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CONCEPT DEVELOPMENT IN ASPECTS
OF ECOLOGY

by

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ABSTRACT

In this study food webs and a case study are used to investigate concepts which university students and high school pupils hold about ecology and the degree to which concept development has taken place at particular educational levels. The sample was drawn from first year zoology students and biology pupils in standards eight and ten.

Present data indicate that students and pupils could solve problems involving the interactions of populations only if they were simple enough to be answered using strategies based on the food chain concept. Very few subjects could successfully determine all the interacting pathways along which effects may be transmitted within a food web. The ability to determine all the pathways along which the effects of a change in population numbers within a community are spread, and to analyse the possible net manifestation of sometimes conflicting forces, requires a clear understanding of the concept of food web. An immature understanding of the food web concept by the subjects of this study is suggested as, in most cases, they identified alternate pathways within the food web when explicitly asked to do so, but did not apply this strategy when asked to solve problems based on the same principle. The case study also revealed immature ecological concepts.

Responses by standard eight pupils indicate that the opportunity exists at this level to develop a clear and mature understanding of the concept of food web, while comparison of data provided by the three age groups suggests that if clear conceptual development regarding food webs does not take place at school, misconceptions are likely to persist among first year university students.

CONTENTS

1.	INTRODUCTION	1
2.	SUBJECTS AND SETTING	8
3.	FOOD WEBS	12
3.1	INTRODUCTION	12
3.2	THE EXERCISE.....	13
3.3	METHOD.....	17
3.4	RESULTS	20
3.4.1	FIRST YEAR ZOOLOGY STUDENTS	20
3.4.2	STANDARD 10 PUPILS	21
3.4.3	STANDARD 8 PUPILS	25
3.4.4	COMPARISON OF RESULTS	27
3.5	DISCUSSION	31
4.	CASE STUDY	36
4.1	INTRODUCTION	36
4.2	METHODS	38
4.3	RESULTS	43
4.3.1	FIRST YEAR ZOOLOGY STUDENTS	43
4.3.2	STANDARD 10 PUPILS	45
4.3.3	STANDARD 8 PUPILS,	47
4.4	DISCUSSION	49

5.	QUESTIONNAIRE	54
5.1	THE QUESTIONNAIRE	54
5.2	RESPONSES	55
5.2.1	STUDENT RESPONSES	55
5.2.2	STANDARD 10 PUPIL RESPONSES	57
5.2.3	STANDARD 8 PUPIL RESPONSES	58
5.3	INFERENCES	59
6.	SUMMARY AND IMPLICATIONS	61
6.1	SUMMARY	61
6.1.1	FOOD WEB	61
6.1.2	CASE STUDY	62
6.1.3	QUESTIONNAIRE	63
6.2	IMPLICATIONS	64
6.2.1	TEACHERS	64
6.2.2	TEXT WRITERS.....	65
6.2.3	CURRICULUM DESIGNERS AND RESEARCHERS	67
	ACKNOWLEDGEMENTS	69
	LITERATURE CITED	70

CHAPTER ONE

INTRODUCTION

Science educators and researchers have in recent years shown great interest in the popularly acquired knowledge of students in narrowly delineated areas of science (Adeniyi, 1985). Specifically, this interest is directed towards describing some of the particular explanations, ideas and beliefs which students hold about natural phenomena and their implications for curriculum development. This reflects a shift in emphasis in science education research for, until recently, explanations of learning difficulties tended to draw on theories of general intellectual development such as Piagetian stage theory rather than the mental constructs of individual learners (Engel Clough and Wood-Robinson, 1985a).

Science education is a field which straddles both science and education and the shift in emphasis in science education research has been influenced, both directly and indirectly, by philosophy of science, as well as notions drawn from psychology and sociology (Gilbert and Watts, 1983). The influence of Baconian empirical-inductivism has lost its grip on the philosophy of science and has been attacked on the grounds of increasing evidence that sensory input involves selective attention and, as such, observation is theory laden. It follows that if observation is driven by theory then the quality of the observation is governed by the quality of the pre-existing theory (Gilbert and Watts, 1983). From this point of departure a series of perspectives have been put forward by philosophers such as Popper (1972), Kuhn (1970), Lakatos (1970) etc., which, despite points of disagreement, share the theory laden view of observation.

In psychology, the decades following the 1920's were dominated by behaviourism. Passivity of mind was emphasised, with the environment providing an input whose information is directly transmitted to, and accumulated by, the organism. This approach to human functioning led to an experimental approach initially closely paralleling empirical inductivism in science (Gilbert and Watts, 1983). During the 1970's the influence of cognitive theorists increased. They argued that the process of development is neither direct biological motivation nor direct environmental pressure, but a reorganisation of psychological structures resulting from organism - environmental interactions. As such they advocated a psychology which monitored such interactions by establishing the personal meaning attached to experience and knowledge.

Students' existing knowledge has been variously described by science educators as misconceptions (Doran, 1972; Helm, 1980; Helm and Novak, 1983; Ivowi, 1983; Weaver 1965), alternative frameworks (Driver and Erickson, 1983), children's conceptions/beliefs (Aguirre, 1978; Albert, 1978; Nussbaum and Novak, 1976), cultural beliefs (Cole, 1975; Odhiambo 1968), popular sayings of students (Za'rour, 1975), children's science (Osborne et al., 1983) and children's early experience (Adenyinka, 1983).

This range of descriptions prompted Gilbert and Watts (1983) to try to identify the epistemological traditions within which this broad range of studies was conducted and to attempt to identify general patterns across studies. Their study reveals that programmes detecting and illuminating "misconceptions" can be seen as an effort to isolate, eliminate or repair failures or "bugs" in the analytical framework in order to continue accretion on a "solid foundation", i.e. they imply that progress in

knowledge is dependent on whether the previous step has been mastered and give rise to the notion that a misconception is a flaw in the system.

Conversely, the phrase "children's science" accords to children's views the status that society frequently gives to science. Other phrases which are supportive of valuing or respecting personal meanings are "alternative frameworks" and "alternative conception" (Gilbert and Watts, 1983). This view has one immediate consequence. Student's "errors" are recognised as being natural developmental phenomena - personally viable constructive alternatives - rather than the result of some cognitive deficiency, inadequate learning, or poor teaching.

Much of the research into children's scientific conceptualisation has been done on aspects of physics, e.g. the particulate nature of matter (Doran, 1972; Novick and Nussbaum, 1978), dynamic equilibrium (Johnstone, McDonald and Webb, 1977), elementary dynamics (Viennot, 1979), heat (Erickson, 1979 and 1980), chemical equilibrium (Wheeler and Kass, 1978), light (Stead and Osborne, 1980), gravity (Gunstone and White, 1981), force and motion (Gunstone and Watts, 1985), electricity in simple circuits (Shipstone, 1985), etc. These studies reveal that students may draw "misleading" information from common experience and then generalise it using "wrong connections" (Gilbert and Watts, 1983). Also, although the studies span a variety of ages and aptitudes, there are no clear cut developmental age related changes. The only "development" which seems to occur is that some of the mistakes are more clearly expressed by the more mature students (Sjoberg and Lie, 1981).

Engel Clough and Wood-Robinson (1985a) suggest that biological topics have been neglected. Various reasons have been put forward for this, one being that the the popularity, at least until recently, of Piagetian frameworks has resulted in the neglect of biological concepts as Piagetian tasks usually involve physical science concepts (Engel Clough and Wood-Robinson, 1985a). Shayer (1974) proposed that researchers have tended to steer clear of biological concepts as they are generally non-hierarchical and less discrete, i.e. they tend to interweave with related concepts and are therefore difficult to isolate. Griffiths and Grant (1985) have attempted to identify an ecological food web learning hierarchy as they feel that the relationships operating within these systems are rule-like in nature, but admit that even in this topic, instruction which follows the order of their hierarchy, will by no means guarantee success.

Although biological topics are considered neglected, work has been carried out on a certain number of topics using differing research approaches. These include interviews on aspects of evolution, inheritance and physiological processes (Brumby, 1979 and 1984; Deadman, 1976; Engel, 1982; Kargbo et al., 1980; Longden, 1982; Okeke and Wood-Robinson, 1980; Bell and Brook, 1984), tests of prerequisite concepts in photosynthesis (Simpson and Arnold, 1982), word association techniques to look at the concept of growth (Schaefer, 1979), classroom intervention strategies as regards the concept of "animal" (Bell and Barker, 1982), written tests on ecology (Griffiths and Grant, 1985) and written tests supplemented by interviews on the same topic (Adeniyi, 1985).

The most common research approaches have been of the written and oral response types. In this study only the written response approach was used as interviews are time consuming and studies (Bell and Barker, 1982; Adeniyi, 1985) have shown that oral responses illustrate exactly the same kind of ideas as written responses, the oral responses merely tending to be longer and more elaborated.

Ecology was chosen as the topic for this study as it has recently become more prominent in the South African Biology core syllabus, with work previously done at matriculation level being shifted to standard eight and population dynamics being introduced in the standard ten year. Trophic relationships form a unifying thread within this topic and food chains are taught to ten year olds, while the concept of food web is expected to be developed at the age of thirteen. The understanding of food webs in turn appears to be central to the understanding of more complex ecological principles (Alexander, 1982) which in turn form the basis for understanding important environmental issues such as conservation, pollution and population management (Griffiths and Grant, 1985).

A food web is a model, a simplified representation of feeding relationships in a given community and the more realistically the model mirrors nature the more complex it becomes. The process of determining how an unusual decrease or increase in one population will affect another population in a real life situation is an onerous task (Summers and Summers, 1976). Similarly, complex food web diagrams present an arduous task to anyone attempting to determine the net effect of a change in one part of a food web on another and the exercise may become one of frustration in trying to untangle endless numbers of pathways (Griffiths and Grant, 1985).

Nevertheless, biology teachers, although they rate the concept of food web as a very important topic in school biology, do not perceive any great difficulty for pupils as regards concept development in this area and students are presented with the task of unravelling food webs in examinations (Finley et al., 1982).

Johnstone and Mahmoud (1980) refute the suggestion that pupils do not have any conceptual difficulty with food webs and note that examiners' reports on school-leaving examinations in Scotland over an eight year period indicate that students in fact experience substantial difficulty, especially when species become separated on the web. This suggests that teachers need to be more aware of pupils' conceptions in ecology and spend more time diagnosing and correcting errors in students' thinking (Strike and Posner, 1982).

