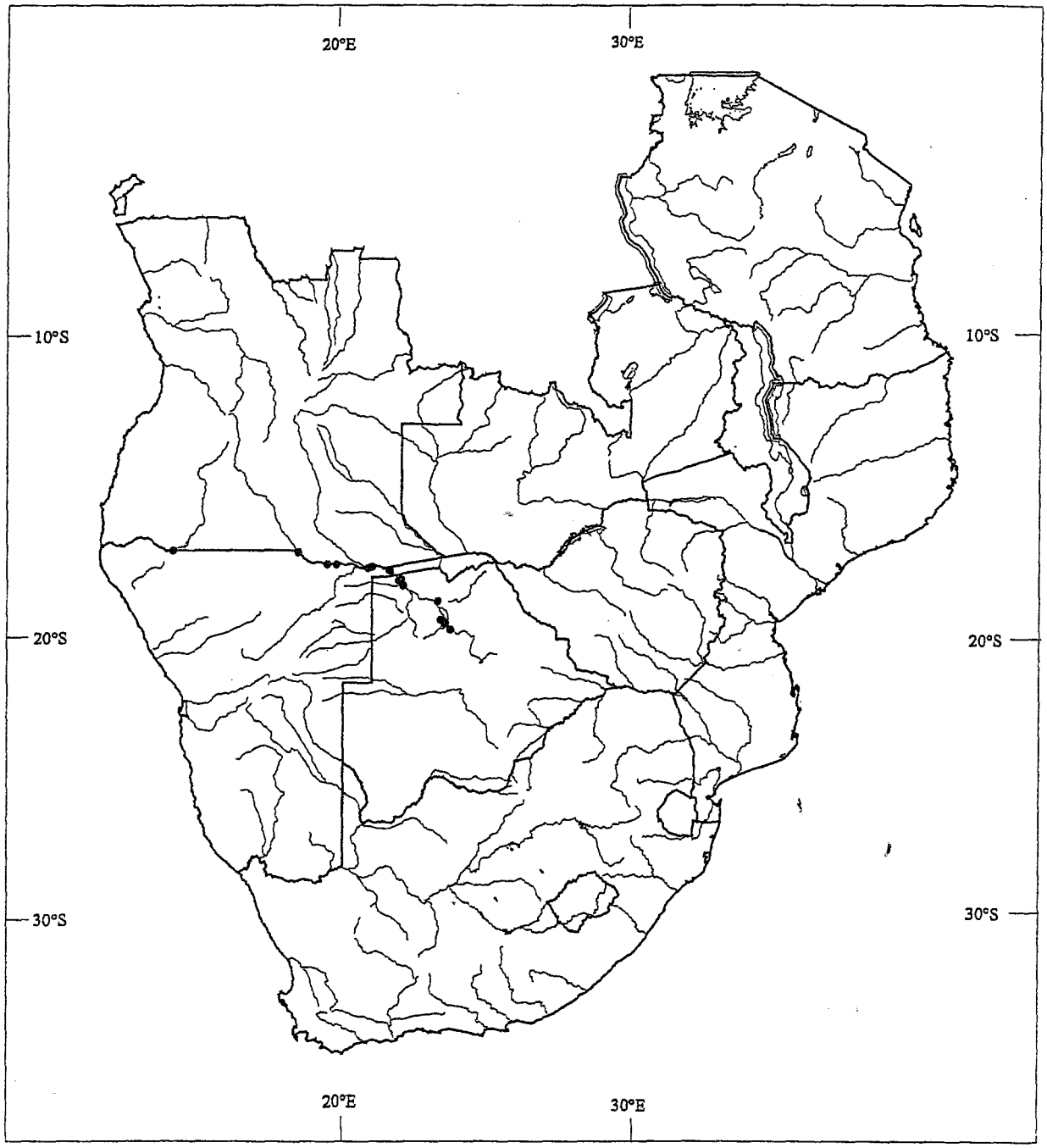


Figure F.678. Point distribution of *Synodontis thamalakanensis*. Scale approximately 1:25 000 000

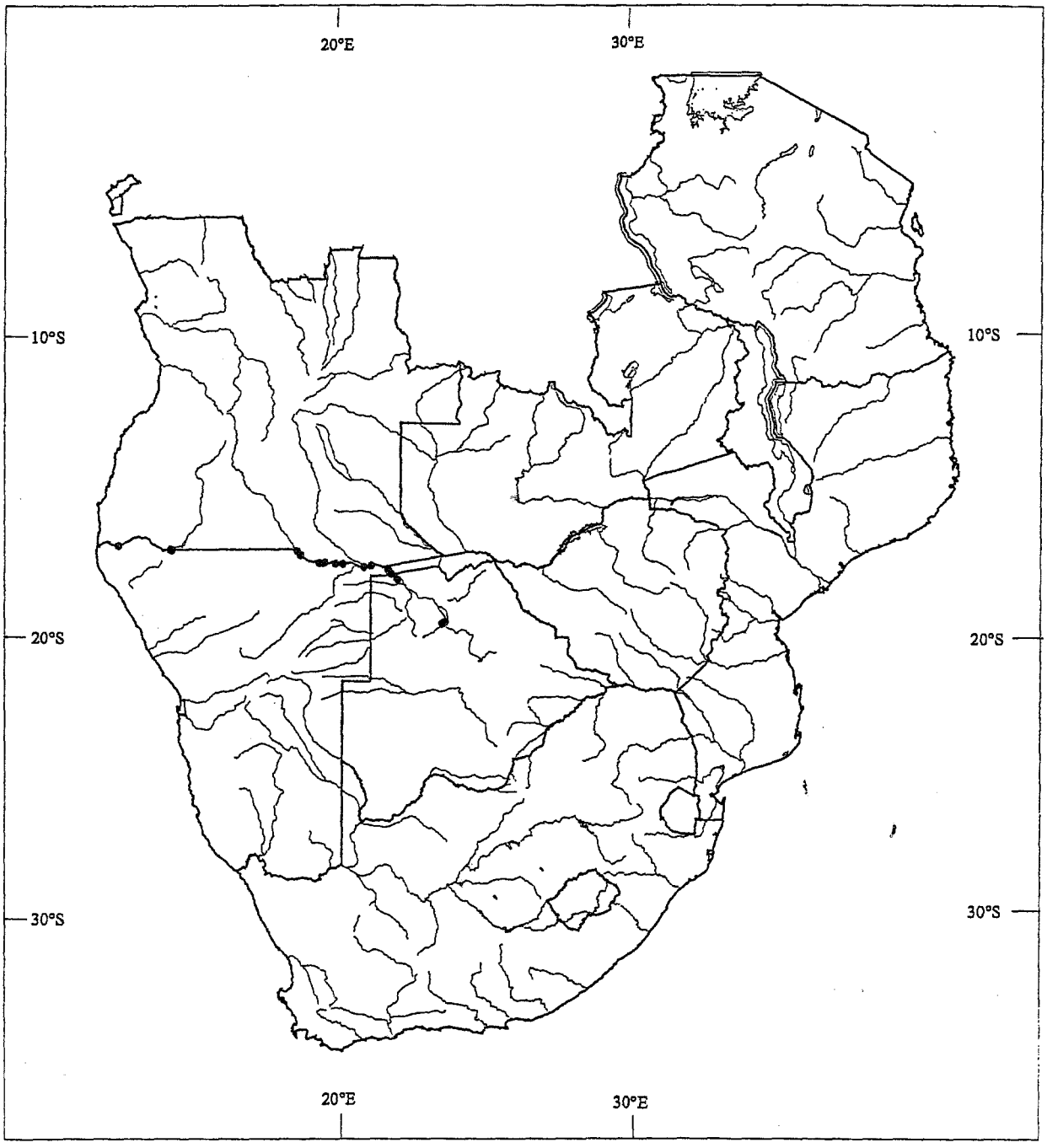


Figure F.679. Point distribution of *Synodontis vanderwaali*. Scale approximately 1:25 000 000

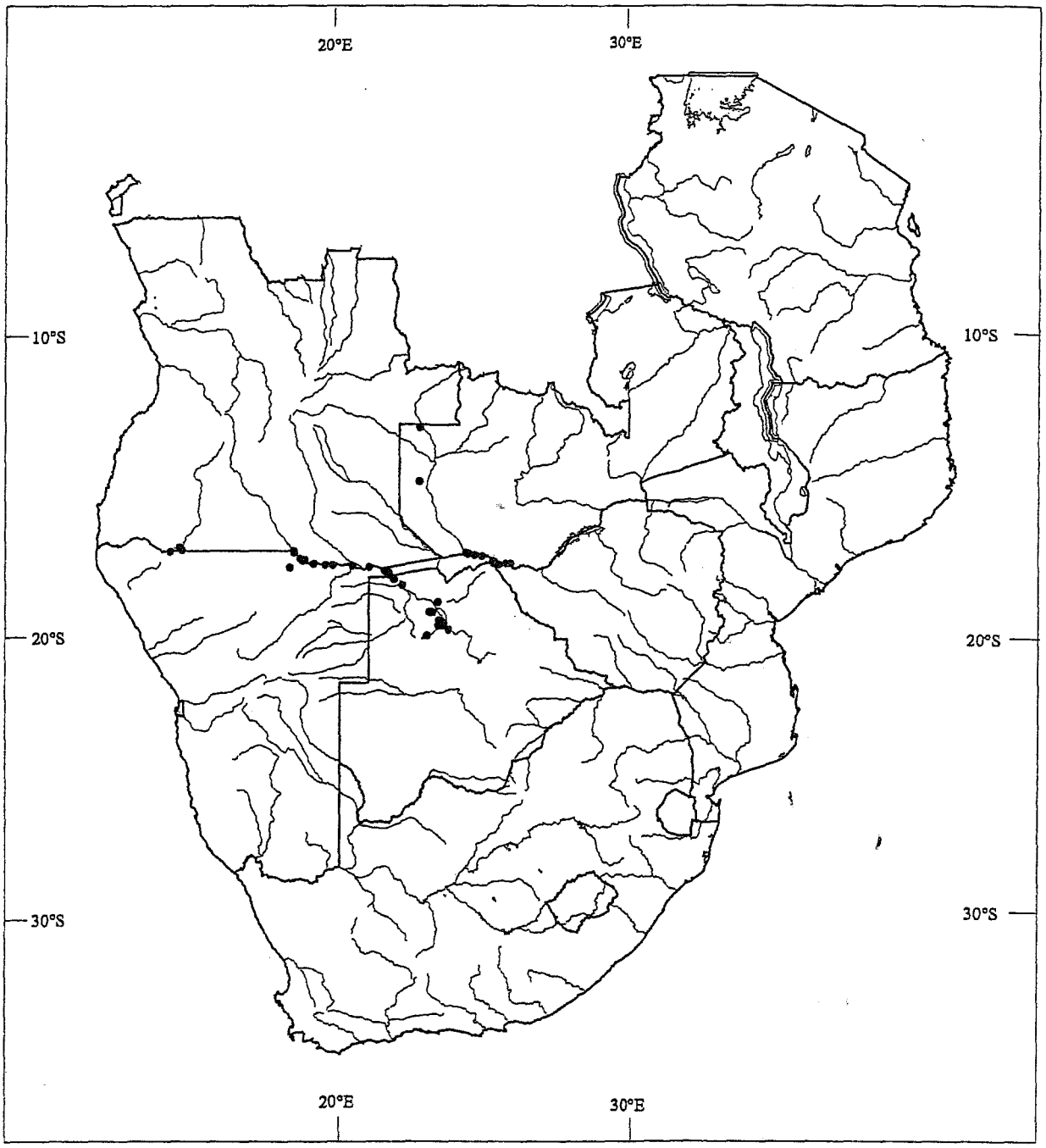


Figure F.680. Point distribution of *Synodontis woosnami*. Scale approximately 1:25 000 000

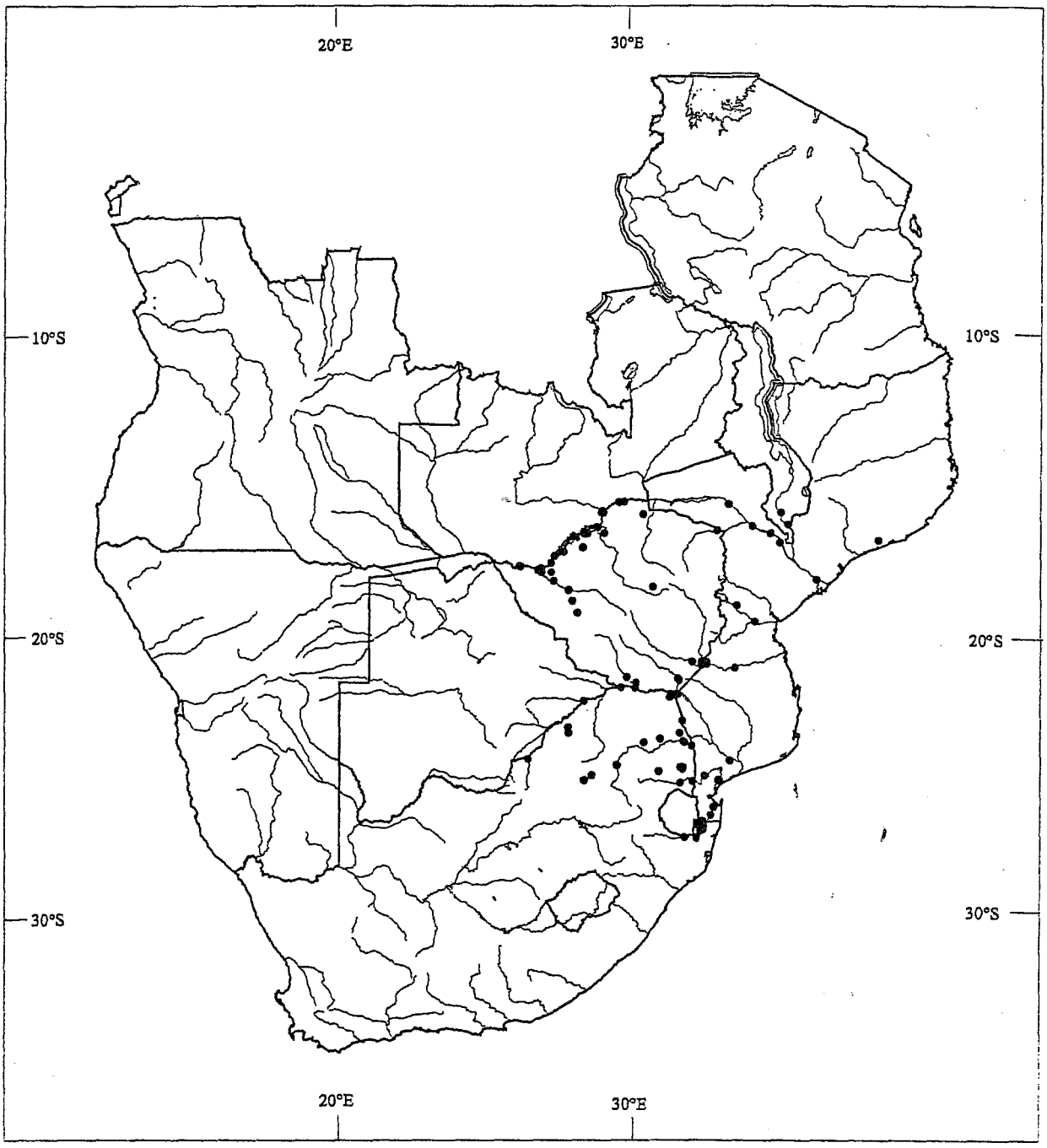


Figure F.681. Point distribution of *Synodontis zambezensis*. Scale approximately 1:25 000 000

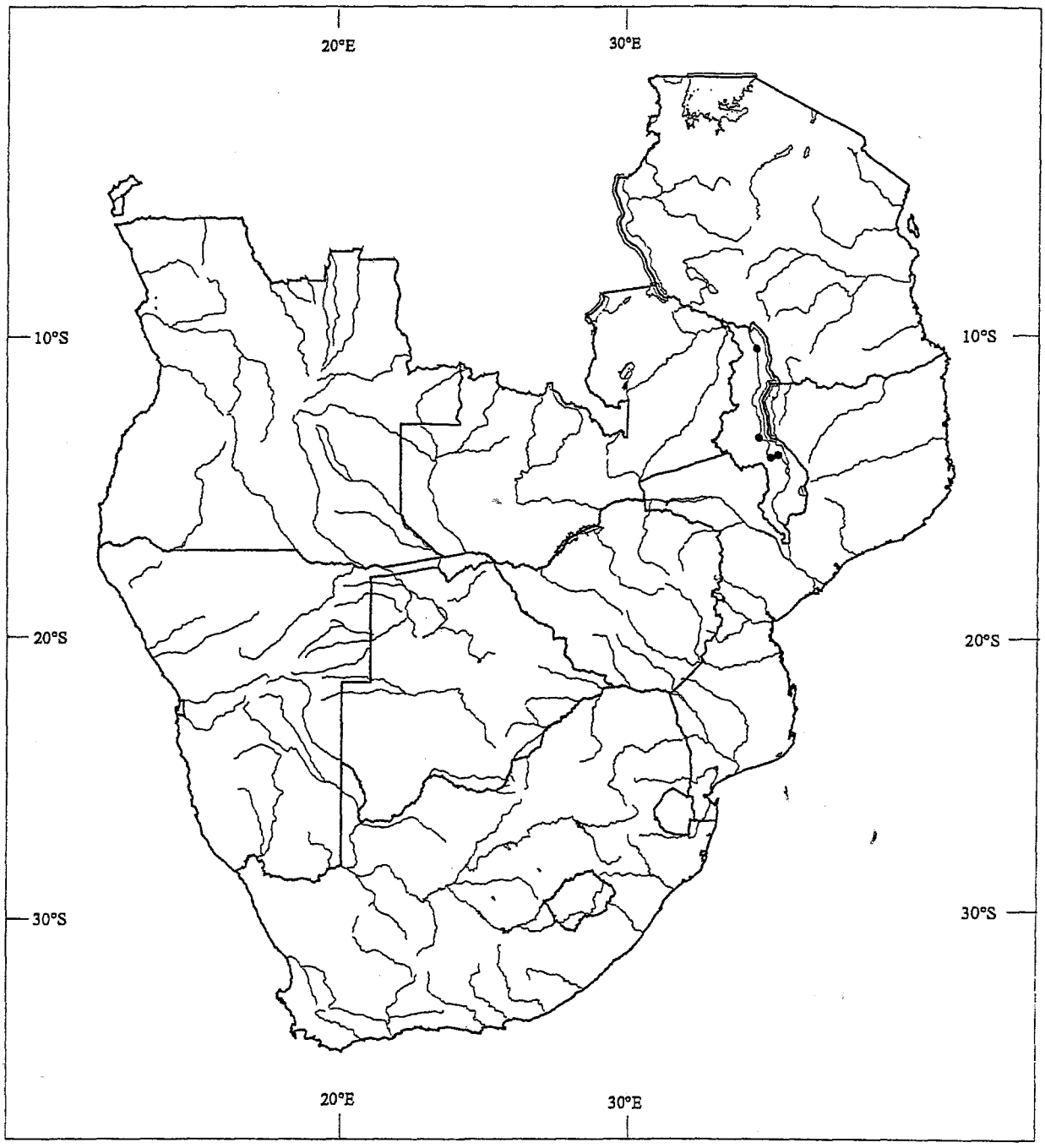


Figure F.682. Point distribution of *Taeniochromis holotaenia*. Scale approximately 1:25 000 000

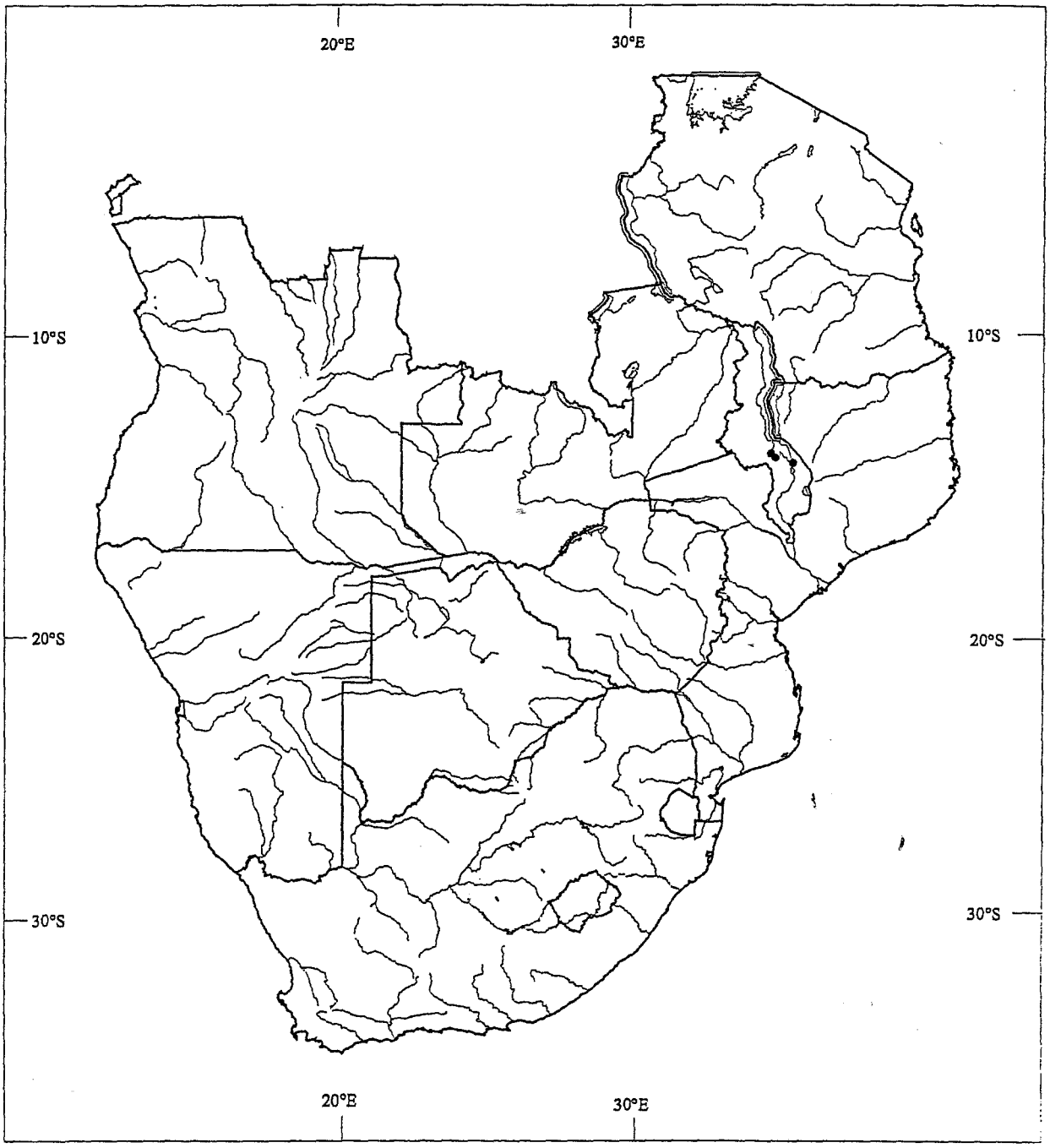


Figure F.683. Point distribution of *Taeniolethrinops laticeps*. Scale approximately 1:25 000 000

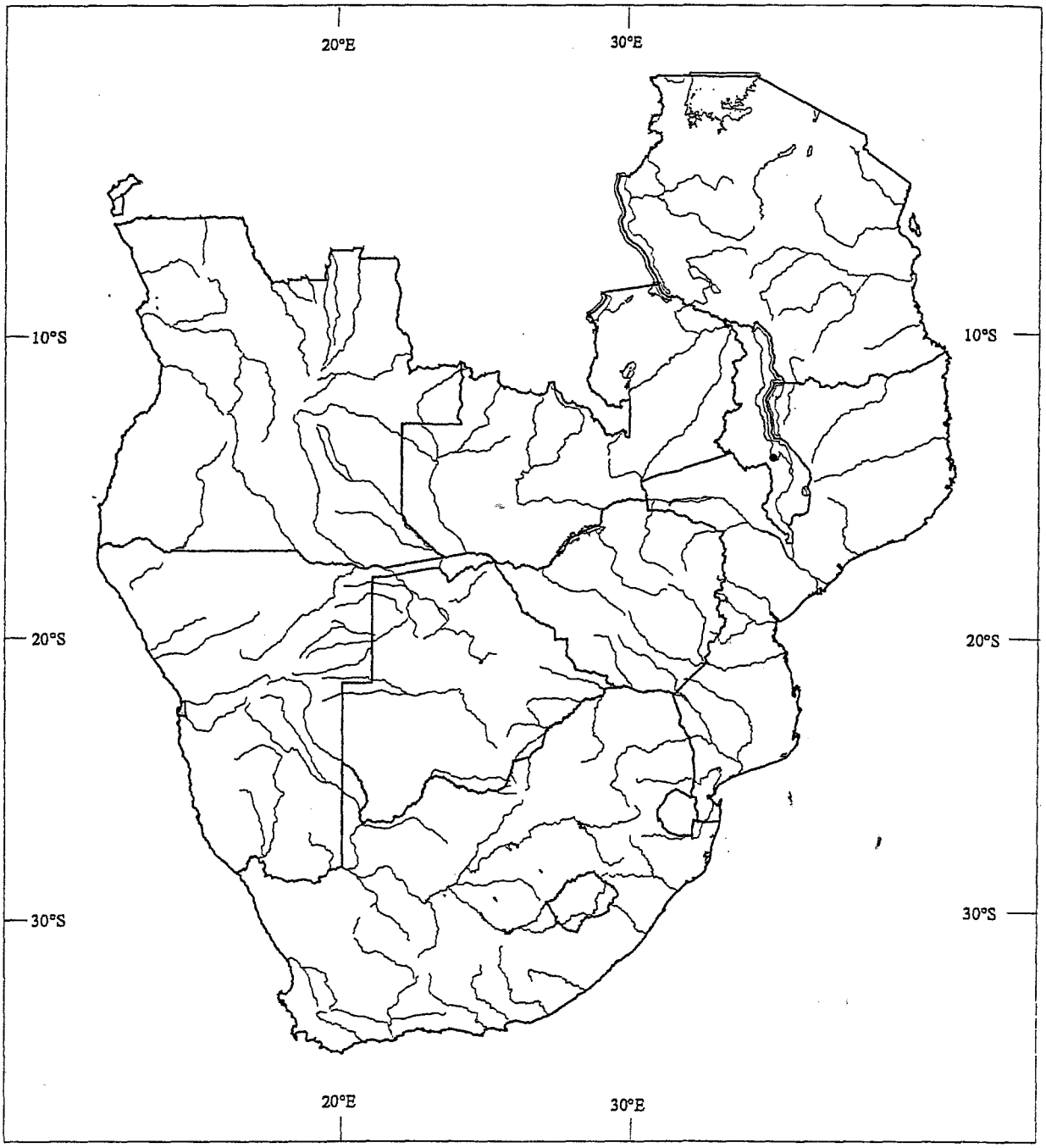


Figure F.684. Point distribution of *Taeniolethrinops praeorbitalis*. Scale approximately 1:25 000 000

