COURSE CODE:	FIS307
COURSE TITLE:	Fish Ecology
NUMBER OF UNITS:	2 Units
COURSE DURATION:	Two hours per week

COURSE DETAILS:

Course Coordinator: Dr. A.O. Agbon

Email: oseremehis@yahoo.co.uk

Office Location: Room D205, COLERM
Other Lecturers: Dr. (Mrs.) N.B. Ikenweiwe and Dr. F.I. Adeosun

COURSE CONTENT:

Ecology of fishes with special reference to distribution and natural history and application of this knowledge for fisheries management and obtaining maximum returns from fishery resources. Characteristics of the equation environment. Organic production in aquatic fauna and flora-algal blooms and eutrophication, plankton, and benthos, biomass assessment. Food and feeding habit of fish food and habitat selection, population, niche concept. Food chains, reproductive behavior of life cycles of some selected species

COURSE REQUIREMENTS:

This is a compulsory course for all students in Department of Aquaculture & Fisheries Management. In view of this, students are expected to participate in all the course activities and have minimum of 75% attendance to be eligible to write the final examination.
.

READING LIST:

References
• Balogun, J. K. (2006) Basic fisheries biology and management. Pp 88
• Lowe-McConnel (1978) Identification of freshwater fishes, in the biological basis of freshwater fish production eds Shelby D. Gerking and E. David Le Cren. Pp 305

LECTURE NOTES

Food and Feeding Habits in Fish
There are four basic eating groups among fish: carnivores, herbivores, omnivores and limnivores. Each group of fish needs to be fed in a particular way.
Carnivores are meat-eating fish. Whilst they will never damage your plant life, you will be lucky

if you do not find any of the smaller fish disappearing mysteriously. If there are smaller fish in the aquarium with a carnivore, sooner or later the smaller fish will end up in the carnivore's stomach. Carnivores need at least 45% of protein in their food, without which they become severely malnourished. Although many of the prepared foods are spiked with extra protein to help such fish, carnivores are happiest when they are fed live food like worms. An added benefit is that chasing their prey seems to whet their appetite even further. Recommended food for the carnivores would be:

- Earthworms, Red worms, Tubifex worms and Daphnia.
- Larvae of mosquitoes or fruit flies.
- Oysters, shrimps, clams and other fish. If these are kept frozen, they need to be thawed and then sliced into slivers.
- Lean chicken, turkey and salmon. These should be cooked, but never fried.
- Supplements in the form of flakes or granules and pellets for added nutrition.

Herbivorous fish are those that will eat only plants. These fish need to graze very often, and whether they are fed regularly or not, they will nip at your plant life. Many aquarists who like herbivores keep plastic plants in their aquarium. If real plants are used, the aquarium runs a risk of having a badly mauled garden. It is a good idea to feed these fish with fresh veggies. Planting leafy vegetables like spinach into the substrate is a good trick. The fish will keep nipping at these. Care should be taken to remove the frayed plants before they start decaying and rotting in the water.

Recommended foods for this variety are:

- Cucumber, peas and potatoes. These can be kept frozen and be chopped into tiny pieces at mealtime.
- Vegetable flakes come in a variety of flavors.
- Algal flakes will also be a favorite among this kind of fish.

Omnivore fish will eat pretty much anything, and that makes them dangerous to plants as well as to other smaller creatures in your aquarium. They are also voracious eaters and aquarists can sometimes mistake their eating frenzy for hunger. It is a common tendency to overfeed these species, and they do tend to pile on the fat very quickly if overfed.

Limnivores are also known as mud-eaters. Limnivore fish feed mainly on algae and on the microorganisms in your aquarium. These kinds of fish are constantly eating, and can be given pellets and algae based foods.

Proper feeding practices are a matter of habit. They require some amount of patience, observation and consideration. Understanding your fish and appreciating the differences between the different species help a lot when you feed them. The type of food, the culture conditions and the individual fish will all affect the quantity of food you should provide. In nature, there may be times when an adult fish starves for a day or two, or even for longer periods of time. The younger fish need more frequent feedings than the older ones. The fry have their own feeding needs.

Most feeding problems arise due to overfeeding. More food also means more waste. The excess food will putrefy and degrade the water quality. Under gravel filters can get clogged with uneaten food wastes. Frequent water changes along with cleaning of decorations, rearranging of plants etc will help to control the debris collection in the aquarium. Loaches, catfish and other common bottom-feeding fish will help keep the aquarium clean.

Deficiencies in vitamins can cause stunted growth, loss of appetite, cloudy eyes, weakness or tumors in fish. For this reason it is advisable to give your fish vitamin supplements from time to time. No supplement should be left too long in your water. Adding any unnatural substance into your aquarium should be followed up by a water change in a day or two. This will keep the fish as well as the beneficial bacterial colony thriving.

NICHE CONCEPT

Every organism has a place to live in nature, a functional role in that place, and a complex set of adaptations for reproducing its kind. On the surface, this observation might seem to be obvious, even trivial. However, in order to understand our biological world—the biosphere, how it operates and ultimately how to protect it—we need to understand at a deep level how organisms interact with each other and with their physical environment.

In this chapter we will examine further some of the concepts that ecologists use to organize their thoughts about the ways in which organisms use their environment, relate to each other, and assemble into communities or ecosystems. The most fundamental and perhaps most difficult of these concepts is that of the **ecological niche**. A niche refers to the way in which an organism fits into an ecological community or ecosystem. Through the process of natural selection, a niche is the evolutionary result of a species' morphological (morphology refers to an organism's physical structure), physiological, and behavioral adaptations to its surroundings.

A **habitat** is the actual location in the environment where an organism lives and consists of all the physical and biological resources available to a species. The collection of all the habitat areas of a species constitutes its **geographic range**. We will examine each of these concepts in turn using a historical approach where appropriate and discuss how these ideas can help us to understand the issues of modern conservation biology.

GEOGRAPHICAL RANGES

One of the first things that people noticed as they started to study and write about the world was that when they visited different parts of the earth they found different species. In fact, most species have limited distributions. Giraffes, for example, are found only in Africa, koalas only in Australia, and lemurs only in Madagascar. If we choose a particular species, plot a point on a map of the world for every place in which it is found, and then draw a line surrounding all of the points, we will have delimited its geographical range. Figure 7.1 is a range map for three species found in the United States. Some species, such as the Devil's Hole pupfish that only lives in one particular desert spring, have a geographical range of just a few square meters; others (e.g., human beings) range over most of the land area of the earth. Most species, though, have intermediate-sized distributions, as does the bighorn sheep.

Food Chains and Food Webs

"What's for dinner?"

Every organism needs to obtain energy in order to live. For example, plants get energy from the sun, some animals eat plants, and some animals eat other animals.

A food chain is the sequence of who eats whom in a biological community (an ecosystem) to obtain nutrition. A food chain starts with the primary energy source, usually the sun or boiling-hot deep sea vents. The next link in the chain is an organism that make its own food from the primary energy source -- an example is photosynthetic plants that make their own food from sunlight (using a process called **photosynthesis**) and chemosynthetic bacteria that make their food energy from chemicals in hydrothermal vents. These are called **autotrophs** or **primary producers**.

Next come organisms that eat the autotrophs; these organisms are called **herbivores** or **primary consumers** -- an example is a rabbit that eats grass.

The next link in the chain is animals that eat herbivores - these are called **secondary consumers** -- an example is a snake that eat rabbits.

In turn, these animals are eaten by larger predators -- an example is an owl that eats snakes.