As ecological concepts are based on the relationships between organisms in their natural environment, field work has an important role to play in developing an understanding of these principles (Saunders, 1972; Dowdeswell, 1974 and 1981; Fido and Gayford, 1982) and allowing insight to ecological relationships (Junck, 1985; Adams, Charles, Green and Swan, 1985; Leonard, 1985; Hale, 1986; Lenton, 1975). The efficacy of field work has been assessed by Gayford (1986) who has shown that it can have a strong motivating effect on many pupils, but an effective field study poses considerable problems of organisation, particularly where large numbers of students are involved and access to a suitable ecological site at the right time of year is difficult.

To overcome these difficulties classroom heuristics have been developed as supplementary and complementary activities to develop insight and understanding of ecological principles (Junck, 1985; Adams et al. 1985; Leonard, 1985; Hale, 1986; Lenton, 1975). One example is the case study heuristic which provides data which could be collected from an actual field study, allowing pupils to analyse the situation and come to a conclusion. A case study of this type, although a valuable supplementary activity, cannot be used as a replacement for field activities. Nevertheless the ability of pupils to manipulate, integrate and analyse data given in the form of a case study provides an indicator of their understanding of ecological principles, superior to that provided by mere reproduction of what has been said by the teacher or what is written in the textbook. Open-ended questions pertaining to the data also allow individuals to make their ideas explicit.

In this study food webs and a case study are used to investigate present concepts which students hold about ecology and the degree to which concept development has taken place at particular educational levels. Although the aim of educators should be to understand each individual pupil's conceptual framework, the elucidation of alternative frameworks and ideas held by groups provides teachers with a base from which they can plan for more effective teaching. Awareness of student concept development allows an educational point of departure far preferable to one where there is little or no understanding of the mental constructs within which pupils operate.

CHAPTER TWO

SUBJECTS AND SETTING

The subjects for this study were pupils from six schools in the Eastern Cape and first year Zoology students of the University of Port Elizabeth.

Of the 108 mixed ability pupils involved, drawn from Biology classes in Catholic, Jewish, Anglican, Methodist and secular private schools in Port Elizabeth and Grahamstown, forty three were in standard eight (age \pm 15 years) and sixty five in standard ten (age \pm 17 years). Classes were co-educational, English speaking and non-racial with a predominance of white pupils. Private schools were selected for the study as access to pupils is provided via the consent of principals and teachers which circumvents the often time consuming process of obtaining written permission from provincial Education Departments.

Fifty four students at the University of Port Elizabeth were drawn from the BS01 (first year Zoology) class which represented roughly equivalent groups of English and Afrikaans speakers of both sexes. Instruction in Zoology at the university is both in English and Afrikaans (lecturer's choice) and it was therefore thought that, although the case study worksheets and the food web exercises were in English only, it would not affect students for whom this was not their home language. When approached to ascertain whether any

difficulty was experienced in understanding the questions, students with Afrikaans as their home language reported no problems.

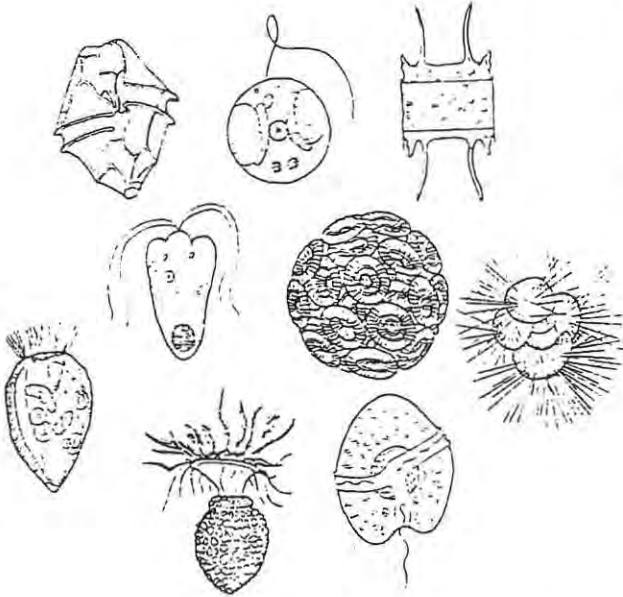
Pupils were presented with the work either during normal school periods or during compulsory "prep". The first year Zoology students worked through the food web and case study in the laboratory after afternoon practical sessions. Time was not a limiting factor and on average the food web took approximately 20 - 30 minutes while 35 - 45 minutes were required for completion of the case study.

162 subjects formed the sample used in this study. This was considered to be an adequate number as it compares satisfactorily with sample sizes used by other researchers working on similar investigations, e.g. elucidation of ecological misconceptions, $n = 26$ (Adeniyi, 1985); student's interpretation of biological adaptation, $n = 84$ (Engel Clough and Wood-Robinson, 1985a); misconceptions held as regards food webs, $n = 200$ (Griffiths and Grant, 1985); children's understanding of inheritance, $n = 84$ (Engel Clough and Wood-Robinson, 1985b) and determination of prerequisite concepts for learning biology, $n = 163$ (Simpson and Arnold, 1982).

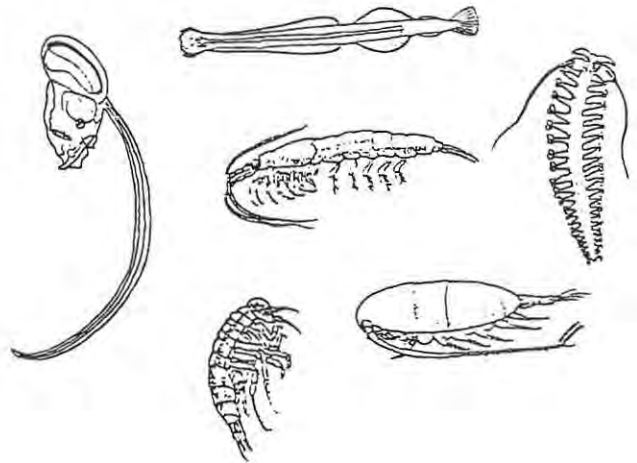
Students and pupils were provided with an information sheet (Figure 1.) to ensure the same level of departure as regards terms used, i.e. phytoplankton, zooplankton and nekton. Pictorial representations of examples of each were given to enable those doing the worksheets to develop the idea that these groups could represent a wide spectrum of plants and animals.

INFORMATION SHEET

Phytoplankton are free floating photosynthetic organisms which produce food from carbon dioxide and water in aquatic systems, i.e. they are the primary producers.



Zooplankton are free floating organisms which feed on the phytoplankton and in turn provide food for larger organisms in aquatic systems.



Nekton are free swimming organisms which move from place to place. They may be herbivorous or carnivorous.

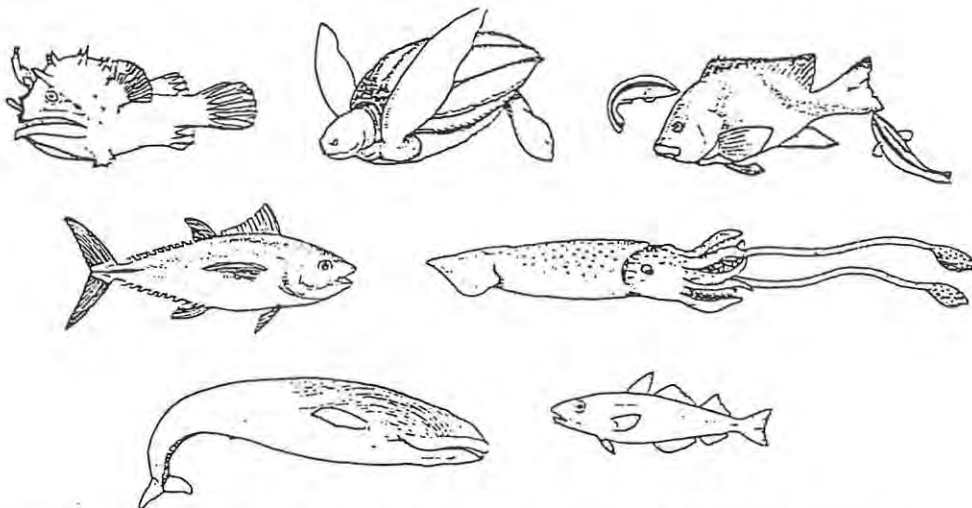


Figure 1. Information sheet provided to all subjects doing the case study and food web exercises.

Instructions were clearly given as to:

- a) the purpose of the testing, i.e. that the worksheets were not testing individual ability nor was the exercise designed to test the efficacy of the worksheets as teaching instruments. It was clearly explained that the purpose was to establish which general ecological concepts were held correctly and incorrectly by the majority of pupils or students at particular levels of study.
- b) the confidentiality of the testing, i.e. that individual results would not be given to teachers or lecturers and that their response sheets could be anonymous.
- c) the organisation of the material, i.e. that the blue sheet was for the participants' information only, the green sheets represented the work on food webs, all yellow sheets pertained to the case study, while the pink sheet was a questionnaire to be answered only after both the food web and case study worksheets had been completed.
- d) the open-ended nature of the questions, i.e. that in many cases there was no absolutely correct answer and that it was the participants' ideas which were of value to the researcher.

It was noted that it was hoped that the exercises would be found to be enjoyable and all were thanked for participating.

CHAPTER THREE

FOOD WEBS

3.1 INTRODUCTION

The ability to determine the effect of a change in one population on another in a food web represents skills fundamental to the understanding of the concept of "food web" (Griffiths and Grant, 1985). These skills range from simple predator-prey interactions to more sophisticated relationships where effects may be transmitted along more than one route between populations not on the same food chain. Pre-requisite knowledge required to solve food web problems is that populations are linked through trophic interactions governed by predation, energy flow and reproductive capacity and that a change in the size of any one population may have an effect on others. Furthermore, the effect is not confined to adjacent populations but may be spread along many routes, up or down trophic levels.

In this study a series of skills (as described in §3.3) was tested using a sequence of questions ranging from those based on the most simple of relationships to the most complex, in order to reveal where general misconceptions lie and to determine how misconceptions at one level affect explanations of relationships at other levels.

Letters were used to represent populations in the food web rather than named species as:

- a) this requires the subjects to focus on the principles operating

within food webs rather than on the individuals making up the community and

b) this reduces the effect of pre-knowledge (both correct and incorrect) as regards the trophic requirements and behaviour of particular species.

