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Winter School on

Towards Ecosystem Based Management of Marine Fisheries – Building Mass Balance Trophic and Simulation Models

INFORMATION ONLY

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Technical Notes

FISHERIES OCEANOGRAPHY – PROCESSES, PATTERNS & VARIABILITY

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Introduction

Oceanography is the scientific discipline concerned with all aspects of the world's oceans and seas, including their physical and chemical properties, their origin and geologic framework, and the life forms that inhabit the marine environment. Traditionally, oceanography has been studied under four separate but related branches: physical oceanography, chemical oceanography, marine geology, and marine ecology. Meteorology is another subject closely related to oceanography and inseparably linked to the physical processes of the ocean.

Fisheries oceanography (or hydrography) is essentially an interdisciplinary area of study focusing on the various factors and conditions of the sea determining the availability of fishery resources in time and space. The methods of fisheries oceanography relate the abundance (more exactly the patterns of behaviour) of species to the surrounding hydrological features and use the relationship for predictive purposes. In short, fisheries hydrography is an applied branch of oceanography, which integrates hydrographical knowledge and behaviour of species and technology of production so as to optimise the yield of commercially valuable species with minimum effort. Thus a prior knowledge of some sea conditions such as thermal structure could be used to locate the availability of certain species of fish and the fishing fleet targeting on the species can save significantly on searching time and fishing effort.

The earth system is fuelled by solar energy. The dynamic interaction among ocean, atmosphere and land, causes many events and mater/energy flows in the system to occur in a cyclic manner. The physical oceanic processes influence the chemical and ecological processes in the sea, which follow definite patterns. The dynamic nature of the system also causes temporal and spatial variability in the factors and dependent components.

The interrelations among various biotic and abiotic components in the ocean system are very complex. Researchers attempting to unravel the intricate relations have to face formidable challenges. A simple way to deal with this situation is to gain an understanding of the processes and underlying principles and then stud the small subsystems. Later this knowledge can be integrated to more complex systems. This approach to understand the processes and patterns in the dynamic ocean systems and associated responses in biological systems will pay rich dividends. This article attempts to provide the readers with glimpses of some important processes, phenomena, patterns and variability of fisheries oceanography in order to establish cause-effect linkages. This would help the readers to understand and intuitively analyse the various situations they encounter in the course of their learning. A list of further reading is also provided to help the readers to gain further knowledge on the subject.

Factors affecting fisheries

The different species in the sea have evolved to make the best use of the surrounding environment. Thus we find species adapted to even the most hostile environment and specialized to exploit every conceivable niche in the ocean. The survival strategies of many species are well tuned to the patterns and processes in the sea. For example, the spawning and seasonal migrations as well as larval drift of many species are well orchestrated with the circulation in the oceans.

Basically the presence of any organism in a particular place and time could be taken as an indication of the existence of some factors favourable (or some factors beyond the control) for the species in question. These factor(s) could be one or many of the following:

- Ambient environment (temperature, light, chemistry, currents)
- Abundance of dissolved gases (oxygen, carbon dioxide)
- Availability of food, shelter and substratum

Sometimes an anomaly in the system such as a change in the circulation pattern may transport certain species to certain localities. If the hydrological conditions most preferred by different organisms are known, it will be easier to relate their probable presence (absence) based on the conditions prevailing in a given location. For predicting potential areas for profitable fishing the following are required:

a) Optimum temperatures (and the optima of other environmental factors of all economically important species must be known.

b) Data from a sufficiently large number of hydrographical and meteorological observations to provide information on location of critical isotherms, sharp temperature gradients, eddies and currents.

c) Predictability of changes in the hydrological conditions.

In the following sections the oceanic processes controlling important hydrological factors and the behaviour of different species in response to these major environmental factors shall be discussed.

Temperature of Seawater

Temperature is one of the important factors affecting life in the ocean and is perhaps the most easily measured basic parameter in hydrographic studies. In fact the spatial difference in temperature (and consequently density and pressure) is the main factor controlling the multitude of processes that takes place in the earth system. There are a number of processes and factors influencing the thermal structure of the surface and sub-surface seawater (Table-1).

The surface waters receive most of the heat energy from the sun, which is not transmitted to the bottom beyond the mixing layer. The vertical profile of temperature measured using Bathythermograph (BT) generally show a mixed layer from surface to a certain depth (MLD) and then a zone of rapid decline called *thermocline* or *temperature discontinuity* *layer*. Thermocline may be permanent or seasonal and is generally observed between 10-200 m depth. Depending on the shape of the vertical temperature profile, different forms of thermoclines are identified (Figure.1). The normal thermocline is most common form and has a mixed layer near surface. On extreme case it may become a continuous density model with a uniform gradient.