The tertiary consumers are are eaten by **quaternary consumers** -- an example is a hawk that eats owls. Each food chain end with a **top predator**, and animal with no natural enemies (like an alligator, hawk, or polar bear).

The arrows in a food chain show the flow of **energy**, from the sun or hydrothermal vent to a top predator. As the energy flows from organism to organism, energy is lost at each step. A network of many **food chains** is called a **food web**.

Trophic Levels:

The trophic level of an organism is the position it holds in a food chain.

1. **Primary producers** (organisms that make their own food from sunlight and/or chemical energy from deep sea vents) are the base of every food chain - these organisms are called **autotrophs**.
2. **Primary consumers** are animals that eat primary producers; they are also called **herbivores** (plant-eaters).
3. **Secondary consumers** eat primary consumers. They are **carnivores** (meateaters) and **omnivores** (animals that eat both animals and plants).
4. **Tertiary consumers** eat secondary consumers.
5. **Quaternary consumers** eat tertiary consumers.
6. Food chains "end" with top predators, animals that have little or no natural enemies.

When any organism dies, it is eventually eaten by **detrivores** (like vultures, worms and crabs) and broken down by **decomposers** (mostly bacteria and fungi), and the exchange of energy continues.

Some organisms' position in the food chain can vary as their diet differs. For example, when a bear eats berries, the bear is functioning as a primary consumer. When a bear eats a plant-eating rodent, the bear is functioning as a secondary consumer. When the bear eats salmon, the bear is functioning as a tertiary consumer (this is because salmon is a secondary consumer, since salmon eat herring that eat zooplankton that eat phytoplankton, that make their own energy from sunlight). Think about how people's place in the food chain varies - often within a single meal.

Numbers of Organisms:

In any food web, energy is lost each time one organism eats another. Because of this, there have to be many more plants than there are plant-eaters.

There are more autotrophs than heterotrophs, and more planteaters than meat-eaters.

Although there is intense competition between animals, there is also an interdependence. When one species goes extinct, it can affect an entire chain of other species and have unpredictable consequences. herbivores, decreasing the herbivore population. It then becomes harder and harder for the carnivores to find herbivores to eat, and the population of carnivores decreases. In this way, the carnivores and herbivores stay in a relatively stable equilibrium, each limiting the other's population. A similar equilibrium exists between plants and plant-eaters.

Reproductive Behaviour and Life Cycle of Nile Tilapia

Nile Tilapia: Life History and Biology

The Nile tilapia (O. niloticus) was one of the first fish species cultured. Illustrations from Egyptian tombs suggest that Nile tilapia were cultured more than 3,000 years ago. Tilapia have been called ÒSaint PeterÕs fishÓ in reference to biblical passages about the fish fed to the multitudes. The Nile tilapia is still the most widely cultured species of tilapia in Africa.

Positive aquacultural characteristics of tilapia are their tolerance to poor water quality and the fact that they eat a wide range of natural food organisms. Biological constraints to the development of commercial tilapia farming are their inability to withstand sustained water temperatures below 50 to 52o F and early sexual maturity that results in spawning before fish reach market size. Following is a discussion of the characteristics and culture of nonhybrid tilapia.

Taxonomy

ÒTilapiaÓ is the generic name of a group of cichlids endemic to Africa. The group consists of three aquaculturally important genera Ð Oreochromis, Sarotherodon and Tilapia. Several characteristics distinguish these three genera, but possibly the most critical relates to reproductive behavior. All tilapia species are nest builders; fertilized eggs are guarded in the nest by a brood parent. Species of both Sarotherodon and Oreochromis are mouth brooders; eggs are fertilized in the nest but parents immediately pick up the eggs in their mouths and hold them through incubation and for several days after hatching. In Oreochromis species only females practice mouth brooding, while in Sarotherodon species either the male or both male and female are mouth brooders.

During the last half century fish farmers throughout the tropical and semi-tropical world have begun farming tilapia. Today, all commercially important tilapia outside of Africa belong to the genus Oreochromis, and more than 90 percent of all commercially farmed tilapia outside of Africa are Nile tilapia. Less commonly farmed species are Blue tilapia (O. aureus), Mozambique tilapia (O. Mossambicus) and the Zanzibar tilapia (O. urolepis hornorum). The scientific names of tilapia species have been revised a lot in the last 30 years, creating some confusion. The scientific name of the Nile tilapia has been given as Tilapia nilotica, Sarotherodon niloticus, and currently as Oreochromis niloticus.

Physical characteristics

Tilapia are shaped much like sunfish or crappie but can be easily identified by an interrupted lateral line characteristic of the Cichlid family of fishes. They are laterally compressed and deep-bodied with long dorsal fins. The forward portion of the dorsal fin is heavily spined. Spines are also found in the pelvis and anal fins. There are usually wide vertical bars down the sides of fry, fingerlings, and sometimes adults.

Banding Patterns and Coloration

The main cultured species of tilapia usually can be distinguished by different banding patterns on the caudal fin. Nile tilapia have strong vertical bands, Blue tilapia have interrupted bands, and Mozambique tilapia have weak or no bands on the caudal fin. Male Mozambique tilapia also have upturned snouts. Color patterns on the body and fins also may distinguish species. Mature male Nile tilapia have gray or pink pigmentation in the throat region, while Mozambique tilapia have a more yellow coloration. However, coloration is often an unreliable method of distinguishing tilapia species because environment, state of sexual maturity, and food source greatly influence color intensity.

The red tilapia has become increasingly popular because its similar appearance to the marine red snapper gives it higher market value. The original red tilapias were genetic mutants. The first red tilapia, produced in Taiwan in the late 1960s, was a cross between a mutant reddish- orange female Mozambique tilapia and a normal male Nile tilapia. It was called the Taiwanese red tilapia. Another red strain of tilapia was developed in Florida in the 1970s by crossing a normal colored female Zanzibar tilapia with a red-gold Mozambique tilapia.

A third strain of red tilapia was developed in Israel from a mutant pink Nile tilapia crossed with wild Blue tilapia. All three original strains have been crossed with other red tilapia of unreported origin or with wild Oreochromis species. Consequently, most red tilapia in the Americas are mosaics of uncertain origin. The confused and rapidly changing genetic composition of red tilapia, as well as the lack of Òhead-to-headÓ growth comparisons between the different lines, make it difficult for a producer to identify a ÒbestÓ red strain. Other strains of tilapia selected for color include true breeding gold and yellow Mozambique lines and a Rocky Mountain white tilapia (a true breeding line originating from an aberrant Blue tilapia, subsequently crossed with Nile tilapia). Most strains selected for color do not grow well enough for food fish culture.

Identifying the species of an individual fish is further complicated by natural crossbreeding that has occurred between species. Electrophoresis is often used to determine the species composition of a group of tilapia.

Reproduction

In all Oreochromis species the male excavates a nest in the pond bottom (generally in water shallower than 3 feet) and mates with several females. After a short mating ritual the female spawns in the nest (about two to four eggs per gram of brood female), the male fertilizes the eggs, and she then holds and incubates the eggs in her mouth (buccal cavity) until they hatch. Fry remain in the femaleÕs mouth through yolk sac absorption and often seek refuge in her mouth for several days after they begin to feed.

