Children's ideas about
ECOSYSTEMS

RESEARCH SUMMARY

This is a brief outline of research setting out the main prior ideas and understandings which teachers might expect to meet among pupils.
Before reading this summary of children's prior ideas, it may be helpful to look at the Science Map and The Teacher's View so as to have a useful overall perspective from which to view children's understandings.

Introduction
There has been little research into children's ideas of ecosystems as such. However, research into children's understandings of component ideas provides some insights into their ecological concepts, and studies of children's conceptual reasoning inform the findings about particular concept areas in this domain.

The research findings are summarised under the following headings:

- Progression in children's reasoning
- Nutrition and Energy flow
- Food chains and webs
- Populations and Competition between organisms
- Environment
- Decay
- Cycling of matter through the ecosystem
- Pollution
- Gas exchange
- Respiration.

Progression in children's reasoning
Leach et al. describe pupils' reasoning about ecological phenomena from ages 5-16. These findings corroborate descriptions of children's thinking in a number of domains reported by many researchers from Piaget onwards.

There is a trend from the egocentric (self-centred) thinking of very young children, through anthropocentric (human centred) reasoning, to reasoning including a wider range of factors in older students. Teleological reasoning (an event is predetermined in order to fulfill a need, for example 'there are a lot of rabbits so that foxes will not get hungry') is common in young children. With age it becomes less pronounced, but
persists to some extent in senior school students. The following progression in children's thinking related to ecosystems was identified by Leach et al.

Younger children, age 5-7, tend to think only in terms of individual organisms which people keep (pets, zoo animals, house plants) and which need humans for their survival. Older junior pupils (7-11) extend their thinking to wild organisms as individuals, though some may think that these are fed and cared for by people. Most pupils over the age of thirteen have a concept of populations of organisms in the wild, but their 'explanations' of relationships are merely descriptions of nature (birds live in trees, foxes eat rabbits). It is not until much later that students think in terms of populations of organisms in the wild competing for scarce resources. There are not distinct stages of reasoning in the conceptual development of any one child or group of children. A child may use different types of reasoning in different contexts.

Nutrition and Energy flow

The main points of children's ideas about food and nutrition, as they relate to understanding of ecosystems, are quoted here. Fuller information about the research in this area is given in the Nutrition Research Summary and in the Growth Research Summary.*

Many children associate the word 'food' only with what they identify as being edible. Few pupils associate substances such as starch with 'food'. Pupils of all ages identify food as necessary to promote growth and health, but do not recognise that it is the source of material to become either part of their bodies in growth and repair, or the source of energy. When they do relate food to energy, many pupils of eleven or twelve years old consider that food is converted directly into 'goodness' or 'energy' and that it vanishes completely in the process.

A universal and very persistent conception amongst children and adults is that plants get their food from the soil. Many pupils think that 'food' for plants is anything taken in from the environment, including water, minerals, fertilisers, carbon dioxide and even sunlight. Even when students have accepted taught ideas about photosynthesis they still believe that plants obtain some food from the environment. They believe that plants have multiple sources of food. Few pupils have any understanding that photosynthesis makes food which provides energy for the plant's life processes.

* See Nutrition Research Summary
See Growth Research Summary
Many children express the idea that plants make food for the benefit of animals and people rather than as essential for the plant itself. (This is an example of teleology.) Children do not recognise that photosynthesis is the process by which energy from the environment becomes available to plants and then to animals.

Many children think of light as 'food' for plants or as a reagent in photosynthesis. Over half of a sample of secondary school children thought that light is made of molecules*. Most children do not understand energy transfers in living things. Most pupils believe that plants get the energy needed for all their processes directly from the Sun, and they use the words 'heat' and 'light' interchangeably in this context. Nearly 80% of a sample of thirteen-year olds thought that plants use heat from the Sun as an energy source for photosynthesis. Most consider that the sun is one amongst many sources of energy for plants, others being soil, minerals, air and water.

Gayford** reports that 17-18 year-old Biology students considered that energy flows, or is transported, from place to place in biological systems, and that it can be stored like a material. They thought that energy was 'formed' or 'used' in biological processes, rather than thinking in terms of energy conversions.

**Food Chains and webs**

Some studies relating to children's ideas about interdependency in food chains and food webs have focussed on children 'getting the right answer' to exam-type questions rather than on the conceptual basis of children's understanding.