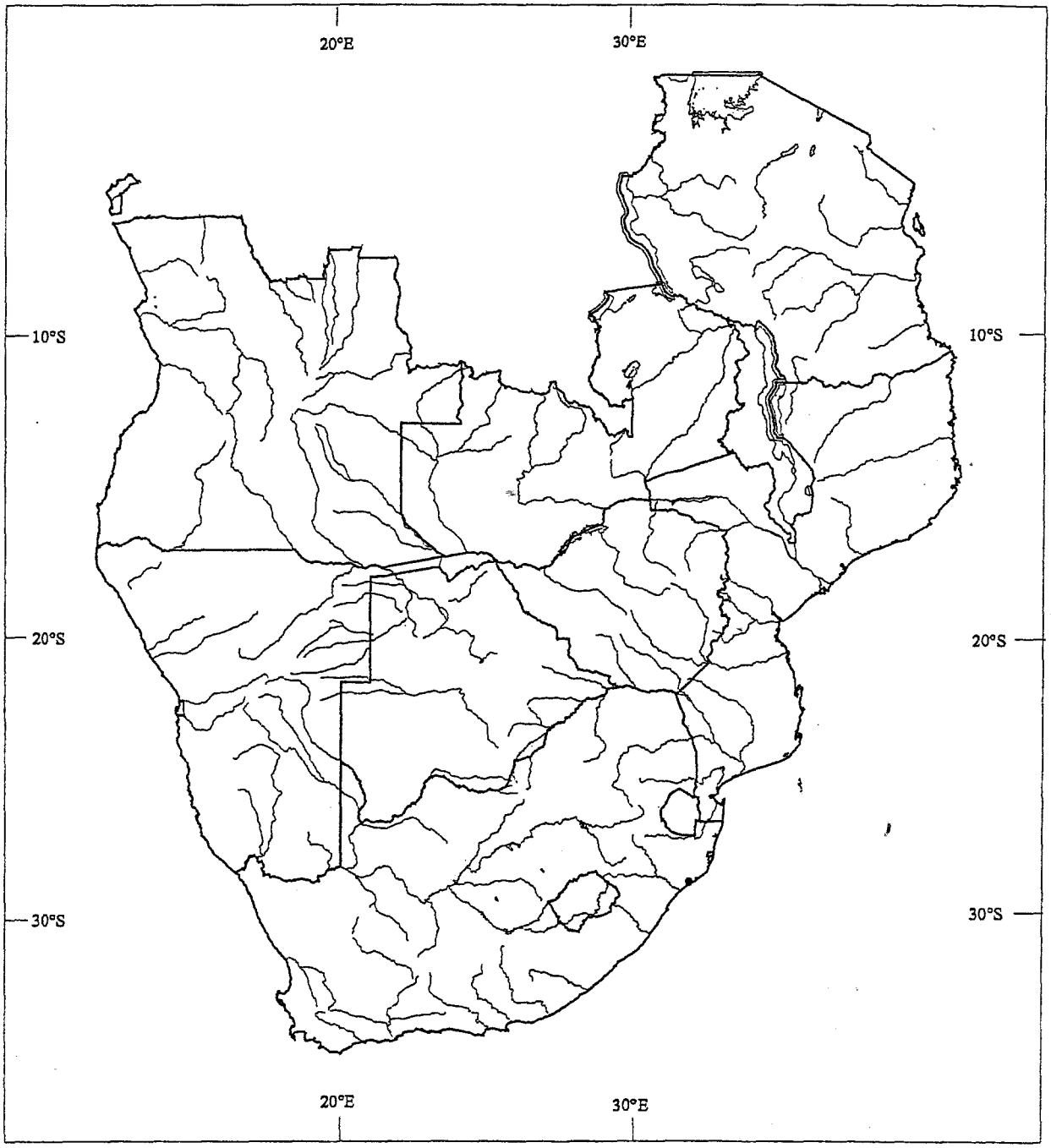


Figure F.685. Point distribution of *Taenoides esquivel*. Scale approximately 1:25 000 000

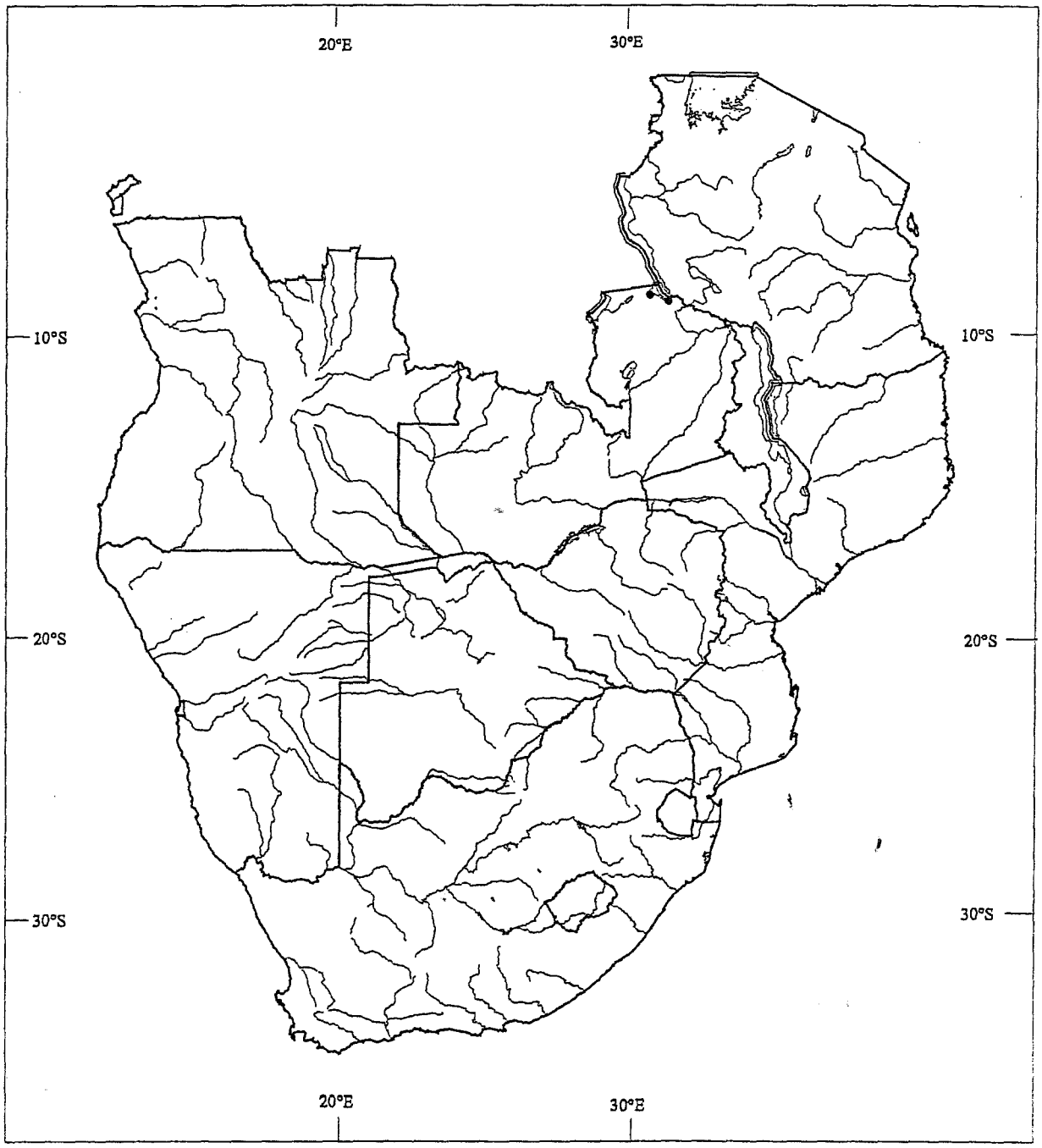


Figure F.686. Point distribution of *Tanganikallabes mortiauxi*. Scale approximately 1:25 000 000

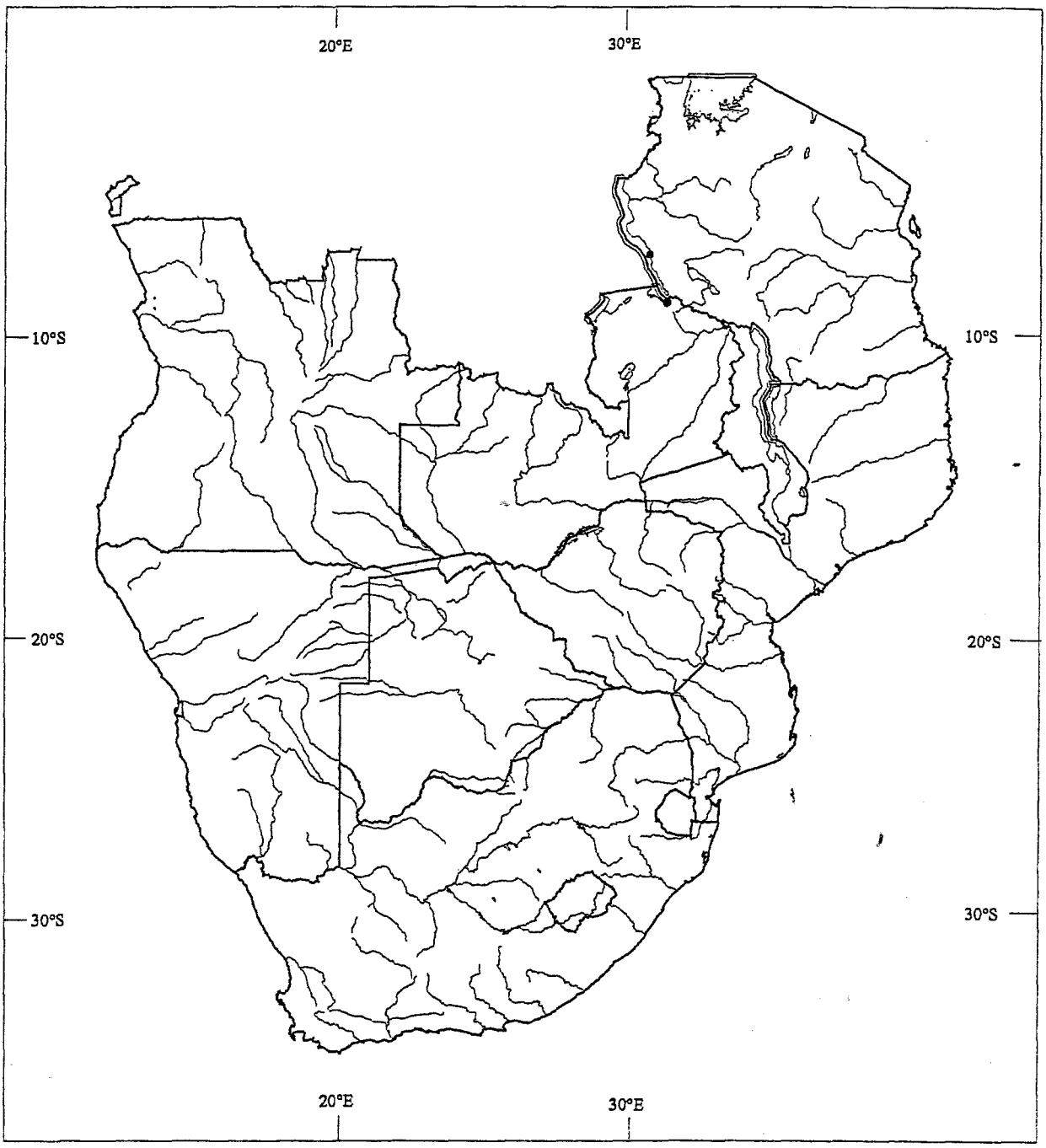


Figure F.687. Point distribution of *Telmatochromis burgeoni*. Scale approximately 1:25 000 000

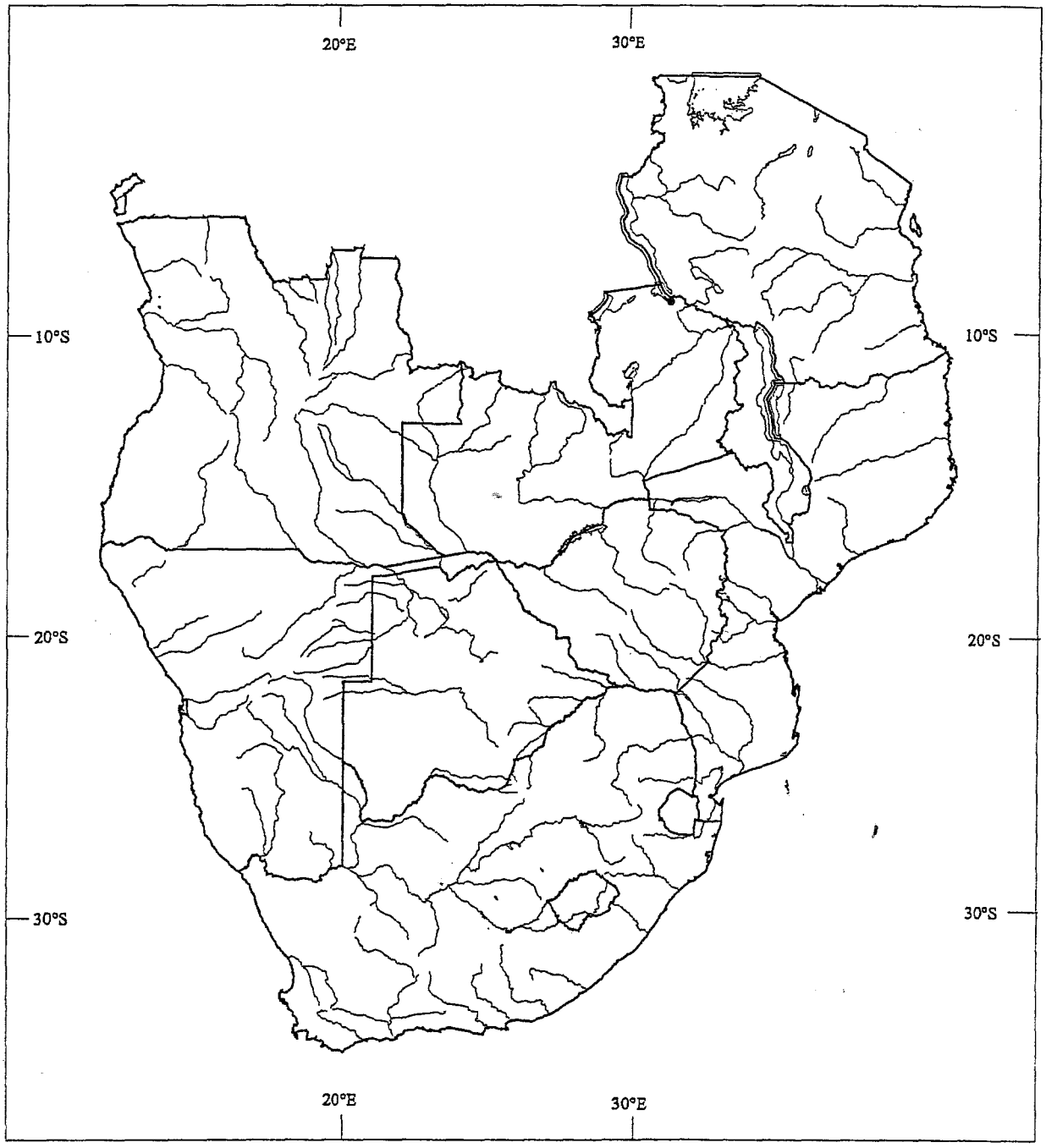


Figure F.688. Point distribution of *Telmatochromis dhoti*. Scale approximately 1:25 000 000

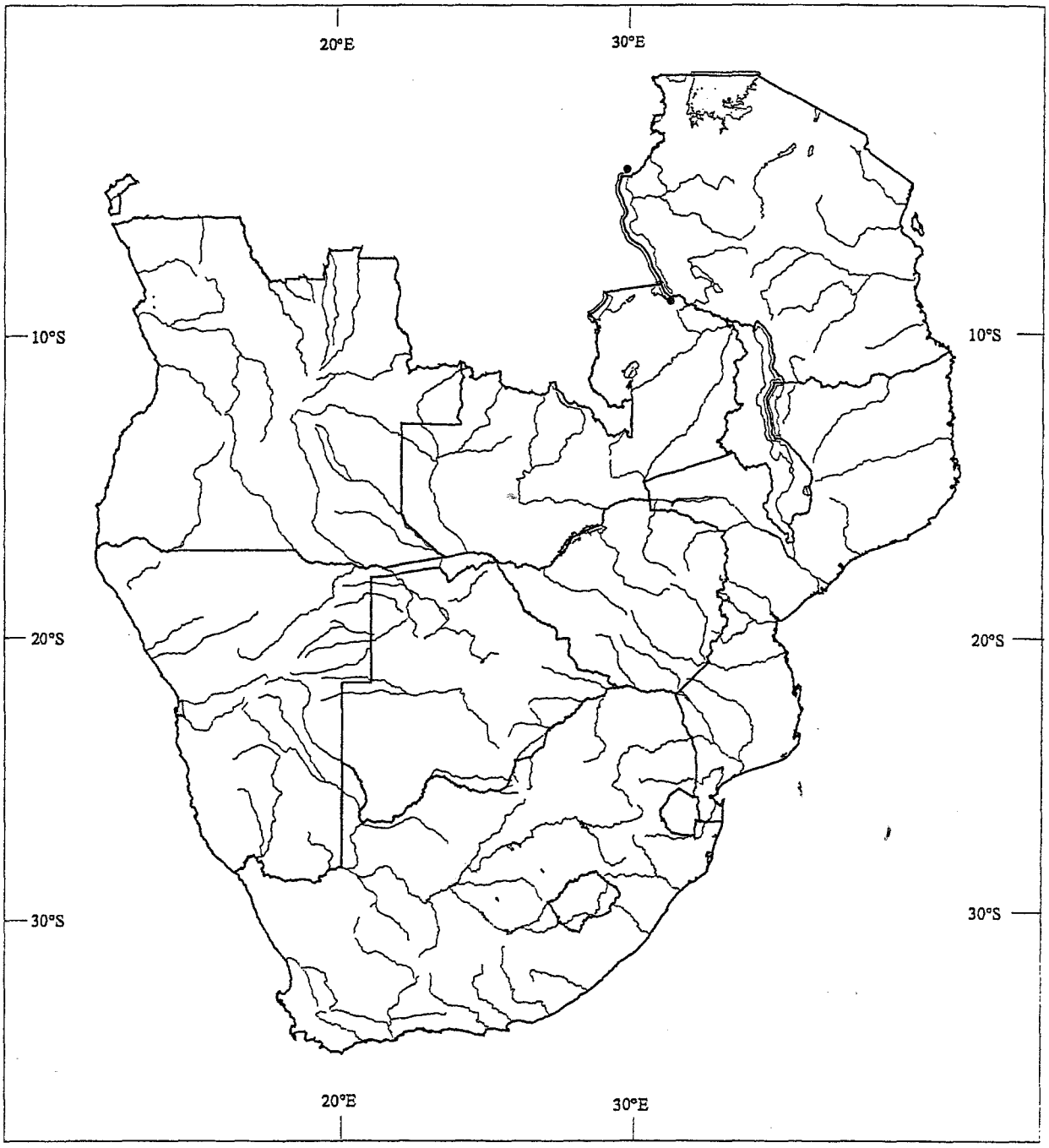


Figure F.689. Point distribution of *Telmatochromis temporalis*. Scale approximately 1:25 000 000

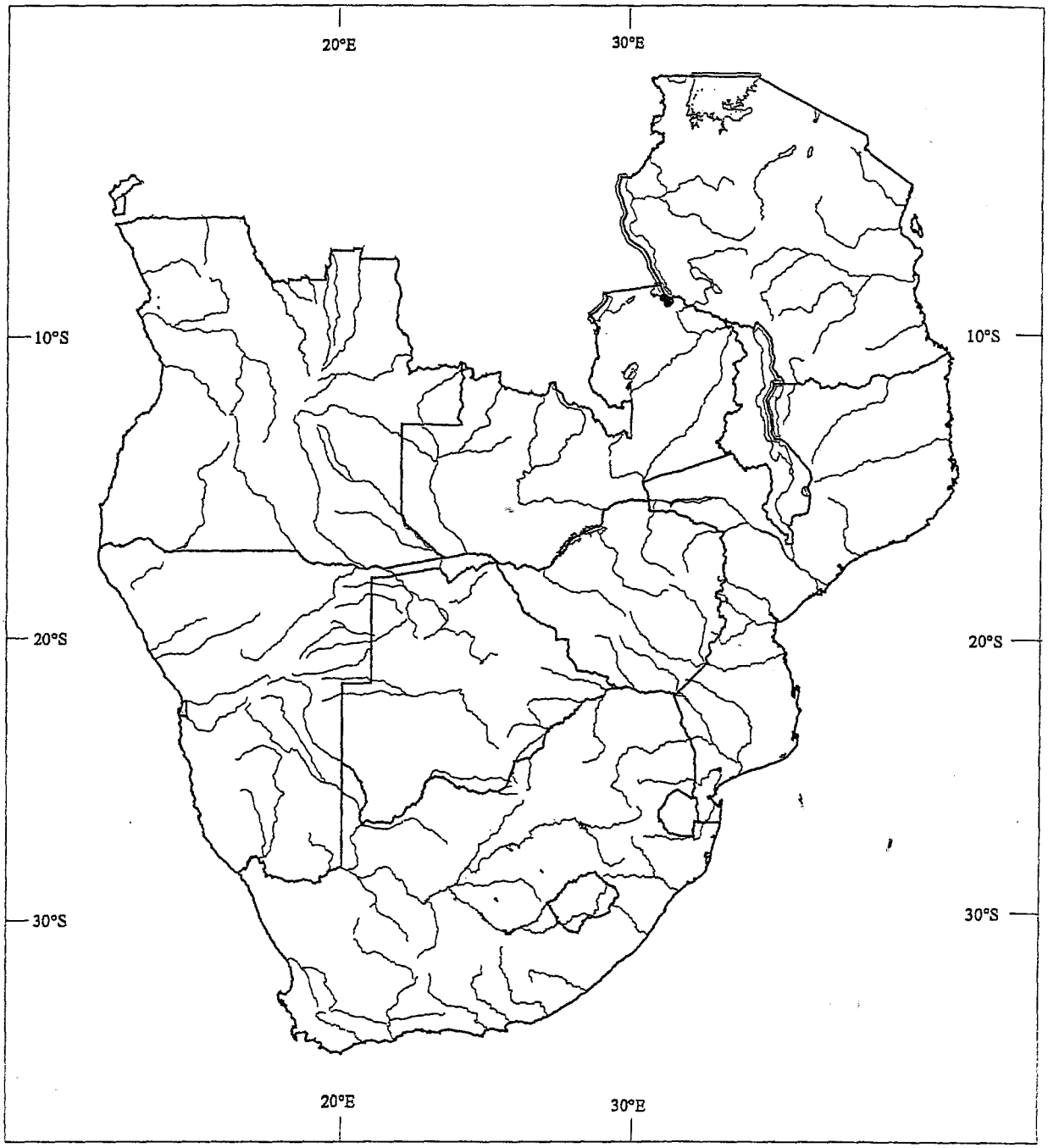


Figure F.690. Point distribution of *Telmatochromis vittatus*. Scale approximately 1:25 000 000

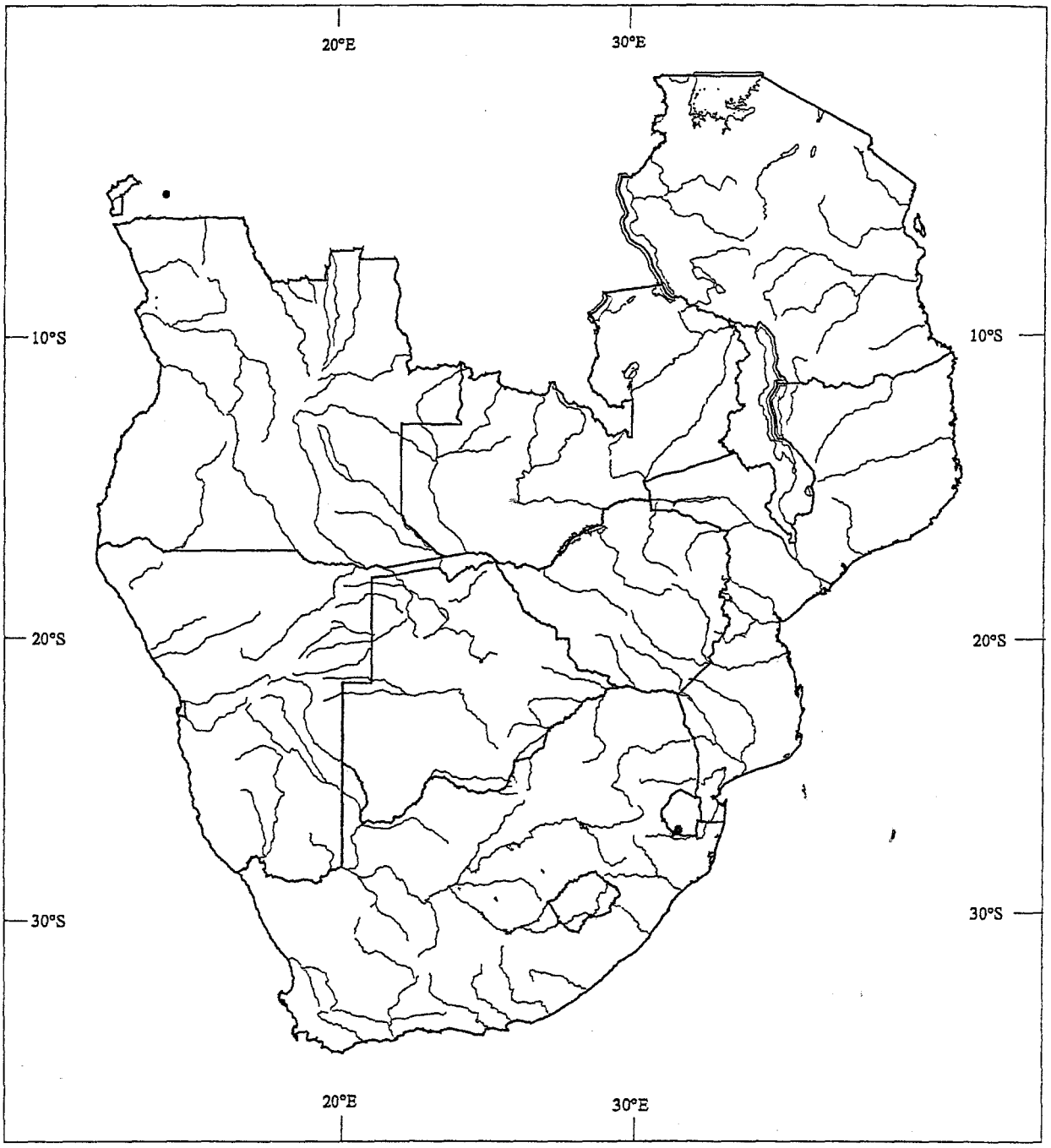


Figure F.691. Point distribution of *Telogramma gracile*. Scale approximately 1:25 000 000