Sexual maturity in tilapia is a function of age, size and environmental conditions. The Mozambique tilapia reaches sexual maturity at a smaller size and younger age than the Nile and Blue tilapias. Tilapia populations in large lakes mature at a later age and larger size than the same species raised in small farm ponds. For example, the Nile tilapia matures at about 10 to 12 months and 3/4 to 1 pound (350 to 500 grams) in several East African lakes. Under good growth conditions this same species will reach sexual maturity in farm ponds at an age of 5 to 6 months and 5 to 7 ounces (150 to 200 grams). When growth is slow, sexual maturity in Nile tilapia is delayed a month or two but stunted fish may spawn at a weight of less than 1 ounce (20 grams). Under good growing conditions in ponds, the Mozambique tilapia may reach sexual maturity in as little as 3 months of age, when they seldom weigh more than 2 to 4 ounces (60 to 100 grams). In poorly fertilized ponds sexually mature Mozambique tilapia may be as small as 1/2 ounce (15 grams).

Fish farming strategies that prevent overcrowding and stunting include: 1) cage farming where eggs fall through the mesh to the pond bottom before the female can collect them for brooding; 2) polyculture with a predator fish, such as fingerling largemouth bass, at 400 per acre; and 3) culture of only males (monosex). All-male culture is desirable in ponds not only to prevent overpopulation and stunting but also because males grow about twice as fast as females. Methods of obtaining predominately male fish include: 1) manually separating the sexes based on visual examination of the genital papilla of juvenile fish (Òhand-sexingÓ); 2) hybridizing between two selected species that produce all-male offspring (for example, Nile or Mozambique females crossed with Blue or Zanzibar males); 3) feeding a male hormone-treated feed to newly hatched fry for 3 to 4 weeks to produce reproductively functional males (Òsex reversalÓ); or 4) YY male technology (currently under development and not yet a commercial option).

The sex of a 1-ounce (25-gram) tilapia fingerling can be determined by examining the genital papilla located immediately behind the anus (Fig. 1). In males the genital papilla has only one opening (the urinary pore of the ureter) through which both milt and urine pass. In females the eggs exit through a separate oviduct and only urine passes through the urinary pore. Placing a drop of dye (methylene blue or food coloring) on the genital region helps to highlight the papilla and its openings.

The management of aquatic ecosystems, particularly the inland water bodies has been of great concern in the recent time. This is because these ecosystems, endowed with some unique natural resources are being increasingly degraded leading to ecological instability and disappearance of valuable resources, some of which are irreversible.

For an ecosystem approach, the fisheries and management systems may be compared using different systems of boundaries relating to biomes, fishing areas, provinces, LMEs, ecoregions, EEZs, mangroves, coral reefs, seamounts, estuaries, etc. The last slide reminds that theses ocean areas are more explicitly tri-dimensional than continental ecosystems. These boundaries do not match, are often fuzzy and shift seasonally, from year to year and with climate change.

The management of inland water bodies and conservation of fisheries resources in Nigeria has therefore been principally in the traditional domain, where traditional strategies such as water tenure, taboos, ritual prohibitions, magic, closed seasons, gear restrictions and flood plain intensification are employed.

According to Scudder and Connelly (1985), some of these traditional strategies (water tenure, taboos, ritual prohibitions, magic etc.) are inadvertent or unintentional in that they were initially put in place for reasons other than the management and conservation of the local fisheries, while others (gear restrictions, closed reasons, flood plain intensification) were termed intentional because they were designed to protect, conserve and increase some specific fisheries for particular events or reasons.

Ita (1993) reported some unintentional traditional strategies in some northern states of Nigeria, for example in Sokoto and Kano, where seasonal rivers and flood ponds are closed for fishing in the rainy season principally to protect the interest of full-time farmers, who return to part-time fishing in the dry season rather than the protection of the fisheries. Ita (1993) also identified intentional traditional strategies e.g. gear restrictions, closed seasons in the management of the Argungun fishing festival and flood plain intensification in Lake Ndakolowu and the flood plains of Anambra and Imo Rivers.

In Edo State, some communities have various forms of traditional beliefs (ritual prohibitions and
taboos), restricting or preventing fishing activities and in some cases as in Ekpoma, even consumption of the fishes from a local water body.

A CPFM (community practise on fisheries management) would be a dynamic community **of people** involved in fisheries management and conservation, knowing each other and working in common ways,
learning jointly how to improve resources conservation and management in fisheries.

It would associate competencies from the necessary disciplines and stakeholder groups and recognize
the value of general concepts, the specificities of ecosystems, political and socio-economic conditions,
jurisdictions, etc. and the possibility to learn from their comparison

It would actively work towards developing a common information repository and memory (social
knowledge)

_ We need to learn our new job faster
_ We need to share more and faster
_ For that, we need:
_ To develop one or more Communities of Practice
_ To support them with a more organized web information network
_ Many elements exist on the web that need to be strengthened and interconnected.
_ If we stay fragmented, fisheries will lose the biodiversity challenge

Freshwater fisheries management

River fisheries management

• Focus on maintaining native fishes, game and non-game
• Shenandoah River: Habitat modeling to inform water use decisions in Shenandoah Basin
• New River: Marker-assisted restoration of the native walleye stock

• Smith River: New operating regimes for Philpott Dam recommended based on 5 years of population and habitat analyses

Reservoir fisheries management

• Focus on sport fisheries
• Reproductive failure of bass in Virginia's trophy lakes:
• Assessing and modeling individual growth and condition
• Protected spawning areas
• Management of striped bass in Smith Mountain Lake

Marine fisheries management

• Population dynamics and stock assessment for fishery resources
• Fisheries management
– design of management programs
– Adaptive management
• Develop new models and new modeling approaches in fisheries
• Groupers, hammerhead sharks, horseshoe crabs
• Single-species management, move towards ecosystem management

Management of non-game species

• Landscape-scale models of fish distribution and abundance
• Habitat associations and causes of rarity in fishes
• Use of fish communities to assess water quality
• Development of risk-assessment tools for conservation planning
• ~300 freshwater mussel species in North America
• 35 sp. considered extinct
• ~70% listed as threatened or endangered
• Tennessee River system a biodiversity hotspot…
• What can we do to conserve freshwater mussels?
• Habitat protection, incl. host fishes, population transfer and augmentation

Human dimensions of fisheries management

• How best to involve the public in setting of management policy?
• Succession planning for the fisheries and wildlife profession
• Management effectiveness of state fish and wildlife agencies
• Evaluation of outreach efforts
• Continuing education—leadership development, public involvement

Lecture 2: Flora-algal Blooms and Eutrophication

Eutrophication is the process whereby water bodies become enriched by nutrients (Phosphorus and Nitrogen) from both external and internal sources. It is considered as one of the most pressing environmental problems in both the developed and the developing countries. Eutrophication and excess blue-green algal (cyanobacteria) growth are one of the major water-quality problems.

Elevated nutrient levels in aquatic ecosystems are normally derived from point sources (e.g. municipal and industrial effluent) and non-point (diffuse) source (e.g. agricultural runoff from fertilised top soils and livestock operation).

Effects of eutrophication on food web structure—Nutrient enrichment causes an intensification of all biological activity and typically leads to dramatic changes in the composition and structure of aquatic food webs. Two of the most consistent eutrophication effects are a shift in algal species composition and an increase in the frequency and intensity of nuisance algal blooms, which in eutrophic freshwater lakes are typically dominated by harmful cyanobacteria. One of the most important recent advances in our understanding of freshwater eutrophication is the discovery that the biological responses of producer organisms to nutrient availability can be strongly modified by consumer communities.

Eutrophication and grazing can also profoundly alter the biotic community structure of marine ecosystems. Olsen et al. (2006) found that mesozooplankton dominated by doliolids (Tunicata), but not by copepods, appeared to buffer the responses of autotrophs to high rates of nutrient loading. Among the many factors that potentially modify the responses of marine primary producers to nutrients, they suggested that the timescale over which the enrichment is made and the precise mode of nutrient enrichment could be very important.