Senior*** analysed the responses of fifteen year-old students to Assessment of Performance Unit (APU) questions about the manipulation of populations of organisms in food webs. He found that students were not comfortable with the arrow notation used in school science to indicate a trophic relationship, and so they fail to understand the underlying principles of the relationship and to complete the activities correctly. Schollum**** identified a similar difficulty for pupils dealing with food chains; they were better able to answer problems about food chains if lines rather than arrows were used to link populations.

Few students relate their ideas about feeding and energy to a framework of ideas about interactions of organisms. Only half of a sample of University Biology students asked about the statements 'life depends on green plants' and 'the web of life' explained these statements in terms of food chains. Only a minority of these mentioned harnessing solar energy or photosynthesis as the reason why green plants are crucial in the food chain.

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*teleology
**Gayford
***Senior
****Schollum
Even at this stage of education many students still think teleologically, for example, nearly a quarter of the students expressed views suggesting that other organisms exist for the benefit of humans 10. A subsequent study on students from age thirteen up to University level revealed very similar proportions of these same ideas. Most students knew that animals could not exist in a plant-free world. Only 25% of biology students and 7% of non-biologists suggested that this is because animals cannot make their own food. Some students thought that carnivores could exist if their prey reproduced plentifully, without apparently relating this to the source of the preys’ food 11.

Students’ understanding of ecological relationships depends on their concepts of ‘plant’ and ‘animal’, and on their knowledge of habitats and physical principles. Even after teaching, 13-15 year-old Nigerian students were not convinced that producers exist in aquatic habitats, since they had little experience or information about specific habitats with plants living under water 12. Leach et al’s subjects recognised the existence of aquatic plants but some said that sunlight and carbon dioxide could not get through the water to the plants, so they did not acknowledge them as producers 1.

Bell et al found that pupils’ limited recognition of ‘producer’ and ‘consumer’ was tied to their meaning of ‘plant’ and ‘animal’. Once the scientific extension of the words ‘plant’ and ‘animal’ were established by teaching, pupils could apply the terms ‘producer’ and ‘consumer’ appropriately 13,14,*

Several studies 13,15,16 involving subjects ranging from twelve-year olds to undergraduate zoology students, have found that most students interpret food web problems in a limited way, focussing on isolated food chains. This focus on linear food chains, rather than recognition of cycles of matter or interdependency with other organisms and systems predominates in their thinking about ecosystems.

Smith and Anderson 17 noted that many eleven and twelve year-olds, who accept that populations in a food web are related, may still see predation as a specific eating event for the benefit of the eater alone. Pupils tend to regard food which is eaten and used for energy as belonging to a food chain; the food which is incorporated into the body material of eaters is seen as something different and not recognised as the material which is the food of the next level.

* See Living Things Research Summary
Communities, populations and competition between organisms

Adeniyi found that students' meanings of ecological terms were related to everyday usage rather than to scientific definitions. For example, a quarter of the students used the term 'community' to mean a group of people living together with similar ideas. Another quarter did not distinguish between the meaning of 'community' and 'population'. He revealed a range of ideas about pyramids of number and biomass, amongst his Nigerian students. Several ideas were anthropocentric (for example, there are more herbivores than carnivores because people breed them) or they implied teleological predestination (for example, the number of producers is large to satisfy the consumers). 'Stronger' organisms were considered to have more energy, which they use to feed on weaker organisms with less energy. Some students saw energy adding up through an ecosystem, so a top predator would have all the energy from the producers and other consumers in the chain.

Leach et al. found that although nearly half of children at all ages between five and sixteen could select pictures of organisms to construct a balanced community which contained a producer and primary and secondary consumers, few at any age used the idea of interdependence to explain their selection. At age 5-16, 22% used the idea of interdependence. Most based their choices of their description of the status quo in nature, or used teleological reasoning. The pupils were asked to predict which population of organisms would be largest, and why. Although most pupils, at all ages, chose producers, a significant number chose primary or secondary consumers. Again, the explanations for the choice were mostly just descriptions of nature (for example, rabbits have many babies) or teleological, with little evidence of reasoning about interdependence or energy flow. There was some progression in reasoning with age.

In the context of seasonal change, children made some links between populations, ranging from simple food or shelter links at age eleven to sophisticated energy flows in food webs by some students at age sixteen. When set questions based on food webs, children responded differently according to which organisms were 'removed' from the hypothetical web. Pupils made least links between the removal of a top predator and the rest of the food web, and most links between the removal of producers and the rest of the food web. They seemed more able to trace links up through the trophic levels than down.