Most of the cold-blooded animals prefer to be in ambient temperature for optimising their body functions and minimising the energy loss. Thermocline is an important thermal feature of the sea, which control the movement of fish. The different commercially important species of fish and shellfish prefer certain range of temperature to live (Table-2). It is worth noting that different species of tropical tunas occupy different positions with respect to the thermocline (Figure.2). The success of midwater trawling depends on the position of the mixed layer depth (MLD) nearer to the surface (Figure.3). For purse seining a shallow thermocline would prevent diving and escape of fish from the seine (Figure.4). Fishermen can use this knowledge to reduce their search time during fishing.

Temperature is also an important criterion in the energy budget of organisms. During winter baleen whales of southern hemisphere cease to feed and migrate to the tropics. Apparently the lower rate of body heat loss in tropical waters justifies energy expended for making 10000 km journey. The

Light in the sea

Light as the source of energy to the photosynthesis is the most important factor in the existence of life in the sea. In shallow areas light is available throughout the water column. In deeper regions surface and subsurface waters are well-illuminated (euphotic zones) supporting photosynthetic activity by plants and micro-algae. Absorption (more on the red side than on the blue side) and scattering (by mineral and particulate suspended matter) reduce the intensity of light in deeper layers. Thus Light becomes a limiting factor in deeper layers. Due to the influence of various processes the optical characteristics of seawater varies greatly (Table –3).

While planktonic production is associated with light, other organisms exhibit varying photo-tactic behaviour. Fishes are known to respond to light stimuli as low as 0.01-0.001 lux, but the lower light intensities, which bring about maximum response range between 50-200 lux. In sufficiently illuminated waters fishes can recognise colours and in turbid waters vision range is very low. Enhanced visibility in clear waters is not favourable for capture of fish in static nets such as gillnets. Attraction of different species (especially the hungry ones) to light is often used advantageously in different fishing techniques (e.g. squid jigging). Fishes tend to avoid high plankton production areas during daytime and remain down below. Fishes tend to actively swim during light period and passively drift during darkness. Mainly light and temperature together influences the common patters of diurnal vertical migration of fish:

- Pelagic species occurring slightly above thermocline during daytime migrate to surface layers at sunset and disperse between surface and thermocline during night.

- Pelagic species occurring below thermocline during daytime migrate through thermocline to surface layers at sunset and disperse between surface and bottom during night, with bulk occurring above thermocline.

- Pelagic species occurring below thermocline during daytime migrate into thermocline at sunset and disperse between thermocline and bottom during night.

- Demersal species occurring close to bottom shows migration and dispersal into the column below (sometime above) thermocline during sunset.

- Species, which are dispersed throughout the water column during the day, descend to bottom layers during night.

All the above species migrate back to their original position at dawn. It must be noted that there are many pelagic and demersal species without any distinct diurnal migration.

Chemistry of Seawater

Seawater contains almost all chemical elements in solution or in colloidal suspension. It is a complex aqueous solution of a variety of dissolved solids and gases. The absolute concentration of total dissolved solids varies from place to place (it may vary from 0 g kg^{-1} in freshwater influx areas to as high as 40 g kg^{-1} in Red sea), but the ratios between more abundant substances virtually remain constant. The composition of important ionic constituents in seawater (of 35 S) is given in Table-4.

Salinity is perhaps the most important parameter controlling the distribution of species. The coastal areas with river influx and the estuaries are of lower salinity and many species or life stages of some species prefer such areas. A large number other species prefer to be in higher range of salinity. All species show tolerance to varying range of salinity, though an abrupt change will have detrimental effect.

Micronutrients such as phosphates, nitrates, and silicates are the basic inputs for the primary production by plankton. Generally these nutrients flow in a cycle within the system with various physical processes and biological agents facilitating the different conversion process and transport. Silicates are generally abundant along coastal areas due to river discharge and interaction with land. Deeper water below thermocline may have phosphate concentration of 2-4 ?g.l^{-1}. In many places, especially the oceanic surface waters, the seawater is poor in phosphates, nitrates and they often become limiting nutrients in primary production. In addition various trace elements such as iron and cobalt, also important for plankton production, may at times become limiting factors in certain areas. Thus the chemical constituents of seawater will have an indirect impact on fisheries through primary production and the food chain.