Effects of eutrophication on aquatic biogeochemistry— Nutrient enrichment of aquatic ecosystems typically results in significant alterations in biogeochemical cycling over both space and time. Elemental fluxes can be followed with a variety of tools, including mass balance methods. Mass balance models is an integral part of the eutrophication modeling process.

Lecture 3: Plankton, benthos, biomass assessment

Plankton

Live organisms, essentially microorganisms those drift, or are visibly mobile are referred to as plankton.

The term ‘plankton’ was coined by Victor Hensen in 1887.Plankton, by virtue of drifting habit and short turnover period, constitutes the major link in the food chain in the reservoir ecosystem. Plankton provides about 50% of total food required for the fish. Due to their balanced nutritional content, plankters are referred to as ‘living capsules of nutrition’. These food organisms are broadly categorized as phytoplankton and zooplankton.

Phytoplankton

Phytoplankton are the microscopic plant life of any water body which forms the primary producers synthesizing the basic food to almost all the animals in an aquatic ecosystem. They form the basic live feed to all the zooplankton and larval forms of crustaceans, molluscs and fishes. Their importance lies in the fact that they are photosynthesizing organisms and serve as first link in the food chain. They belong to the Class Algae which besides chlorophylls possess other characteristic pigments. Most phytoplankton organisms are unicellular, some are colonial and filamentous in habit. Phytoplankton in reservoirs include both pelagic and (attached) benthic algae that have broken off from the bottom. By major taxonomic category, the following traits are characteristic of each major taxon:

Diatoms (Bacillariophyceae):

These mostly non-motile organisms may be pelagic(suspended in the water column) or benthic (attached to or residing on the bottom of lakes). Diatoms are considered desirable because of their value as food sources for the rest of the aquatic food web.

Chlorophytes:

These "green" algae are a diverse group that includes forms considered ecologically desirable (i.e., suitable for grazing by crustacean zooplankton) as well as those that are not (e.g., flagellated forms and eutrophic indicator species such as *Cladophora* spp.). Some make colonies surrounded by a gelatinous matrix that can be eaten by zooplankton, but pass through the gut undigested. It is difficult to generalize regarding this group, as they range in size from very large to very small, some are mobile, and many are not.

Blue-green algae (Cyanophyceae) :

This major category of phytoplankton known as the "blue-green algae" has certain species that may produce toxins harmful to humans and animals in some circumstances. They are more bacteria-like than plant-like, but since they may photosynthesize, they are included with the phytoplankton. They can alter the entire structure of the food web in a lake when they become prevalent, and are generally considered as less desirable or noxious species. Besides toxins, some forms are filamentous and therefore less desirable for grazing by many forms of zooplankton. Extensive studies of these properties have been conducted, but the factors that triggers or control toxin production and the suitability of various types of blue-greens as crustacean zooplankton food are still a research issue. Blue-green algae from the mainstay of plankton community in vast majority of the reservoirs studied. The overwhelming presence of *Microcystis aeruginosa* in Indian reservoirs is remarkable. The productive water of Gangetic plains, Deccan plateau, south Tamil Nadu and Orissa invariably has good standing crop of *Microcystis*.

The species is almost omnipresent in the southern Peninsula, except in the reservoirs of Karnataka and Kerala, which tend to be oligotrophic and have poor plankton count with desmids and other green algae as the main constituents.

Dinoflagellates: Dinoflagellates are motile, heterotrophic, or autotrophic forms that can be considered midway between plant and animal kingdoms. They can form extensive blooms in fresh and salt water, but are typically more of a problem in marine coastal areas where they may cause red tides or harmful algal blooms.

Zooplantkon

Zooplankton are planktonic animals that are the primary consumers of phytoplankton. They are important food web components in the reservoir ecosystem for larval, juvenile and even larger fishes.

The zooplankton communities in reservoir ecosystem are not species enriched. The principal constituents of zooplankton are rotifers, cladocerans, copepods and protozoans. Some of the food organisms include the rotifer (*Brachionus, Keratella*). Copepods (Diatoms and Cyclops) and cladocerans (*Daphnia* and *Moina*). They have high reproduction rate, short generation time and have the ability to grow and live in crowded conditions.

Copepods: The copepods constitute one of the important components of the food chain in aquatic ecosystem. Planktonic copepods consist of two major groups, the calanoids and the cyclopoids. Along with cladocerans, they are the principal food of a whole series of freshwater fishes. The most common and important ones are the *Cyclops* spp. And *Diaptomus* spp.

Rotifer : Rotifers are very small microscopic animals found in large numbers in the planktonic fauna. When abundant in a water body they are generally indicative of detritus-based food webs that may be eutrophic or approaching eutrophy. Most of the rotifer forms are well known food of freshwater fishes. Fry and small fishes eat rotifers. Among them *B. calcyflorus* and *B. rubusta* have been proposed as food for fishes. *B. plicatilis* have become one of the important components in fish hatcheries.

Cladocerans: Cladocerans are one of the most important of the zooplankton groups, which is good natural food for fishes. The lower crustacean is the principal food item of plankton and is eaten by fry and young fish and also by adults in plankton eating fishes like Catla. Adult carnivorous fishes consume the higher crustaceans. The most common and important ones are the *Sida, Alona, Daphnia,* and *Bosmina* etc.

Benthos

The benthos occupies an important position in the reservoir ecosystem and it plays a key role in the food chain, which in turn affects the cycling of minerals hence as a component of fish food in an aquatic ecosystem, the benthos assumes great significance.

Benthic invertebrate fauna show an erratic distribution in Indian reservoirs. The main factors that retard this community are the predominantly rocky bottom, frequent water level fluctuation and the rapid deposition of silt and other suspended particles. In spite of this, a number of reservoirs harbour rich communities of benthic invertebrates. The distribution of benthic organisms depend on (i) physio-chemical characteristics of water (ii) the nature of sediment (iii) the biological complexes such as food, predation and other factors. The benthic organisms are also distributed according to the zones of l a k e f l o or wh i c h i nc l u d e s t h re e z on e s viz . , s u b- l i t t o r a l an d p r of u n d a l . T he v a r i o us zoobenthos encountered in reservoirs of India the freshwater ecosystem is generally divided into two categories – lotic and lentic type.

(a) Benthos of lotic system:

Benthic communities of lotic environments have gained considerable importance as it contributes towards the organic production besides serving as main source of fish food.

The abundance of benthos is directly related to the availability of food supply in the form of decaying organic matter. This is in consonance with the fact that the benthos, particularly oligocheates are related to detritus and detritus in turn, to plant production. Several other factors like amount of sunshine, dissolved calcium and vegetation are further responsible for the increase of population, which ultimately constitute the fish food.

(b) Benthos of lentic system:

The lentic benthos shows a remarkable decrease with the increase of altitude.

Certain other ecological factors like eutrophication, pollution, quality and quantity of aquatic vegetation, texture of lake substratum the physico-chemical features of water etc affect the distribution and relative abundance of benthos. The period of abundance of aquatic Hemipterans coincides with the spawning period of some important fishes. Some of the macro invertebrates occur in association with certain species of aquatic rooted plants viz., *Ceratophyllum, Myriophyllum, Hydrilla* and *Potamogeton*.

Phytobenthos: The phytobenthos comprises of epiphytic algae and aquatic soil fungi. The algae consisted of Cyanophyceae Chlorophyceae, Bacillariophyceae, Xanthophyceae, Chrysophyceae, Dinophyceae, Cryptophyceae and Euglenaceae.