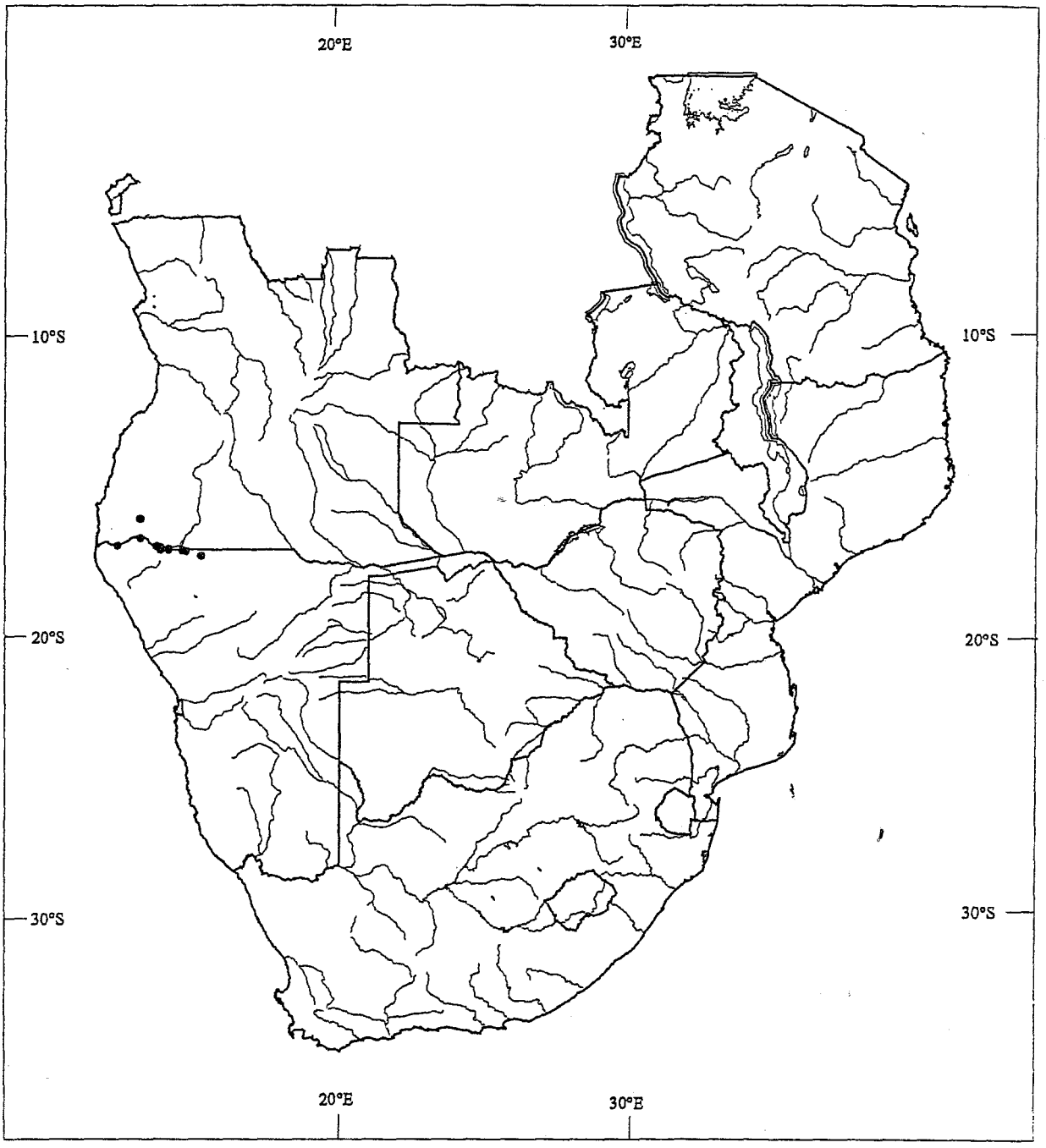


Figure F.692. Point distribution of *Thoracochromis albolabris*. Scale approximately 1:25 000 000

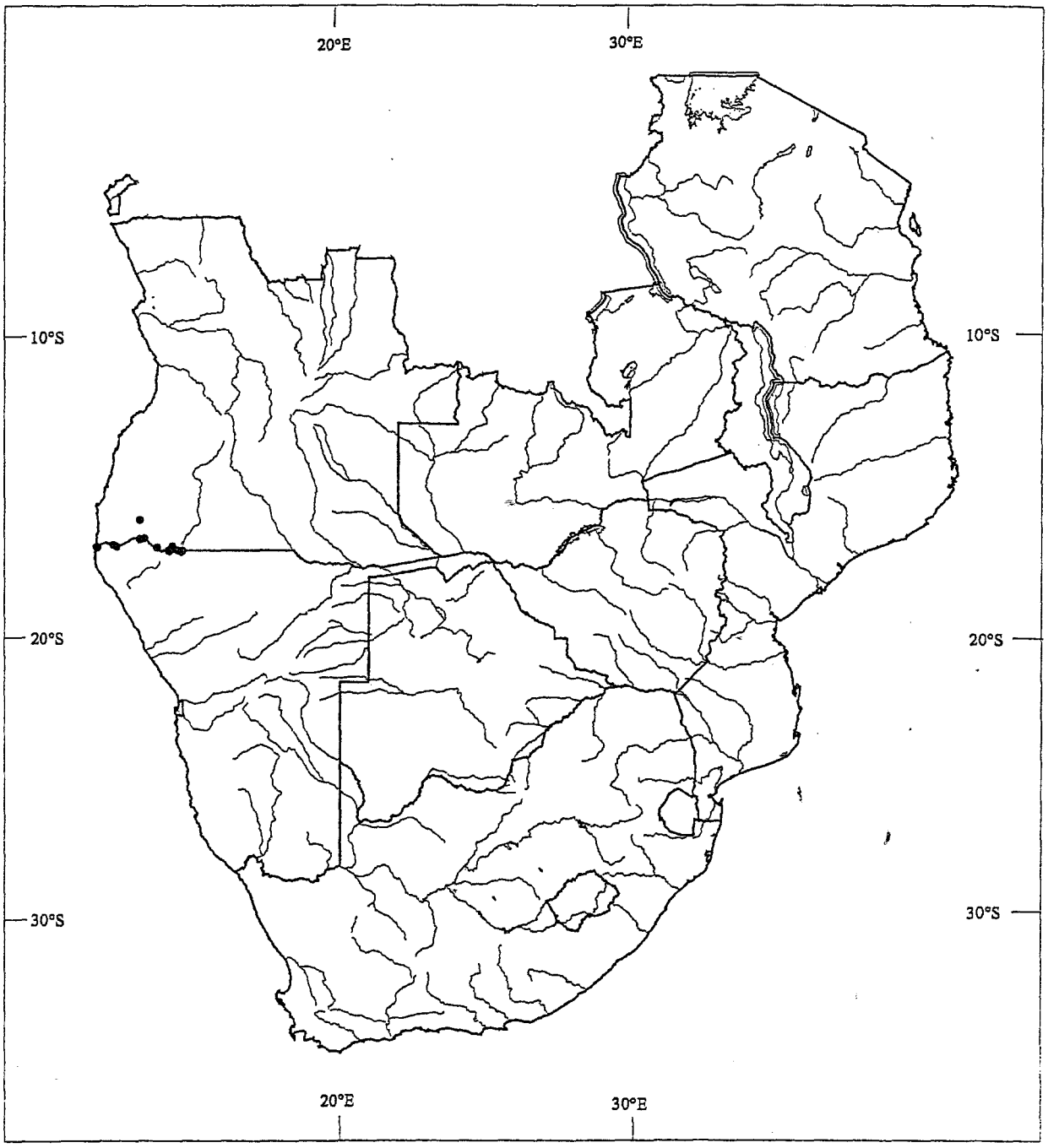


Figure F.693. Point distribution of *Thoracochromis buysi*. Scale approximately 1:25 000 000

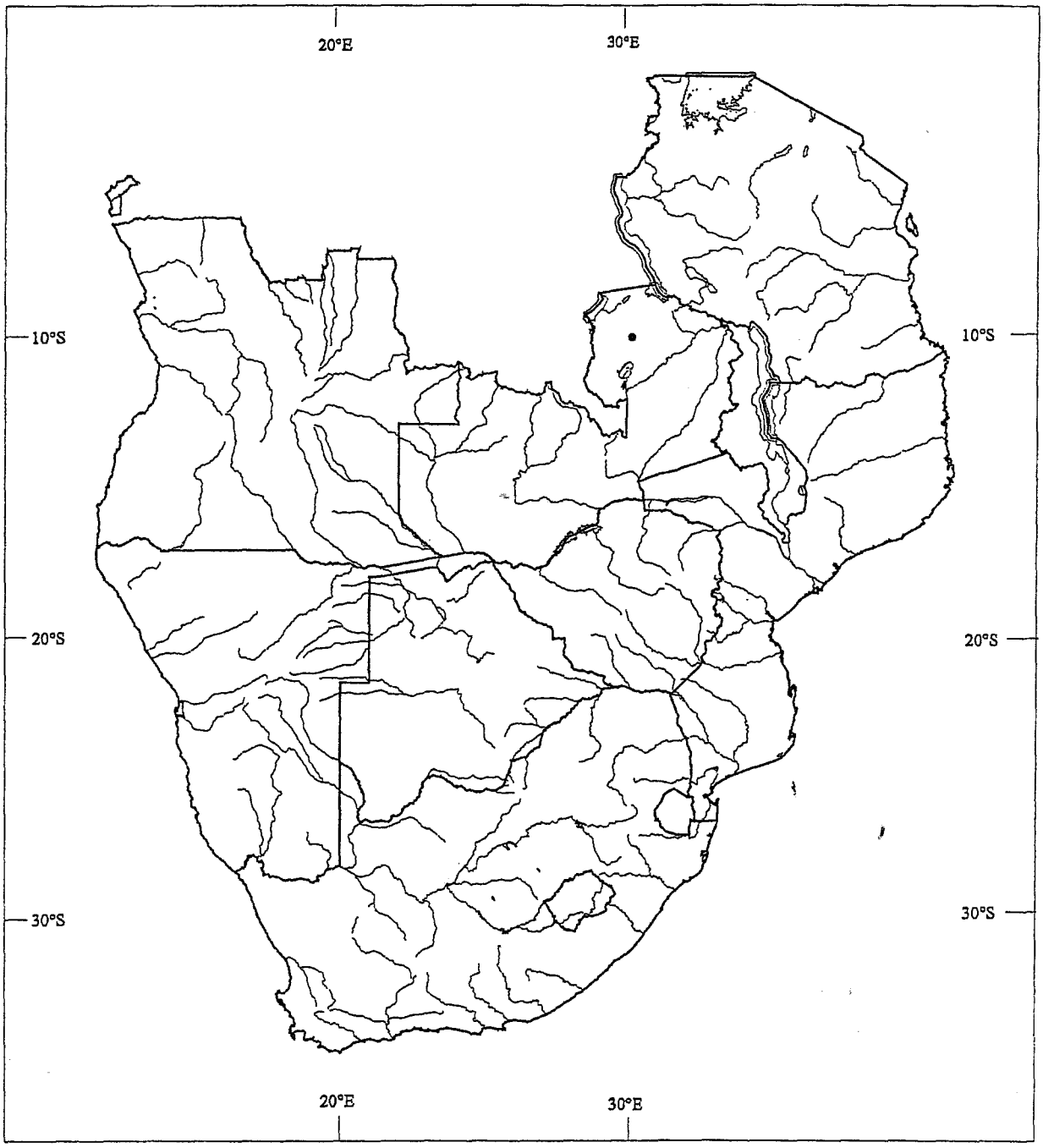


Figure F.694. Point distribution of *Tilapia baloni*. Scale approximately 1:25 000 000

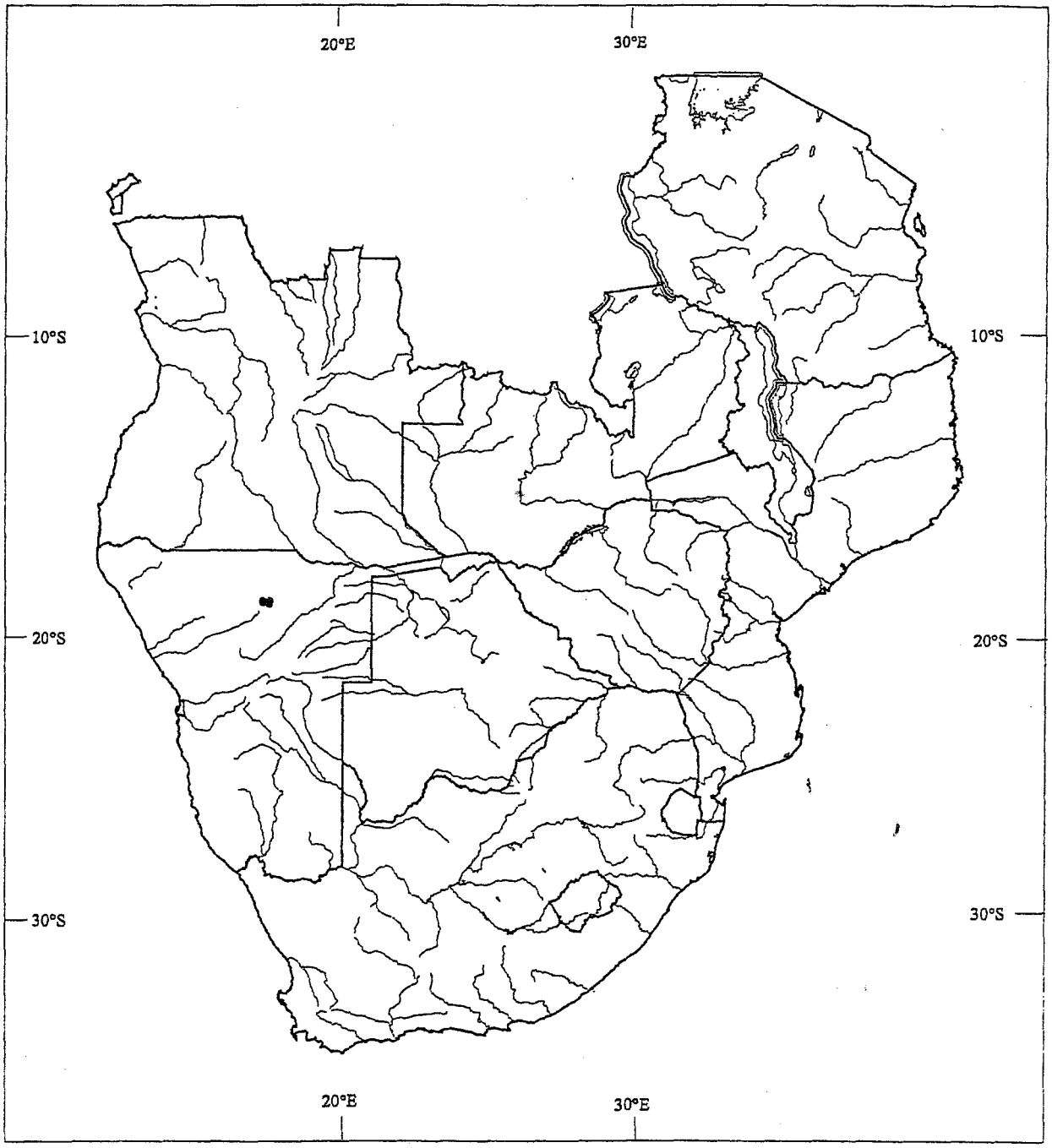


Figure F.695. Point distribution of *Tilapia guinasana*. Scale approximately 1:25 000 000

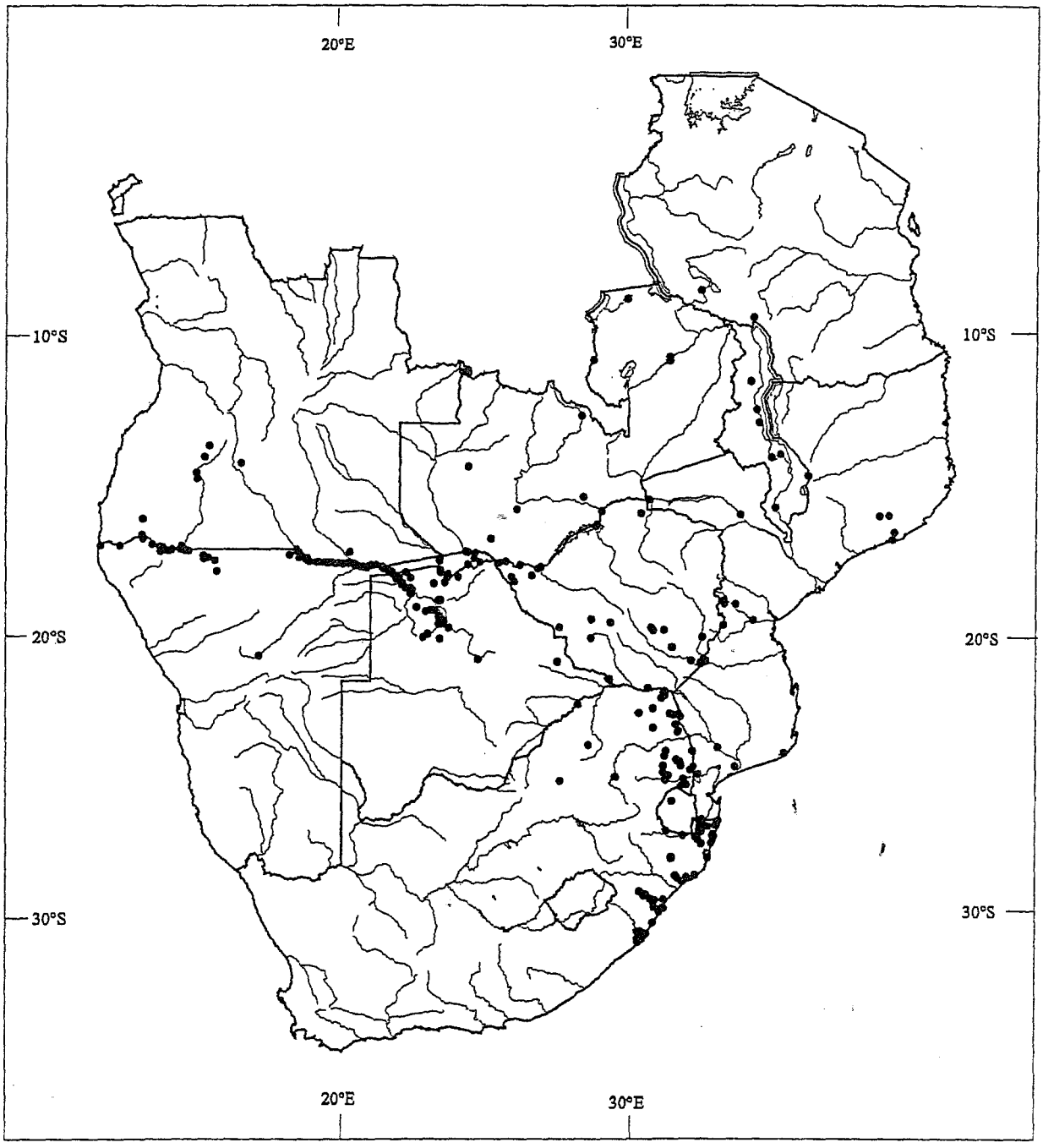


Figure F.696. Point distribution of *Tilapia rendalli*. Scale approximately 1:25 000 000

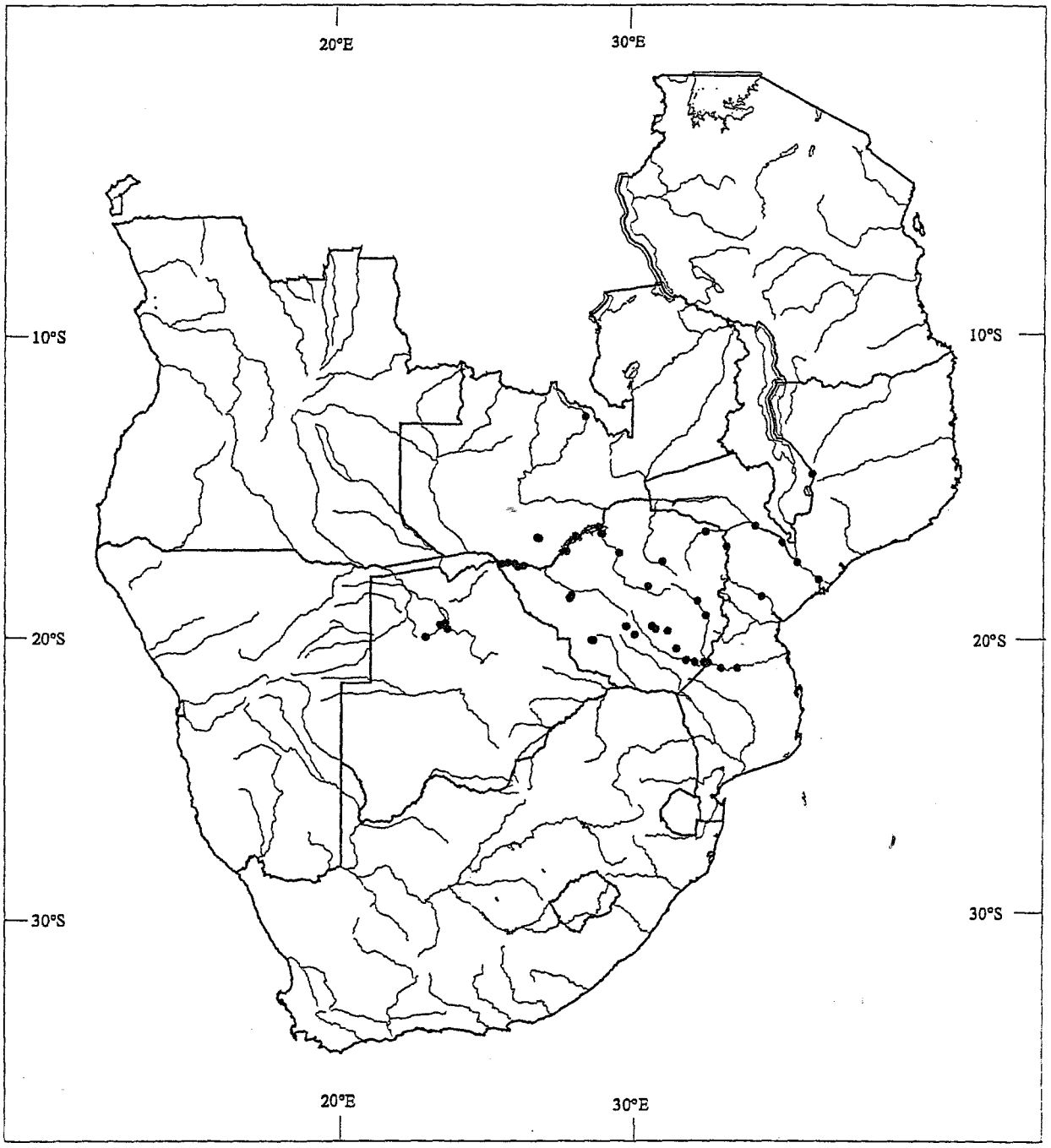


Figure F.697. Point distribution of *Tilapia rendalli rendalli*. Scale approximately 1:25 000 000

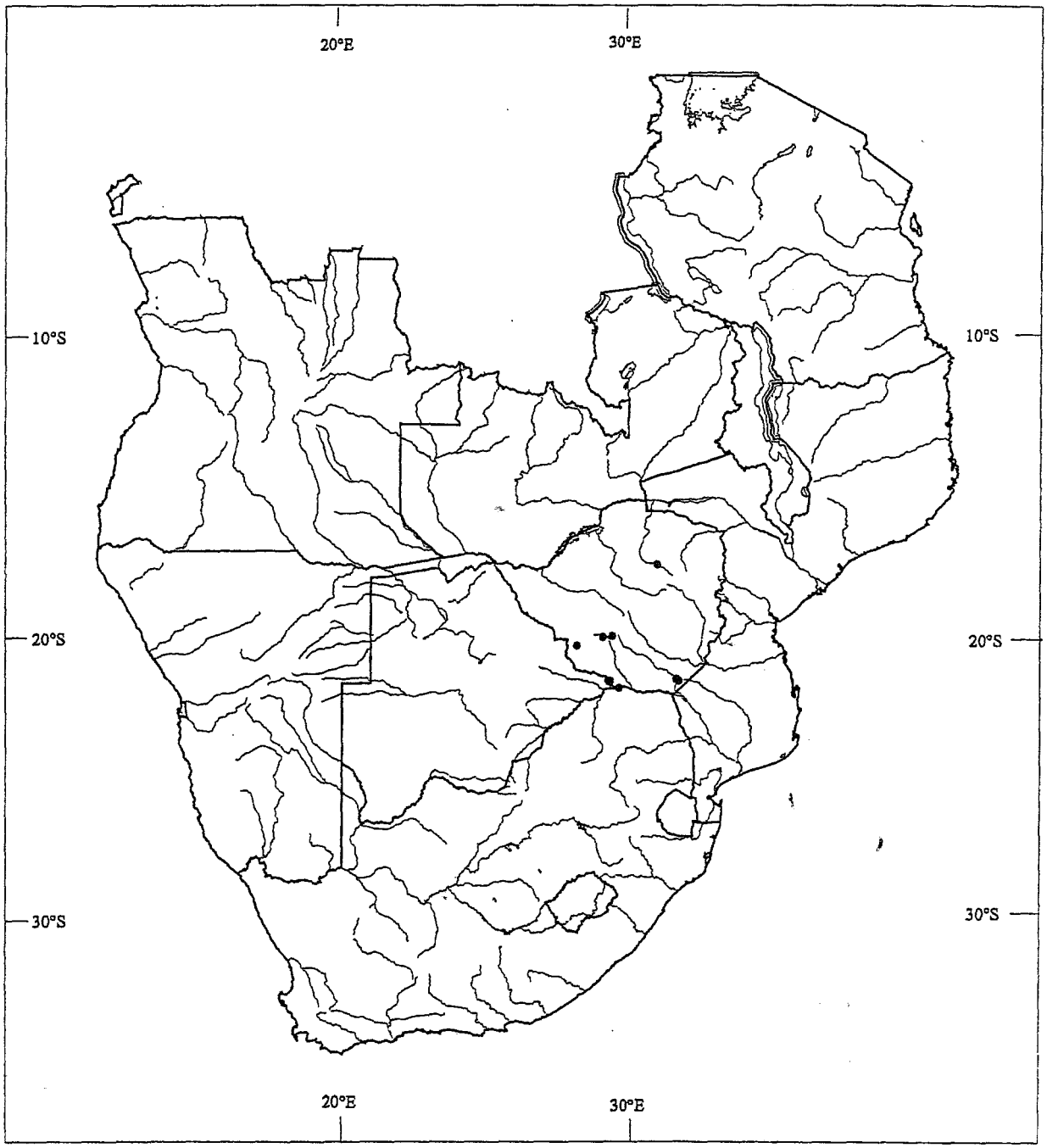


Figure F.698. Point distribution of *Tilapia rendalli swierstrae*. Scale approximately 1:25 000 000

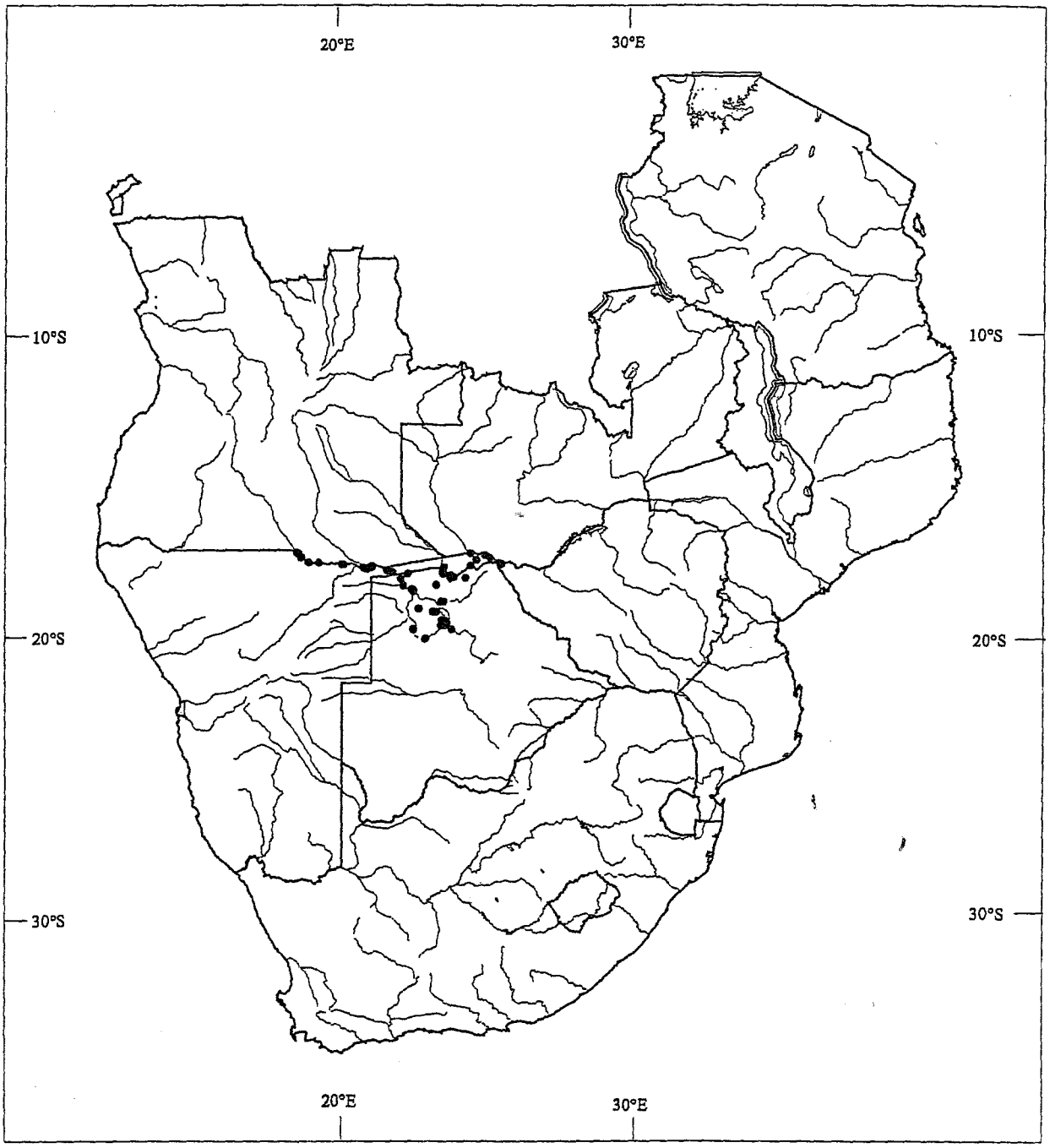


Figure F.699. Point distribution of *Tilapia ruweti*. Scale approximately 1:25 000 000