Griffiths and Grant reported that a fifth of fifteen year-olds thought that a population higher on a food chain is a predator on all the organisms below it. Many of these pupils thought that a change in the population of one species would affect only those species...
related to it directly as predator or prey, while others thought that a change in the size of prey population would have no effect on its predator population. These authors suggest that the introduction of the food chain concept as a precursor to food webs is a reason for children failing to use ideas about interdependency to explain relationships in complex ecosystems.

Environment

Leach et al. investigated children's ideas about what various organisms need to stay alive and healthy, and the source of these requirements in the environment. Most children recognised plants' need for soil, water and sunlight in their habitat. The need for air, oxygen or carbon dioxide was identified by a small minority of pupils; less than a third of sixteen year-olds noted the need for carbon dioxide or oxygen. The needs of consumers were identified as water, food and shelter and many pupils at all ages identified food and shelter links between organisms in communities. However, younger children (up to thirteen) seemed to think in terms of the needs of individual organisms rather than populations. Many pupils at all ages seemed unable to conceptualise organisms and their environments independent of human involvement, and many younger pupils thought that all organisms are fed by people.

Most pupils, at ages 11-16, were able to mention some features of organisms that are related to a specific habitat, and some were able to make predictions of the habitat of organisms with particular features.

Several studies of ideas of adaptation have suggested that students use teleological and anthropomorphic reasoning to explain the relationship between an organism and its environment.∗

Decay

Recent research in Portugal, USA and England indicates a remarkably similar progression in children's concepts about decay. The research questions related to the 'disappearance' of dead animals or fruits on the surface of the soil. (See Figure 1). The youngest children think that dead things just disappear or they have human-centred notions which do not allow for ideas about continuity of matter after death. All these studies found that most children conceptualise decomposition as the total or partial disappearance of matter. The concept seems resistant to change, with 70% of 11-13 year-olds giving responses implying a lack of conservation of matter, even after teaching about the topic. (See Figure 2.)

∗ See Living Things Research Summary
Progression in children’s thinking about decay

Figure 1
They were not aware that material from dead organisms becomes part of the non-living environment nor that microbes initiate the process of decay. They tended to think that it is insects which break up material once it has started to rot of its own accord. A later concept is that bugs or germs eat the partly rotted matter. They think that rotted material ‘enriches’ or ‘fertilises’ the soil but do not identify it as part of the soil. After tuition, up to 65% of 15-16 year-olds use the words ‘bacteria’, ‘fungi’ or ‘decomposers’ but are not clear about their role. Although progression is characterised by an increasing number of factors being used to explain phenomena, there is little evidence that pupils at fifteen or sixteen have an understanding of how various physical factors relate to the action of microbes. (See Figure 3.)

Some Swedish children expressed the belief that all dead material decays to form soil, and that the Earth is thus getting bigger all the time. This idea recapitulates historical notions *. Very few children seem to be aware of ideas about organic matter changing to mineral matter during decay, or of any other recycling *.

Generally, pupils are unaware of the role that micro-organisms play in nature, especially as decomposers and as recyclers of carbon, nitrogen, water and minerals ¹.
Cycling of matter through the ecosystem

Children's understanding of the cycling of matter through the ecosystem and of the component processes of photosynthesis and cellular respiration requires a level of commitment to conservation of matter in chemical changes. This depends on their concepts of matter, states of matter, chemical change and energy. Children's ideas on these topics are reviewed in the Research Summaries of the relevant domains. *

Smith and Anderson ¹ found that almost all of their twelve year-old sample were aware that some kind of cyclical process takes place in ecosystems. However most tended to think in terms of sequences of cause and effect events, with matter being created or destroyed in these events, and then the sequence starting again. Some recognised a form of recycling through soil minerals, but failed to incorporate water, oxygen and carbon dioxide into matter cycles. Their ideas about gas balance are noted below. They saw no connection between the oxygen/carbon dioxide cycle and other processes involving the production, consumption and use of food, and their understanding of the matter cycling process remained fragmentated. Following instruction there was little change, with only 4% of pupils achieving the 'goal conception' that matter is converted.

* See Materials, Solids, Liquids and Gases, Chemical Change, Particles, Energy Research Summaries
back and forth between organisms' bodies and substances (carbon dioxide, water and minerals) in the environment. A few pupils had picked up the idea of food being converted but they thought of it being converted into energy.

Leach et al. report that, even at age sixteen, few pupils have a view of matter that involves conservation in a variety of contexts such as photosynthesis, assimilation of food, decay and respiration. Moreover, pupils did not appear to distinguish food, matter and energy. No pupils in this study presented an integrated view of a consistent amount of matter cycling, though a few older pupils showed evidence of conserving matter in decay and in photosynthesis.