Zoobenthos: The majority of zoobenthos in detritus food chain mostly exhibit diverse feeding habits depending upon the trophic status. The basic source of food in the form of detritus is supplied by the annual litter besides other important sources such as animal waste and organic matter transported to the system. In the next level of trophic system are microbes like bacteria and fungi which act as primary decomposers (directly feeding on detritus),forming an organic detritus microbe complex. The quantitative role of decomposers onthe break down process is, however, unknown.

Besides primary decomposers (snail) ,zoobenthos (*Chironomus*) partly takes the role of secondary decomposers and thus some animals play the duel role of primary as well as secondary decomposers (eg.*Chironomus*). These animals are finally the source of food for benthic predators thus completing the detritus food chain. The benthic community succession especially that of chironomids is sometimes used to characterize habitat changes.

Chironomid larvae form the most important constituent of benthos, reported from all soil types and geographic locations and depths. Gastropods and annelids from the next important groups. *Viviparus bengelensis* enjoys countrywide distribution. The sequence of dominance of benthic communities closely follows the soil fertility pattern, the pre-impoundment debris often providing suitable habitats.

Factors affecting the abundance and distribution of benthos

High shoreline development, variable slopes and vegetation act as favourable factors for the development of a rich assemblage of benthic organisms. Besides the physico-chemical parameters of water and soil, the morphometry and hydrography also influence the benthic community. The water level fluctuations limit the colonisation of bottom inhabiting organisms. The annual water renewal as well as the incoming floodwaters affect and dislodge the bottom fauna. Some of the organisms, the population is relatively high, but then species adopt to bottom dwelling the deeper profundal region is very small.

On the contrary, the shallow littoral zone has rich diversity of bottom fauna. Most of the fishes including major carps and catfishes are feeding on the bottom at varying degrees of intensity.

Hence, a detailed knowledge of the composition, distribution and seasonal abundance of the bottom fauna is prime requisites form the fisheries point of view.

The abundance of benthos is determined generally by weed infestation, sedimentation, and pollution. Excessive deposition of sediment at the bottom of water h ampe r t h e g r owt h o f b e n t h i c o r g a ni sms . Po l l ut i o n f r om i n d us t r i a l , mu ni c i p a l a n d agricultural effluents directly influence the bottom fauna. If any peripheral area of the lake or reservoir is converted into agricultural field, a direct threat of pollution from pesticides is definite.

S ome g r o up o f a nima l s wh i c h ha v e a wi de ba t hyme t r i c a l di s t r i bu t i o n e g . Chironomids and Oligochaete, increase in their abundance in the total fauna, while the l i t t o r a l ge t r e duc e d . Th e p h e nome na a r e d ue t o mi g r a t i o n , wh i c h ma y b e a c t i v e or passive, the latter case is influenced by other factors. The dissimilarity i f any, in the bathymetrical distribution is due to the mobility of the particular species. The gastropods mainly utilize detritus and algae and adapt themselves to thin depth zone.

The bottom fauna distributed in Karnataka was mainly chironomus fol lowed by Molluscs (*Lamellidens marginalis, L. corianus, Viviparus bengalensis, Thiara tuberculata, Lymnea luteola, L. acuminata and Indoplanorbis exustus*), oligochaetes and prawns. Insect group included mainly mayfly nymphs, dragonfly nymphs,Chaoborus and Caddisfly larvae. These forms are wel l utilized by fishes particularly *P . k ol u s , P . sarana, P. dubius* and catfishes like *M. aor, M. seenghala, M. cavasius* and *S. childreni* as food items.

Benthic Organism: An organism that lives on or in the bottom of an aquatic ecosystem. It feeds on the sediment at the bottom of a water body such as an ocean, lake, or river.

Definition of Benthic Zones: The word "benthic" is an aquatic term that's used in association with anything at the bottom of a body of water. Animals and plants that live on or in the bottom are called benthos, and there are innumerable habitants that occupy the different depth levels of the water floor.

The levels are divided into zones called, Benthic Zones, and each zone is home to specific habitats and plants, and each bears its own characteristics that come with the particular depth.

How Zones are Determined : The zones of the marine benthic habitats are mapped out according to the depth of the water. These zones include the Hadal zone, which is over 6,000 meters deep; the Abyssal zone, which is 2,000 to 6,000 meters; the Bathyal zone, which is 200 to 2,000 meters, and the Nearshore and Estuarine zones which are less than 200 meters.

Why Benthic Zones are Important: Each zone is part of the big picture in nature's life cycle and the ecology of wildlife. The shallow zones, which support spawning, are a nursery, a refuge and foraging grounds for fisheries species. Other zones produce coral reefs and eelgrass beds that shelter and protect

other species. The recycling of habitats acts as a water filter, removing water contaminants and helping
to keep the body of water as a whole clean. The Near shore zones are not only nesting grounds for small
organisms--they are the food sources for the other zones as well as for birds.

Biomass

Definition (2):

1. Quantity or weight of all living matter in a given area or biological community.
2. Organic matter available on renewable basis, such as agricultural crops, aquatic plants, animal,
municipal, and wood wastes.

Lecture 4: Food and Feeding Habits of Fish

Food habits and feeding ecology research are a fundamental tool to understand fish roles within their
ecosystems since they indicate relationships based on feeding resources and indirectly indicate
community energy flux (Yánez-Arancibia & Nugent 1977, Hajisamaea *et al.* 2003), which allows inferring
competition and predation effects on community structure (Krebs 1999). Other resources such as space
and time have also been important for community ecology and the ecological theory predicts that
resource partitioning at spatial, temporal and trophic level may increase tolerance of
niche overlap reducing competition pressure between co-occurring species. Ross (1986) identified that
in aquatic environments food is the main factor and that its partition defines functional groups within
the community, which get together in guilds according to trophic similarity.
These trophic guilds (Root 1967) seem to be a consequence of such resource partitioning, which could
explain how several species can coexist in the same space by differing in use of several resource
dimensions. Several studies have focused on competitive exclusion and resource partitioning in teleost
fishes (Zaret & Rand 1971, Hixon 1980, Ross 1986) and have found that habitat partitioning could be
related to high dietary overlap among competing species or to interactive competition, where
competing species have the same preference by preys (Hixon 1980, Jansen *et al.* 2002).

Feeding habits of some important fishes

Food relationships do at least in part determine the population levels, rates of growth
and condition of fish. They serve as a partial basis for determining the status of various
predatory or competing forms. For any species, food habits change with the
season, life history changes and the kind of food available. Food composition in the gut
of fishes are very important basic inputs in various modeling tools and could provide
useful information in positioning of the fishes in a food web in their environment and in formulating
management strategy options in multi species fishery. The data on stomach composition of fish
is vital in providing straightforward models of stomach content dynamics.

Catla catla

Catla is predominantly a planktophagic surface feeder having preference

f o r crustaceans and algae. Based on periodic availability of food, catla changes over to more p l a n t
f o o d f r om a n i m a l f o o d a n d v i c e v e r s a . F o r p l a n k t o n f e e d i n g h a b i t a
g r e a t inters-pecific food competition is seen in catla with almost all the inhabiting species at fry stage
as they all mainly prey upon the plankton. The minnows and clupeids are the main competitors of catla
in reservoirs.