3.2 THE EXERCISE

A food web exercise was presented to the subjects which involved only four routes between the populations in question, as increasing the complexity of the web beyond this would have increased the tediousness of the task without demanding greater understanding. The exercise read as follows:

FOOD WEB EXERCISE

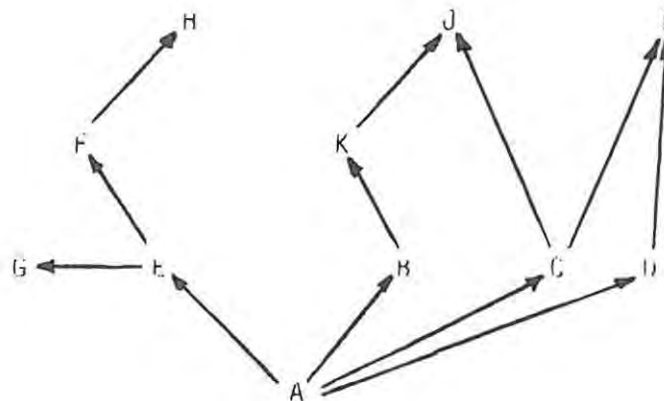


Figure 1. The above figure represents a food web (each letter denotes a component population of the web).

The exercise firstly tests the concept that autotrophs form the base of a food web and that these organisms are the most numerous and contain the most available energy. Populations referred to are the ones illustrated in the food web shown in figure 1 above and the skills tested by the exercise are noted after each question, when appropriate. Reference to the skill being tested did not appear on the worksheet provided to the subjects.

QUESTIONS.

1. a) Which letter represents the organism on which all the other organisms depend? Explain why.

.....
.....
.....

b) What do we call this group of organisms in a food web?

.....

c) Which group do you think will contain the most organisms; K, B, A or J?.....

d) Which group do you think has the most available energy; K, B, A or J?.....

2. What effect will a sudden decrease in population F have on the size of population H ? Explain your answer.

.....
.....
.....

Skill tested: the effect of a sudden size change in a prey population

on its predator population.

3. What effect will a sudden increase in population H have on the size of population F ? Explain your answer.

.....
.....
.....

Skill tested: the effect of a sudden size change in a predator population on its prey population.

4. What effect will a sudden decrease in population E have on the size of population H ? Explain your answer.

.....
.....
.....

Skill tested: the effect of a sudden size change in one population on a second non- adjacent population located higher on the same food chain, when the effect is transmitted along only one route.

5. What effect will a sudden increase in population G have on population F ? Explain your answer.

.....
.....
.....

Skill tested: the effect of a sudden size change in one population on a second population not located on the same food chain, when the effect

is transmitted along only one route.

6. What effect will a sudden decrease in population H have on population E ? Explain your answer.

.....
.....
.....

Skill tested: the effect of a sudden size change in one population on a second non-adjacent population located lower on the same food chain.

7. Write down the letters indicating populations through which the effect of an increase in population A is passed on to population J. Explain your answer.

.....
.....
.....

Skill tested: recognition of all the possible pathways through which effect of a change in one population is transmitted to a second.

8. What effect will a sudden increase in population B have on population J? Explain your answer.

.....
.....
.....

Skill tested: the effect of a sudden size change in one population on a second non-adjacent population located higher on the same food chain where the effect is transmitted along more than one route.

9. What effect will a sudden decrease in population J have on B ? Explain your answer.

.....
.....
.....

Skill tested: determination of the effect of a sudden size change in one population on a second, non-adjacent population located lower on the the same food chain, when the effect is transmitted along more than one route.

10. What effect will a sudden increase in population I have on the size of population K. Explain your answer.

.....
.....
.....

Skill tested: determination of the effect of a sudden size change in one population on a second population which is not on the same food chain, when the effect may be transmitted along more than one route.

3.3 METHOD

Test items in the present study followed a free-response format. Upon responding to a given item subjects were asked to indicate the reasoning used in arriving at their answer. This information proved to be valuable in evaluating the pupil's mastery status with respect to a given skill and was useful in providing information which gave clues to subjects' misconceptions. In some cases it was only possible to infer underlying misconceptions from the errors made by subjects while in other cases the

misconceptions were stated openly.

The subjects' explanations, when answering individual items, were analysed for key ideas and common criteria and a series of categories of answer types developed. These categories were developed only after the major common groups had been identified and were not predetermined. The frequency with which answers fell in each category was recorded.

Examples of subject responses falling into each category are:

Category A: correct answer accompanied by the correct explanation.

e.g. Question 3. "H feeds directly on F and so an increase in number of predator population would decrease the number of prey".

e.g. Question 5. "Both G and F feed on E, so if there was an increase in G there would be more competition for E. Therefore there would probably be a decrease in F".

The above answers indicate a full understanding of the principles which apply in a food web.

Category B: correct answer with a partially correct explanation.

e.g. Question 5. "F will decrease but there won't be much effect as they are not dependent on each other. They are both dependent on E".

The above answer indicates that the subject has an idea of interactions in the food web but is unclear as to the exact relationship between the two populations.

Category C: Correct answer with a mostly incorrect answer.

e.g. Question 5. "F might decrease but probably not much because it is a side product."

e.g. Question 4. "H will decrease as it depends directly on E for survival".

The above answers indicate that the subjects have given the correct answer but have mostly erroneous ideas about the relationships between the populations.

Correct answers with no accompanying explanation were also placed in this category.

Category D: Incorrect answers with incorrect explanations as well as items which elicited no response were placed in this category.

No attempt was made at any form of statistical analysis of variance as this seemed inappropriate for the following reasons:

- a) the categories into which the responses are classified are not clear cut but are demarcations across a continuum, particularly as regards the clarity and sophistication of the explanations given

- b) although the pupils taking part in the study were all from fee-paying private schools, the groups were not selected uniformly by any other criteria

- c) the subjects at university might be considered a select subset of the groups represented by the pupils.

The fact that the university students represent a select group did not weaken the study, but in fact enhanced the findings as it was found that general alternative frameworks held by pupils persist, even in groups selected for higher education.

3.4 RESULTS

3.4.1 FIRST YEAR ZOOLOGY STUDENTS

95% of the students ($n = 54$) could identify population A as producers but 40% did not explain the relationship between the producers and other populations in terms of energy flow or primary production. These students explained the relationship in terms of the arrows on the food web, e.g. "it is the only population that has arrows leaving it and linking up with the other populations". 5% of the students did not provide the term "producer" for population A. 8% did not identify population A as the group containing the most individuals, while 30% did not respond that population A contained the most available energy.

94% of the students could not correctly determine and fully explain the effect of a sudden size change in one population on a second population not on the same food chain when the effect was transmitted along more than one

route. 66% of the students nevertheless answered the problem partially correctly, with 42% of those answering partially correctly choosing to explain the probable effect along the route transmitted through reduced numbers of consumers (populations C and D), allowing an increase in producers which in turn is transmitted via primary consumers (population B) to secondary consumers (population K). 24% explained the effect via increased predation by population J on population K because of reduced alternative prey population (C). Only 6% of the students explained that effects could be transmitted along both pathways. Answers using only one pathway were given by the 94% and 89% of students answering questions 8 and 9 respectively partially correctly, i.e. the questions on the effects produced by an increase in population on other populations respectively higher and lower on the food chain when the effect is transmitted along more than one route.

21% of the students were unable to determine all the population paths through which the effect of an increased producer population is passed to a tertiary consumer population (J), while 17% could not determine the effect of a sudden change in population size on a second population not located on the same food chain when the effect is transmitted along only one route (question number 5). Results are reflected in summary form in Table 1.

3.4.2. STANDARD 10 PUPILS

92% of the pupils (n = 65) could identify population A as producers. 8% did not explain the relationship between the producers and other populations in terms of energy flow or primary production, preferring to explain the relationship in terms of the arrows on the food web. 94% of the pupils provided the term "producer" for population A and 86%

Table 1: Results of responses of **first year Zoology students** (n = 54) answering the questions on the food web exercise.

A indicates the correct answer accompanied by the correct explanation;
 B indicates a correct answer with a partially correct explanation;
 C indicates the correct answer with a mostly incorrect explanation;
 D indicates an incorrect answer and explanation.

<u>REQUIREMENT</u>	<u>% RESPONSE</u>			
	A	B	C	D
Identification of base of food chain	61	24	0	15
Naming of population A	91	0	0	9
Identification of the population containing the most organisms	93	0	0	7
Identification of the population containing the most energy	70	0	0	30
Effect of prey on predator	100	0	0	0
Effect of predator on prey	95	0	0	5
Effect of change in population on a non-adjacent population higher on the food chain with the effect transmitted along only one route	100	0	0	0
Effect of change in population on a second population not on the same food chain when the effect is transmitted along only one route	83	0	0	17
Effect of a change in population on a second non-adjacent population lower on the same food chain when the effect is transmitted along one route	87	0	0	13
Recognition of all possible pathways through which the effect of a change in one population is transmitted to a second	83	0	0	17
Effect of a change in population on a second non-adjacent population located higher on a food chain when the effect is transmitted along more than one route	2	94	0	4
Effect of a change in population on a second non-adjacent population located lower on a food chain when the effect is transmitted along more than one route	0	89	0	11
Effect of a change in population on a second non-adjacent population which is not on the same food chain and the effect is transmitted along more than one route	6	67	0	27

identified it as the group containing the most individuals, but 25% did not respond that population A contained the most available energy.

Only one of the pupils could correctly determine the effect of a sudden size change in one population on a second population not on the same food chain when the effect was transmitted along more than one route. 49% of the subjects nevertheless answered the problem partially correctly, with 69% of those answering partially correctly choosing to explain the probable effect along the route transmitted through reduced numbers of consumers (populations C and D), allowing an increase in producers which in turn is transmitted via primary consumers (population B) to secondary consumers (population K). 31% explained the effect via increased predation by population J on population K because of reduced alternative prey population (C). Answers using only one pathway were given by 78% and 58% of the pupils answering questions 8 and 9 respectively partially correctly, i.e. the questions on the effects produced by an increase in population on other populations respectively higher and lower on the food chain when the effect is transmitted along more than one route. Examples of pupils' responses are: "There is no effect as the populations are too far apart", "Not much effect as the populations are only slightly related" and "Not too much effect as the chains are spread out".