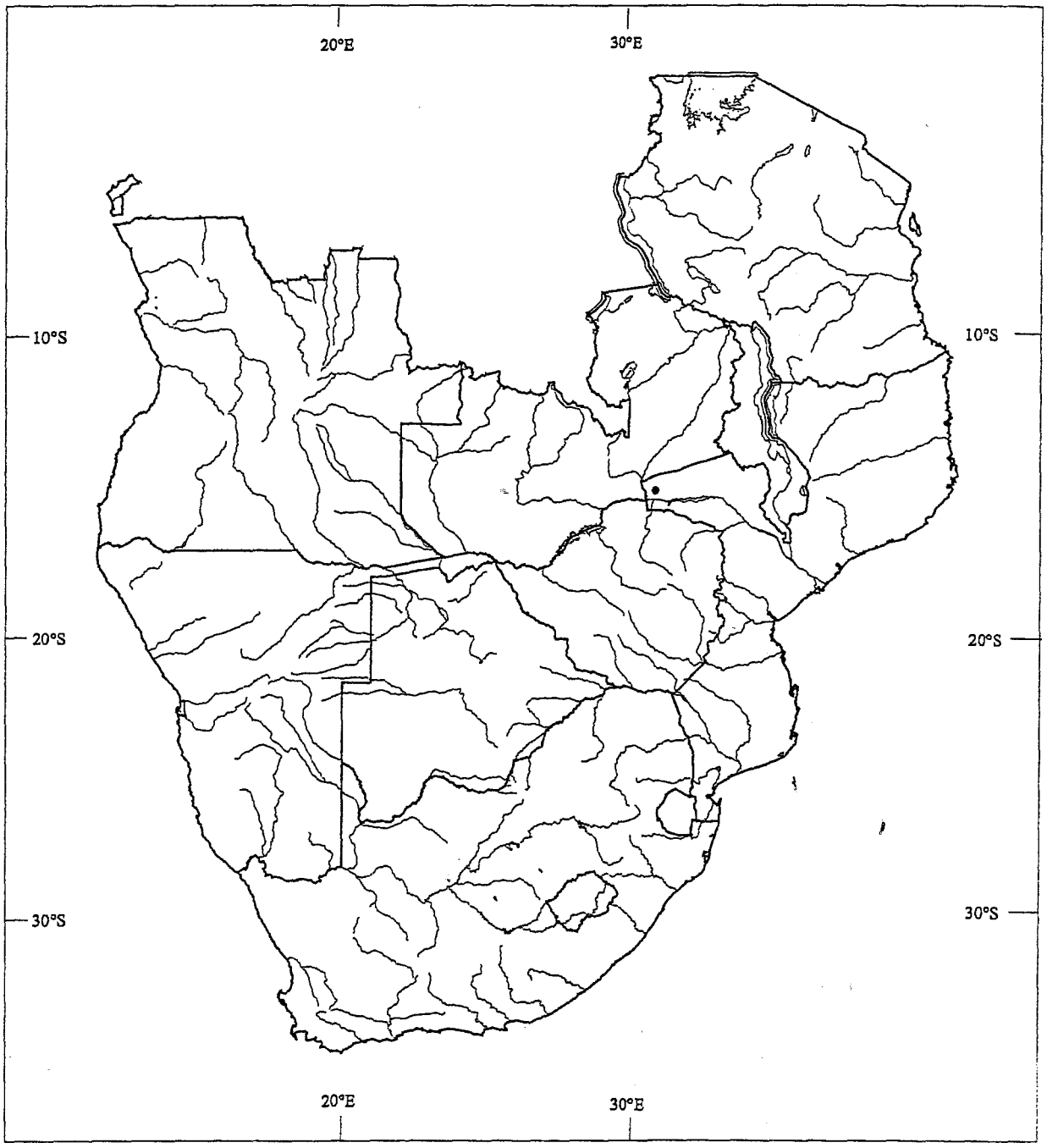


Figure F.700. Point distribution of *Tilapia shirana chilwae*. Scale approximately 1:25 000 000

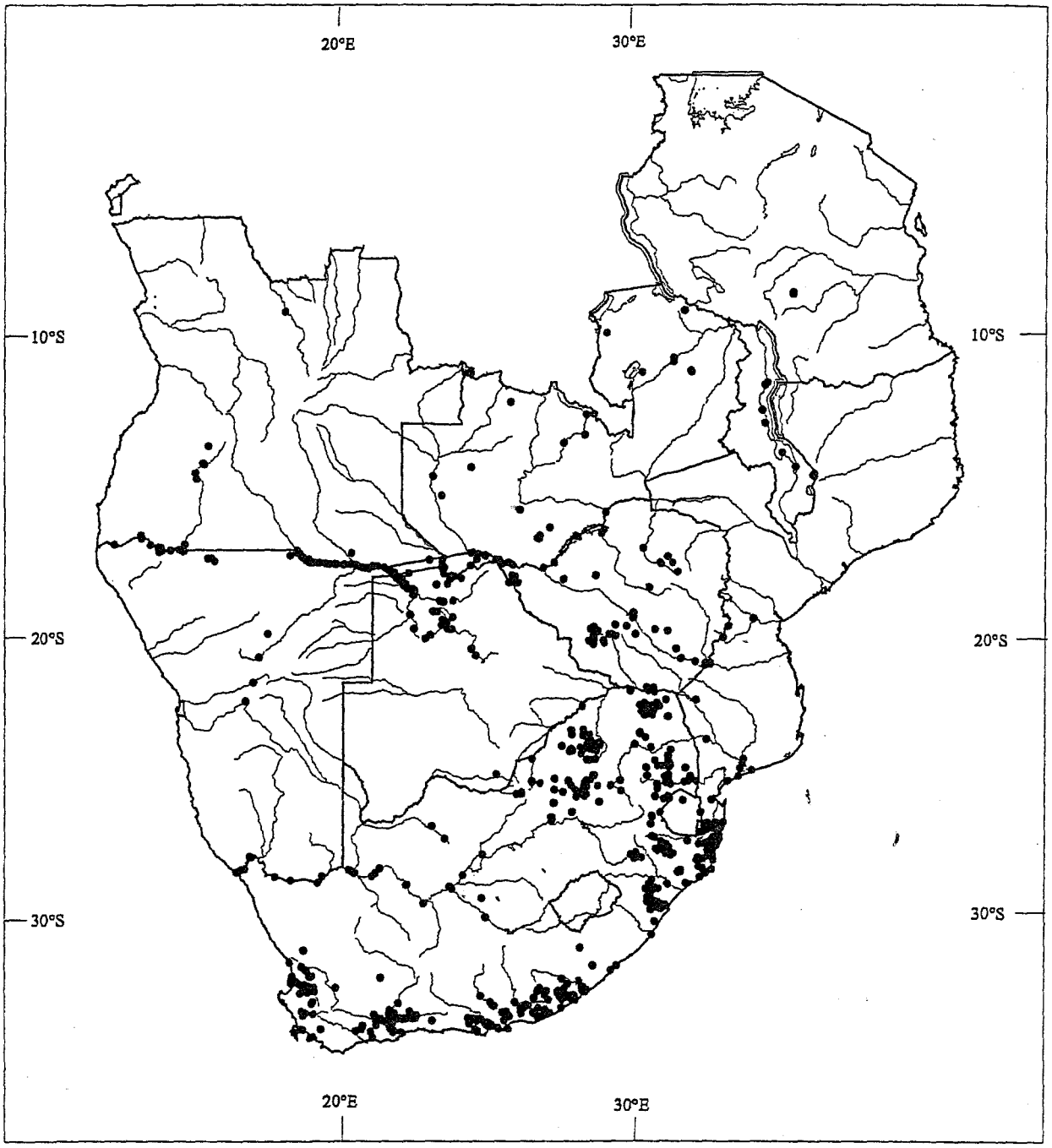


Figure F.701. Point distribution of *Tilapia sparrmanii*. Scale approximately 1:25 000 000

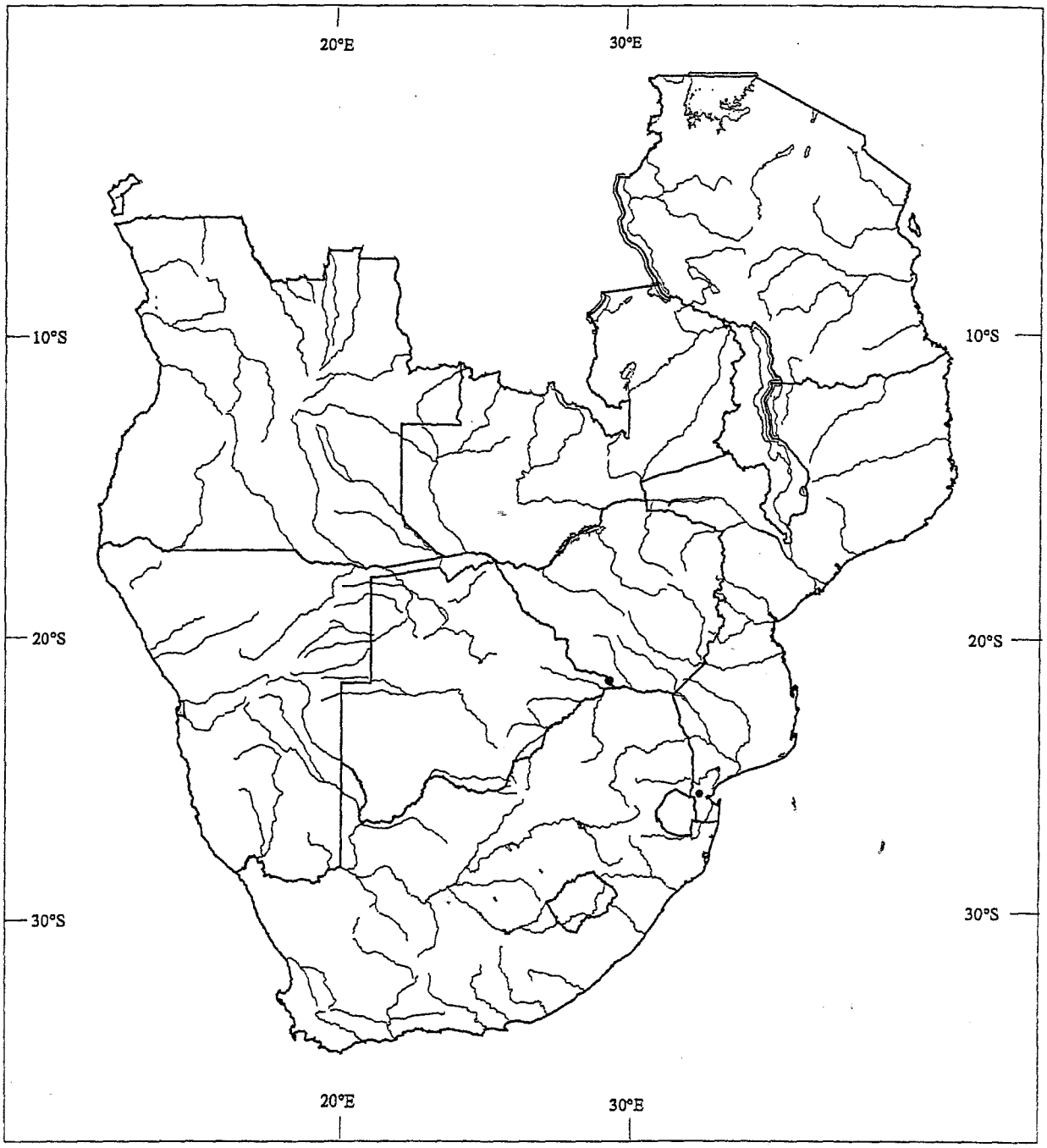


Figure F.702. Point distribution of *Tilapia swierstrae*. Scale approximately 1:25 000 000

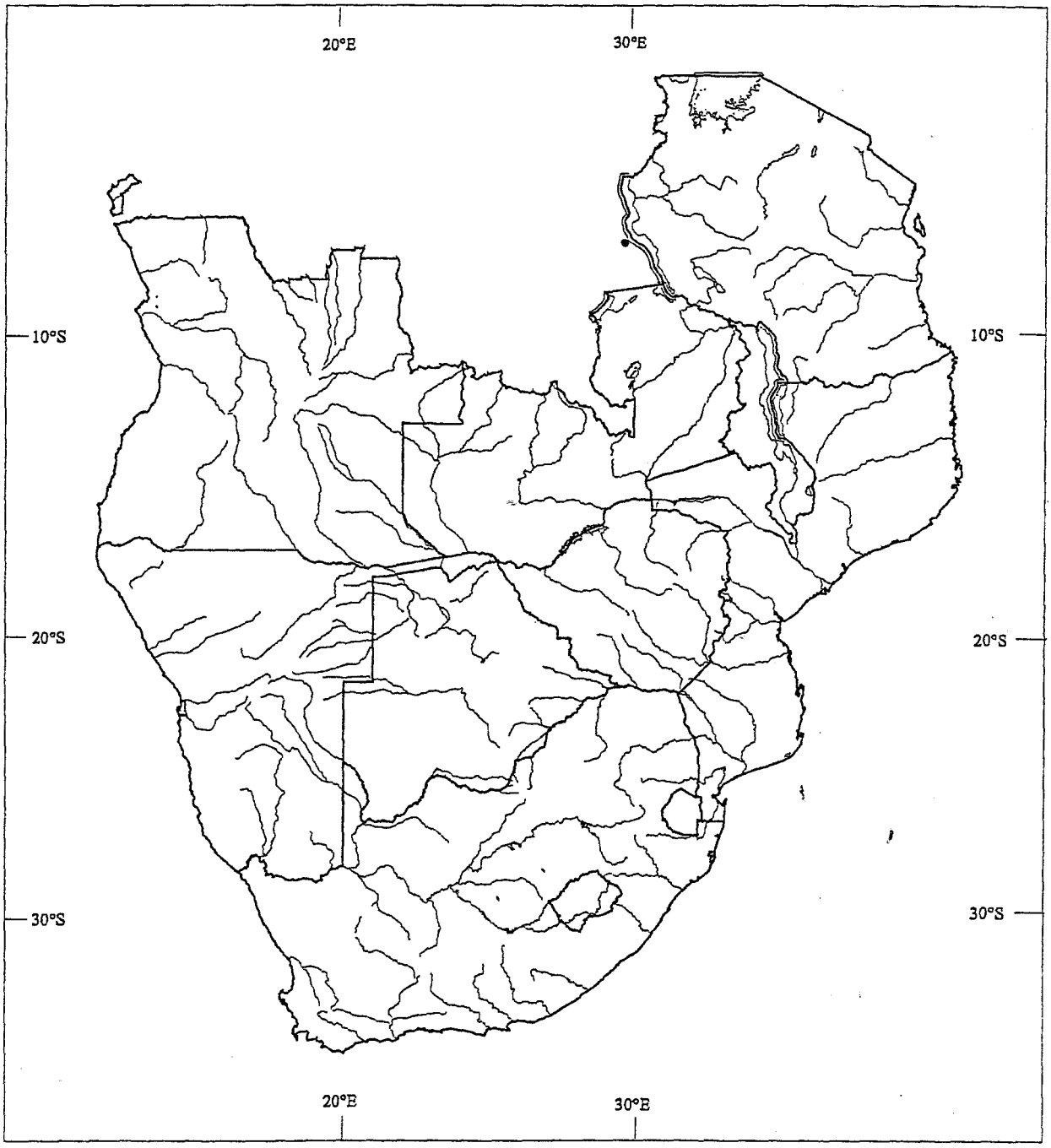


Figure F.703. Point distribution of *Tilapia tanganicae*. Scale approximately 1:25 000 000

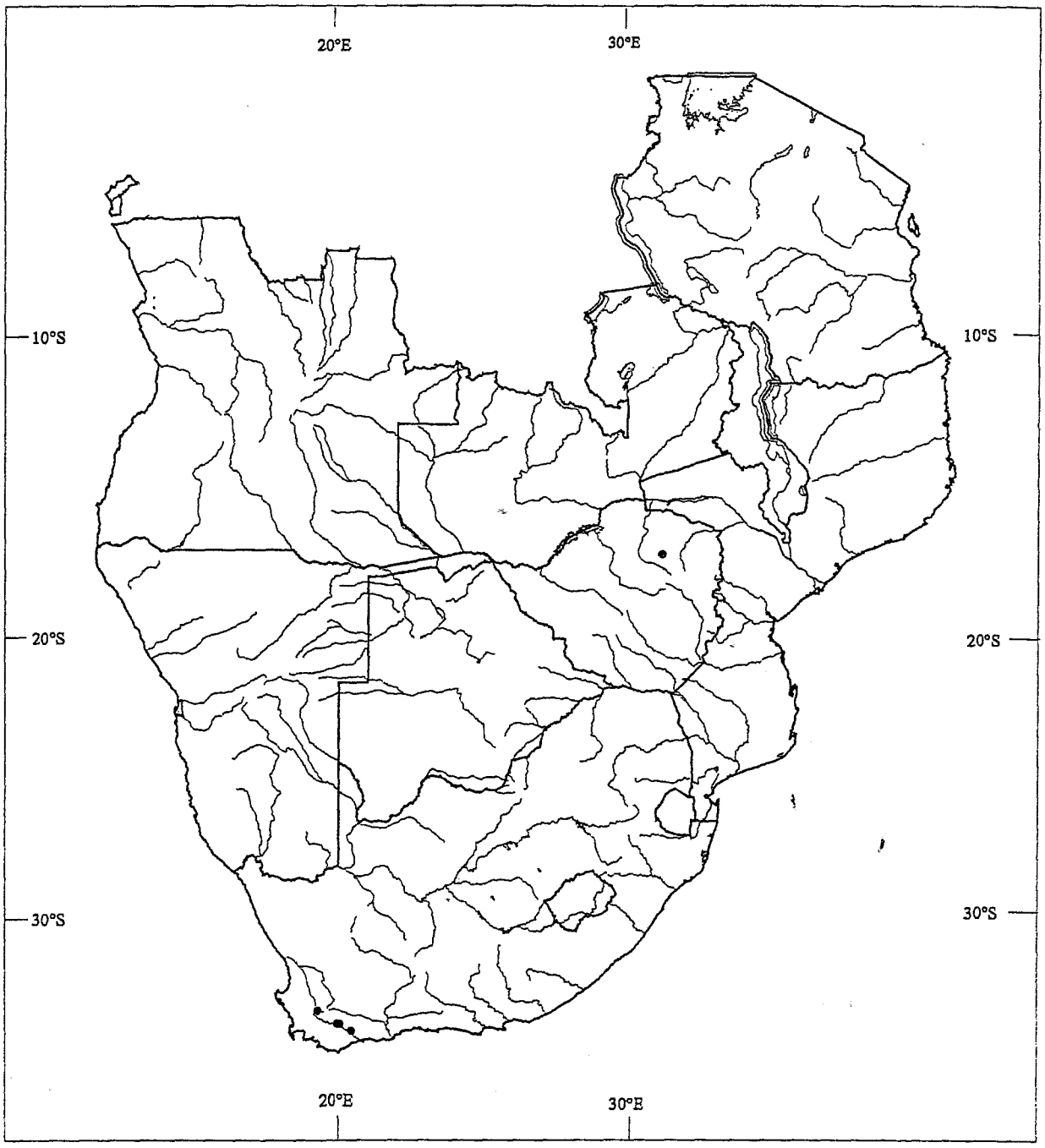


Figure F.704. Point distribution of *Tinca tinca*. Scale approximately 1:25 000 000

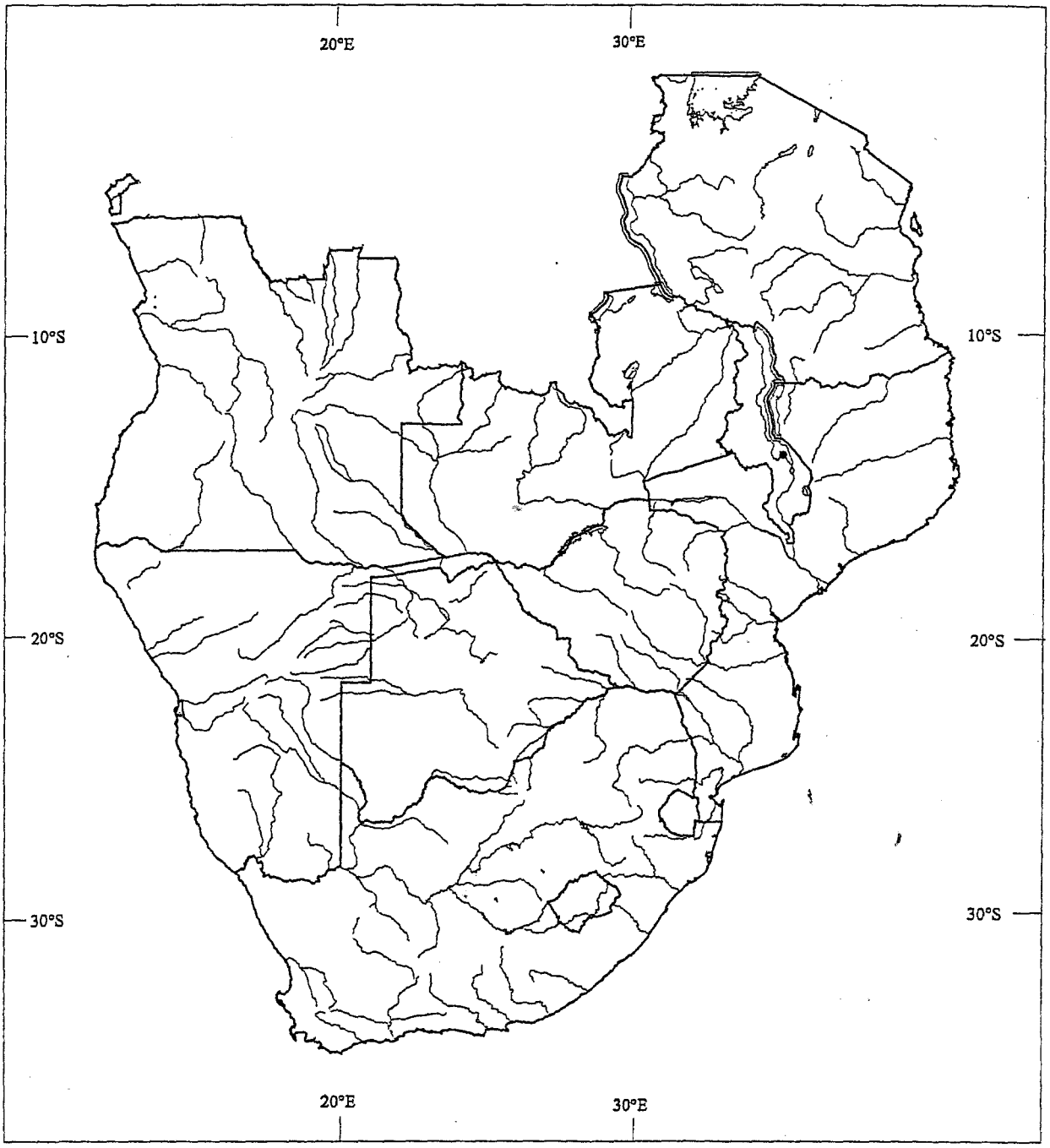


Figure F.705. Point distribution of *Tramitichromis liturus*. Scale approximately 1:25 000 000

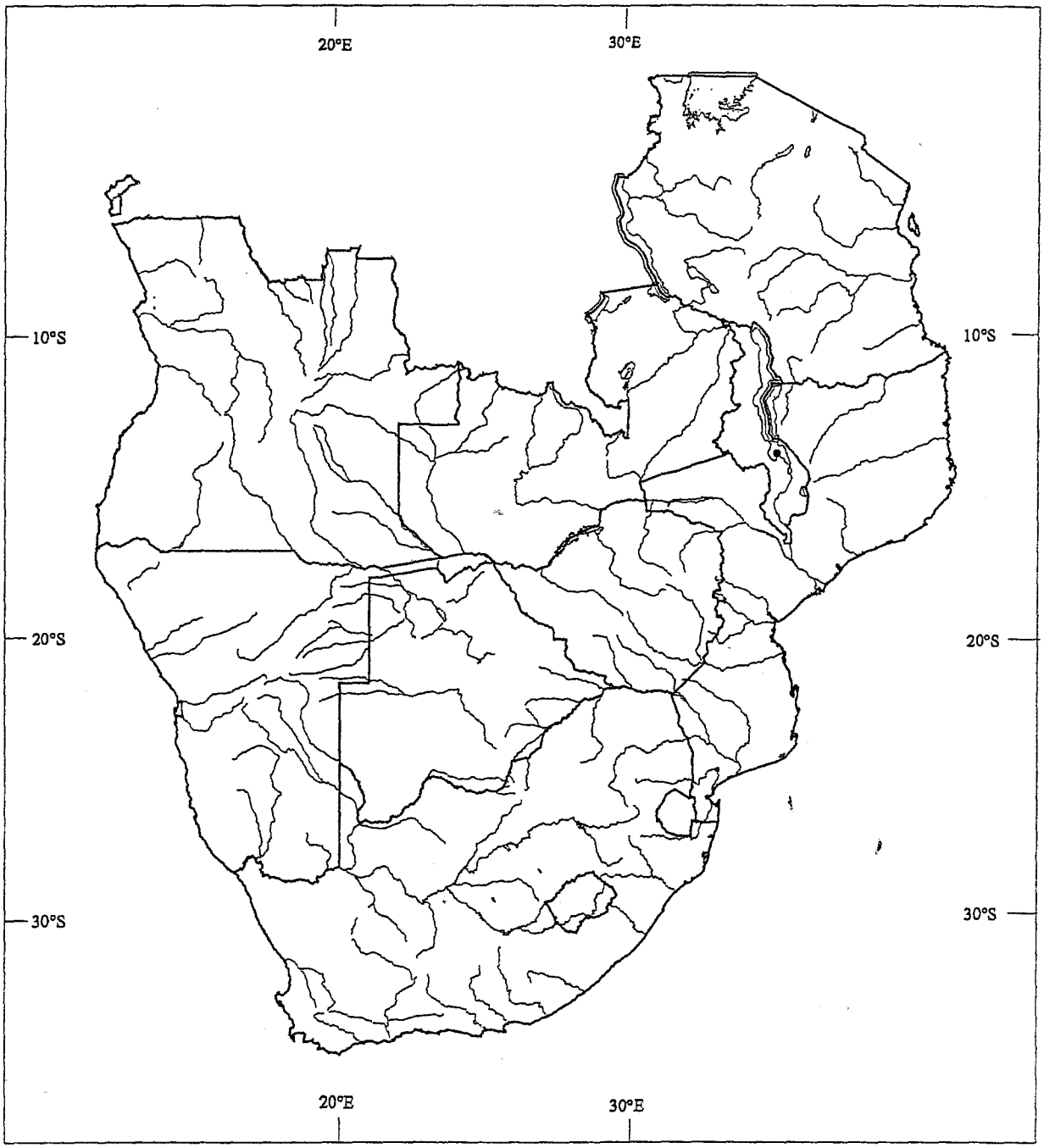


Figure F.706. Point distribution of *Tramitichromis variabilis*. Scale approximately 1:25 000 000