**Pollution**

A recent American study indicates few changes in knowledge about ecological crises, from age 9-16. However, it identified some progression in children's ideas of pollution. Nine year-olds regard pollution as something which is directly sensed by people, and affects people or other animals. They do not consider that harm to plants constitutes an environmental problem. Their responses indicate that air can somehow circulate pollution.

Thirteen year-olds have a more conceptual understanding of ecological crises including a concept of cumulative ecological effects. They do not have to sense it for it to be there and unseen chemicals like acid rain are considered pollutants. These students' responses include the idea that pollution kills (rather than harms) animals (particularly fish) and also plants. Human populations, factories and cars are considered to be possible sources of ecological crises.

By sixteen, students have a greater number of relevant concepts and meaningful connections between them. They believe that pollution can affect everything. Biodegradable materials are considered less harmful to life than non-biodegradable, and the concentration of pollutants is considered to be important. At this age, the students recognise that environmental issues are complex and they relate economic concepts to cause and effects of ecological crises.

Several important misconceptions were held by at least half of the large sample of students interviewed. They included:

- anything natural is not pollution
- biodegradable materials are not pollutants
- the oceans are a limitless resource
solid waste in dumps is safe
the human race is indestructible as a species.
The researchers also found little evidence that pupils used science concepts, learnt elsewhere in the curriculum, to inform their understanding of ecological issues.

Gas exchange and balance
Various studies of children from 9-16 have revealed that they think either that air is not used by plants, or that plants and animals use air in opposite ways. 'Oxygen' is often used synonymously with 'air'. Children display a better understanding of what happens to oxygen than of what happens to carbon dioxide.

Anything about gases going in and out of organisms is considered as breathing. Barker found that children aged nine hold the 'plant breathing - animal breathing' model: that animals breathe in oxygen and breathe out carbon dioxide, whereas plants breathe in carbon dioxide and breathe out oxygen. Plant breathing is often viewed teleologically and anthropomorphically: it is thought to happen so that humans' oxygen supply is replenished.

Leach et al found that by thirteen most pupils stated that animals need oxygen and a few stated that plants need carbon dioxide. By sixteen, more pupils held these ideas and some were aware of the role of carbon dioxide in photosynthesis.

Arnold and Simpson devised a test for sixteen year-old students, who had been taught the topic, to identify conceptions regarding gas exchange which indicated interference between the concepts of photosynthesis and respiration. 46% of students did not understand that increased photosynthesis decreased carbon dioxide in a closed system. Specific distractors identified the following misconceptions:

- 25% believed that water plants absorb carbon dioxide at night, 25% that photosynthesising leaves produce high carbon dioxide levels and 18% that pond weed produces bubbles of carbon dioxide in light.

Eisen, Stavey et al investigated students' understanding of the importance of photosynthesis in the ecosystem in maintaining oxygen levels. Most (82%) of 13-15 year-olds knew that plants release oxygen in photosynthesis and that this oxygen supports a range of living things. However, only about half of the students at each age level indicated that animals could not live without plants because of their oxygen need, and only about 10% mentioned the oxygen cycle in relation to the sun as the origin of life. The same questions posed to older students produced similar proportions of
Wandersee tested 1405 students aged 10-18 by a written test. When asked about the flow of gases during photosynthesis, 62% of the youngest children, rising to 85% of the college students knew that carbon dioxide flows into the leaf during photosynthesis. The figures for oxygen flow were similar except for the youngest students, only 51% of whom knew the correct direction. Most students seemed to think that the two gases always flow in opposite directions. However, questions set in the context of a diagrammatic replication of Priestley’s experiment, where a mouse and an illuminated plant were placed in a sealed container, indicated that many students had difficulty in applying their knowledge of gas exchange to an ‘ecosystem’. Although an increasing proportion through the age groups (38% to 67%) suggested that both the plant and the mouse would live, many thought that both would die or that only the plant would live. In explaining their answers, the percentage of students who used the word ‘air’ decreased with age (26% to 4%) while there was a corresponding rise in the proportion using ‘carbon dioxide’ and ‘oxygen’ (18% to 58%) to justify their choice of answer.

Respiration

Although students may have notions about gas exchange and consider any gas exchange as a kind of breathing, few at any age have a coherent concept of respiration. Respiration and breathing are thought, by most students, to be synonymous \(^a\). Children learn from an early age that they breathe oxygen and oxygen is often equated with air \(^b\).