63% of the subjects were able to determine all the population paths through which the effect of an increased producer population is passed to a tertiary consumer population (J), while only 29% could not determine the effect of a sudden change in population size on a second population not located on the same food chain when the effect is transmitted along only

Table 2: Results of responses of **standard 10 pupils** (n = 65) answering the questions on the food web exercise.

A indicates the correct answer accompanied by the correct explanation;
 B indicates a correct answer with a partially correct explanation;
 C indicates the correct answer with a mostly incorrect explanation;
 D indicates an incorrect answer and explanation.

<u>REQUIREMENT</u>	<u>% RESPONSE</u>			
	A	B	C	D
Identification of base of food chain	92	8	0	0
Naming of population A	94	0	0	6
Identification of the population containing the most organisms	86	0	0	14
Identification of the population containing the most energy	75	0	0	25
Effect of prey on predator	97	2	0	1
Effect of predator on prey	83	0	0	17
Effect of change in population on a non-adjacent population higher on the food chain with the effect transmitted along only one route	91	5	0	4
Effect of change in population on a second population not on the same food chain when the effect is transmitted along only one route	69	2	0	29
Effect of a change in population on a second non-adjacent population lower on the same food chain when the effect is transmitted along one route	58	2	2	38
Recognition of all possible pathways through which the effect of a change in one population is transmitted to a second	63	3	0	34
Effect of a change in population on a second non-adjacent population located higher on a food chain when the effect is transmitted along more than one route	0	78	3	19
Effect of a change in population on a second non-adjacent population located lower on a food chain when the effect is transmitted along more than one route	0	58	2	40
Effect of a change in population on a second non-adjacent population which is not on the same food chain and the effect is transmitted along more than one route	1	49	0	50

one route (question number 5). Results are reflected in summary form in Table 2.

3.4.3 STANDARD 8 PUPILS

The mistakes encountered on the standard eight answer sheets closely resembled those of the standard 10 pupils. 90% of the pupils (n = 43) could identify population A as producers while 10% could not explain the relationship between the producers and other populations in terms of energy flow or primary production.

90% of the pupils provided the term "producer" for population A and 95% identified it as the group containing the most individuals, but 30% did not respond that population A contained the most available energy.

Only one of the pupils could correctly determine the effect of a sudden size change in one population on a second population not on the same food chain when the effect was transmitted along more than one route. 52% of the subjects nevertheless answered the problem partially correctly. Most of these answered the question in terms of an increase in the number of producers (38%) while 14% considered the route via increased predation. Examples of explanations offered by those that answered the question incorrectly are "there is no effect as they are not related as predator and prey", "there is no effect as I doesn't feed on K", "nothing happens really as K and I aren't really linked at all" and "no effect as they are on different parts of the food web". Two pupils identified more than one route for question 8 while answers using only one pathway were given by 55% of the pupils. One pupil recognised more than one route in question 9 while 62% gave answers based on one route only (see table 3).

Table 3: Results of responses of **standard 8 pupils** (n = 43) answering the questions on the food web exercise.

A indicates the correct answer accompanied by the correct explanation;
 B indicates a correct answer with a mostly correct explanation;
 C indicates the correct answer with a mostly incorrect explanation;
 D indicates an incorrect answer and explanation.

<u>REQUIREMENT</u>	<u>% RESPONSE</u>			
	A	B	C	D
Identification of base of food chain	90	0	0	10
Naming of population A	90	0	0	10
Identification of the population containing the most organisms	95	0	0	5
Identification of the population containing the most energy	70	0	0	30
Effect of prey on predator	92	0	0	3
Effect of predator on prey	88	0	0	12
Effect of change in population on a non-adjacent population higher on the food chain with the effect transmitted along only one route	92	0	0	8
Effect of change in population on a second population not on the same food chain when the effect is transmitted along only one route	88	0	0	12
Effect of a change in population on a second non-adjacent population lower on the same food chain when the effect is transmitted along one route	86	0	0	14
Recognition of all possible pathways through which the effect of a change in one population is transmitted to a second	70	0	0	30
Effect of a change in population on a second non-adjacent population located higher on a food chain when the effect is transmitted along more than one route	5	55	0	40
Effect of a change in population on a second non-adjacent population located lower on a food chain when the effect is transmitted along more than one route	2	62	0	36
Effect of a change in population on a second non-adjacent population which is not on the same food chain and the effect is transmitted along more than one route	2	52	0	46

3.4.4 COMPARISON OF RESULTS

The standard 10 pupils could more readily identify the base of the food chain and give reasons as to why the other populations depended on the producers than the first year university students. They were also marginally better at providing the name producer or autotroph but were less accurate in determining the population containing the most organisms and the most energy. Almost all the students and matriculants could explain and determine the effect of prey on predator, predator on prey and the effect of a change in population on a non-adjacent population on a food chain with the effect transmitted along only one route.

The first year students scored marginally better than the standard 10 pupils when considering the effect of a change in population on a second population not on the same food chain when the effect is transmitted along only one route (83% and 69% respectively), but scored considerably better (>20%) when the relationship became more complex (Question 6). They also scored better than the standard 10 pupils when asked to identify all the possible pathways through which the effect of a change in producer population is transmitted to a secondary consumer (Question 7). The students were also able to determine possible routes through which effects may travel, albeit along one path only, better than the standard 10 pupils, i.e. they answered questions 8, 9 and 10 more successfully.

The standard 8 pupils of one school impressed with the degree of clarity and quality of logic used when explaining the answers they had given to the questions asked. For the first time the terms competition, interspecific, breeding stock and limited resources were used. This suggests that their

teacher had succeeded in clarifying these terms and that the pupils understood them well enough to apply them to the situations as described by the worksheet. The exercise was done immediately after classroom instruction on the topic and this may partially explain the high degree of motivation as reflected by the great care taken when answering questions.

The standard 8 pupils scored almost as well as the standard ten pupils in all sections, including the more complex relationships, but like the standard 10 pupils generally had great difficulty in recognising more than one route for the transmission of effects. Nevertheless some responses revealed that a similar conceptual level could be attained in standard 8 as that which had been developed by older learners i.e. some standard eights were able to synthesise all the routes for energy flow in question 8 (two pupils) and question 9 (one pupil). This suggests that an opportunity exists at standard eight level to develop clear concepts regarding food webs, while the data produced by the standard ten pupils and first year zoology students leads one to believe that if these concepts are not clearly developed at school, misconceptions have a good chance of persisting at university level.

The results attained by the three groups as regards correct answers for questions 1 to 7 may be compared in tabular form as follows:

Table 4: Comparison of the number of correct responses attained by the BS01 students and standard 10 and standard 8 pupils.

<u>REQUIREMENT</u>	<u>% RESPONSE</u>		
	STD	STD	
	BS01	10	8
Identification of base of food chain	61	92	90
Naming of population A	91	94	90
Identification of the population containing the most organisms	93	86	95
Identification of the population containing the most energy	70	75	70
Effect of prey on predator	100	97	92
Effect of predator on prey	95	83	88
Effect of change in population on a non-adjacent population higher on the food chain with the effect transmitted along only one route	100	91	92
Effect of change in population on a second population not on the same food chain when the effect is transmitted along only one route	83	69	88

Effect of a change in population on a second non-adjacent population lower on the same food chain when the effect is transmitted along one route	87	58	86
Recognition of all possible pathways through which the effect of a change in one population is transmitted to a second	83	63	70

The above results do not show any significant trends between the groups but the following comparison of the answers given, utilising only one route within the food web as opposed to following all possible pathways, indicate that the first year zoology students were more skillful in tracing extended pathways.

Table 5: Comparison of answers using only one route given by BS01 students and standard 10 and standard 8 pupils.

<u>REQUIREMENT</u>	BS01	<u>% RESPONSE</u>	
		STD	STD
Effect of a change in population on a second non-adjacent population located higher on a food chain when the effect is transmitted along more than one route	94	78	55
Effect of a change in population on a second non-adjacent population located lower on a food chain when the effect is transmitted along more than one route	89	58	62

Effect of a change in population on a second non- 67 49 52
adjacent population which is not on the same food
chain and the effect is transmitted along more
than one route

3.5 DISCUSSION

Almost the entire sample of pupils and first year university students consistently answered the questions incompletely when asked to consider the effect of a change in numbers of one population on another when the effect is transmitted along more than one route. They failed to consider that the effects could be passed along several different pathways as they approached the population in question. Subjects tended to select one of alternative pathways and considered successive predator-prey links until they reached the population on which the question was based. This strategy is suitable for explaining effects within food chains, but the very nature of the food web model is based on the interdependence of organisms where the effects of change in one population spread through a "web" of pathways prior to reaching a population in another part of the web.

When the subjects were asked to explain their answer they indicated the pathway they had chosen without explaining why they chose that particular route before any of the alternative pathways, or why they based their consideration on one pathway only. This lack of explanation is consistent with the results reported by Griffiths and Grant (1985) working with Grade 10 biology pupils. Brumby (1982) encountered a similar problem in a study involving 52 biology students at a British University where half of the

sample interpreted statements involving the food web concept in terms of a food chain.

Nevertheless, when asked to identify the letters indicating the populations through which a change in population A is passed on to population J (question 7), 83% of the students and 67% of the pupils recognised that there was more than one route, suggesting that the subjects possessed an understanding of the concept but failed to apply their knowledge clearly when the relationships became more complex, i.e. when effects were passed both up and down food chains from alternative routes and the populations were far removed from one another.

Food chains represent a model on which pupils begin their understanding of feeding relationships between different populations in a community. Food webs are then introduced to present a more realistic relationship. These webs resemble a network of food chains and misconceptions may occur if pupils consider a food web to be functionally like a network of food chains. The data in this study suggests that unless this misconception is explicitly and specifically corrected, it will continue to blur the development of a clear and complete understanding of the concept of food web. Without clear conceptual development pupils and students can be expected to persist in arbitrarily singling out food chains or individual pathways of populations in the food web structure and considering only those populations as regards the spreading of effects. Subordinate misconceptions, identified by Griffiths and Grant (1985) in their development of a learning hierarchy for food webs, which hinder full

understanding of the web concept are:

- a) that a change in one population will only affect another population if the two populations are directly related as predator and prey
- b) that a population located higher on a food chain within a food web is a predator of all populations located below it in the food chain
- c) that a change in the size of a prey population has no effect on its predator population

- d) that if the size of one population in a food web is altered, all other populations in the web will be altered in the same way.