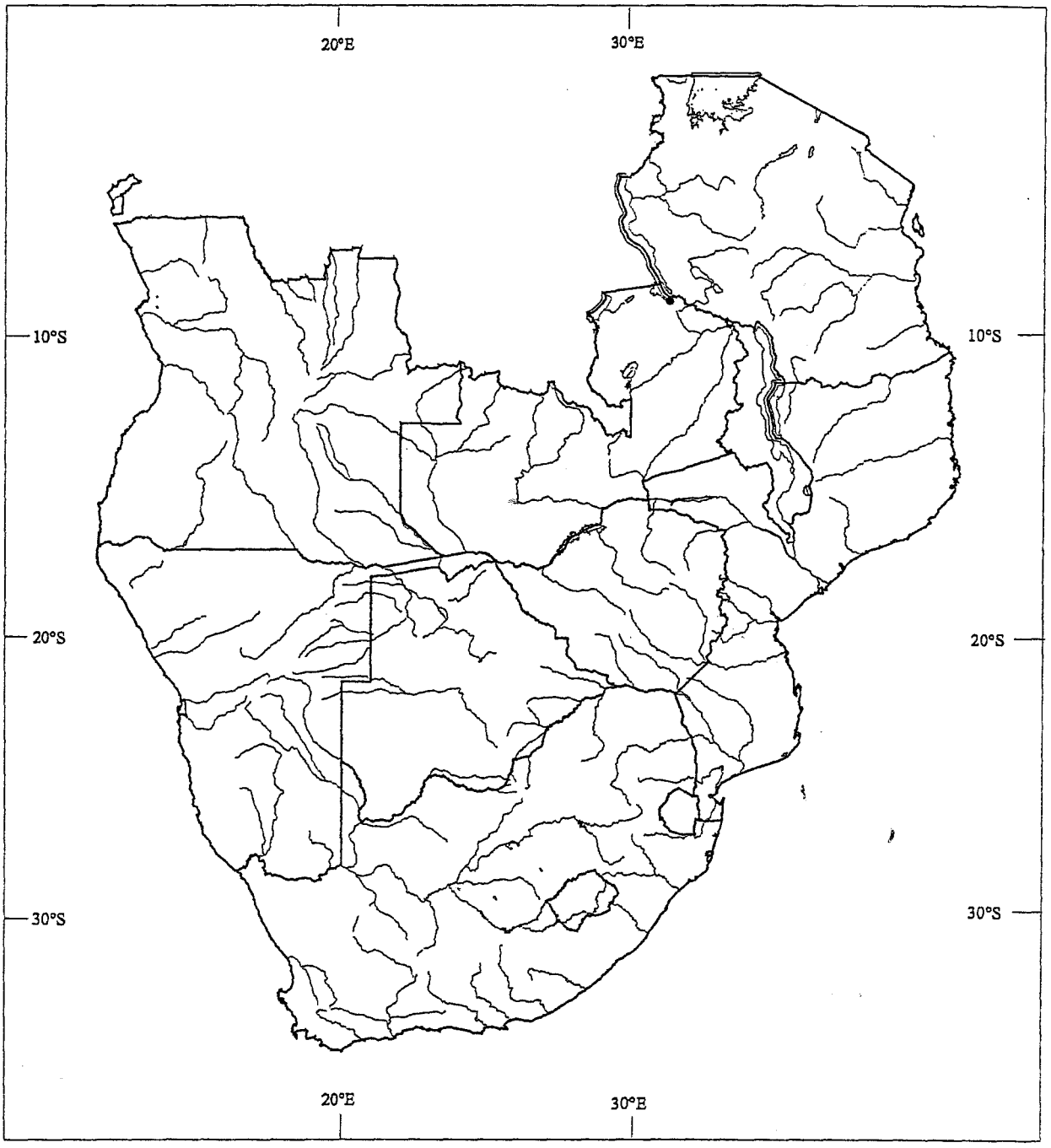


Figure F.707. Point distribution of *Trematocara macrostoma*. Scale approximately 1:25 000 000

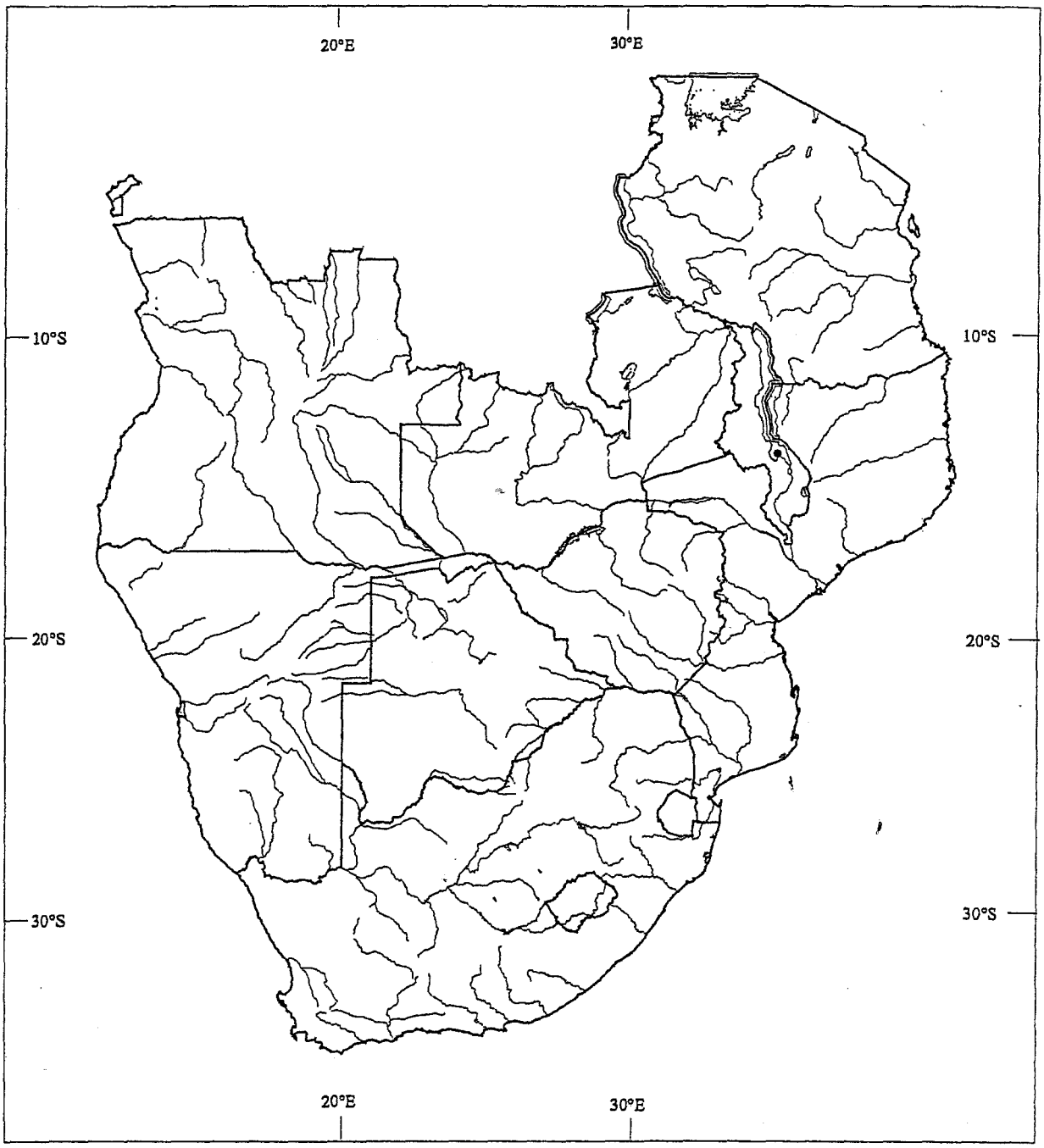


Figure F.708. Point distribution of *Trematocranus jacobfreibergi*. Scale approximately 1:25 000 000

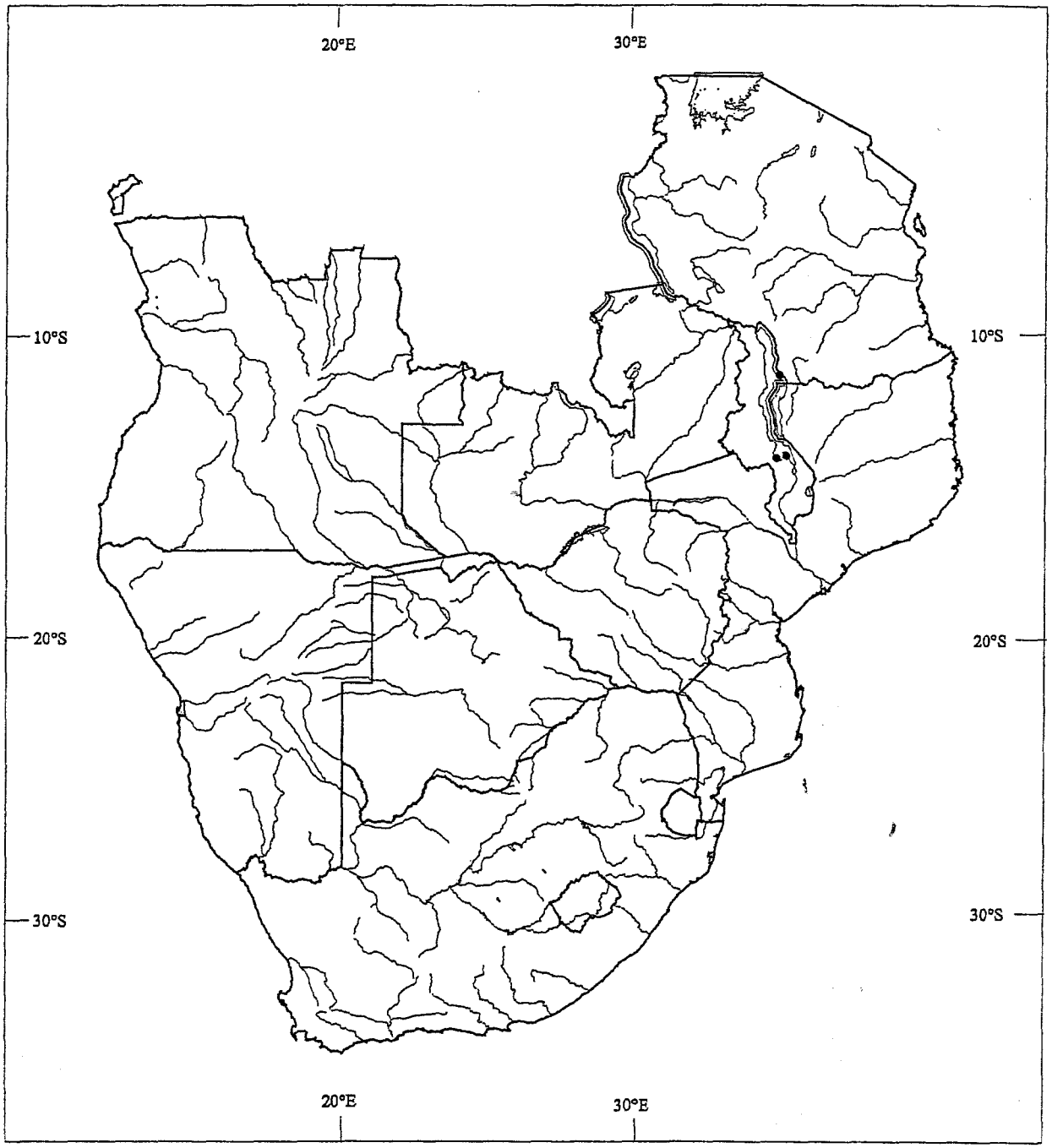


Figure F.709. Point distribution of *Trematocranus placodon*. Scale approximately 1:25 000 000

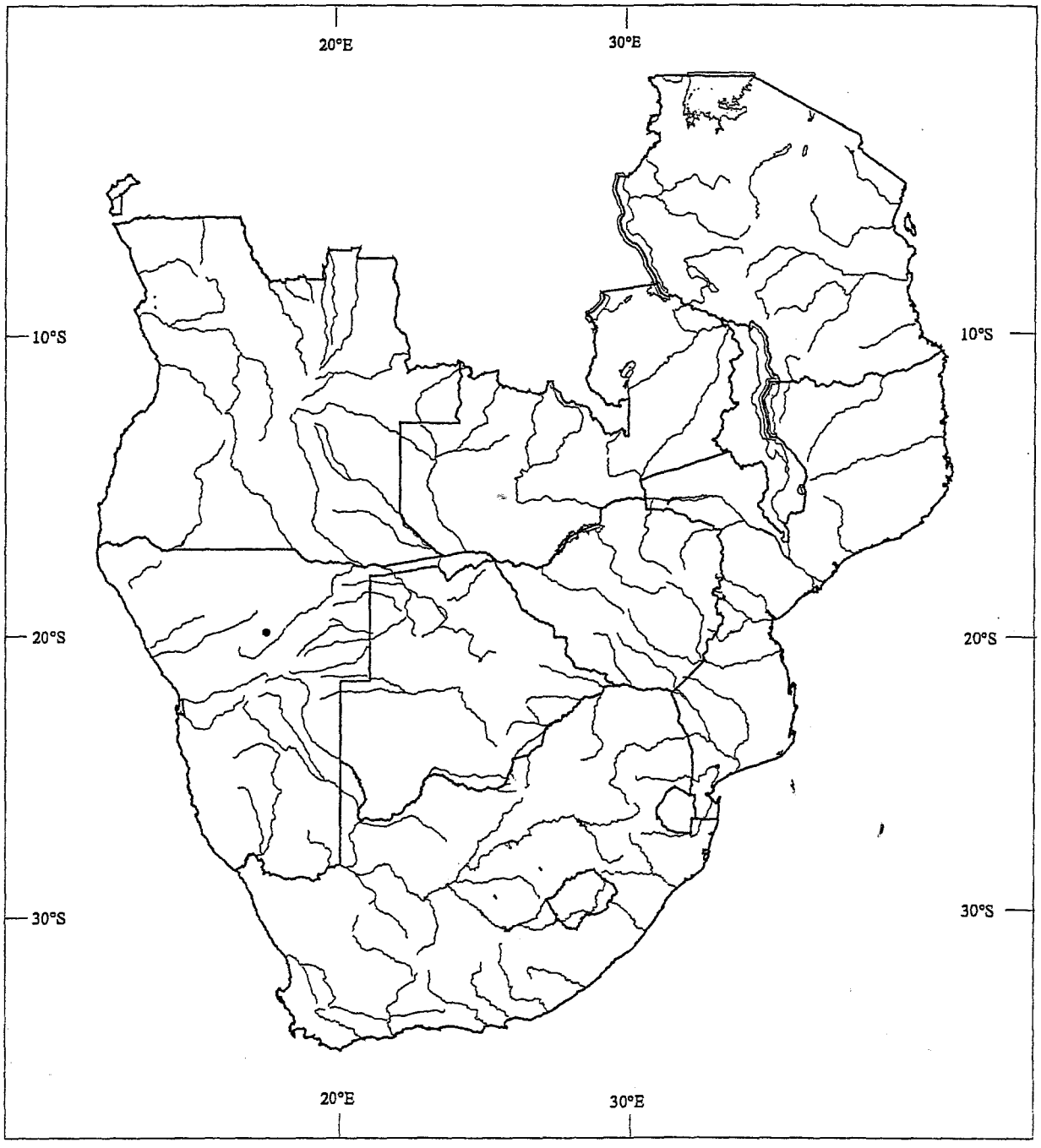


Figure F.710. Point distribution of *Trichogaster trichopterus*. Scale approximately 1:25 000 000

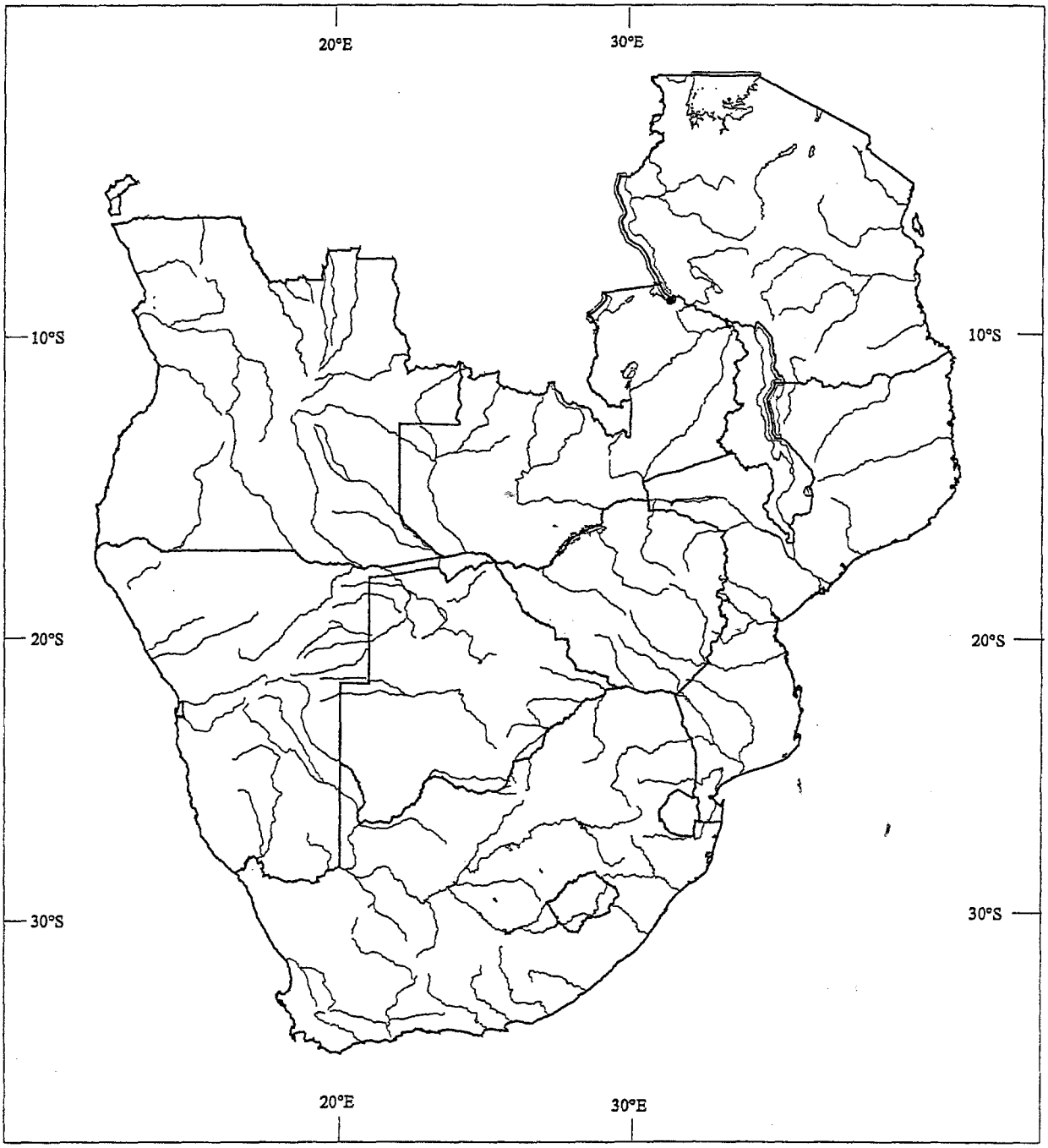


Figure F.711. Point distribution of *Triglachromis otostigma*. Scale approximately 1:25 000 000

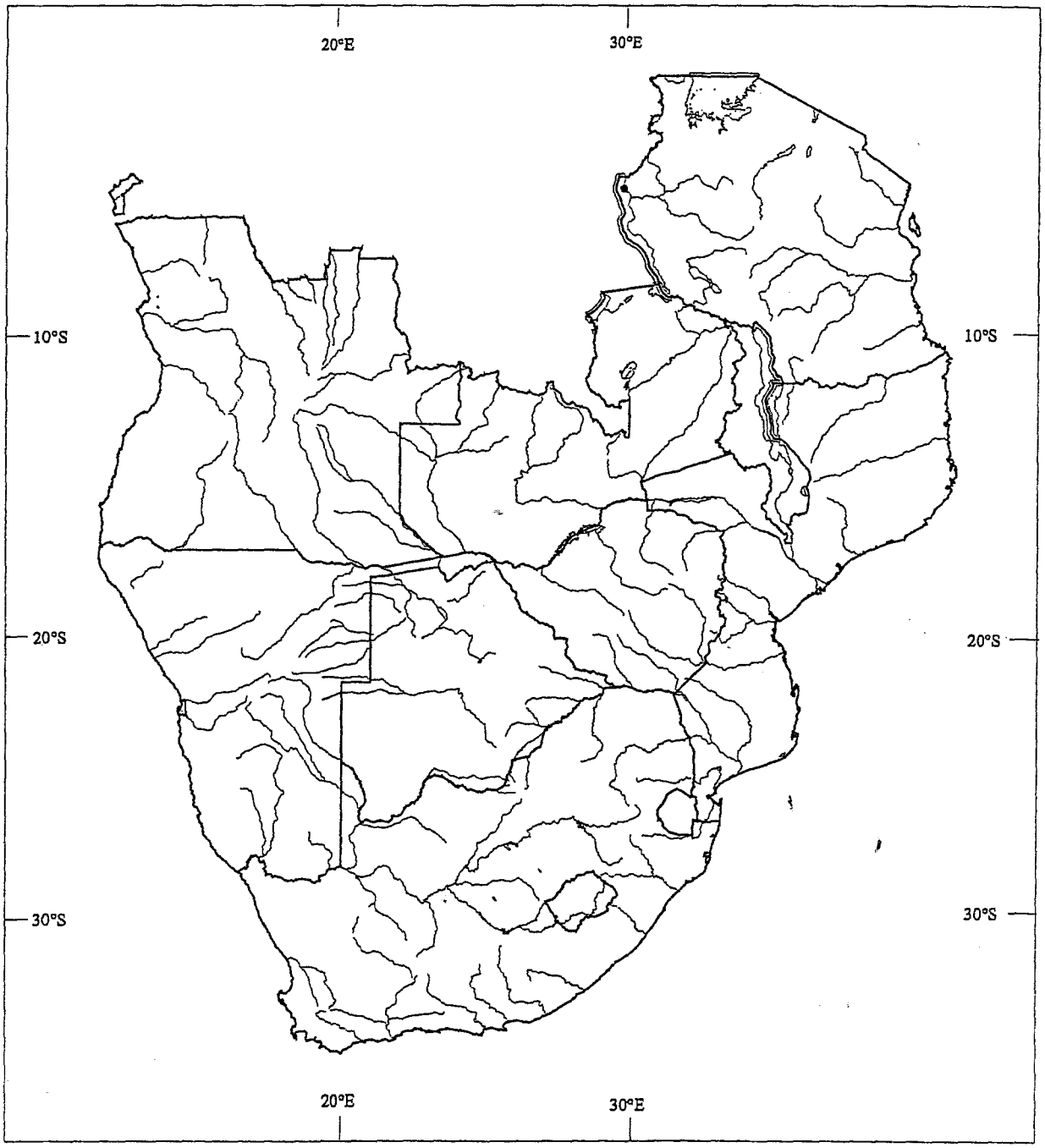


Figure F.712. Point distribution of *Tropheus moorei*. Scale approximately 1:25 000 000

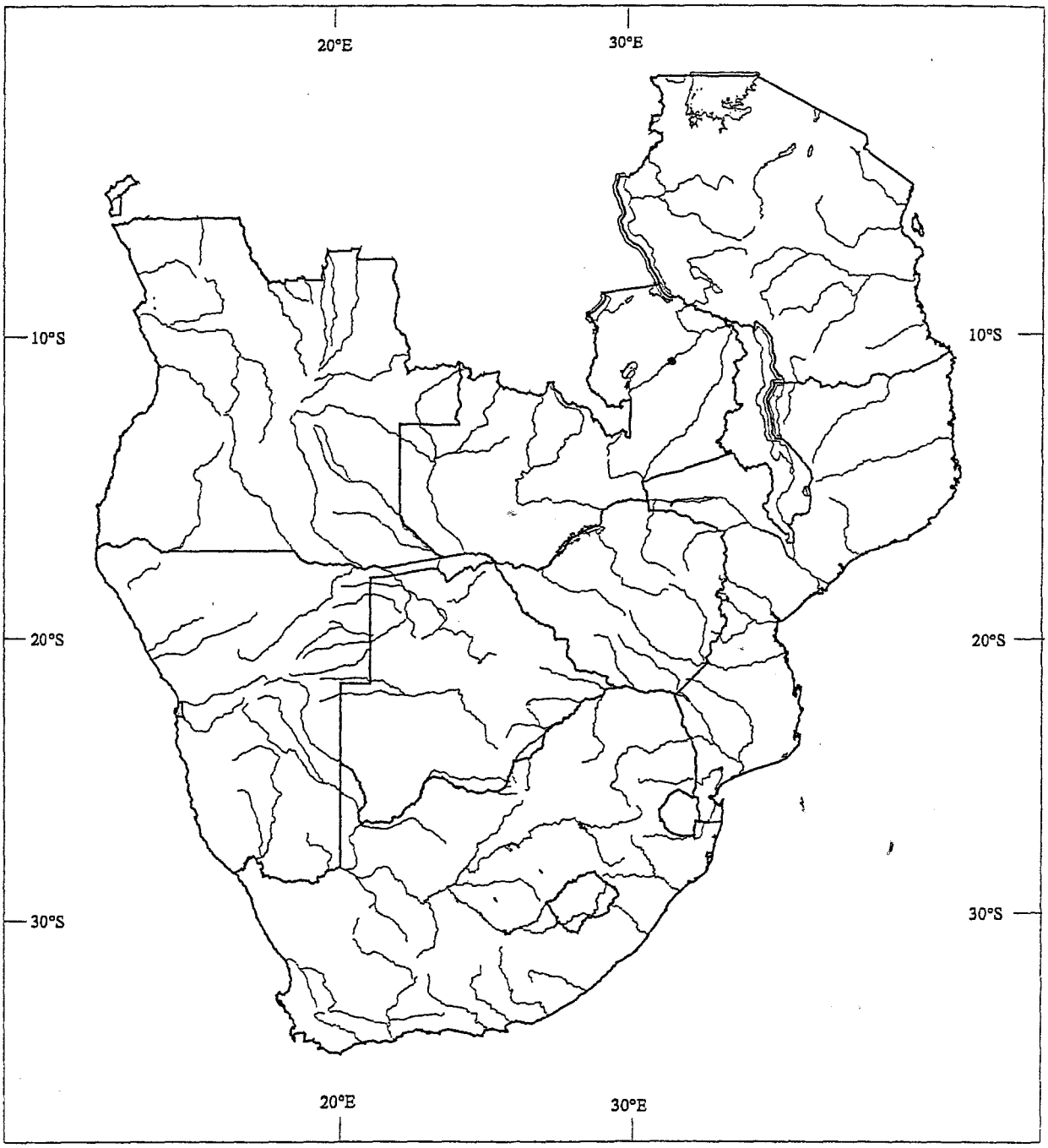


Figure F.713. Point distribution of *Tylochromis bangwelensis*. Scale approximately 1:25 000 000

