TEACHING ECOLOGICAL PRINCIPLES AS A BASIS FOR UNDERSTANDING ENVIRONMENTAL ISSUES

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SUMMARY

In this study an abstract food web and ecological case study data were used to determine high school pupils' and university students' ability to predict possible outcomes of interactions between populations within a community. Present data indicate that the majority of respondents could predict interactive outcomes within a food web if they were simple enough to be answered using strategies based on the food chain concept, but most respondents were unable to predict probable outcomes when the effects of a change in one population within a community are spread along multiple routes. Almost all the pupils and students could reorganise population data into satisfactory tables and graphs, but less than 50% of the respondents could integrate clues and predict outcomes acceptably. Data provided by three respondent age groups suggest that if clear conceptual development regarding interactions between populations does not take place at school level, misconceptions are likely to persist among first year university students. Also, the poor quality of answers given by respondents indicates that explicit teaching, prior to the use of such exercises, may greatly enhance their value. It is suggested that, by asking pupils to forecast events from supplied data, one is making explicit one of the implicit, applied reasons for studying ecological processes, i.e., conservation and management.

INTRODUCTION

During the last few decades ecology has crystallised around the related themes of energy flow, nutrient cycling and the spatial and temporal distribution of organisms. During this period ecology has also become more prominent in the South African senior school biology core syllabus, with work previously done at matriculation level recently being shifted to standard 8, and population dynamics being introduced in the standard 10 year.

Trophic relationships weave a unifying web throughout ecology and form the basis for an understanding of the food web concept which, once mastered, allows for a clearer understanding of more abstract representation and treatment of data as presented in the population dynamics section of the syllabus.

Food webs, and the models used to illustrate the dynamics of interactions within and between populations in a community, are simplified representations of what may occur in the field. The more realistically these models mirror nature, the more complex they become, and the process of predicting how field interactions between populations may affect other populations in a community becomes an onerous task (Summers and Summers 1976). Nevertheless, a clear understanding of webs and population dynamics models are central to the understanding of ecological principles and the ability to logically forecast possible ecological outcomes (Alexander 1982). These abilities in turn form the basis for understanding important environmental issues such as conservation, pollution and population management (Griffiths and Grant 1986).

In order to gain some insight into high school pupils' and university students' understandings of ecological principles, 43 standard 8 pupils, 65 standard 10 pupils and 54 first year zoology students were presented with questions based on a food web and population data. These data required reworking into tables and graphs in order to provide reasonably clear indicators of trends in the ecosystem.

METHODS

General

Pupils were presented with worksheets during normal school periods and the first year zoology students answered questions voluntarily on completion of afternoon practical sessions. It was made clear to all that the purpose of the testing was not to evaluate individual ability or knowledge and that the worksheets could be returned anonymously. It was also stressed that the questions were open ended and that it was the participants' ideas which were of value to the researchers.

Food Webs

A food web (figure 1) and a number of questions (table 1) ranging sequentially from those based on the most simple of trophic relationships to those based on complex interactions, were presented to the subjects in order to probe their understanding of ecological concepts. The food web involved only four routes between the populations in question, as increasing the complexity of the web beyond this would have only increased the tediousness of the task without demanding greater understanding (Griffiths and Grant 1985).

Test items followed a free response format and, when responding to any given question, the subjects were

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asked to indicate the reasoning they used to arrive at their answer. This information was used to evaluate a respondent's mastery status at different levels of complexity and each subject's explanations were analysed for key ideas and common criteria. Statistical analyses of significant differences between groups was made using one-way analysis of variance (Anova).