The misconceptions listed above did not feature strongly amongst the answers given by first year university students to questions based on the correct understanding of these relationships. 100% of the students responded correctly that an increase in the size of a prey population may cause an increase in size of the predator population (Question 2), while only three students did not relate an increase in predator population to a possible decrease in prey population (Question 3). All the students related an increase in food supply lower on the food chain to a possible increase in an indirectly linked predator population (Question 4), while slightly less than 20% of the students had difficulty relating effects between non-adjacent populations not located on the same food chain (Question 5). These results, juxtaposed with the difficulties found by the majority of students in determining more than one route for the passage of

effects; suggest that the majority of students who correctly hold basic concepts do not successfully integrate their ideas to produce a holistic concept of food web.

Likewise, standard ten pupils had little difficulty with question 2, while 17% had difficulty with question 3. Only 4% had any difficulty with question 4, while 29% and 38% had difficulty with questions 5 and 6 respectively. Again, these data cannot explain the failure to list alternative routes for the transmission of effects by 99% of the pupils in terms of misunderstandings at lower levels. The same problems became apparent on analysis of the standard eight answer sheets, suggesting that previously acquired knowledge in terms of food chains was interfering with the development of a correct concept of food web.

Previously acquired knowledge has been shown in some instances to be highly resistant to change (Osborne et al., 1983). For change to occur learners must first find their present conceptions inadequate or unsatisfactory (Hewson, 1980). Dissatisfaction stems from loss of fruitfulness and plausibility of ideas, and for this to occur the subject must be presented with well chosen learning experiences which highlight the inadequacies in a present view (Driver and Erickson, 1983; Helm, 1980; Kelly, 1971; Osborne et al., 1983; Strike and Posner, 1982). Dissatisfaction with a present framework in itself may not be sufficient reason for a pupil or student to change viewpoint and access to new and better ideas is required for change to occur (Osborne et al., 1983). Also learners cannot be expected to change their ideas immediately when new or contradictory evidence is

provided, as concepts which may be linked to other ideas in complex ways may have to be changed or rethought, and this takes time.

Understanding that pupils have difficulty in progressing from the food chain to the food web concept, and that this may constitute a "block" in later understanding, forms a valuable point of departure for teachers. They have to integrate the pupils existing ideas with new knowledge and, if pupils are to change the way they think about food webs, they need opportunities to explore their own ideas in a non-threatening atmosphere (Engel Clough and Wood-Robinson, 1985b).

Worksheets of the type used in this study allow the learners to make their ideas explicit after which the teacher can provide structured, feedback-based opportunities for the pupils to talk through their ideas and alternative perspectives. In order to construct meaning for themselves pupils must be actively involved in reflecting on their own thinking and be encouraged to generate a range of conceptual themes (Driver et al., 1985).

Pupils should also be encouraged to generalise and practise their ideas in a variety of situations and given the opportunity to check out the range and limits of their ideas, possibly through the analysis of actual field data supplied in the form of a case study as described in the following chapter. In this way meaningful concepts, such as that of food web, may be developed.

CHAPTER FOUR

CASE STUDY

4.1 INTRODUCTION

Although it is generally accepted that successfully executed field work is the single most important and effective way of developing real understanding of ecological concepts and motivating pupils (Gayford, 1985; Saunders, 1972; Dowdeswell, 1974 and 1981; Fido and Gayford, 1982), as it combines first hand experience as well as requiring skills in recording and interpreting data, many classroom heuristics have been developed as supplementary and complementary activities to promote insight and understanding. Examples are the use of case studies (Roode, 1977), problem posing (Jungck, 1985), conservation design (Adams et al., 1985), conceptual models (Leonard, 1985), use of the local environment in built-up areas (Hale, 1986), analogies (Amos, 1986) and laboratory exercises (Lenton, 1975).

These activities have been developed as fieldwork often poses problems of organisation, particularly when large numbers of pupils are involved and access to a suitable ecological site is difficult. These problems are exacerbated by the fact that population processes extend for days, weeks, seasons and even years, thus a second practical difficulty concerns time. Because of these difficulties field work often degenerates into occasional forays into the out-doors where analysis is limited to the study of types of plants and animals and the preparation of long lists of names which the pupil "can neither spell nor pronounce" (Southwood, 1967), and numerous

descriptive accounts of the flora and fauna of a particular habitat or the behaviour and adaptations of plants and animals to various environmental variables. Earlier deriders of ecology have referred to these two types of research as "scientific nature study" and "bad physiology" respectively (Southwood, 1967). Summers and Summers (1976) confirm this perception and the paucity of recent literature on ecological techniques at school level suggests little change in methods until the recent introduction of population dynamics into most South African school syllabi in 1987.

Inadequate field work without synecological interactional analysis by means of data interpretation means that the pupils' first contact with ecology is such that they become familiar with loose concepts, without knowing how these can be implemented in the assessment of practical situations (Roode, 1977). Many teachers have little or no formal training in the subject and ecology appears amorphous and complex, bristling with difficulties by virtue of its very magnitude and depth. The blame for the failure to provide learning experiences which allow the creation of clear ecological concepts in the minds of the young cannot be laid entirely at the feet of teachers, as it is only in the last few decades that ecology has begun to crystallise itself around the related themes of energy flow, nutrient cycling and the spatial and temporal distribution of organisms. Also, the ecologist is faced with complex situations in which it is often impossible to forecast a reaction exactly, and therefore must become acquainted with thinking in terms of probabilities. Besides familiarity with the above, he must be able to derive sound generalisations from a variety of observations and at times even attempt to rank and quantify judgements or values.

The use of the case study described in this exercise, based on one produced by Roode (1977), requires pupils to analyse data similar to what they could have collected for themselves on an actual field study and therefore forms a heuristic promoting learning second only to actual field experience. Also, the ability or inability of pupils to manipulate, integrate and analyse these data provides the teacher with a clear indicator of their ideas and understanding of ecological principles and should at the same time make explicit what they are expected to understand, i.e. the importance of particular relationships in an ecosystem, how they interact and how this understanding can be used to make predictions based on sound ecological principles.

4.2 METHODS

After being introduced to populations represented in an aquatic ecosystem by means of a pictorial information sheet, the pupils and students were presented with the following exercise entitled "Case Study" which read as follows:

A stream was chosen for an ecological survey by a group of research workers as it appeared to be a typical example of an unbalanced system because of the construction of a reservoir near by. The flow of water was temporarily stopped and only recently resumed and the ecologists wanted to assess the changes that would take place in a section of the stream while the system was balancing itself again. The workers visited the area on five occasions corresponding with the different seasons (two summer visits). The following is a summary of the data obtained during these visits :

Biological data : January.	numbers/m ³	biomass/m ³
Phytoplankton	100	40 g
Zooplankton	0	0 g
Vertebrate Nekton (herbivores)	20	50 g
Predators	5	250 g

Biological data : April	numbers/m ³	biomass/m ³
Phytoplankton	1000 000	40 000 g
Zooplankton	10 000	600 g
Vertebrate nekton (herbivores)	30	400 g
Predators	5	350 g

Biological data : July	numbers/m ³	biomass/m ³
Phytoplankton	500 000	20 000 g
Zooplankton	80 000	900 g
Vertebrate nekton (herbivores)	45	800 g
Predators	12	1 500 g

Biological data : September	numbers/m ³	biomass/m ³
Phytoplankton	450 000	18 000 g
Zooplankton	100 000	1 000 g
Vertebrate nekton (herbivores)	30	600 g
Predators	12	1 750 g

Biological data : December	numbers/m ³	biomass/m ³
Phytoplankton	600 000	24 000 g
Zooplankton	5 000	64 g
Vertebrate nekton (herbivores)	5	250 g
Predators	15	2 000 g

The predators may prey on both herbivorous nekton and zooplankton.

The following energy values were determined in the laboratory for the different groups:

Phytoplankton 10 KJ/g

Nekton 12 KJ/g

Zooplankton 20 KJ/g

Predators 10 KJ/g

ANALYSIS OF THE SITUATION

Subjects were required to write a report on the data in the following manner:

1. Reorganise the data into meaningful **tables** and **graphs** using the frameworks provided. Construct a diagram to illustrate a food web for this system by filling in the blocks provided in the figure labelled "Food web".
2. Fill in arrows to show the direction of energy flow and write down the names of the trophic levels on the dotted lines.

3. Construct **ecological pyramids** of numbers, biomass and energy for December. Use the frames provided (yellow sheets). Explain why each pyramid has the shape and distribution that it has and explain what each means to you.
4. **Predation:** Using the data provided explain what you think are the effects and state between which populations they occur? Explain your answers.
5. **Population growth:** Use the population number data provided to comment on the growth of the populations and give explanations for the phenomena encountered.
6. **Composition of populations:** Compare the biomass and numbers over the five sampling occasions and explain what you think has happened in each case.
7. **Forecast** the composition of the community and the changes within the populations in the future. Explain your answer.

The subjects were provided with an answer sheet entitled "Case Study" and colour coded yellow to match the yellow question sheet. The question sheet was photostatically reduced onto one page as this allowed the pupils to see the data and questions together without having to turn over a page. Instructions were given that neatness was not a priority and that the graphs could be drawn fairly roughly as long as they represented the correct shape as dictated by the data.

An information sheet containing visual representations of examples of phytoplankton, zooplankton and nekton was provided, as the worksheet was based on an aquatic system which many pupils find difficult because of the apparent lack of producers (Adeniyi, 1985). The rationale for using an aquatic ecosystem as opposed to a terrestrial one is that:

- a) the unfamiliarity of the populations making up the community requires the subjects to concentrate on ecological principles
- b) it emphasises the universality of ecological interactions
- c) it requires positive identification of phytoplankton as producers and illustrates the contribution made in terms of numbers and biomass by these microscopic organisms.

Appendix A provides an example of the case study worksheet used by the subjects of this exercise.

The subjects' explanations, when answering individual items, were analysed for key ideas and common criteria and a series of categories of answer types developed. These categories were developed only after the major common groups had been identified and were not predetermined. The frequency with which answers fell in each category was recorded.

For a correct answer, as regards the ecological pyramids, the subjects were expected to subdivide the pyramids according to trophic levels, giving an approximate division size as indicated by the data on numbers, biomass and energy. Explanations needed to have expressed why the candidate had drawn

the pyramid in that particular form. A second category of answer was classified as those who drew the pyramids correctly but gave confused or unclear explanations for their representations, e.g. an explanation for the shape of the biomass pyramid: "the predators are the most heavy and are found on the top of the pyramid". Pyramids with the trophic levels incorrectly placed were classified as incorrectly answered, and a fourth category was allocated to those who made no attempt to answer the question.