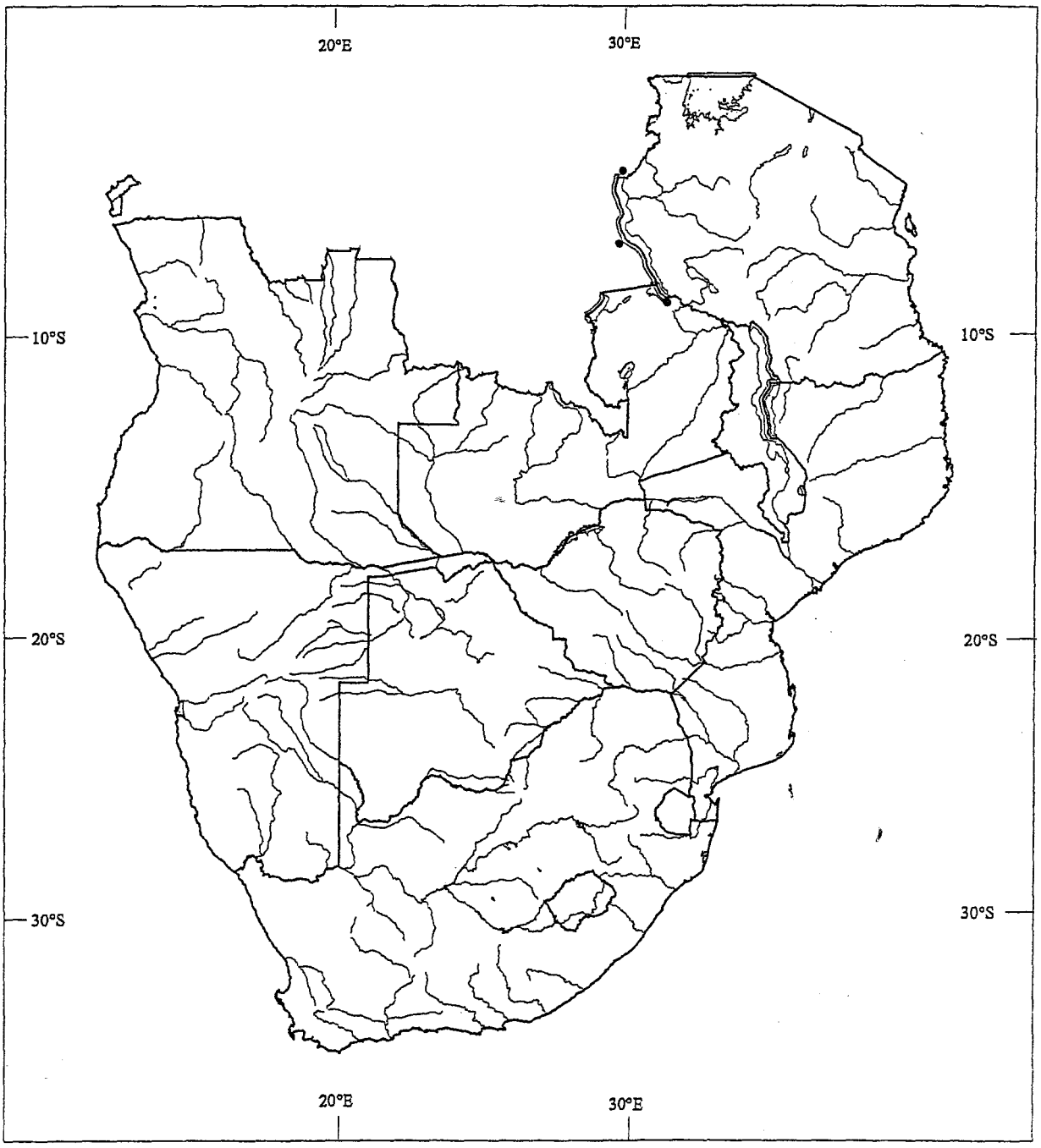


Figure F.714. Point distribution of *Tylochromis polylepis*. Scale approximately 1:25 000 000

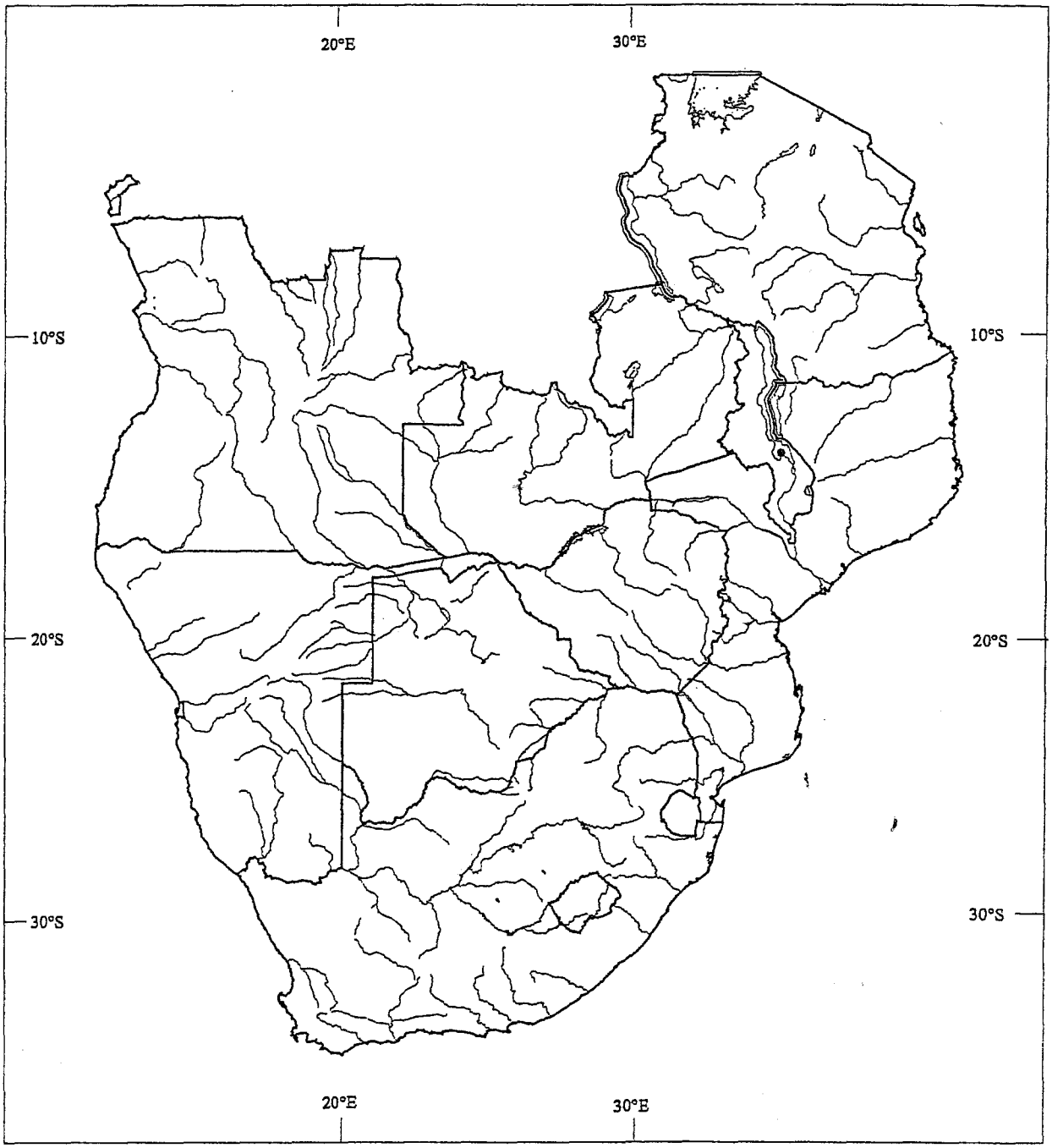


Figure F.715. Point distribution of *Tyrannochromis macrostoma*. Scale approximately 1:25 000 000

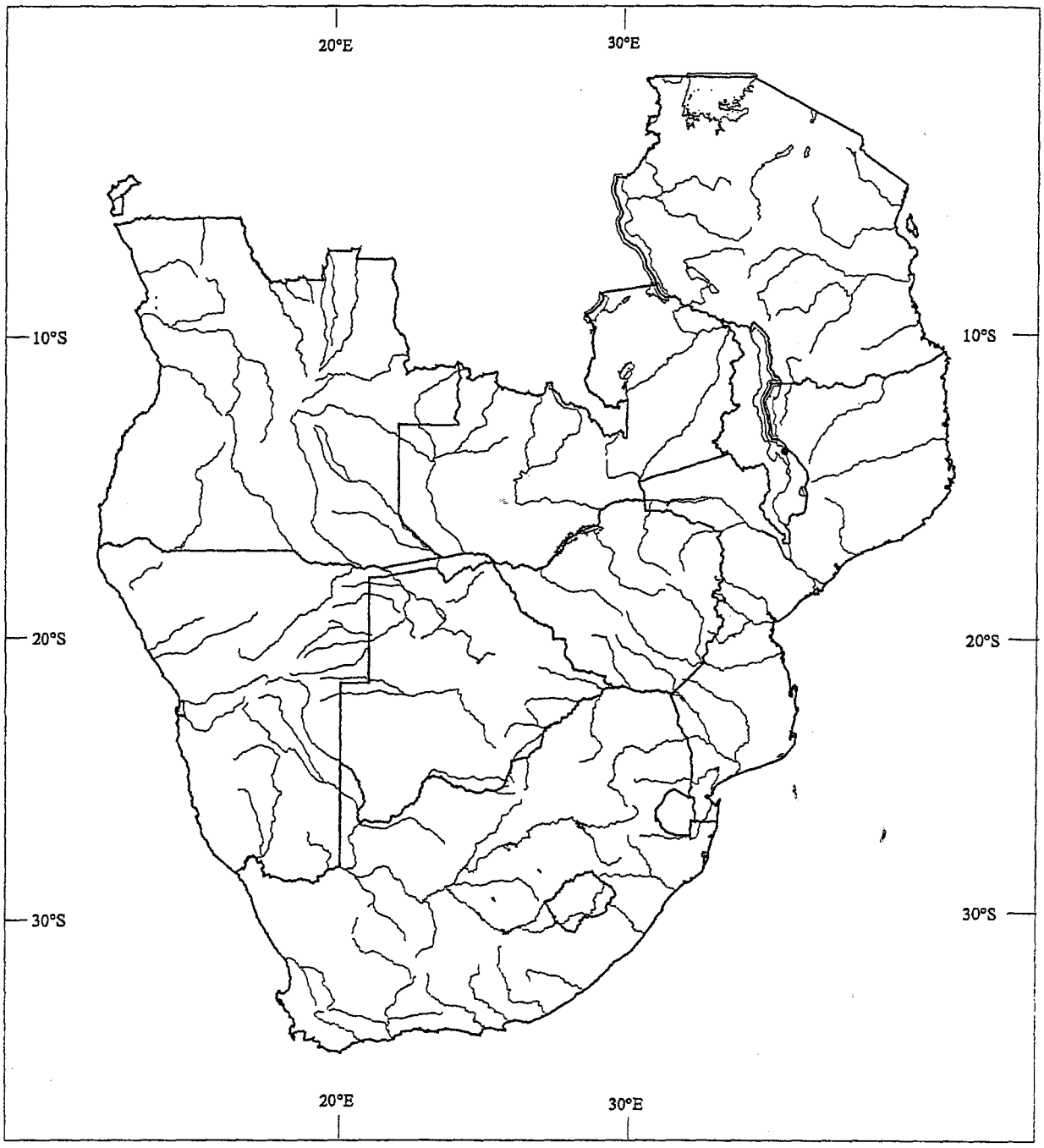


Figure F.716. Point distribution of *Tyrannochromis nigriventer*. Scale approximately 1:25 000 000

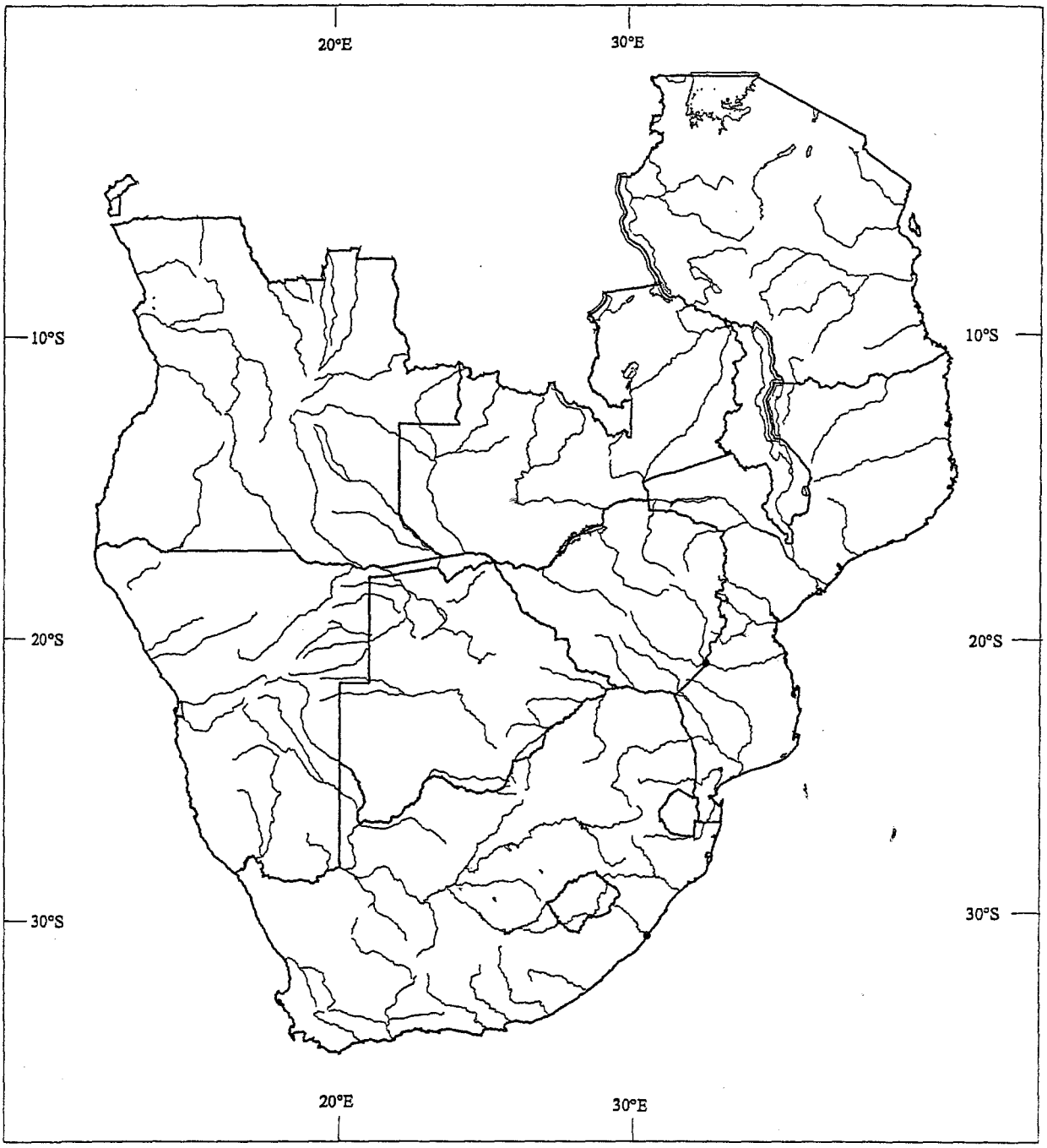


Figure F.717. Point distribution of *Valamugil cunnesius*. Scale approximately 1:25 000 000

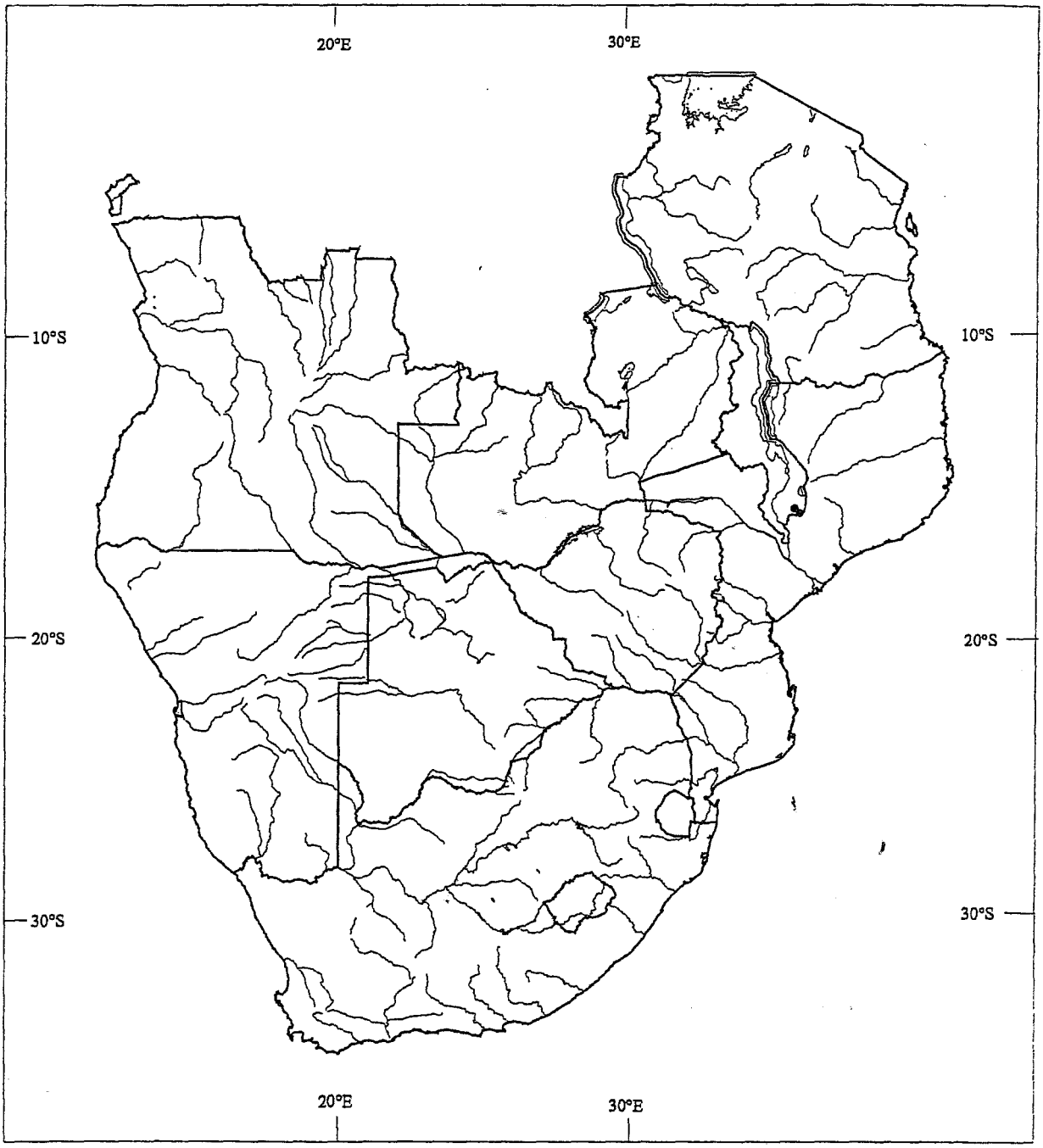


Figure F.718. Point distribution of *Varicorhinus dimidiatus*. Scale approximately 1:25 000 000

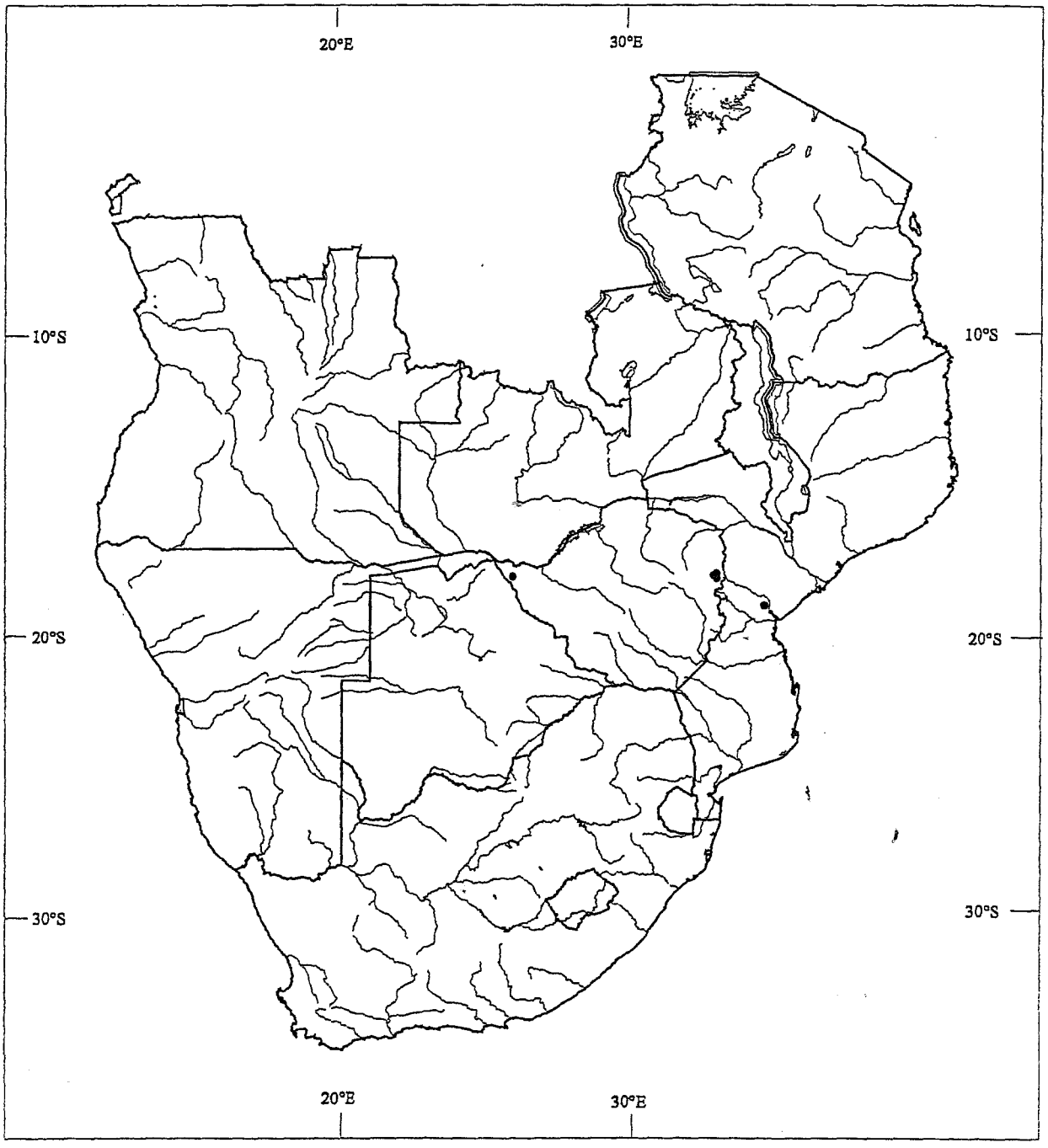


Figure F.719. Point distribution of *Varicorhinus nasutus*. Scale approximately 1:25 000 000

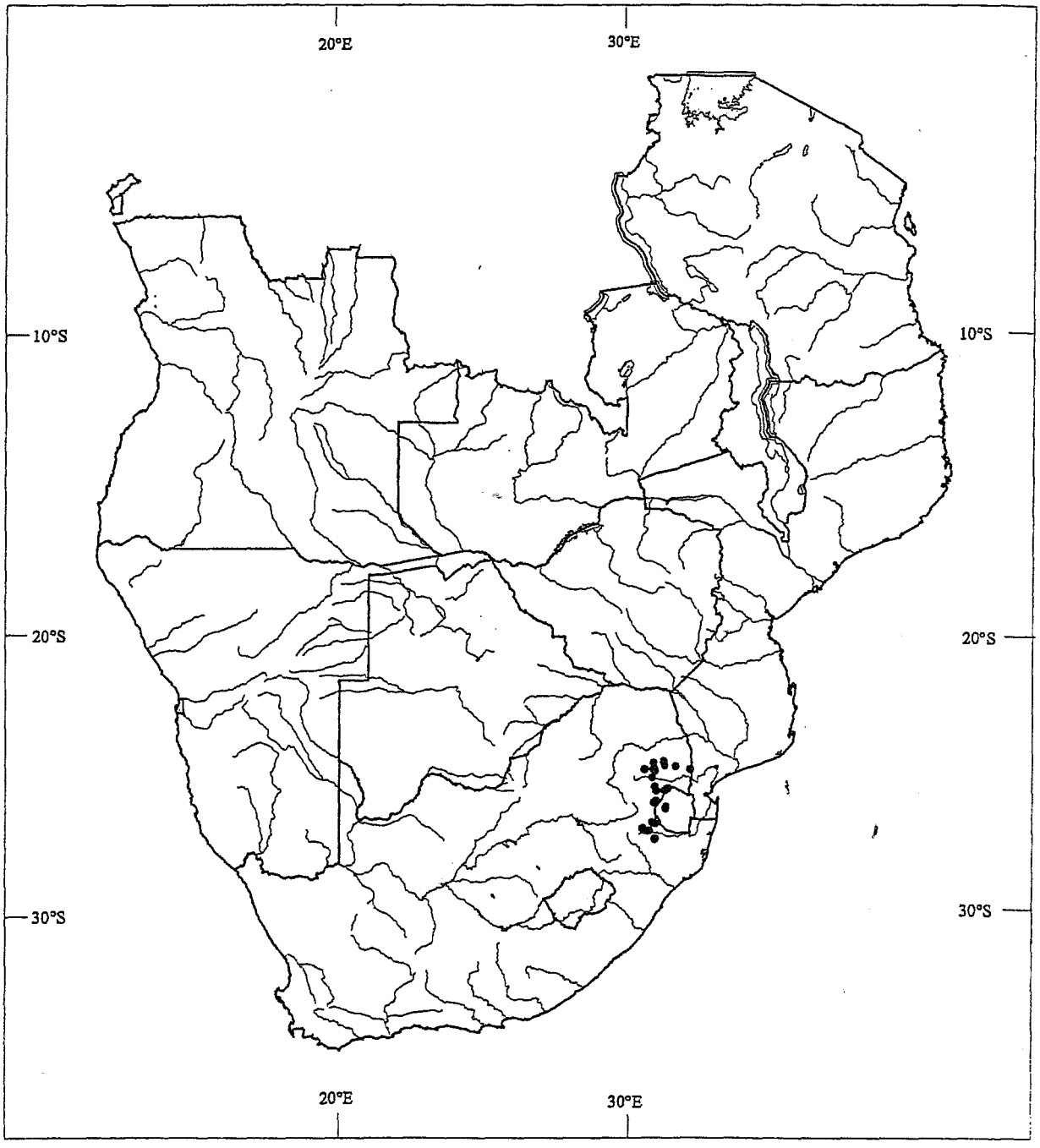


Figure F.720. Point distribution of *Varicorhinus nelspruitensis*. Scale approximately 1:25 000 000

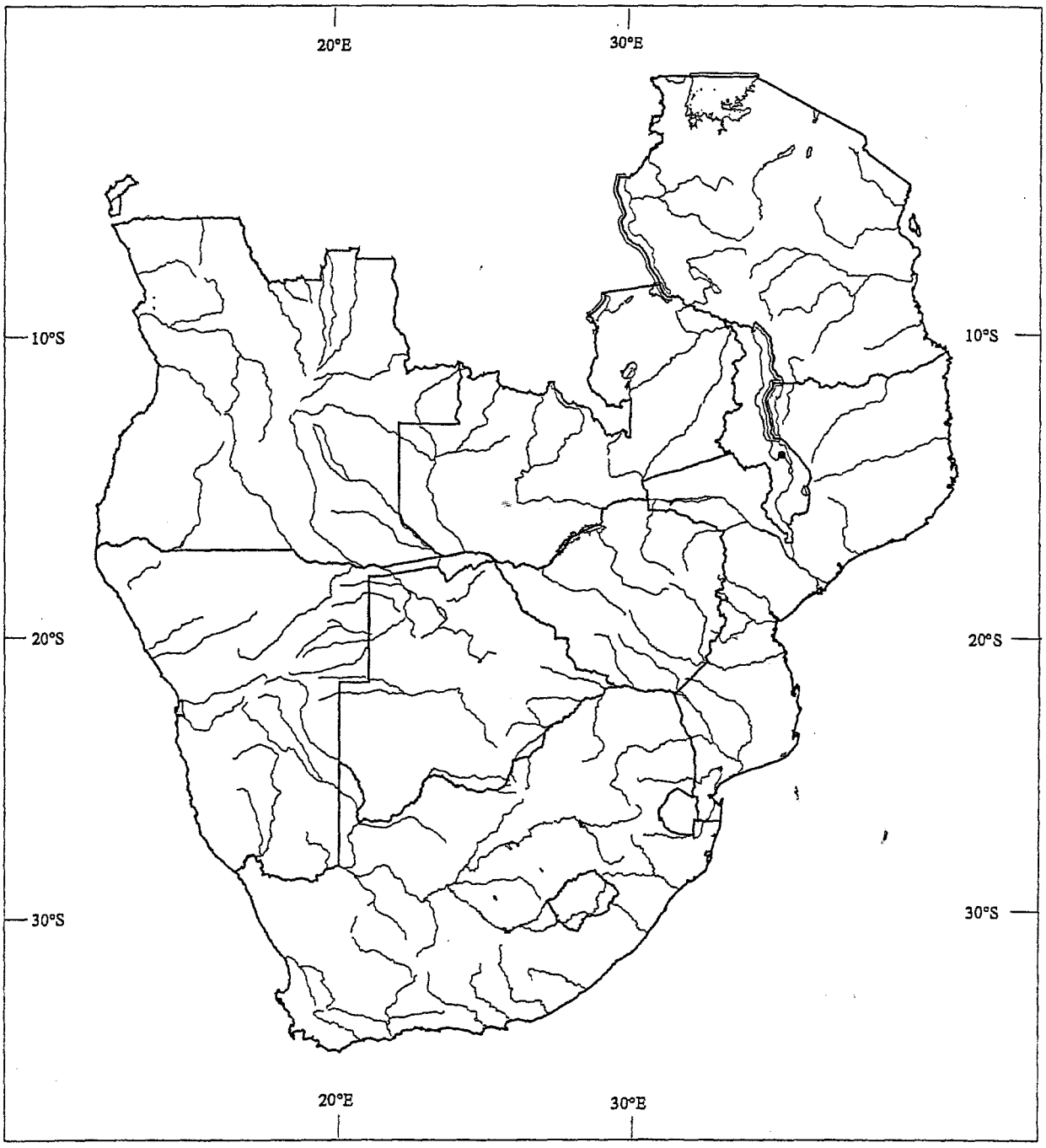


Figure F.721. Point distribution of *Varicorhinus nyasensis*. Scale approximately 1:25 000 000