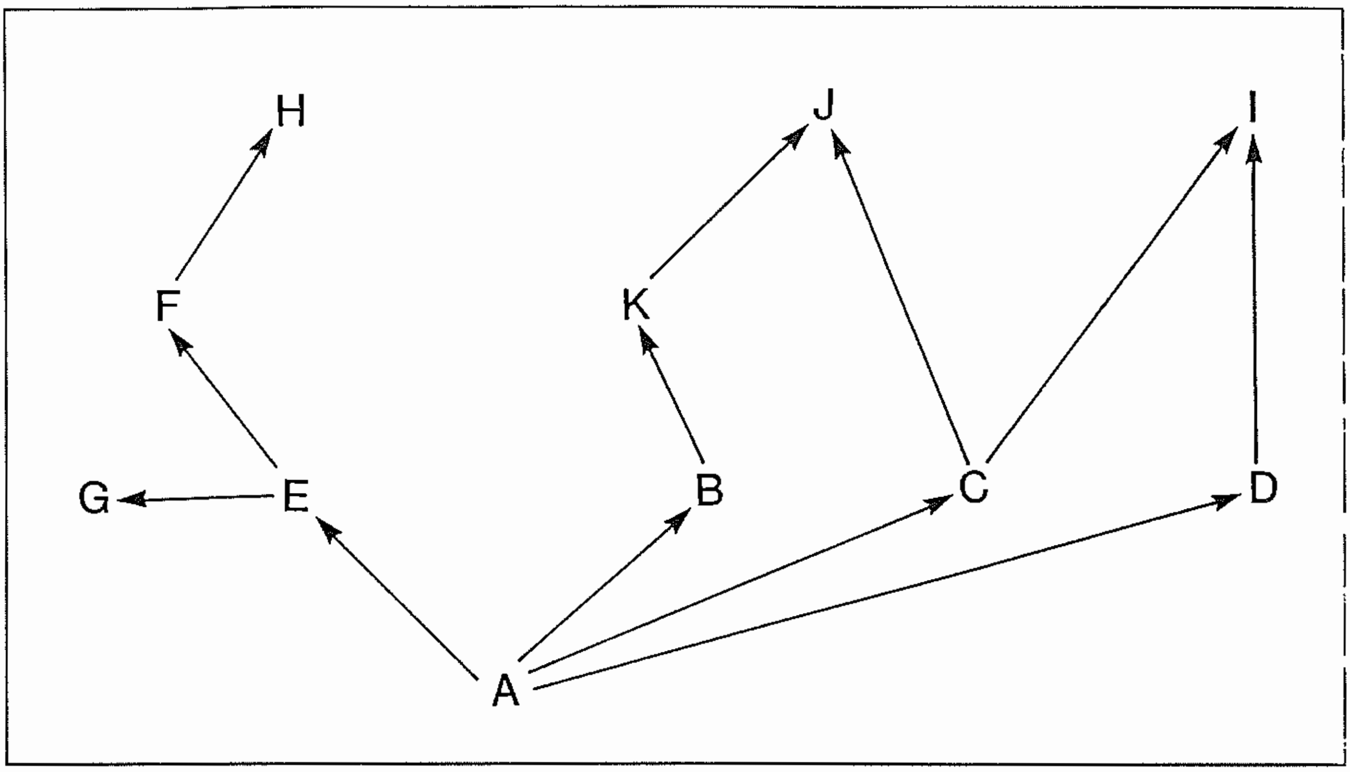

Figure 1: Food web on which population interaction questions were based.

Table 1 : Sequence of questions asked on food web relationships.

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

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

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

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

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

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

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

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

9. What effect will a sudden increase in population I have on population K? Explain your answer.

Data Interpretation

Pupils and students were presented with a case study exercise, similar to one proposed by Roode (1977), based on a river system recently disturbed by the construction of a dam upstream. Prose form population density, biomass and energy data were supplied for re-working into tables and graphs (figure 2). Frameworks for both the tables and graphs were provided and instructions were given that neatness was not a priority as long as the tables were legible and the graphs represented the correct shape as dictated by the data.

The respondents were asked to produce a simple food web for the system by: a) filling in the blocks provided (figure 3), b) writing down the trophic levels on the dotted lines, and c) filling in arrows to show the direction of energy flow. They were also asked to draw an ecological pyramid of numbers using data from a specified month.

Following this, a sequence of questions requiring interpretation of the tables and graphs, was presented.

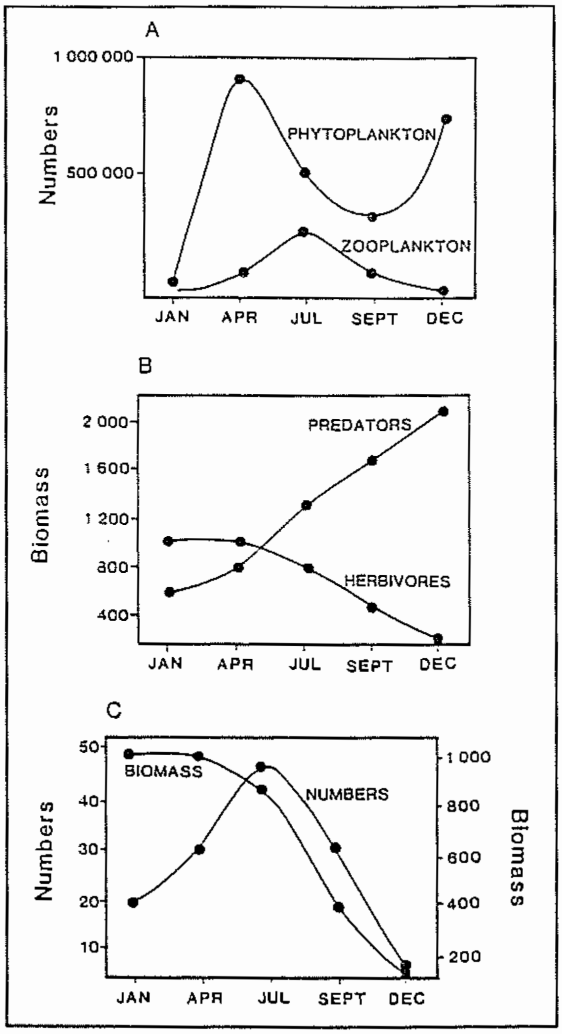

Figure 2: Examples of graphs on which population interaction questions and forecasts were based: A represents phytoplankton and zooplankton numbers versus time; B represents predator and herbivore biomass versus time; C represents herbivore biomass and numbers versus time.