Answers to the predation, growth and community composition questions were classified into those which referred to all possible interactions correctly; those that only referred to one interaction between certain levels and not others; those that were incorrect; and those where no attempt was made to answer the question.

The prediction answers were scrutinised as to whether the subjects recognised that the system was in a state of imbalance and those answers which stated that the system had reached a state of equilibrium were classified as incorrect. The number of "no-responses" was also noted.

4.3 RESULTS

4.3.1 FIRST YEAR ZOOLOGY STUDENTS

100% of the students could set up tables and produce graphs accurately from the data provided, but only 31% depicted the food web accurately with the producers forming the base. 20% placed the predators in the base block provided while 43% drew the arrows depicting energy flow pointing in the

wrong direction, or did not fill in the arrows although instructed to do so. 6% did not attempt to answer the question.

The questions on the food pyramids were unsatisfactorily answered, the majority of students being unable to subdivide the pyramids with the respective populations at the correct trophic levels nor being able to explain the reasons for their answers coherently.

Pyramid type:	numbers	biomass	energy
Pyramids drawn and explained correctly	35%	17%	13%
Correctly drawn but explanation unclear	2%	20%	18%
Incorrect	57%	63%	63%
No attempt made to answer the question	6%	0%	6%

Table 1. Breakdown of results expressed as a percentage obtained from questions answered by first year zoology students on ecological pyramids.

More than 40% of the students answered the questions on predation and population growth correctly or partially correctly, while 69% could not answer the population composition question.

	Predation	Growth	Composition
All relationships mentioned	22%	20%	11%
Partially correct answers	20%	28%	20%
Incorrect answers	37%	41%	43%
Question not attempted	21%	11%	26%

Table 2. Results of the questions answered by first year zoology students on predation, population growth and population composition expressed as a percentage.

34% of the students were able to forecast that there would be a rapid decrease in numbers of predators as their food source had become depleted and that this would probably lead to a re-establishment of equilibrium. 13% attributed the population fluctuations to seasonal changes, e.g. that the phytoplankton "died off" in winter, rather than to predatory interactions, and predicted a cyclical system of increases and decreases. 33% of the students gave incorrect predictions, the majority stating that the system had reached equilibrium and was now stable, while 20% made no attempt at a prediction.

4.3.2 STANDARD 10 PUPILS

All the pupils could set up tables and produce graphs accurately from the data provided and 41% depicted the food web accurately with the producers forming the base. 30% placed the predators in the base block provided while 23% drew the arrows depicting energy flow pointing in the

wrong direction, or did not fill in the arrows although instructed to do so. 6% did not attempt to answer the question.

The questions on the food pyramids were poorly answered, the majority of pupils being unable to subdivide the pyramids with the respective populations at the correct levels nor being able to explain the reasons for their answers coherently.

Pyramid type:	numbers	biomass	energy
Pyramids drawn and explained correctly	15%	6%	6%
Correctly drawn but explanation unclear	0%	3%	3%
Incorrect	76%	76%	79%
No attempt made to answer the question	9%	15%	12%

Table 3. Breakdown of results obtained from questions answered by standard 10 pupils on ecological pyramids expressed as a percentage.

Only 32% and 21% of the pupils answered the questions on predation and population growth respectively correctly, while 97% could not answer the population composition question fully.

	Predation	Growth	Composition
All relationships mentioned	32%	21%	3%
Partially correct answers	29%	32%	29%
Incorrect answers	28%	32%	41%
Question not attempted	11%	15%	27%

Table 4. Results of the questions answered by the standard 10 pupils on predation, population growth and population composition expressed as a percentage.

Only 18% of the pupils were able to forecast that there would be a rapid decrease in numbers of predators as their food source had become depleted and that this would probably lead to a re-establishment of equilibrium. 3% attributed the population fluctuations to seasonal changes rather than to predatory interactions, and predicted a cyclical system of increases and decreases. 50% of the students gave incorrect predictions, the majority stating that the system had reached equilibrium and was now stable, while 29% made no attempt at a prediction.

4.3.3 STANDARD 8 PUPILS

All except one of the pupils could set up tables and produce graphs accurately from the data provided and 43% depicted the food web accurately with the producers forming the base. 9% placed the predators in the base block provided while 48% drew the arrows depicting energy flow pointing in

the wrong direction, or did not fill in the arrows although instructed to do so. All of the pupils attempted to answer the question.

The questions on the food pyramids were not well answered by the majority of standard eight pupils, but nevertheless they were more successful than the standard 10 pupils. The same problems were experienced by both groups, i.e. they were unable to subdivide the pyramids into respective population groups at the correct trophic levels nor were they able to explain the reasons for their answers coherently.

Pyramid type:	numbers	biomass	energy
Pyramids drawn and explained correctly	24%	19%	4%
Correctly drawn but explanation unclear	9%	5%	4%
Incorrect	33%	43%	48%
No attempt made to answer the question	34%	33%	44%

Table 5. Breakdown of results obtained from questions answered by standard 8 pupils on ecological pyramids expressed as a percentage.

Only 24% and 14% of the pupils answered the questions on predation and population growth respectively correctly, while 99% could not answer the population composition question fully. Some however noted that the

zooplankton and phytoplankton communities' biomass was proportional to their numbers.

	Predation	Growth	Composition
All relationships mentioned	24	14	1
Partially correct answers	19	1	1
Incorrect answers	19	37	19
Question not attempted	38	48	79

Table 6. Results of the questions answered by the standard 8 pupils on predation, population growth and population composition expressed as a percentage.

Only two pupils were able to make a reasonable forecast as to the future community composition based on the data supplied. 14% of the students gave incorrect predictions but by far the majority (67%) made no attempt at prediction, suggesting that they found difficulty in interpreting and answering the questions.

4.4 DISCUSSION

The generalisations under scrutiny in the case study exercise were:

- a) In every ecosystem, all consumers directly or indirectly depend on producers for food.

- b) At any trophic level there are generally more organisms than there are at the next higher trophic level.
- c) Available energy decreases as one progresses from producer to consumer levels in a food chain.
- d) Because of the relatively large numbers of producers, with decreasing numbers of consumers at higher trophic levels, there exists a pyramid of numbers.
- e) Populations in an ecosystem may be directly or indirectly affected by changes in population numbers in other groups.

A free response format was chosen for this exercise in preference to misconception test items used in earlier studies by Helm (1980) and Za'rour (1975), as this enabled the subjects to make their own ideas explicit and enabled the post-operative identification of misconceptions and inadequacies in ideas.

The data suggest that pupils and students are often not clear in their own minds as to what an arrow in a food web represents, i.e. a route of energy flow. Also the subjects, more often than not, do not clearly understand what ecological pyramids represent, merely using the pyramid as a ladder, placing whatever population contained the most organisms below a group containing less organisms, regardless of the trophic level. Answers offered for the questions on biomass and energy pyramids indicated even greater confusion. Pupils and students did not relate the biomass of

organisms to the KJ/g figure quoted for the population and often merely placed the population groups on the pyramid in order of their energy content per gram.

The poor responses to the questions on predation and population composition as indicated by the large number of "no-responses" and answers such as "an increase in predators causes a decrease in primary producers"; indicate that if pupils and students are to understand the processes involved in population dynamics, these relationships and effects must be made explicit and the learner allowed to generalise and use this knowledge in a range of situations. Knowledge of these relationships may then allow pupils and students alike to understand how resources can be over-exploited and the carrying capacities of systems exceeded.

Very few subjects were able to relate changing number/biomass ratios to possible reproductive periods, age distributions within the population, individual growth, immigration and emigration of organisms. These possibilities should also be made explicit by the teacher and the learners allowed to work with concrete examples.

That pupils can integrate information and solve problems successfully in standard eight is indicated by the calibre of answers of some of the pupils at this level. One answer to a question relating growth in numbers to biomass read as follows:

"In January the large phytoplankton population was grazed down and grazing kept their mass even. As numbers increased so did biomass. The same happened to the zooplankton. Nekton were plentiful in small sizes at the beginning of the year but towards the end of the year numbers started

diminishing with the increase in predator presence. The average biomass increased steadily as the larger individuals were not preyed upon as much as the smaller types. Predator biomass and numbers increased steadily with the increasing amount of food available".

Nevertheless, both students and pupils generally found the case study difficult to answer. This may be attributed to the fact that they had never been required to do exercises of this nature before, and possibly because the manner in which they had been taught the nature of the relationships, required for the elucidation of the processes under question, had not led to sound concept development.

Asking individuals to forecast events from provided data makes explicit one of the implicit applied reasons for studying ecological processes, i.e. conservation and management. Explicit teaching of the nature of relationships within an ecosystem, supplemented by concrete examples before pupils are asked to complete a worksheet such as was used in this study, may make it easier for them to produce correct answers and generate meaningful concepts. Simpler and more striking data may also have the desired effect as long as the effects are not exaggerated to such an extent that they no longer have any bearing on real life experiences of the learner. The large number of unanswered questions by standard eight pupils supports the premise that simplification of the case study might enable younger pupils to better order their impressions and more easily create their own framework of understanding.

Pupils in general had the ability to produce graphs from the data provided and therefore this suggests a method which may be used successfully as a

starting point in the classroom. Subsequent failure by most pupils in this study to analyse the system correctly from these representations suggests that the value of the exercise may stem from the discussion generated, rather than from the completion of the worksheet alone. Discussion of this sort allows the re-organisation of ideas in the light of the thoughts and frameworks of others in the class, including those of the teacher.

Topics brought to light in this study which need particular attention and discussion are those pertaining to interactions determining population size, e.g. predation, competition, immigration - emigration and fecundity - mortality states. The importance of these concepts is highlighted by the recent introduction of population dynamics in the South African Senior Biology syllabus. Also, the concepts involved as regards energy supply and flow within an ecosystem need careful airing, and the concrete examples (such as the well known "Kaibab deer explosion" of the 1930's in the United States of America and the "grass, rabbit, lynx" population cycles) need to be used to promote understanding of the delicate balance within ecosystems and the principles of conservation.