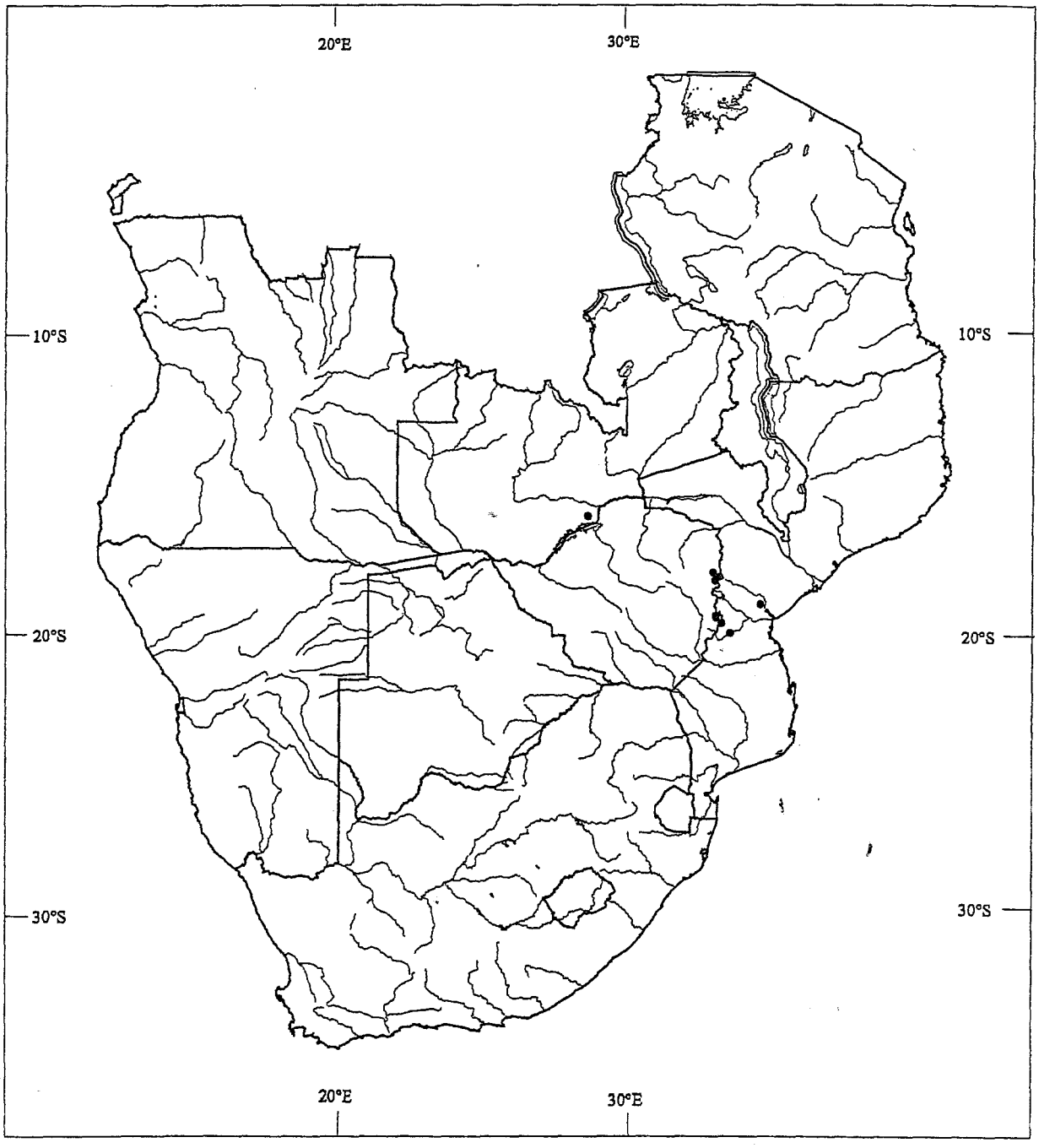


Figure F.722. Point distribution of *Varicorhinus pungweensis*. Scale approximately 1:25 000 000

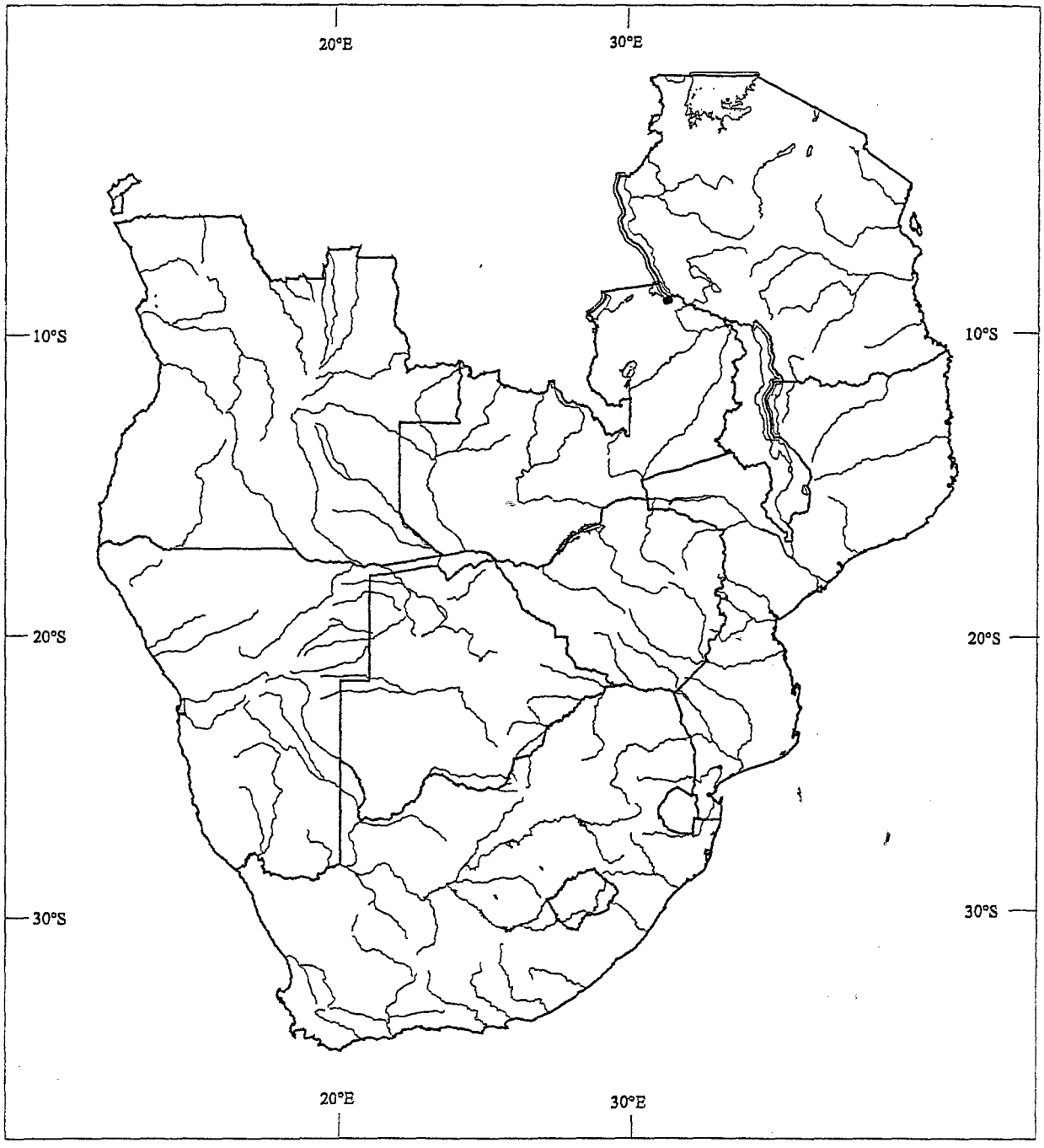


Figure F.723. Point distribution of *Varicorhinus tanganicae*. Scale approximately 1:25 000 000

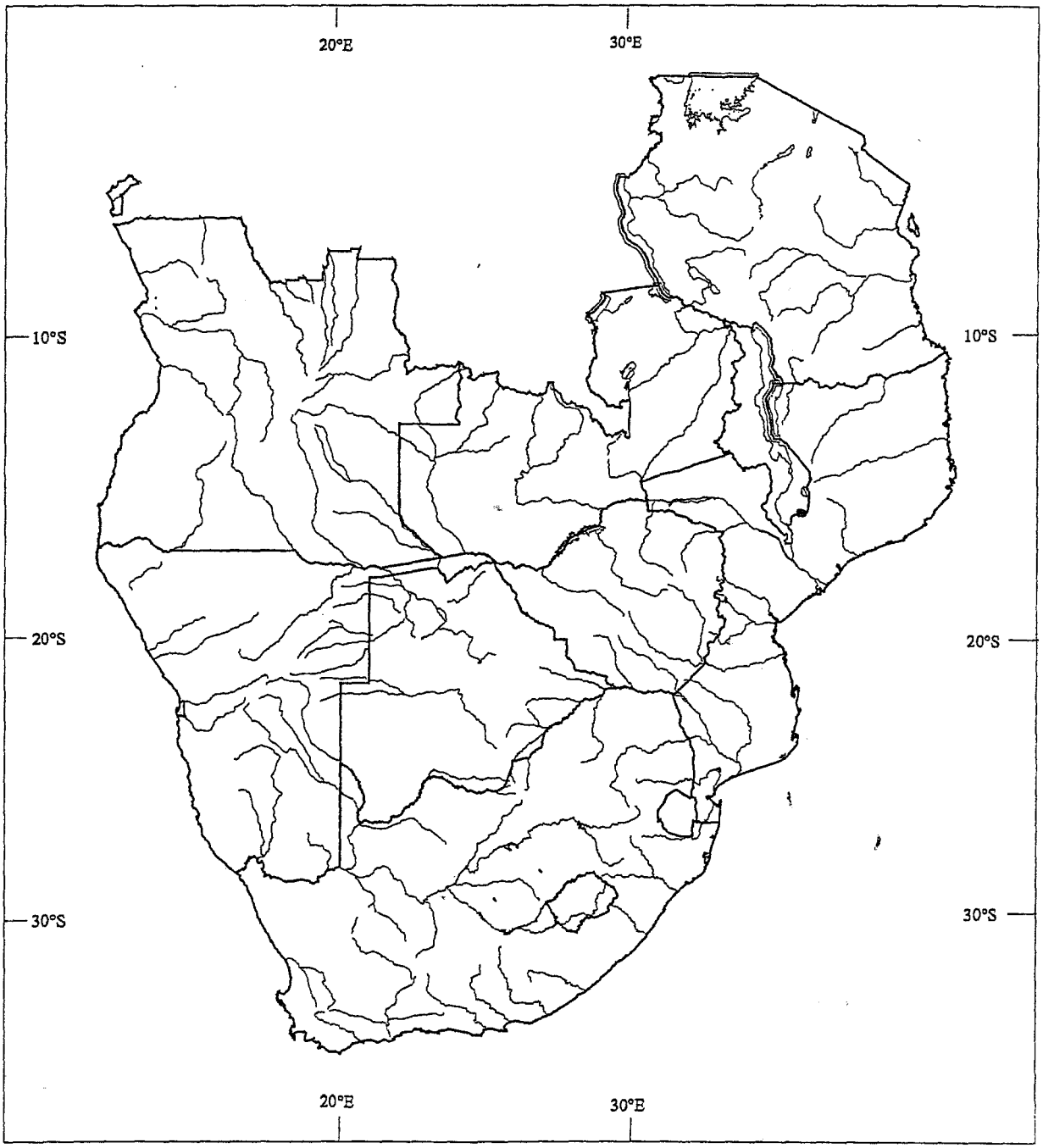


Figure F.724. Point distribution of *Varicorhinus tyrocheilus*. Scale approximately 1:25 000 000

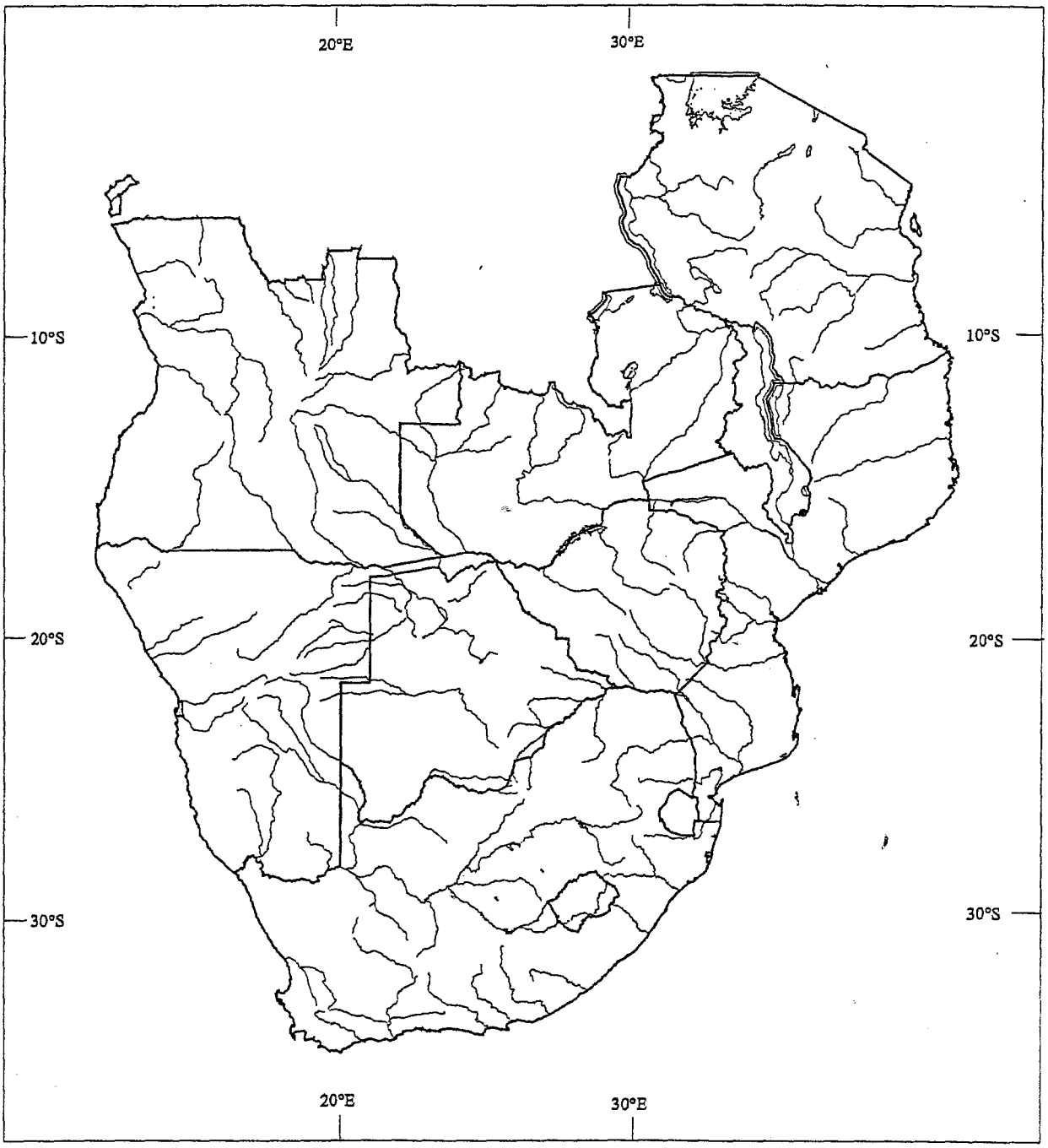


Figure F.725. Point distribution of *Varicorhinus xyrocheilus*. Scale approximately 1:25 000 000

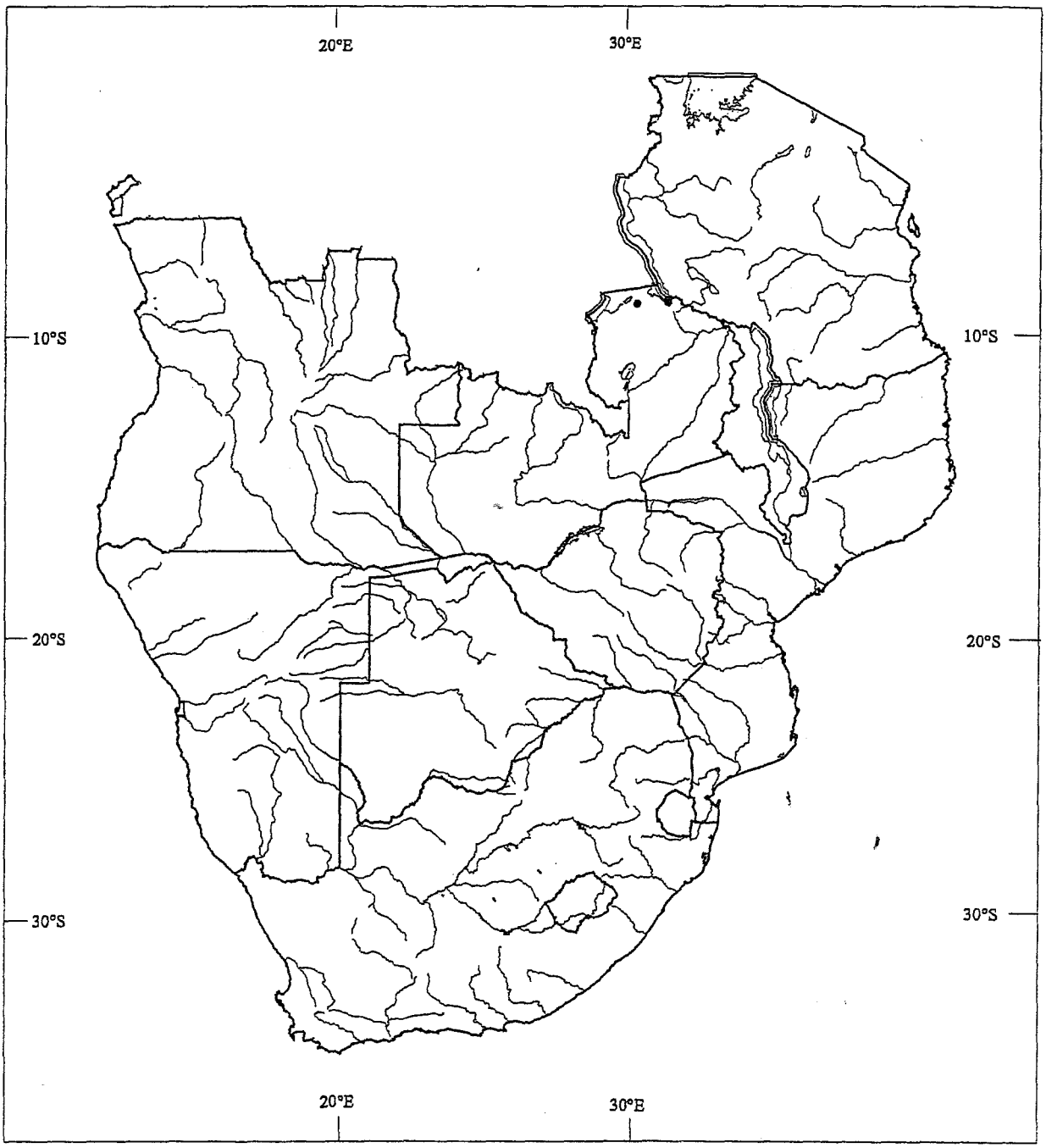


Figure F.726. Point distribution of *Xenotilapia bathyphila*. Scale approximately 1:25 000 000

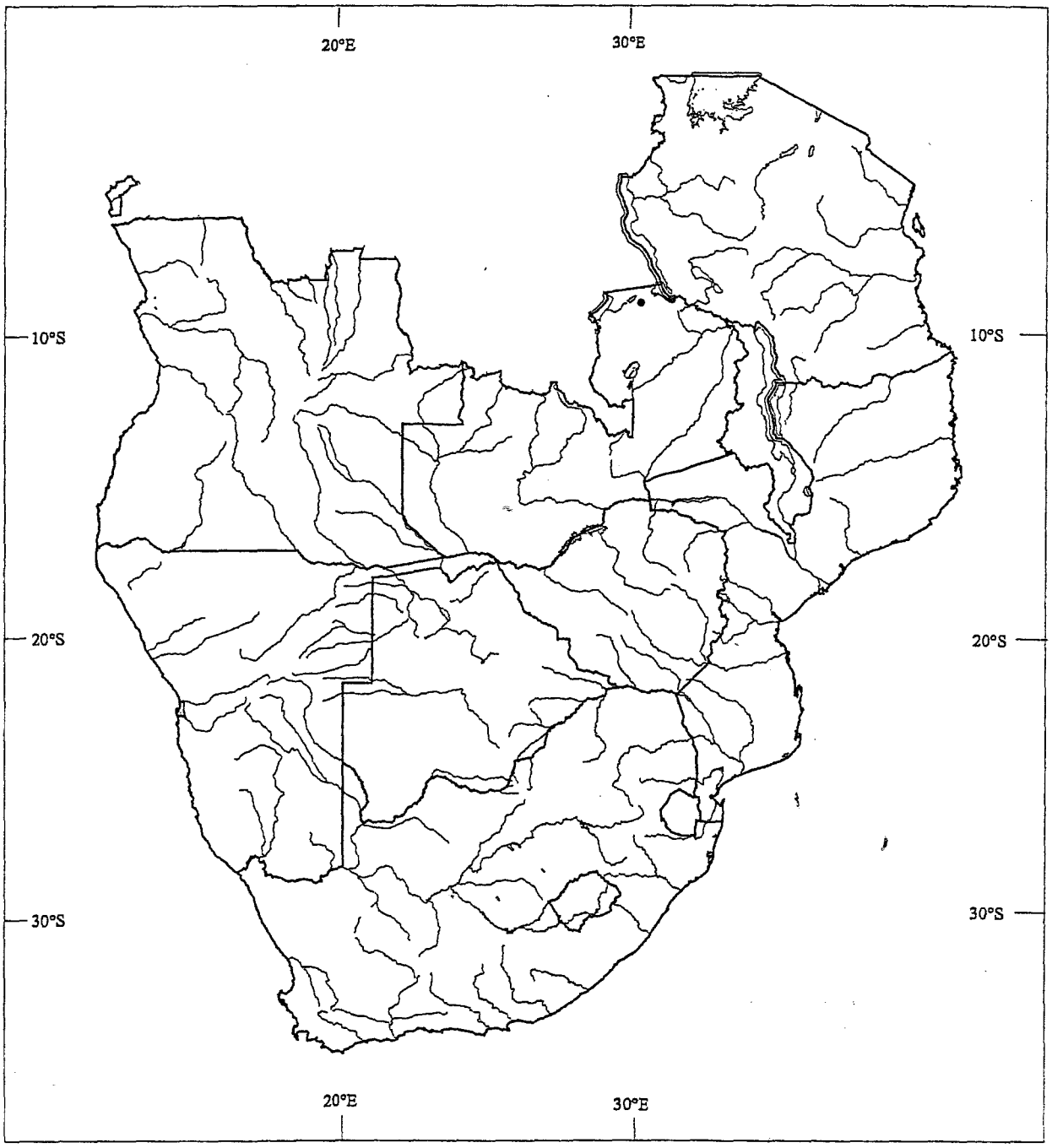


Figure F.727. Point distribution of *Xenotilapia caudofasciata*. Scale approximately 1:25 000 000

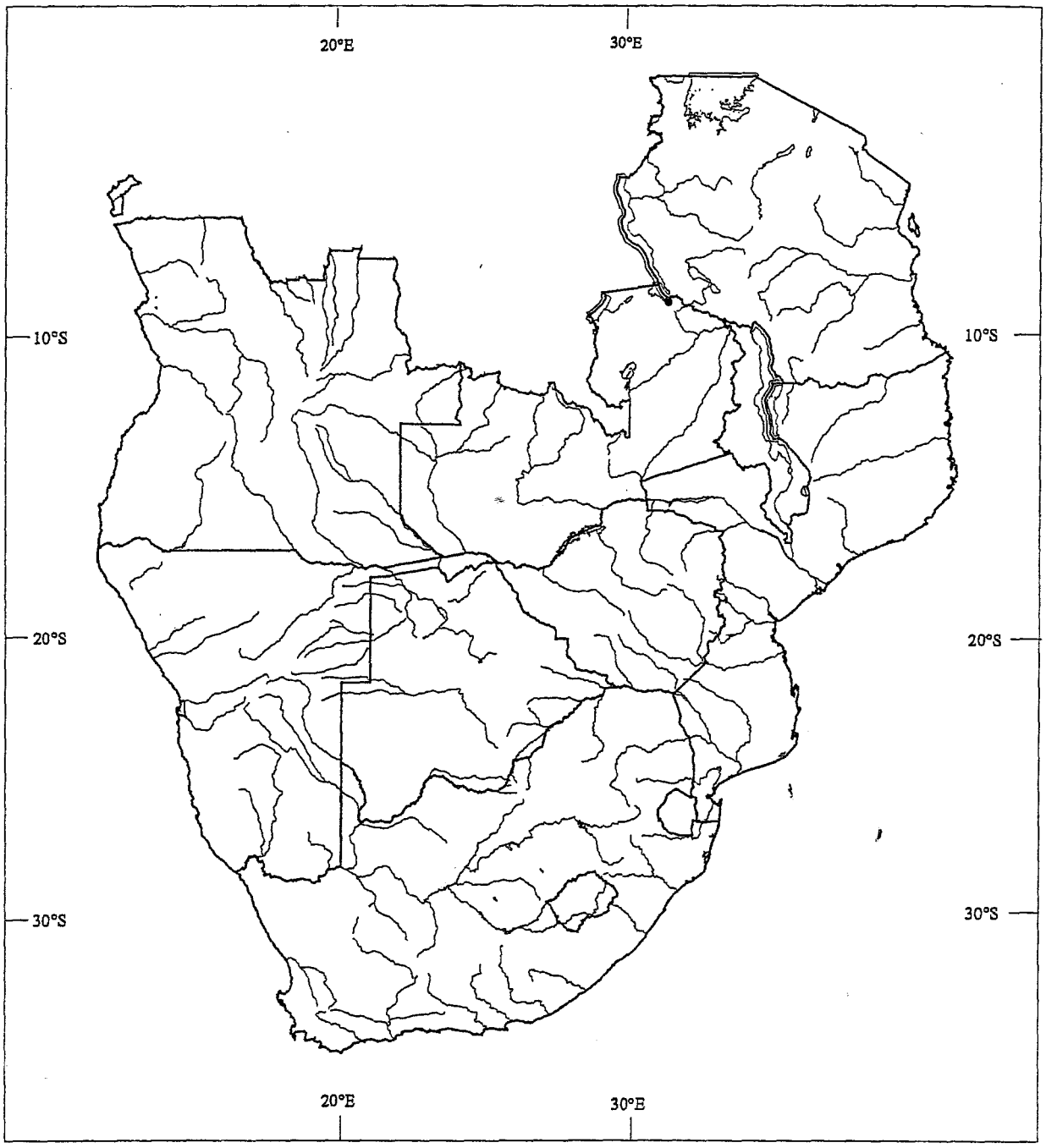


Figure F.728. Point distribution of *Xenotilapia flavipinnis*. Scale approximately 1:25 000 000