Labeo rohita

Rohu is predominantly a surface feeder and planktivore in the fry stage. Rohu forms a great inter-specific competitor with almost all other inhabiting carp species at the earlier stages of life.
But this competition is considerably reduced from fingering stage o nwa r d s wh e n r oh u
c ha n ge s t h e f e ed i ng h a bi t a n d ha bi t a t , b e c ome a c ol umn- b o t t om feeder and start consuming food mainly the fi lamentous algae, mud and sand. Rohu is found to be a herbivorous fish, consuming more than 75% plant food (unicellular algae a n d
f i l ame n t ou s a l g ae) a n d t h e r ema ini n g r e p re s e nt e d b y a n ima l fo o d
(br y oz oa ns , rotifers, insect larvae and crustaceans). The dominant occurrence of algae and submerged vegetation in the gut indicates the column feeding habit while the presence of decayed organic matter and mud supports the bottom feeding habit too.

Cirrhinus mrigala

Mrigal is predominantly a bottom feeder in adult stage but surface and mid-water feeder in fry and
fingerl ing stages. The long intestinal coil in the adult is found to be more suitable for digestion of the vegetable matter and detritus in the food item. The gut contents are mainly comprised
of decayed organic and vegetable debris, phytoplanktonic organisms and mud.

Cyprinus carpio

Common carp is an omnivorous and it has wide food spectrum. It can adjust the dietary habit according to the local availability of natural food. It is not usually a plankton f e e de r b ut t he y
a re s ome t ime s f o un d f e e di ng on z oo pl a nk t o n i f i t i s a bu n da nt i n t h e environment. It has in general a preference for bottom flora and fauna (Chironomidae, Ephemeridae, Crustacea, Mollusca and Trichoptera). Fingerlings normally switch over tocolumn and
bottom dwelling food organisms. Feeding intensity is found to vary with thewater temperature.

Ctenopharyngodon idella

Grass carp at larval stages feeds on plankton with preference to nanoplankton, rotifers and small-sized cladocerans. But they quickly switch over their feeding habits on macrophytes entirely. The
feeding intensity during post spawning months is high and the adults consume
Hydrilla, Vallisneria, Najas, Utricularia and soft leaves of *Eichornia*.

Hypothalamicthys molitrix

Silver carp is a planktivore. The young and adult exhibit almost similar feedingha bi t s
wi t h ma j o r d e p e n d en c e on *Spirulina, Osci llatoria, Chlorel la, Microcystis* and dominance
on *Desmidium*, *Cosmarium*, *Staurastrum*, *Synedra*, and *Fragilaria*.

Puntius spp.

The presence of wide variety of food items in the diet of these cyprinids, indicates a n omn i vo r ous
f e e di n g ha bi t . De t a i l ed d i e t a r y c omp o s i t i o n a l s o s h owe d t ha t a l l a r e
omn i v o r o us , b ut mor e d e p e n d en t o n be n t hi c f o o d i t ems . Bu t t he pr e s en c e of
i n s e c t matters, microbenthos, mol luscs and crustacean in large biovolumes indicates

that both *P . c h o l a* and *P. dorsalis* are insectivorous, and benthivorous fish, while *P . s ar a n a* is molluscivorus and insectivorous. Furthermore, the preference on benthic matter by *P.chola* and *P. dorsalis* indicate their bottom feeding habit. The preference on mollusc and insect matter in *P. sarana* indicates their ability to feed throughout water column.

Mystus spp.

M. aor in general is a zooplankton feeder at an early stage but the feeding a bit changes to animal organisms (fishes, may-fly nymphs, molluscs and oligochaetes) in the adult stage. Juveniles are mostly insectivorous and marginal feeders.

M. seenghala is a bottom and column feeder, predominantly a carnivore right from the advanced fry stage t o a d u l t . F i s h i s t h e m a i n f o o d i t e m t h o u g h i t c o n s um e s g o o d q u a n t i t y o f i n s e c t s depending upon the availability in the environment during different seasons.

Wallago attu

This is an extremely voracious carnivore, feeds predominantly on fish. Insects, crustacea and algae are sometimes encountered in the gut. Fingerl ings consume insects, other fish fry and fingerlings. The food of freshwater fish species is a subject of continuous research because it constitutes the basis for the development of a successful fisheries management programme on fish capture and culture.

Lecture 5: Food chains and Food Web

Every organism needs to obtain energy in order to live. For example, plants get energy from the sun, some animals eat plants, and some animals eat other animals.

A food chain is the sequence of who eats whom in a biological community (an ecosystem) to obtain nutrition. A food chain starts with the primary energy source, usually the sun or boiling-hot deep sea vents. The next link in the chain is an organism that make its own food from the primary energy source -
- an example is photosynthetic plants that make their own food from sunlight (using a process called **photosynthesis**) and chemosynthetic bacteria that make their food energy from chemicals in hydrothermal vents. These are called **autotrophs** or **primary producers**.

Next come organisms that eat the autotrophs; these organisms are called **herbivores** or **primary consumers** -- an example is a rabbit that eats grass.

The next link in the chain is animals that eat herbivores - these are called **secondary consumers** -- an example is a snake that eat rabbits.

In turn, these animals are eaten by larger predators -- an example is an owl that eats snakes.

The tertiary consumers are are eaten by **quaternary consumers** -- an example is a hawk that eats owls.

Each food chain end with a **top predator**, and animal with no natural enemies (like an alligator, hawk, or polar bear).

The arrows in a food chain show the flow of **energy**, from the sun or hydrothermal vent to a top predator. As the energy flows from organism to organism, energy is lost at each step. A network of many **food chains** is called a **food web**.

Trophic Levels:

The trophic level of an organism is the position it holds in a food chain.
1. **Primary producers** (organisms that make their own food from sunlight and/or chemical energy
from deep sea vents) are the base of every food chain - these organisms are called **autotrophs**.
2. **Primary consumers** are animals that eat primary producers; they are also called **herbivores**
(plant-eaters).
3. **Secondary consumers** eat primary consumers. They are **carnivores** (meat-eaters) and **omnivores** (animals that eat both animals and plants).
4. **Tertiary consumers** eat secondary consumers.
5. **Quaternary consumers** eat tertiary consumers.

Food chains "end" with top predators, animals that have little or no natural enemies.
When any organism dies, it is eventually eaten by **detrivores** (like vultures, worms and crabs) and
broken down by **decomposers** (mostly bacteria and fungi), and the exchange of energy continues.
Some organisms' position in the food chain can vary as their diet differs. For example, when a bear eats
berries, the bear is functioning as a primary consumer. When a bear eats a plant-eating rodent, the bear
is functioning as a secondary consumer. When the bear eats salmon, the bear is functioning as a tertiary
consumer (this is because salmon is a secondary consumer, since salmon eat herring that eat zooplankton that eat phytoplankton, that make their own energy from sunlight). Think about how
people's place in the food chain varies - often within a single meal.

Numbers of Organisms:

In any food web, energy is lost each time one organism eats another. Because of this, there have to be many more plants than there are planteaters. There are more autotrophs than heterotrophs, and more planteaters than meat-eaters. Although there is intense competition between animals, there is also an interdependence. When one species goes extinct, it can affect an entire chain of other species and have unpredictable consequences. herbivores, decreasing the herbivore population. It then becomes harder
and harder for the carnivores to find herbivores to eat, and the population of carnivores decreases. In
this way, the carnivores and herbivores stay in a relatively stable equilibrium, each limiting the other's
population. A similar equilibrium exists between plants and plant-eaters.

Lecture 6: Habitat selection, Population, Niche Concept

Aquatic fisheries science is currently undergoing a conceptual shift in understanding of fish-habitat
linkages, assessment, and management. In the present models, habitat is identified using relatively
static indicators: e.g. depth, cover, substrate, and to a lesser extent velocity, which depend on geology,
physiography and landscape – variables used in the Aquatic Ecosystem Classification.