Dissolved Gases

Oxygen (O_2), Nitrogen (N_2) and carbon dioxide (CO_2) are the three important dissolved gases in seawater. The concentration of gases in seawater is inversely related to temperature and salinity (Table-5). While carbon dioxide is the basic input for the primary production by plants and plankton in the sea, oxygen is indispensable to the maintenance of all organisms. Carbon dioxide is sufficiently abundant in seawater either as dissolved gas (replenished by excretion of living organisms and from atmosphere) or as a fixed constituent of the bicarbonates to meet the requirements of plants. Therefore CO_2 is never a limiting factor in the sea. Dissolved CO_2 is the main factor controlling the pH of seawater, which generally vary between 8.1 and 8.3.

The concentration of oxygen even in well-oxygenated seawater is very small (9 ml l^{-1}) compared to that present in the air (200 ml l^{-1}). Generally surface waters and surf zones are rich in oxygen due to mixing of atmospheric oxygen during wave action. Plants also release oxygen during photosynthesis. There is greater irregularity in the distribution of oxygen and in some instances sharp gradients can be observed. Within only 10 m the dissolved oxygen may range from 0 to 6.4 ml l^{-1}. In isolated and stagnant fjords the oxygen deficiencies are markedly reflected in the fauna.

A concentration of oxygen in the water column is controlled mainly by the atmospheric diffusion, temperature, salinity, primary production and consumption. At certain depth the rate of depletion may nearly equal replenishment. Fishes tend to avoid this layer of water having low oxygen known as *oxygen minimum layer*. The movement of fishes during upwelling is related to the movement of oxygen minimum layer (figure.5).

All marine organisms (except mammals and reptiles) need to absorb this small quantity of dissolved oxygen through the surfaces of their body or specialized organs such as gills. Thus obtaining adequate oxygen for metabolic needs is one of the major problems for marine organisms. As calorific return may be limited by either the amount of food ingested or by the amount of oxygen available to metabolise it, organisms may be compelled to trade off between availabity of oxygen and availability of food in the time space continuum.

The need for oxygen is more in the case of larger organisms since body volume increase at a greater rate than body surface area. As fish grow, retaining the geometric shape of the body, the gill’s surface area increases more slowly than the body volume. Therefore due to increased demand for oxygen, larger fishes tend to remain at relatively cooler deeper waters rich in oxygen. Tunas have very large heads (and gills) and shortened bodies to suit their high-energy life style. Even then, certain tropical tunas often are forced to dive down into deeper waters because they are unable to meet their need for oxygen in the warm surface waters. The tendency of many species of tunas to orient their position with respect to the thermocline is advantageous for the fishermen.

Food, Shelter and Substratum

Food is the most important factor for the survival of any organism. The marine organisms move vertically and horizontally in search of food. The sedentary organisms attach to suitable places where supply of food is ensured by the moving water. Successful of attachment of larvae to suitable substratum is a critical factor in the life of sedentary organisms. Plankton feeders flourish in places of high plankton production. Carnivores make a living in the proximity of prey population. Apex predators chase the prey over larger areas.

Many marine ecosystems share one striking aspect in configuration of their biological diversity. They typically contain a very large number of species at the lower trophic levels and a substantial number of species that feed (as adults) at apex or near apex level. However in many richly productive ecosystems of the world (upwelling areas) there is often a crucial intermediate trophic level, occupied by small, plankton-feeding pelagic fishes like sardine or anchovies. Because of the distribution of many species at top and bottom of trophic levels and few dominant species at the middle level, these ecosystems are often referred to as wasp-waist ecosystems (J. Rice as quoted in Bakun, 1996).

Different species flourish in different localities of the sea where conditions are favourable and individuals are protected from the vagaries of environment, including predation. Larval fish require very small food particles and thus feed at a lower tropic level and also protection from predators. The reason for many fishes having an estuarine larval form is obviously to avail the benefits of abundant food supply and protection from predators to ensure better survival. Reef ecosystems are also highly productive and provide abundant substratum and shelter for a rich diversity of species

In the featureless open ocean, the floating objects attract fish and other organisms. Sargasso Seas support a rich diversity of epifauna and serve as a spawning ground for many species. The tendency of fish to aggregate near floating objects is behind the development of Fish Aggregating Device (FAD).