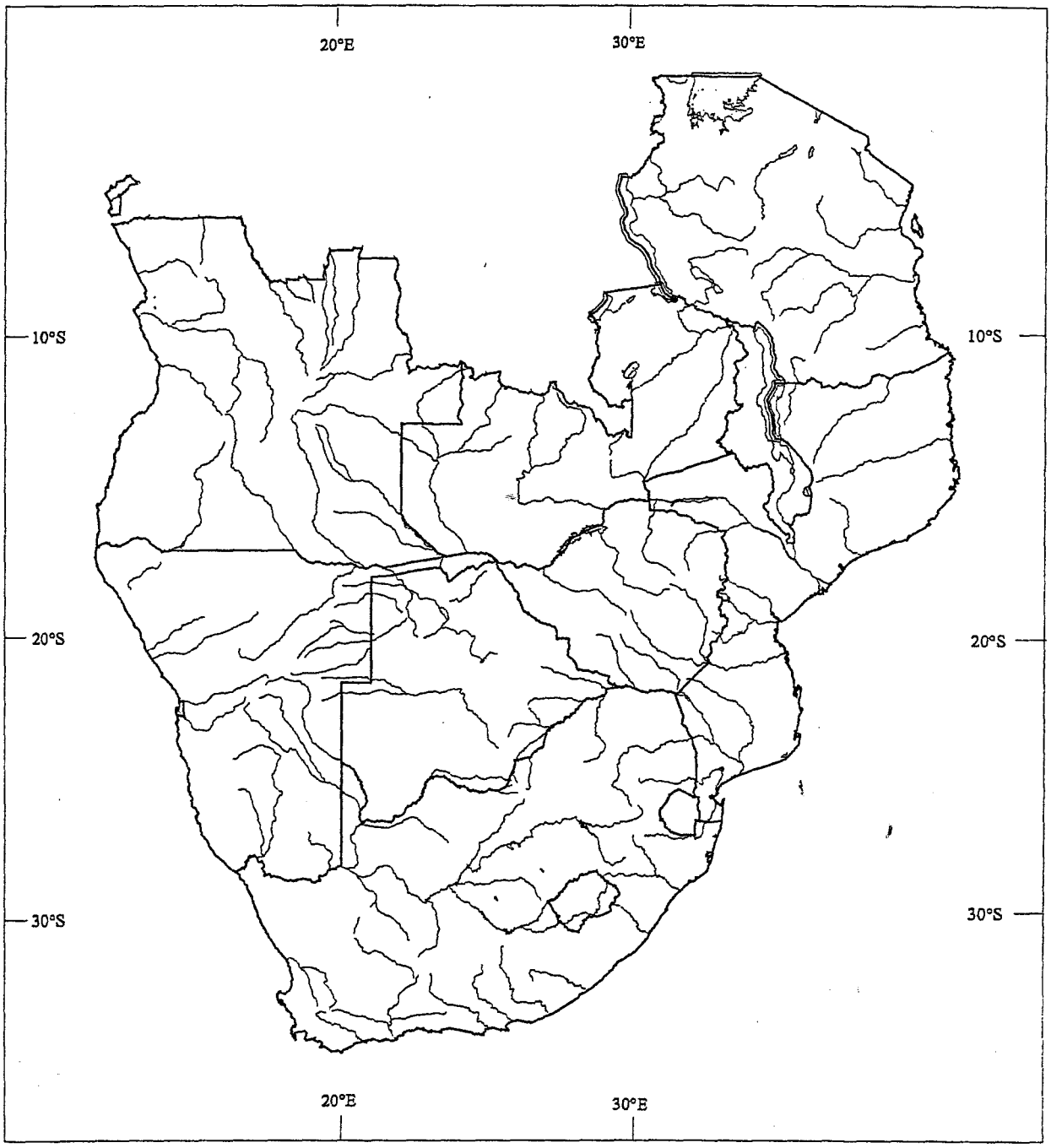


Figure F.729. Point distribution of *Xenotilapia ochragenys*. Scale approximately 1:25 000 000

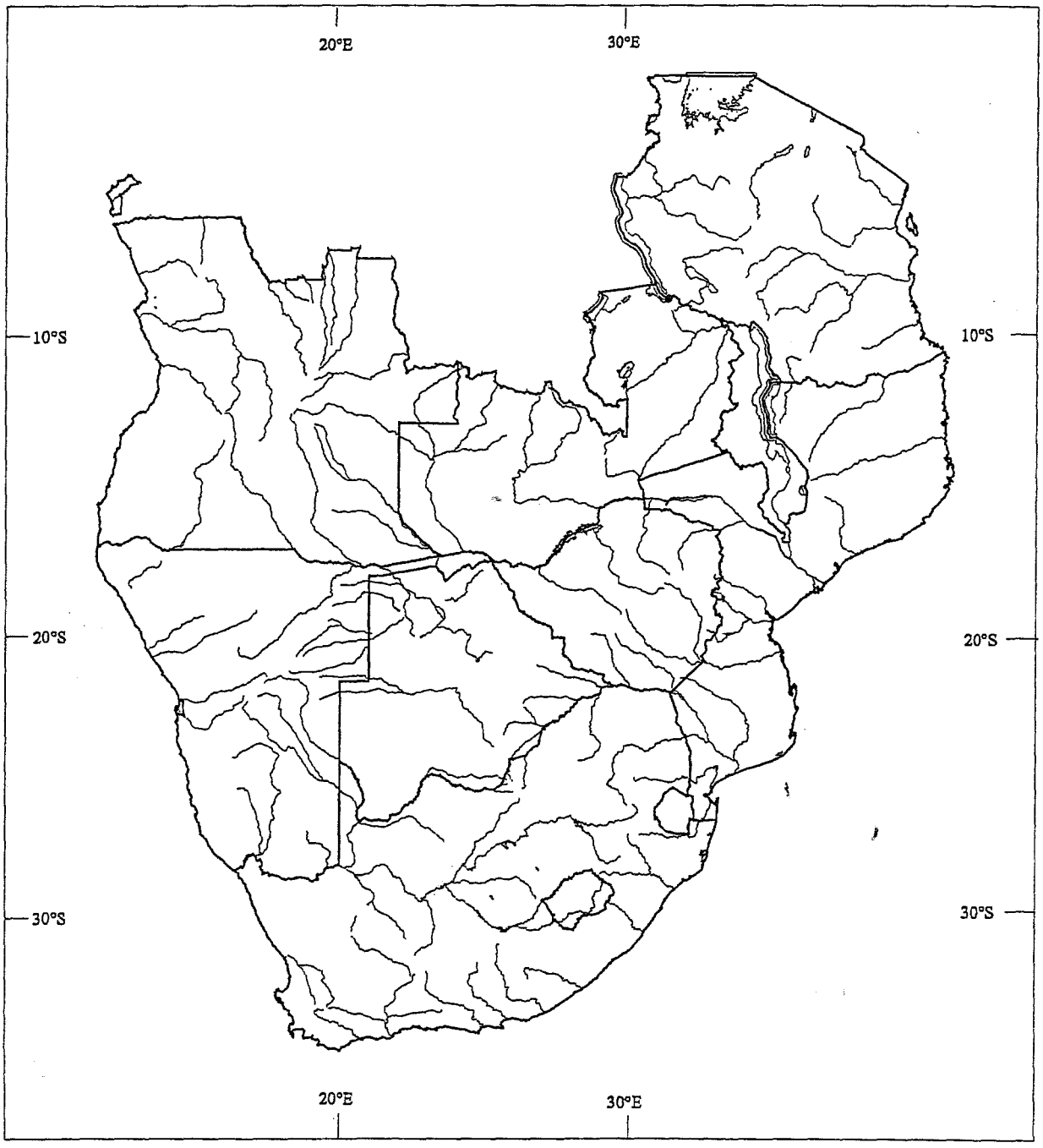


Figure F.730. Point distribution of *Xenotilapia papillio*. Scale approximately 1:25 000 000

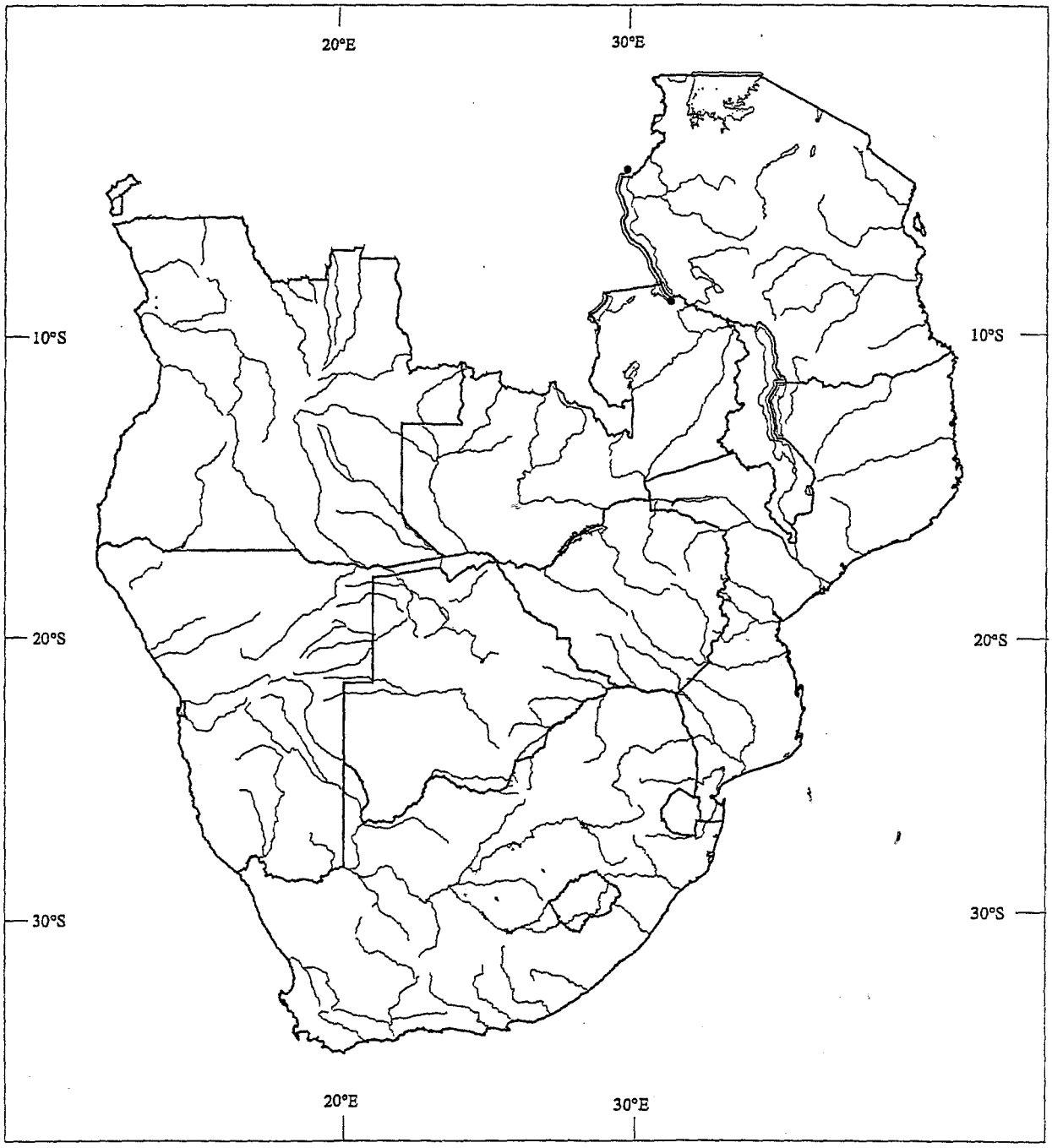


Figure F.731. Point distribution of *Xenotilapia sima*. Scale approximately 1:25 000 000

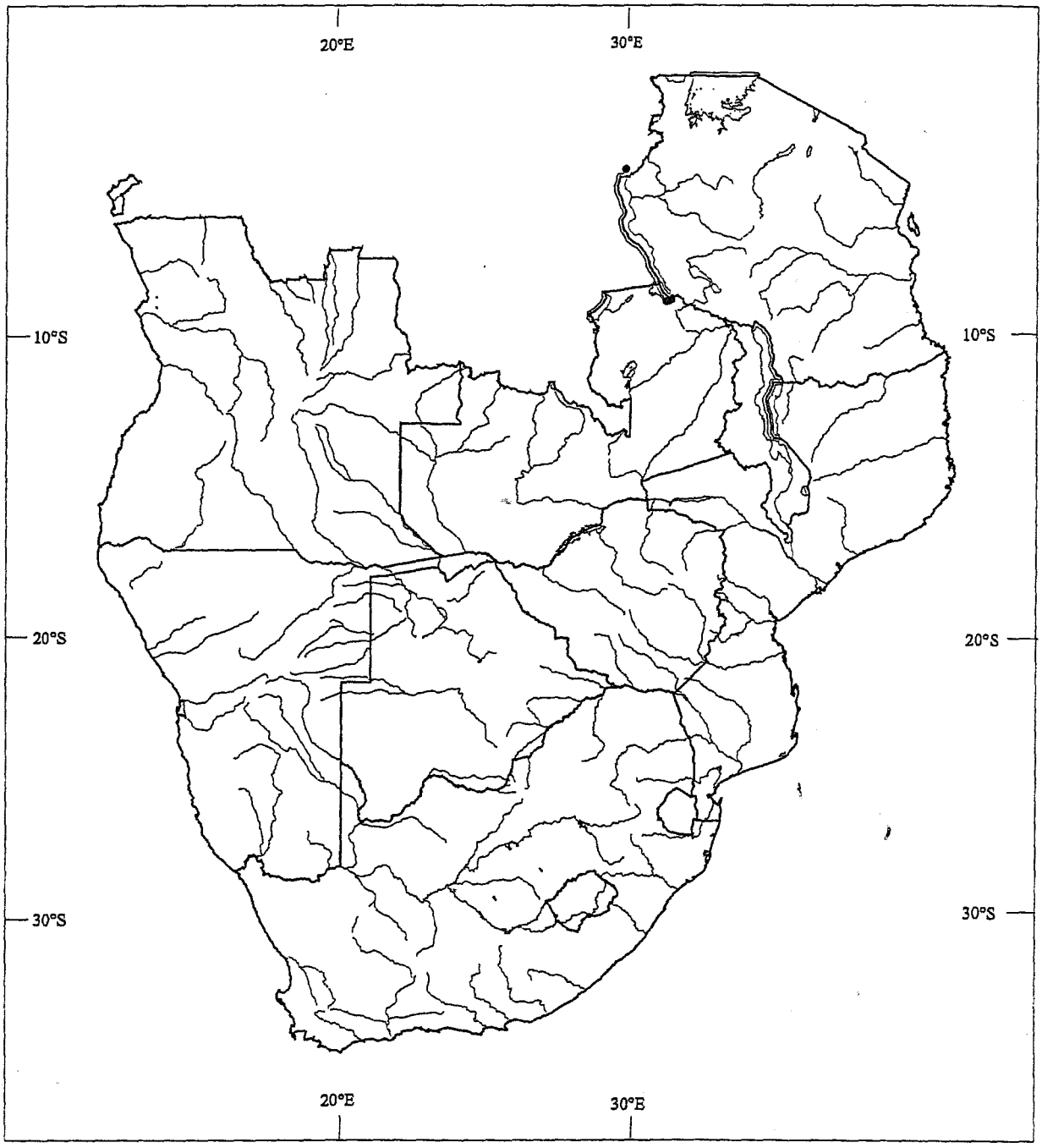


Figure F.732. Point distribution of *Xenotilapia spiloptera*. Scale approximately 1:25 000 000

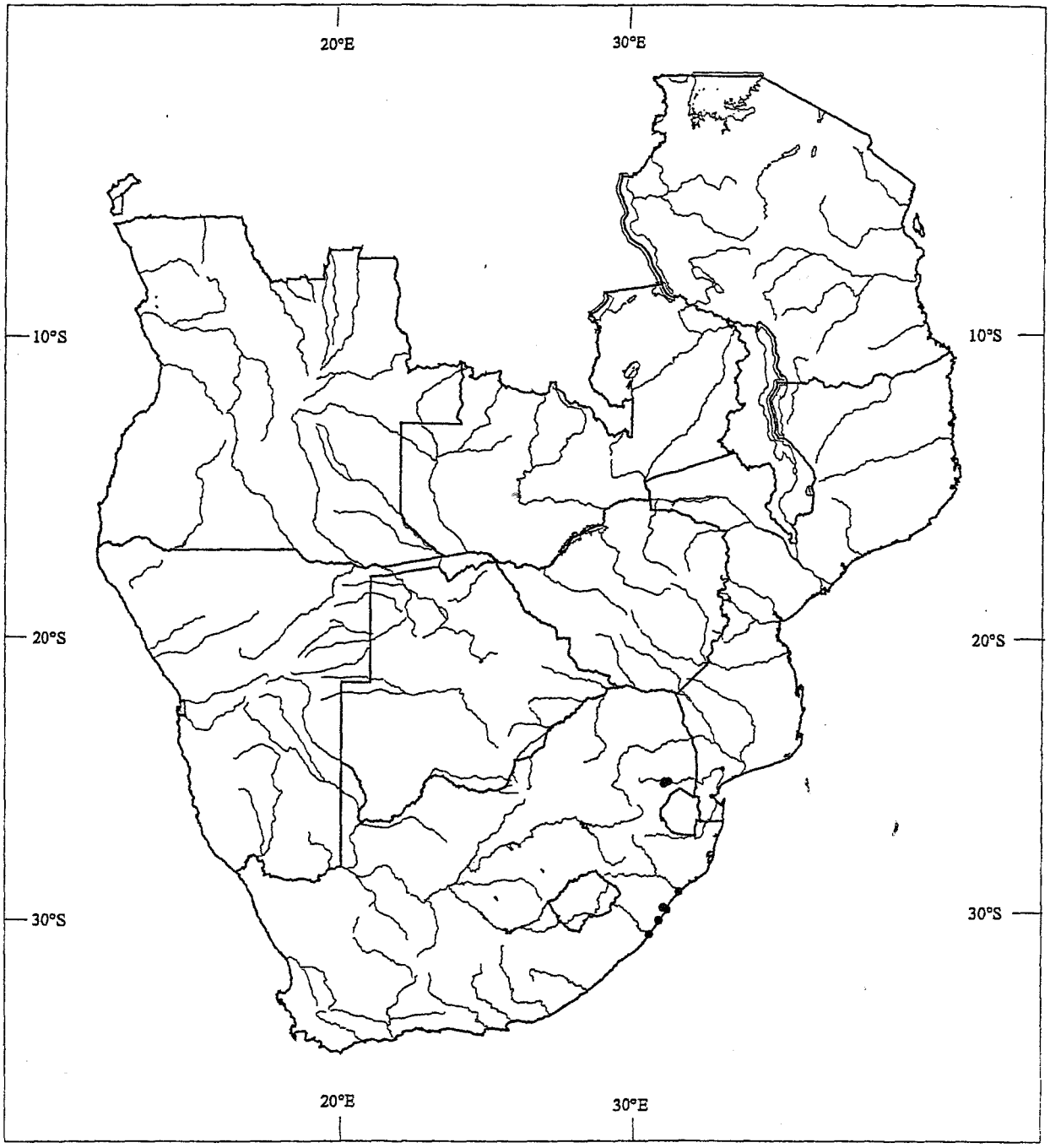


Figure F.733. Point distribution of *Xiphophorus helleri*. Scale approximately 1:25 000 000

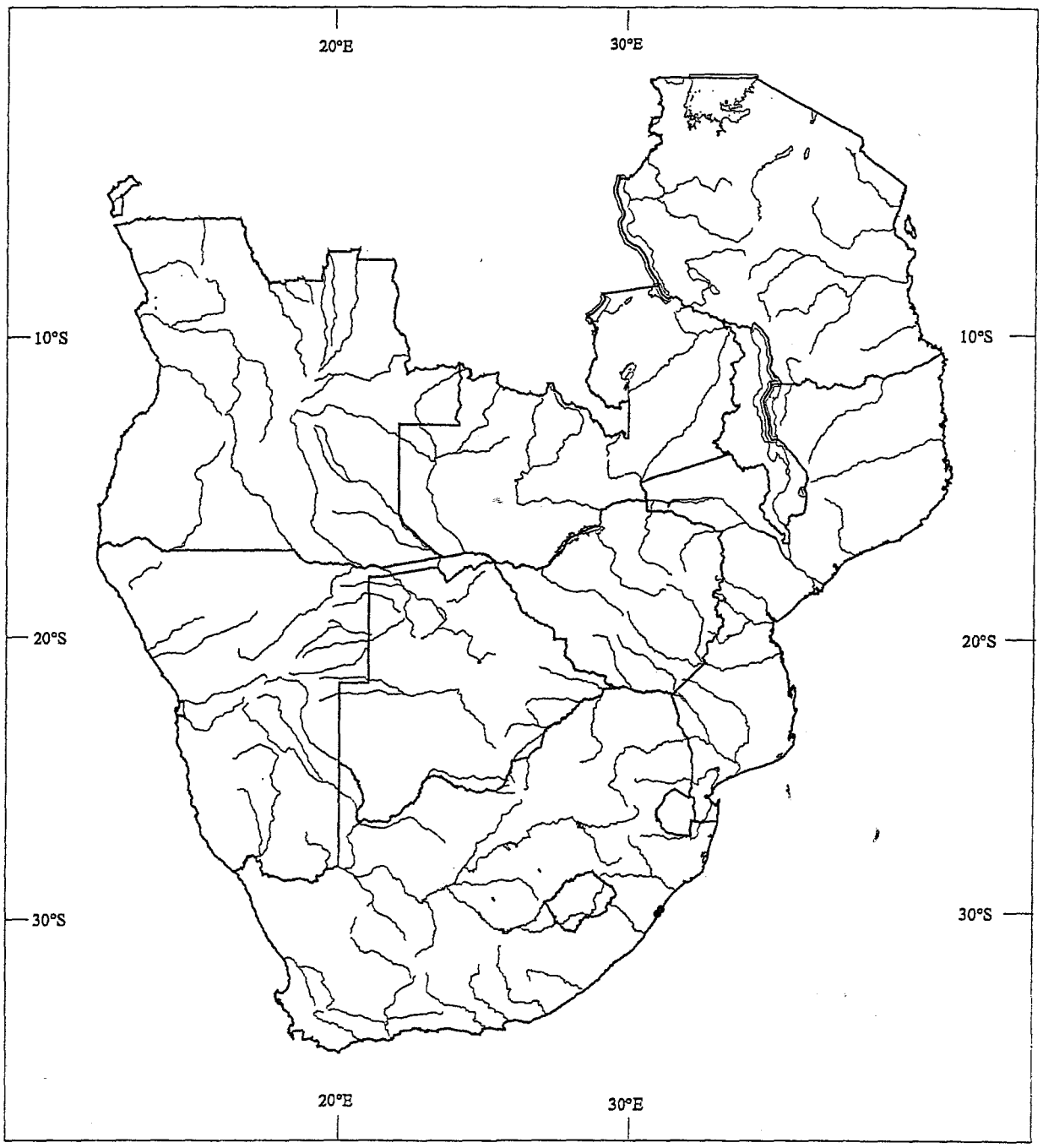


Figure F.734. Point distribution of *Xiphophorus maculatus*. Scale approximately 1:25 000 000

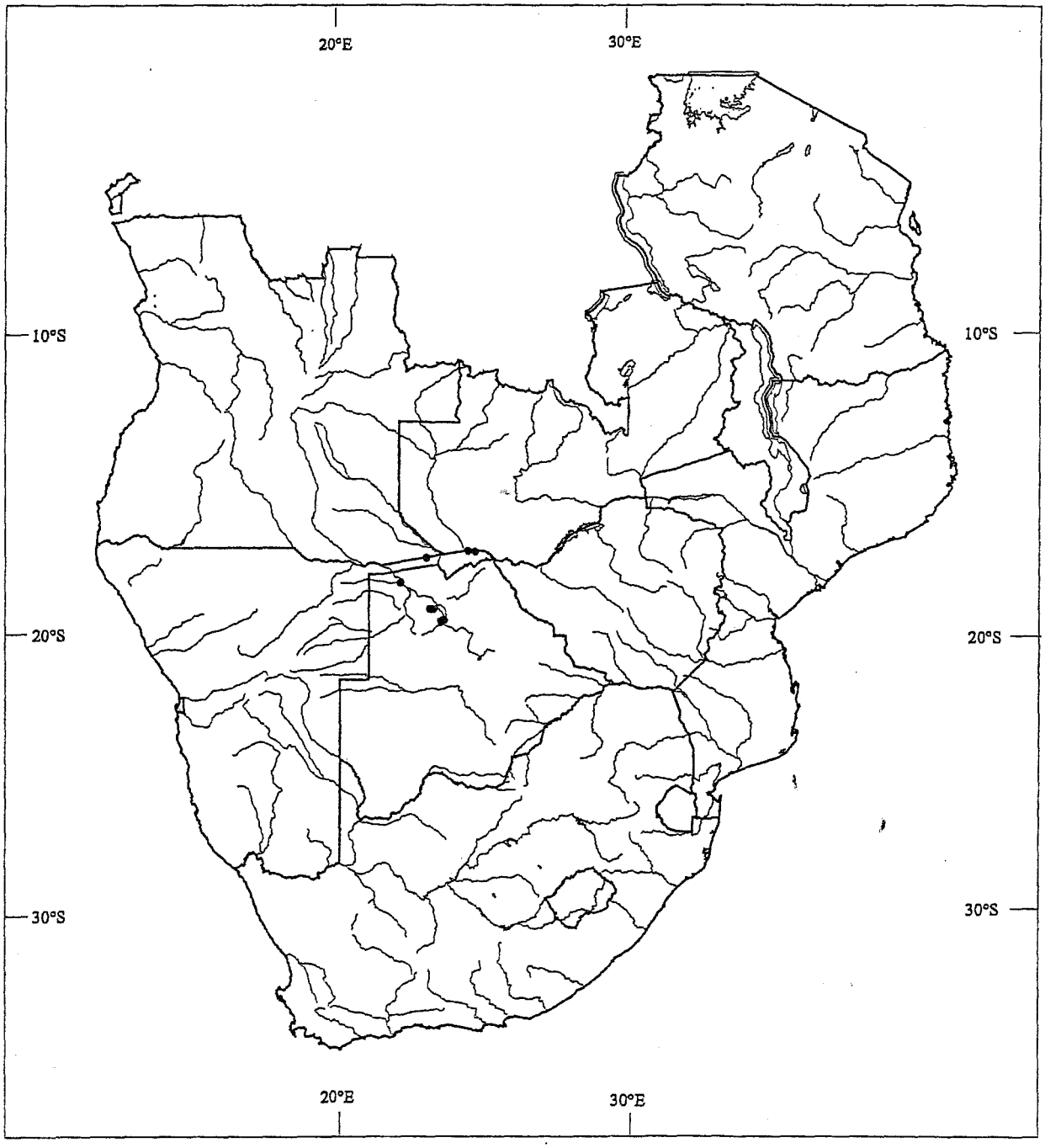


Figure F.735. Point distribution of *Zaireichthys chobensis*. Scale approximately 1:25 000 000