The questions asked the respondents to describe all predatory interactions and effects and to name thepopulations concerned in each case, as well as to use the data on population numbers to comment on the growth of the populations, compare the biomass to numbers ratios during the sampling period and to forecast the composition of the community and any changes which might take place within the populations in the near future. The respondents were also required to explain their answers and give reasons for their forecast.

RESULTS

Food web

Responses given to the questions asked on interactions between populations within the food web indicated no statistically significant differences between the number of correct answers given by the three age groups to questions based on effects transmitted along only one route, i.e., questions 1 to 5 ($F = 0{,}672$, $p > 0.05$). Both pupils and first year zoology students had little difficulty answering these questions and a pooled average of 86% was attained.

No statistically significant differences were found between the number of correct answers given by the three groups to questions based on effects transmitted along more than one route, i.e., questions 7, 8 and 9 ($F = 2{,}501$, $p > 0{,}05$), but in the case of these three questions, only a pooled average of 2% of the respondents answered the questions correctly by recognising that the effects could be transmitted along more than one route. 67% of the respondents selected only one of the alternate pathways and considered successive predator-prey links until they reached the target population on which the question was based. 30% of the respondents gave incorrect answers or did not respond while only 1% gave the correct answer but did not venture an explanation.

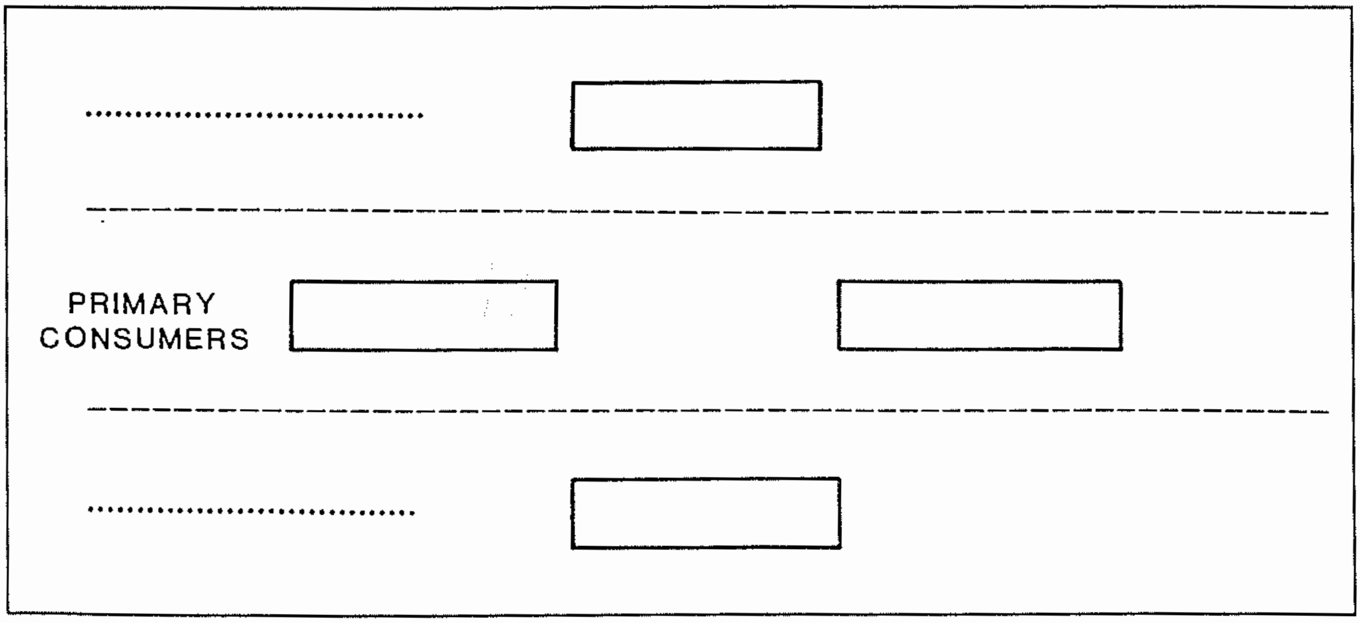

Figure 3: Framework provided to respondents for construction of a simple food web.