Gellert \(^a\) and Nagy \(^b\) found that young children know that air is necessary for life but appear to have a limited idea of what happens to inhaled air, often thinking that it remains in the head. Both researchers found that half of 9-10 year-olds associated lungs with breathing and some pupils recognised that an exchange of gases with the air is important to all parts of the body. However, young secondary pupils are unlikely to relate the need for air or oxygen with the use of food.

Leach et al \(^1\) note an absence of ideas about the physiological role of the gases. By age eleven, pupils recognise that animals need air or oxygen. Pupils mentioning oxygen said that it was needed to breathe or to keep the animal alive. No pupils mentioned the release of energy from food in connection with the need for oxygen. Responses indicated that pupils had no ideas about the physiological role of breathing, seeing the

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Footnotes:

\(^a\) Gellert, \(^b\) Nagy

Research Summary
process as an end in itself. Arnauadin and Mintzes * found one third of school children and one quarter of college students thinking of 'air tubes' connecting the lungs and heart, with up to a third of all their sample suggesting that air is simply inhaled into the lungs then exhaled without links to the heart and circulatory system.

Asked explicitly 'What is respiration', the 13-15 year-olds studied by Stavy et al. * referred only to gas exchange by inhaling and exhaling air. Most merely said 'we breathe in order to live'; a few had ideas about oxygen: 'oxygen revives the cells', 'oxygen activates the heart and causes blood to circulate'.

Anderson et al. * studied ideas about respiration held by American college non-biology majors. The students identified oxygen as a need of animals and carbon dioxide as a need of plants. They used the everyday language meaning to identify respiration with breathing. They did not link food, oxygen, carbon dioxide and energy into any coherent view about respiration. They exhibited a lack of knowledge about respiration, unlike the range of alternative ideas contradictory to the science view which they offered about photosynthesis.

A notion evident from several studies is that plants do not respire, or they respire only in the dark * "". Pupils who refer to respiration in plants do not perceive it as an energy conversion process; many think that photosynthesis is the energy-providing process for plants. Many children believe that respiration in plants occurs only in the cells of leaves since only leaves have gas exchange pores *.

Children tend to believe that energy is used up by living things in general, and that plants use up energy in growing. They think that energy is created or destroyed in different life processes * "". Even advanced Biology students aged 17-18 do not think in terms of energy transfer. Of Gayford's sample, 79% did not consider that biological processes such as respiration involve energy conversions. They think that respiration actually forms energy which is used later in synthetic reactions. Also, 74% though that 'ATP has high energy bonds which release energy', a view probably arising from the teaching of out-dated ideas.

Global warming and ozone depletion

Boyes and Stanisstreet * " found some scientifically acceptable ideas about global warming, already present amongst eleven year-olds. These include the notion that an increase in the Greenhouse Effect will cause changes in weather patterns. Other ideas, generally held by the science community, take time to become established over the
A number of 'misconceptions' are identified amongst 11-16 year-old pupils. Some of these persist in the oldest school students and amongst undergraduate students. The idea that the use of lead-free petrol will reduce global warming is an example. The results also reveal underlying themes in children's thinking. Confusion between ozone layer depletion and the Greenhouse Effect is one such theme. It seems that students are aware of a range of environmentally 'friendly' and 'unfriendly' actions, and know about a range of environmental problems, but they do not link particular causes with particular consequences. Rather, children appear to think in a general way that all environmentally 'friendly' actions help all the problems.

In a study of primary school children, the same research team found that most children were aware that generating electricity from renewable resources, using recycled paper and replacing trees by planting would reduce global warming. Although the majority of children realised that a reduction in automobile use would diminish the Greenhouse Effect, the preponderance of this idea was lower in older primary school children. More than half of the children thought that keeping beaches clean or protecting wild species would reduce the Greenhouse Effect, although the frequency of these ideas was lower in the older children. Furthermore, the most common misconception, held by 87% of the pupils, was that the use of lead-free petrol would reduce global warming.

Like the older students studied by Boyes and Stanisstreet, primary school children confuse the causes of global warming, ozone layer depletion, and atmospheric lead pollution by leaded gasoline. The researchers suggest that it will require specific efforts to disentangle these important environmental issues in the minds of children, especially since the problems are intangible and so not readily open to experiential learning. They suggest that this education should begin early, before misunderstandings become embedded concepts leading to entrenched attitudes.
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The Frontline of Public Intelligence

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Children’s Rights and

INFORMATION