CHAPTER FIVE

QUESTIONNAIRE

5.1 THE QUESTIONNAIRE

A free-format questionnaire was given to the students and pupils to be filled in on the completion of both exercises. It read as follows:

PUPIL QUESTIONNAIRE

1. When last were you taught ecology/population dynamics?
2. Which exercise did you do first, the case study or the food web?
3. Was the order in which you were given the exercises correct, i.e. did the first exercise help you to understand the second? Explain your answer.
4. What did you find
 - (a) helpful?
 - (b) confusing?

5. Is there anything you understand now that you did not before?
.....
.....
 6. What did you find most difficult to do in the worksheets?
.....
.....
 7. Why do you think you found the above difficult?
.....
.....
 8. Were you able to develop a picture of what was happening in the ecosystem from the a) tables?
b) graphs?
- Please comment
-
-

5.2 RESPONSES

The first year zoology students and the standard 10 pupils had all been taught ecology during the course of the year while most of the standard 8 pupils were given the exercises immediately on completion of this section of work.

5.2.1 STUDENT RESPONSES

26 of the 54 students answered the case study first while 28 began with the food web exercise. 75% of the students who answered the food web exercise

first felt that it had helped them answer the case study questions, while 25% felt that it had made no difference. 42% of the students who had begun with the case study felt that this was the correct order in which the two exercises should be done, but 42% felt they would have done better in the case study had they done the food web first, some articulating the reason for this as being that the food web was a simpler exercise. 16% felt that it made no difference. Combined responses favouring doing the food web first totalled 56%.

Factors which the students found helpful were the graphs (13 responses), the tables (6 responses) and the information sheet (6 responses), while three students responded that doing the case study and food web exercises was helpful to their understanding of ecological relationships.

The most common student response as to what they found most confusing was ecological pyramids (11 responses), while 30 students stated that they found the questions on the pyramids the most difficult items to answer. Examples of reasons given for this were that:-

- a) there was insufficient information provided
- b) the pyramids were "not well explained"
- c) they did not understand this concept when it had been taught in class.

Two students noted that the case study was the most difficult to do because "there was too much to think about" and one rather revealingly stated that "I had to think"!

All the students except one felt that they were able to develop a picture of what was happening in the case study from the graphs, while 19 of the 54 felt that they could not visualise the situation from the information given in the tables alone. Responses were that "tables are merely numbers to me", while others answered that the graphs "helped visualisation" and enabled them to "understand the situation at a glance".

Unsolicited responses were that "the food web is a good way to learn" and that "the case study gave insight to the balance of nature".

5.2.2 STANDARD 10 PUPIL RESPONSES

All of the pupils answered the case study first with two to every one feeling that this was the correct order in which to do the exercises. 58% felt that drawing the graphs was the most helpful aspect of the case study, while 8 of the 60 pupils noted that they found the information sheet helpful. Eight pupils also noted that they found both exercises helpful to their understanding of ecology.

Nearly 40% of the the pupils (23) found the food web exercise confusing, while 52% (31 pupils) perceived the ecological pyramids as being the most difficult items to complete. The comments of six pupils suggested that they felt the work had exercised them mentally, e.g. "I had to think hard to find answers", "it took time to think out answers" and "you had to think quite a while before getting it right".

37% of the standard 10 pupils stated that they could not get a clear picture of what was occurring from the tables alone, while only three

pupils felt that they could not visualise the situation from the graphs. Only one student made an unsolicited response which was a statement that the exercises were "interesting".

5.2.3 STANDARD 8 PUPIL RESPONSES

All the standard eight pupils began with the case study and half felt that this was the correct order in which to do the worksheets, while the rest felt that it would have been better to start with the food web. Working through the food web was cited as being helpful by 38% of the pupils, while 29% felt that the graphs had helped them in the elucidation of the case study. 14% identified the information sheet as being helpful.

35% of the pupils found the pyramids confusing and 43% identified them as the most difficult section to do. Nearly 20% found the case study confusing. Many more responses were made by the standard eight pupils than were given by the other groups when asked if there was anything they knew on completion of the exercise that they had not known before. These were quoted as: biological terms (3 pupils), the effects of predation (2 pupils), the complexity of relationships in a food web (4 pupils) and how food chains work (2 pupils).

The usual responses were made to the questions asking if the pupils could determine interactions in the ecosystem from the tables and graphs, with almost all stating that the graphs enabled a clearer interpretation than the tables. Examples of comments were "It was easier to picture the proportional changes in population and mass from the graphs" and "the tables and graphs complemented each other". An unsolicited response as to

the perceived value of the exercises read as follows: "A valuable exercise in understanding ecology. It is good to get some practical experience at working out how and what happens in an ecosystem".

5.3 INFERENCES

The data give no clear indication of student or pupil preference as to which exercise should be done first in order to understand better the second. Nevertheless they do suggest that the subjects saw relationships between the two and that involvement with either made for easier understanding of the other. One may possibly infer from this that pupils and students felt that exercises such as these may be of value in concept development in ecology.

Both students and pupils felt that the drawing of graphs gave them insight into the processes taking place in the case study and that this was preferable to trying to analyse data presented in tabular form. Also, both pupils and students admitted that they had difficulty in providing visual representation and explanations of ecological pyramids, the reasons given being, "this was not well explained in class" and "I did not understand this work when it was done". This suggests that teachers, possibly perceiving ecological pyramids to represent simple concepts, may be unaware that pupils need to work through the concept themselves and explicitly create ecological pyramids on paper in order that misconceptions may be detected and corrected. This is supported by the pupils' and students' perceptions that drawing visual representations, in this case graphs, promotes understanding. Comparison of pyramids representing balanced and unbalanced ecosystems will allow the learner to see at a glance what is

causing the imbalance.

52% of the standard 10 pupils perceived the food web to be difficult while only one student noted that difficulties were experienced in this exercise. One may possibly be tempted to attribute this to the fact that first year students are a selected group more able to deal with abstractly presented problems, but this notion is dispelled by the fact that the standard 8 pupils did not identify food webs as an area of difficulty at all. Responses indicating that 8% of both students and pupils felt that they knew something more about ecological concepts after doing the exercises than they had known before nevertheless suggests that food web relationships should be made explicit by teachers and that pupils be given the opportunity to work through similar exercises themselves. This is supported by student and pupil responses which indicate that the exercises made them think in order to produce an analysis to their satisfaction as well as by the unsolicited positive responses from all three groups.

CHAPTER SIX

SUMMARY AND IMPLICATIONS

6.1 SUMMARY

The results of this open-ended, free-format study on concept status in aspects of ecology by high school pupils and first year zoology students may be summarised as follows:

6.1.1 FOOD WEB

Students and pupils could solve problems satisfactorily if they were simple enough to be answered using strategies based on the food chain concept, but very few subjects could successfully determine all the interacting pathways along which effects may be transmitted within a food web. The ability to determine all the pathways along which the effects of a change in population numbers within a community are spread, and to analyse the possible net manifestation of sometimes conflicting forces, requires a clear understanding of the concept of food web.

Present data suggests an immature understanding of the food web concept in most of the subjects in this study, as in most cases they identified alternate pathways within the food web only when explicitly asked to do so, but did not apply this strategy when asked to solve problems based on the same principle.

It is suggested that previously held knowledge, in this case in the form of

the food chain concept, may hinder or block mature development of the food web concept. It is consequently suggested that all the ramifications of the transfer of effects within a food web be made explicit by the teacher, and that pupils be encouraged to talk through and test their ideas against those of their peers and teachers in order to construct meaning for themselves. The evaluation of ideas for plausibility and fruitfulness by learners against the frameworks of others may successfully highlight inadequacies and offer alternatives for a change in viewpoint.

Responses by standard eight pupils indicate that the opportunity exists at this level to develop a clear and mature understanding of the concept of food web, while comparison of data provided by the three age groups suggests that if clear conceptual development regarding food webs does not take place at school, misconceptions are likely to persist among first year university students, despite instruction.

6.1.2 CASE STUDY

The data suggest that pupils and students are often not clear in their own minds as to what an arrow in a food web represents. Subjects also did not understand that ecological pyramids were subdivided according to trophic levels and were confused when numbers, biomass and energy data in the unbalanced system described conflicted with the order of levels. It is suggested that pupils be required to draw ecological pyramids for balanced and unbalanced systems to allow visual perspectives of the effect of imbalances in a system.

The questions on predation, population composition and numbers/biomass ratios were also poorly answered and it is suggested that for maximum benefit teachers make these relationships explicit before allowing learners to work through a case study.

Both students and pupils had difficulties answering the questions asked in the case study, but the quality and calibre of answers offered by some standard eight pupils suggests that pupils at this age can produce the required ideas and cope with the concepts involved, particularly if the data provided produces a clear, perhaps even exaggerated, picture.

It is suggested that case studies be used to enable teachers to understand the level of development of concepts held by their pupils and to focus class discussion in order to allow the re-organisation of individual's ideas in the light of the thoughts and frameworks of others.

6.1.3 QUESTIONNAIRE

Both pupils and students felt that the drawing of graphs gave them insight into the processes taking place in the case study but felt that the ecological pyramids represented the most confusing and difficult questions to answer. It is suggested that teachers possibly perceive ecological pyramids as representing simple concepts but, as this perception is not shared by students or pupils, need to allow pupils to work through the concept themselves by requiring them to draw and compare pyramids of balanced and unbalanced systems.

Many pupils and students perceived that the case study and food web exercises made them think in order to produce satisfactory analyses and some, after completion of the exercises, felt that they understood ecological concepts and relationships better than they had before.

6.2 IMPLICATIONS

The results of this study have implications for teachers, text writers, curriculum designers and researchers in the field of concept development in ecology.

6.2.1 TEACHERS

The work described in this study provides evidence that pupils and first year university students find ecology a difficult conceptual area and therefore, for successful teaching, educators must know the level of conceptual development of their learners, both generally and specifically. A teacher cannot predict an individual's knowledge and understanding prior to teaching the topic but, on available evidence, can be fairly confident that pupils will hold similar views. In this case teachers should be aware that previous knowledge can hinder or form a block to the formation of new concepts, e.g. the food chain concept may hinder the mature formation of the food web concept.

Other specific areas which should be made explicit and worked through carefully are:

- a) that an arrow in a food chain or food web indicates the direction of energy flow from a lower to a higher trophic level

- b) that ecological pyramids are subdivided according to trophic levels and that in a balanced system a pyramid of numbers, biomass or energy may be formed, but in an unbalanced system the numbers, biomass or energy may form variable proportions

- c) that pupils and students should be allowed to work through manageable data illustrating real life situations to encourage understanding of the effects of inter-specific relationships affecting population compositions within ecosystems.