Nevertheless, when asked specifically to indicate the populations through which the effect of an increase or decrease in numbers within a specific population may be passed to another specified population, 72% of the respondents were able to identify more than one route.

Data Analysis

Only one of the 162 respondents could not reorganise the data into satisfactory tables and graphs. These tables and graphs, even in fairly rough form, gave enough information for tentative conclusions to be drawn.

Little difference was found between the abilities of the standards 8 and 10 pupils, and first year university students, to correctly depict the food web, with only an average of 38% being able to do so. 20% of the respondents placed the predators in the base block, while 38% drew the arrows depicting energy flow pointing in the wrong direction. 4% did not fill in any arrows.

Data chosen for the constructions of an ecological pyramid of numbers represented a situation of imbalance in the ecosystem. The majority of pupils and students (75%) were unable to subdivide the pyramids with the respective populations at the correct trophic levels, or coherently explain their reasons for doing so.

Only 4% of the 15 year-olds, 18% of the 17 year-olds, and 11% of the first year zoology students were able to forecast a rapid decrease in the number of top predators as their food resource became depleted, and that their depletion should contribute towards the re-establishment of equilibrium. A number of university students (33%) and final year high school pupils (50%) stated that the system had already reached equilibrium and was stable. The majority of the 15 year-olds (67%) made no attempt at prediction, suggesting that they found difficulty in interpreting the data and answering the question. Only two pupils in this age group were able to make a logical forecast as to future community composition based on the data provided.

Although asked to consider outcomes in terms of population interactions, some pupils and students attributed population fluctuations to seasonal changes, e.g. "the phytoplankton died off in winter", rather than to population interactions, and predicted a cyclical system of increases and decreases.

DISCUSSION

Food webs

Almost the entire sample of pupils and first year zoology students consistently answered questions incompletely when asked to consider the effect of a change in numbers of one population on another when the effect could be transmitted along more than one route. Subjects tended to select one of alternate 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 answers they merely indicated the pathway they had chosen without explaining why they chose that particular route above alternative pathways, or why they based their argument on only one route.

Juxtaposition of an 86% success rate in solving single pathway problems against a 2% success rate in solving and explaining multiple pathway problems, particularly in the light of the ability of 72% of the respondents to recognise alternate pathways when explicitly asked to do so, suggests that the majority of students who correctly hold basic concepts do not successfully integrate their ideas to produce a holistic concept of food web.

Misconceptions which appeared regularly at all levels were based on the proximity of populations in the food web, e.g. respondents' answers to questions based on populations which were separated by any distance on the web included: "there is no effect as the populations are too far apart", "not much effect as the populations are only slightly related", "not too much effect as the chains are spread out", "no effect as they are on different parts of the food web" and "nothing happens as they aren't really linked at all."

Data Analysis

Almost all the pupils and students could reorganise data into satisfactory tables and graphs, indicating that these basic skills are well within the abilities of learners in the respondents' age range. In contrast, the fact that less than 50% of the respondents could integrate clues and predict outcomes acceptably, suggests that these skills require careful development.

The data suggest that pupils and students are not clear in their own minds as to what arrows in a food web represent, i.e., routes of energy flow. The subjects also, more often than not, do not clearly understand what ecological pyramids represent, and merely use the pyramid as a ladder, placing populations sequentially in order of numbers, starting with the largest population at the base of the pyramid and the smallest at the apex, regardless of the trophic level.

The responses to questions on predation and population composition were also very poor and very few subjects were able to relate changing number/biomass ratios to age distributions and possible reproductive periods. This suggests that if pupils and students are to understand the processes involved in populatio dynamics, the effects of these relationships must be made explicit and learners allowed to use this knowledge in a range of situations.

IMPLICATIONS

Difficulties experienced by the respondents in certain aspects of the exercises suggest that explicit teaching of the nature of relationships within an ecosystem, supplemented by concrete examples, before pupils or students are asked to complete worksheets such as those used in this study, is required in order for them to produce acceptable answers and develop meaningful concepts.

Recognition of the fact 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, should form a valuable point of departure for teachers as lack of any significant difference between the results of the three groups used in this study suggests that if clear ecological concepts are not developed at school, misconceptions have a good chance of persisting at university level.

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

Discussion generated by the exercises allows learners to talk through and test their ideas against those of others in order to construct meaning for themselves. At the same time data analysis should make explicit to the learner 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 acceptable predictions.

Development of sound ecological concepts in this manner should then allow pupils and students to understand, *inter alia*, how carrying capacities of systems may be exceeded, resources be over exploited and population numbers regulated. By asking pupils to forecast such events for supplied data one is making explicit one of the implicit, applied reasons for studying ecological processes, i.e., conservation and management.

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