Emerging science links aquatic species life history traits and rate processes – hatching success, growth rate, survival – to dynamic habitat features that influence species more directly – temperature, light and water movements (currents, turbulence etc.). These dynamic habitat features are energy based and are driven by climate and hydrological processes and phenomena and draw more explicit links between physiology and habitat.

Every organism has a place to live in nature, a functional role in that place, and a complex set of adaptations for reproducing its kind. On the surface, this observation might seem to be obvious, even trivial. However, in order to understand our biological world—the biosphere, how it operates and ultimately how to protect it—we need to understand at a deep level how organisms interact with each other and with their physical environment.

The most fundamental and perhaps most difficult of these concepts is that of the **ecological niche**. A niche refers to the way in which an organism fits into an ecological community or ecosystem. Through the process of natural selection, a niche is the evolutionary result of a species' morphological (morphology refers to an organism's physical structure), physiological, and behavioral adaptations to its surroundings. A **habitat** is the actual location in the environment where an organism lives and consists of all the physical and biological resources available to a species.

Linking Habitat Selection, Emigration and Population Dynamics: A Conceptual Model

One of the most important attributes of fish and other mobile animals is the ability to move away from unsuitable conditions. However, for mobility to have its greatest adaptive advantage, organisms must be able to assess biotic and abiotic conditions such that exploratory behaviour is triggered 'on' by inadequate or unsuitable conditions, and triggered 'off' when individuals encounter suitable conditions (Sale 1969a; Bell 1991). To do this, animals must be able to perceive environmental features that, over evolutionary time, have been associated with survival and reproductive success for the species (Kristan 2003).

During habitat selection, animals respond by remaining in areas that hold the proper suite of environmental cues, but continuing to search more widely when these cues are not present in a local area, even if this requires that they move through areas unsuitable for the species (Matter et al. 1989; Bonte et al. 2004). Cues that trigger exploratory behaviour may include unfavorable environmental conditions, inadequacy of resources, or unacceptable interactions with resident animals, including intraand interspecific competitors and predators (Bell 1991). In this way, movement is viewed as a conditiondependent trait that can be triggered by many different cues (Ims & Hjermann 2001).

Sale (1969a) provided an early conceptual model linking resource availability, motivation, and exploratory behaviour in fish (Fig. 1). Sale theorized that habitat selection is a continually active process governed by the intensity of exploratory (appetitive or searching) behaviour via a negative feedback loop, with exploratory behaviour governed by the interaction of internal drives (motivation) for needed resources (A) with the perceived availability of those resources in the environment (B). External and internal stimuli perceived by the central nervous system serve to regulate exploratory behaviour (C).
Sale hypothesized that exploratory behaviour leads to variation in the immediate environment (D) experienced by an individual, which, in turn, leads to changes in the level of stimuli (B) animals use to assess availability or access to needed resources. Thus, the model predicts that exploratory behaviour will be most intense when environments are perceived as less adequate (E), and exploration will diminish when an environment is perceived as suitable (F), leading to residency (G). As a result of this process, the intensity of exploratory behaviour (movement rate) is inversely proportional to the quality of available habitat (Winker et al. 1995). Furthermore, the model suggests that exploratory behaviour can be triggered by a host of factors affecting both resource needs and availability. Tests of the model in the laboratory with manini (*Acanthurus triostegus sandvicensis*), a tropical reef fish, confirmed that the intensity of searching behaviour varied greatly dependent on water depth and presence of cover.
Searching behaviour was lowest when fish had access to shallow water with cover, the preferred habitat of manini in the field (Sale 1969b).
Sale did not address emigration directly in his model, so the question remains: How does exploratory behaviour relate to emigration? We hypothesize that emigratory behaviour can be viewed as a more intense form of exploratory behaviour (H). This is analogous to Sale’s observation that searching behaviour was expressed nearly continuously in the presence of deep water with no cover- the least preferred conditions in the field. Thus, emigration events are likely to occur when environments that lack adequate resources (or access thereof) trigger continued exploration until animals eventually emigrate from an area in search of suitable conditions elsewhere. Experiments with several different animals support this hypothesis (Matter et al. 1989; Nelson et al. 2002). Viewed in this way, the decision to stay in an area or emigrate represents two ends of a continuum of complementary behavioural responses that may be elicited from any individual of a mobile animal species in response to the

adequacy of the site currently occupied. The summation of the many such individual behavioural responses of fish to local conditions in relation to their environmental and physiological requirements will not only be a key determinant of the density of individuals occupying a site but, in turn, the resulting emigration will drive the larger scale spatial (I) and temporal (J) population dynamics within a landscape (Fig. 1) (Lidicker 2002; Humston et al. 2004; Kritzer & Sale 2004).

Although this habitat selection-emigration model is conceptually simple, we believe it provides a useful explanatory tool for linking individual behaviour to population dynamics. To date, habitat selection has been explained primarily through the optimization models based on ideal-free and ideal-despotic theories. According to optimization models, well summarized for fishes by Kramer et al. (1997), population density in concert with habitat quality is the main driver of the decision of individuals to settle in or move away from habitat patches of differing quality. These models have been used profitably to predict local fish distributions in the field based on balancing survival and net energy functions (e.g., Hughes 2000; Railsback & Harvey 2002). However, in these studies it is frequently unclear which proximate environmental cues or stimuli individual animals are using to assess habitat suitability (Grossman et al. 1995). Also, few habitat selection studies have explored the relationship of local movement within habitat patches to emigration and larger-scale population dynamics (Doncaster 2000). Furthermore, an important assumption of optimality models is that animals 'sample' all available habitats before settling, yet animals often leave a site, in some cases moving across expanses of unsuitable conditions, without knowledge of the quality nor availability of other sites (McMahon & Tash 1988; Matter et al. 1989; Bonte et al. 2004). Our model suggests that the quality of the local site in relation to current resource needs and access is the primary driver of habitat selection and exploration decisions, rather than information about conditions at distant sites.

Detailed observations of fish habitat selection and movement in nature also show a great deal of complexity and individual variation (e.g., Armstrong et al. 1997, 1999; Smithson & Johnston 1999; Diana et al. 2004) that are not readily explained by optimization models (Thorpe et al. 1998). For example, marked seasonal habitat shifts of fishes during autumn may occur abruptly, without any apparent changes in food availability or habitat quality (Riehle & Griffith 1993; Jakober et al. 1998). Similarly, nutritional or hormonal state can trigger movement away from a site of residence (Forseth et al. 1999), movement that is not strictly dependent on density or resource availability per se, but rather reflects changes in physiological needs of individuals (Bell 1991). Thus we believe that our model complements current habitat selection theory by extending it to include the underlying motivations and proximate environmental cues that govern habitat selection, and to explore the population dynamics consequences of habitat selection and movement patterns (see also Grossman et al. 1995).

The degree to which fish movement is a rather fixed trait has been the subject of much discussion among fish ecologists (Gowan et al. 1994; Rodríguez 2002), and the idea that there are 'mobile' and 'resident' factions among individuals within populations is common (see Gowan et al. 1994 for discussion). Indeed, dispersal has generally been viewed as an adaptive trait that evolved for colonization of new environments, prevention of inbreeding depression, or risk spreading in stochastic environments (e.g., Kisdi 2002; Hendry et al. 2004). In our model, individual differences in access to resources or changes in environmental or physiological requirements could elicit variation in movement among individuals from very limited to very mobile, thereby accounting for the wide variation in movement observed both within and among fish populations (Smithson & Johnston 1999; Gowan & Fausch 2002; Rodríguez 2002; Hilderbrand & Kershner 2004). Experiments with fishes and other animals demonstrating that individual emigrants readily become residents when needed resources are supplied and that residents become emigrants when resources are limited (Matter et al. 1989; Nelson et al. 2002), lend support to this inherent flexibility in switching between residency and emigratory behaviour.