Upwelling and tidal mixing

Having discussed some important oceanic factors having a significant role in the distribution of different species in time and space, it is appropriate to briefly discuss some important processes and which control other factors. Seasonal overturn of sweater is an important process, which brings the nutrient rich bottom waters to the surface areas. Tidal mixing and turbulence are frequent in shallow areas. *Upwelling* is an interesting process that takes place in many parts of the ocean.
The process of upwelling involves movement of subsurface water towards surface consequent to the displacement of surface waters by prevailing forces and may be of the following types:

- Coastal upwelling (most common)
- Shelf breaking upwelling
- Equatorial upwelling
- Vortex driven upwelling

In the case of coastal upwelling (as in the case of East Coast of India), the prevailing winds and currents running parallel to the coast and coriolis force causes surface water to drift away (Ekman's transport) from the coast. The deeper water raises up nearer to the coast to replace the drifting surface waters. Oceanic upwelling takes place near at the area of divergence where surface water move apart allowing deeper water to raise up. A converse process called *downwelling* or *sinking* also takes place in certain parts (as along the East Coast of India).

The significance of upwelling is that the process replenishes the nutrients in the surface waters and thereby enhancing the primary and secondary productivity. Highly productive upwelling areas are characterised by a dominant single species fishery (as Peruvian anchovy). As oceanic systems are subject to variability, the dependent fisheries collapse when the patterns and conditions vary. In other areas of upwelling, the oxygen minimum layer controls the movement of fish (Figure.5).

Currents

Ocean currents are the most important factor causing changes in the environmental properties of the sea over large areas. The great permanent currents (like the Gulf Steam) develop due to the horizontal density gradient by differential heating of oceanic water in different localities or are maintained by the trade winds. The major oceanic currents run along the continental boundaries and facilitate a number of coastal processes. In addition, short-tern currents, periodic tidal currents and advective movements also play an important role in the oceanic and coastal processes. The influence currents on the fishes may be direct or indirect. The following are some of the important aspects of fish behaviour related to currents.

- Currents transport fish eggs and fry from spawning grounds to nursery grounds and from nursery grounds to feeding grounds. Any variation in the pattern will affect the survival of the particular brood.

- Migration of adult fish could be affected by current, which serves as a means of orientation.

- Currents (especially tidal) may affect the diurnal behaviour of fish.

- Currents influence distribution of fish, especially at its boundaries, though direct effect as well as aggregation of food or bringing the favourable environmental boundaries (temperature).

- By affecting the properties of the environment, currents decide the geographic limits and boundaries of fish distribution.

Knowledge about the currents, thus, could be of immense use in the exploitation of fishery resources. Proper hydrogrpahic sampling focussing on changes in the patterns and abundance of eggs and larvae are very important for predicting the fishery yield.

Ecosystem Approach

Having understood the important factors determining the abundance of fish in the sea, it is appropriate to briefly discuss the different approaches to management fishery resource. The abundance of a species in a system is controlled by various environmental factors as well as the biological characteristics of the species itself. The models hitherto used for assessment of fisheries stocks often fail to explain many changes in the abundance of stocks as several important factors were not considered in deriving various parameters. The principal processes and interactions in the marine ecosystem are to be considered while developing models for fisheries management (figure.6).

Gary Sharp (1995) has voiced his concern that fisheries studies have simply ignored climate signals or have buried these and other environmentally mediated signals in mystical parameters. He called for truly interdisciplinary approaches to aquatic ecology and marine fisheries research and reincorporating of operational oceanography and climatology into fishery science. While observing that 'for some obscure reason, fisheries management has become welded to biomass as the principal measure of resource status', he points out that stock assessment tools need to be expanded to cope with ecosystem status. In fact Sverdrup (1952) had succinctly explained much earlier the practical aspects of fishery oceanography with respect to prediction of the availability and size of the stock of any exploited species of fish. These voices are reflected in the new approaches of fisheries management being evolved at various places.

Further Reading

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Table-1
Major causes that change sea surface temperature

Basic cause	Processes and factors
Advection	Permanent (gradient) flow, Wind currents, Inertia and tidal currents
Heat Exchange	Insolation (affected by clouds), Evaporation (affected by wind speed and e_w-e_a), Other heat exchange components
Mixing	Wave action, Convective stirring, Currents

Special causes	Upwelling and divergence/convergence, Precipitation, Runoff, Freezing and melting of Ice
Source: *Laevastu & Hela, 1970.*	

Table-2

The temperature (^oC) range in which some commercially important species prefer to live.