Subject responses to the questionnaire indicate that some pupils felt that the use of case studies and food web exercises was a valuable way of learning. Also, the knowledge of individual pupil's ideas attained through the explanation of answers, given by subjects working through fairly open-ended but objective-directed worksheets after normal classroom instruction, may then be used to direct classroom discussion in a non-threatening atmosphere so that pupils can talk through their ideas and reflect on their plausibility in comparison to the frameworks of others. Pupils should also be encouraged to generalise and practise their ideas in a variety of situations and given the opportunity to check out the range and limits of their ideas in order to produce mature mental constructs.

6.2.2 TEXT WRITERS

The implications for the writers of biological texts are much the same as those for teachers as regards making explicit the basic concepts governing interactions within ecosystems. Past matriculation texts such as "Senior Biology for Standards 9 and 10" (du Toit et al., 1975) which was

extensively used in the Cape Province, devoted one page to food chains and one brief reference to food webs. The reference read "Isolated food chains never occur in nature. Usually a number of food chains are so interwoven that they form a large and often very complex food web". The three types of ecological pyramids were also inadequately dealt with, these topics covering one page, half of which was used for illustrations. "Exploring Life" (Thienel et al., 1975) has only a one page description of food chains, food webs and ecological pyramids and an inadequate half page explanation of energy flow in ecosystems. All the concepts described above are afforded less than a page in "Modern Biology for South African Schools Standards IX and X" (Schutte et al., 1975), while energy flow is not discussed at all. The topics of Ecology, Natural Selection and Evolution are combined in "Revised Biology for Matriculants" by Austoker and Cheeseman (1966) and cover a mere six and a half pages.

New texts such as "Discovering Biology 10" (Ayerst et al., 1987) make explicit the mathematical relationships required by the new population dynamics syllabus and provide three pages of exercises on this topic. Energy flow is also fairly effectively dealt with over three pages, which is an improvement on earlier texts. The standard eight text by the same authors also deals with energy flow within ecosystems but unfortunately deals with food chains, food webs and ecological pyramids in much the same superficial way as the standard ten texts described above.

A standard six text by Clarke et al. (1987) discusses food chains effectively but the only statement as regards food webs is that "in nature there is hardly ever one simple food chainFood webs consist of many food chains"! In the standard five "Nasou Panel" (1984) text, pupils are asked to draw up "two or three food chains for the plants and animals

within your ecosystem", but nowhere in this text is an example of a food chain given!

Although the above examples come from a small sample of South African texts available, they are fairly representative as most authors follow the core syllabus closely. Since texts provide the basis for what is taught in the classroom, these examples suggest that a more detailed investigation of all South African Biology texts would be useful in order to understand better what ecology is being taught in the classroom. It would also form the basis for the preparation of better texts by making explicit the weaknesses in current issues.

An earlier text by Smit and van Dijk (1970), designed for pupils, teachers and Training Colleges, but unfortunately not extensively used in South African schools, is an example of a text which addresses in more detail the fundamentals of ecology and which could act as a guide to future text writers. Real life examples of food webs are given and examples of ecological imbalances described. Ecological pyramids, energy flow and population growth curves are clearly explained and actual data used to illustrate examples.

6.2.3 CURRICULUM DESIGNERS AND RESEARCHERS

Curriculum developers need to know the misconception areas commonly held by learners and understand which previous knowledge may hinder more mature concept development, in order to select and organise intended learning outcomes which would challenge alternative explanations and help pupils and

students restructure them in the light of experience. There is also need for further research into the nature of the information that is presented by text books and to determine what learners get out of this instruction. Also, the strategies used and the emphasis placed on this area of biology by teachers, should be investigated. Content research studies should be embarked upon to find out what knowledge is being taught to students and how this knowledge compares with intended curricula as well as how these findings may be incorporated into the design and organisation of new syllabi and texts.

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CASE STUDY WORKSHEET

1. TABLES AND GRAPHS

TABLES

	JAN	APR	JUL	SEPT	DEC
Phytoplankton					
Zooplankton					
Nekton					
Predators					

Table 1 : Number of organisms at each sampling time

	JAN	APR	JUL	SEPT	DEC
Phytoplankton					
Zooplankton					
Nekton					
Predators					

Table 2 : Biomass of organisms at each sampling time

GRAPHS

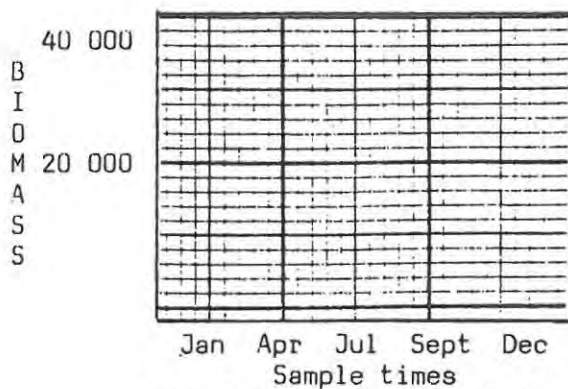


Figure 1 : Graphs of Phytoplankton and zooplankton biomass versus time

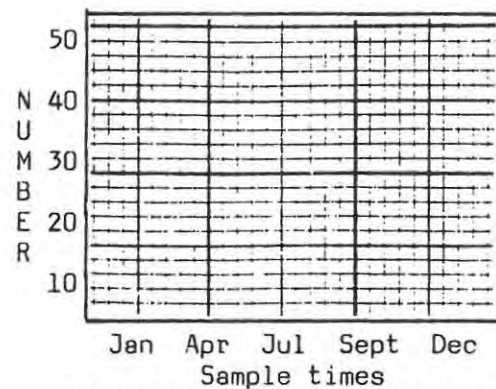


Figure 2 : Graphs of Predator and herbivorous nekton numbers versus time

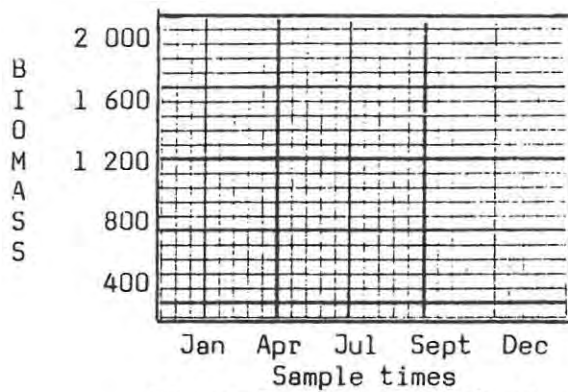


Figure 3 : Graphs of Predator and herbivorous nekton biomass versus time

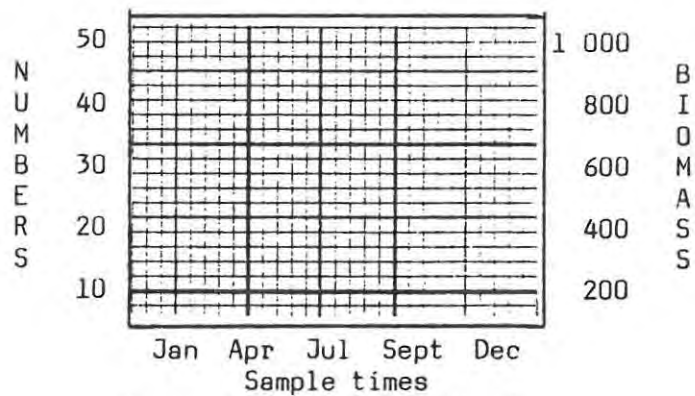
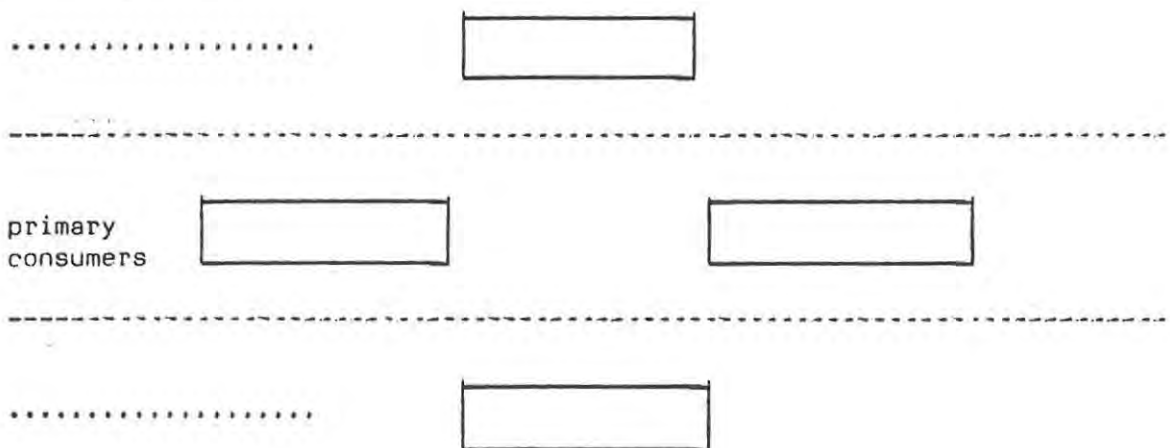


Figure 4 : Graphs of Herbivorous nekton numbers and biomass versus time

2. FOOD WEB



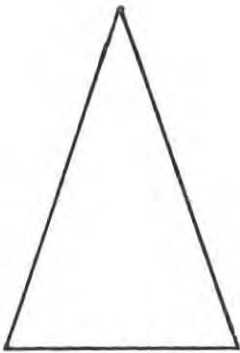
3. ECOLOGICAL PYRAMIDS



pyramid of numbers

Explanation :

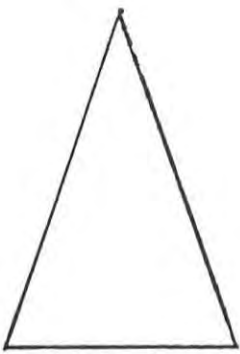
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pyramid of biomass

Explanation :

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pyramid of energy

Explanation :

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4. PREDATION ANSWER :

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5. POPULATION GROWTH ANSWER :

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6. COMPOSITION OF POPULATION ANSWER :

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7. FORECAST :

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