We hypothesize that emigration is primarily an adaptive response to the inadequacy of conditions at the site of residency, and other benefits of movement to species persistence (risk spreading, gene flow, colonization of open habitat, rescue effect in metapopulations) accrue largely as a byproduct of the movement resulting from habitat selection decisions as portrayed in our model.

Lecture 7: Reproductive Behaviour and Life Cycle of Selected Species

1) Tilapia: Life History and Biology

The Nile tilapia (*Oreochromis niloticus*) was one of the first fish species cultured. Illustrations from Egyptian tombs suggest that Nile tilapia were cultured more than 3,000 years ago. Tilapia have been called Saint Peters fish in reference to biblical passages about the fish fed to the multitudes. The Nile tilapia is still the most widely cultured species of tilapia in Africa.

Positive aquacultural characteristics of tilapia are their tolerance to poor water quality and the fact that they eat a wide range of natural food organisms. Biological constraints to the development of commercial tilapia farming are their inability to withstand sustained water temperatures below 50 to

52o F and early sexual maturity that results in spawning before fish reach market size. Following is a discussion of the characteristics and culture of non-hybrid tilapia.

Taxonomy

Tilapia is the generic name of a group of cichlids endemic to Africa. The group consists of three aquaculturally important genera *Oreochromis, Sarotherodon* and *Tilapia*. Several characteristics distinguish these three genera, but possibly the most critical relates to reproductive behavior. All tilapia species are nest builders; fertilized eggs are guarded in the nest by a brood parent. Species of both *Sarotherodon* and *Oreochromis* are mouth brooders; eggs are fertilized in the nest but parents immediately pick up the eggs in their mouths and hold them through incubation and for several days after hatching. In *Oreochromis* species only females practice mouth brooding, while in *Sarotherodon* species either the male or both male and female are mouth brooders.

During the last half century fish farmers throughout the tropical and semi-tropical world have begun farming tilapia. Today, all commercially important tilapia outside of Africa belong to the genus *Oreochromis*, and more than 90 percent of all commercially farmed tilapia outside of Africa are Nile tilapia. Less commonly farmed species are Blue tilapia (*O. aureus*), Mozambique tilapia (*O. Mossambicus*) and the Zanzibar tilapia (*O. urolepis hornorum*). The scientific names of tilapia species have been revised a lot in the last 30 years, creating some confusion. The scientific name of the Nile tilapia has been given as *Tilapia nilotica, Sarotherodon niloticus*, and currently as *Oreochromis niloticus*.

Physical characteristics

Tilapia are shaped much like sunfish or crappie but can be easily identified by an interrupted lateral line characteristic of the Cichlid family of fishes. They are laterally compressed and deep-bodied with long dorsal fins. The forward portion of the dorsal fin is heavily spined. Spines are also found in the pelvis and anal fins. There are usually wide vertical bars down the sides of fry, fingerlings, and sometimes adults.

Banding Patterns and Coloration

The main cultured species of tilapia usually can be distinguished by different banding patterns on the caudal fin. Nile tilapia have strong vertical bands, Blue tilapia have interrupted bands, and Mozambique tilapia have weak or no bands on the caudal fin. Male Mozambique tilapia also have upturned snouts.

Color patterns on the body and fins also may distinguish species. Mature male Nile tilapia have gray or pink pigmentation in the throat region, while Mozambique tilapia have a more yellow coloration.

However, coloration is often an unreliable method of distinguishing tilapia species because environment, state of sexual maturity, and food source greatly influence color intensity.

The red tilapia has become increasingly popular because its similar appearance to the marine red

snapper gives it higher market value. The original red tilapias were genetic mutants. The first red tilapia,
produced in Taiwan in the late 1960s, was a cross between a mutant reddish- orange female Mozambique tilapia and a normal male Nile tilapia. It was called the Taiwanese red tilapia. Another red strain of tilapia was developed in Florida in the 1970s by crossing a normal colored female Zanzibar tilapia with a red-gold Mozambique tilapia.
A third strain of red tilapia was developed in Israel from a mutant pink Nile tilapia crossed with wild Blue tilapia. All three original strains have been crossed with other red tilapia of unreported origin or with wild *Oreochromis* species. Consequently, most red tilapia in the Americas are mosaics of uncertain origin. The confused and rapidly changing genetic composition of red tilapia, as well as the lack of headto-head growth comparisons between the different lines, make it difficult for a producer to identify a best red strain. Other strains of tilapia selected for color include true breeding gold and yellow Mozambique lines and a Rocky Mountain white tilapia (a true breeding line originating from an aberrant Blue tilapia, subsequently crossed with Nile tilapia). Most strains selected for color do not grow well enough for food fish culture.
Identifying the species of an individual fish is further complicated by natural crossbreeding that has occurred between species. Electrophoresis is often used to determine the species composition of a group of tilapia.

Reproduction

In all Oreochromis species the male excavates a nest in the pond bottom (generally in water shallower than 3 feet) and mates with several females. After a short mating ritual the female spawns in the nest (about two to four eggs per gram of brood female), the male fertilizes the eggs, and she then holds and incubates the eggs in her mouth (buccal cavity) until they hatch. Fry remain in the females mouth through yolk sac absorption and often seek refuge in her mouth for several days after they begin to feed.
Sexual maturity in tilapia is a function of age, size and environmental conditions. The Mozambique tilapia reaches sexual maturity at a smaller size and younger age than the Nile and Blue tilapias. Tilapia populations in large lakes mature at a later age and larger size than the same species raised in small farm ponds. For example, the Nile tilapia matures at about 10 to 12 months and 3/4 to 1 pound (350 to 500 grams) in several East African lakes. Under good growth conditions this same species will reach sexual maturity in farm ponds at an age of 5 to 6 months and 5 to 7 ounces (150 to 200 grams). When

growth is slow, sexual maturity in Nile tilapia is delayed a month or two but stunted fish may spawn at a weight of less than 1 ounce (20 grams). Under good growing conditions in ponds, the Mozambique tilapia may reach sexual maturity in as little as 3 months of age, when they seldom weigh more than 2 to 4 ounces (60 to 100 grams). In poorly fertilized ponds sexually mature Mozambique tilapia may be as small as 1/2 ounce (15 grams).

Fish farming strategies that prevent overcrowding and stunting include: 1) cage farming where eggs fall through the mesh to the pond bottom before the female can collect them for brooding; 2) polyculture with a predator fish, such as fingerling largemouth bass, at 400 per acre; and 3) culture of only males (monosex). All-male culture is desirable in ponds not only to prevent overpopulation and stunting but also because males grow about twice as fast as females. Methods of obtaining predominately male fish include: 1) manually separating the sexes based on visual examination of the genital papilla of juvenile fish (hand-sexing); 2) hybridizing between two selected species that produce all-male offspring (for example, Nile or Mozambique females crossed with Blue or Zanzibar males); 3) feeding a male hormonetreated feed to newly hatched fry for 3 to 4 weeks to produce reproductively functional males (sex reversal); or 4) YY male technology (currently under development and not yet a commercial option).

The sex of a 1-ounce (25-gram) tilapia fingerling can be determined by examining the genital papilla located immediately behind the anus (Fig. 1). In males the genital papilla has only one opening (the urinary pore of the ureter) through which both milt and urine pass. In females the eggs exit through a separate oviduct and only urine passes through the urinary pore. Placing a drop of dye (methylene blue or food coloring) on the genital region helps to highlight the papilla and its openings.