Species	*Distribution Range*	*Fishing range*
Cod	1-5	2-4
Pollock	0-8	2-5
Halibut	2-5	3-4
Herring	3-11	4-7
Salmon	4-11	6-8
Sardine	5-25	12-16
Squid	10-18	12-16
Pacific mackerel	12-18	14-16
Bluefin tuna	14-21	15-21
Bonito	12-25	15-22
Albacore	14-23	15-21
Bigeye tuna	11-28	18-22
Swordfish	13-27	19-22
Skipjack	17-28	19-23
Little tuna	17-28	18-23
Yellowfin	17-31	18-23

Source: adapted from Uda, M, (1952) and Monin, et al. (1977)

Table-3

Classification of sweater base on optical characteristics

Class	***Characteristics***
Oceanic clear	Clear oceanic waters in low productive areas especially in low latitudes. Water colour 0-2 (Forel scale).
Oceanic normal	Medium productive oceanic waters in medium and low latitudes. Water colour 2-5.
Oceanic turbid and coastal clear	High productive oceanic areas, especially during plankton bloom. Tropical coastal waters, especially over deep shelves. Water colour 5-8.
Coastal normal	Normal medium productive coastal waters and waters over shallow shelves. Water colour 8-10
Coastal turbid	Estuarine and coastal waters during intensive plankton bloom and waters close to the coast where wave action cause whirling up of sediments. Water colour 10

Source: *Laevastu & Hela, 1970.*

Table-4

Ionic composition (g/kg) and percentage (of total salts) in seawater of practical salinity 35.0

Ion	*Symbol*	*Composition*	*Percentage*
Chloride	Cl^-	19.35	55.04
Sodium	Na^+	10.77	30.62
Sulphate	SO_4^-	2.71	7.71
Magnesium	Mg^{++}	1.29	3.68
Calcium	Ca^{++}	0.41	1.17
Potassium	K^+	0.40	1.14
Bicarbonate	HCO_3^-	0.12	0.33
Bromine	Br^-	0.07	0.19

Source: Based on Millero, F. J., 1974. *Ann. Rev. Earth Planetary Sci*., 2, 101

Table-5

Coefficient of saturation of atmospheric gases (C_s) in water (as ml l^{-1} in equilibrium with 760 Torr of designated gas)

Temperature	***0º***			***12º***			***24º***		
Chlorinity (º/oo)	O_2	N_2	CO_2	O_2	N_2	CO_2	O_2	N_2	CO_2
0	49.24	23.00	1715	36.75	17.80	1118	29.38	14.63	782
16	40.10	15.02	1489	30.60	11.56	980	24.80	9.36	695
20	38.00	14.21	1438	29.10	10.99	947	23.60	8.96	677

Source: Sverdrup et al., 1942

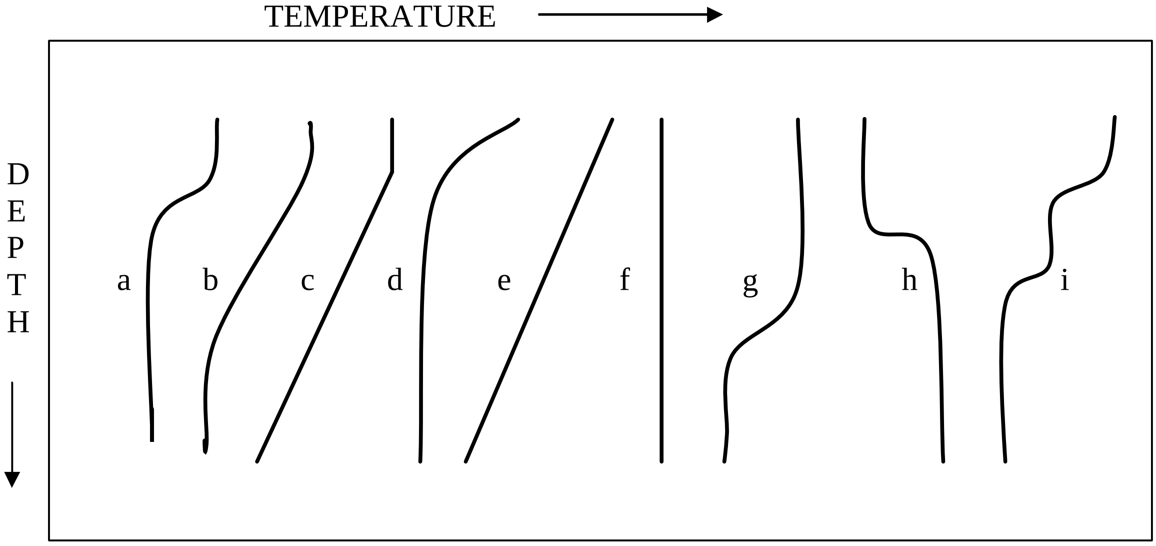


Figure.1. Different types of thermoclines: a) normal themocline, b) extended themocline, c) Epithermocline, d) Surface thermocline, e) Continuous density model, f) Homothermocline, g) Sub-thermocline, h) inverse thermocline, i) Double thermocline. (*Adapted from*: *Laevastu & Hela, 1970).*

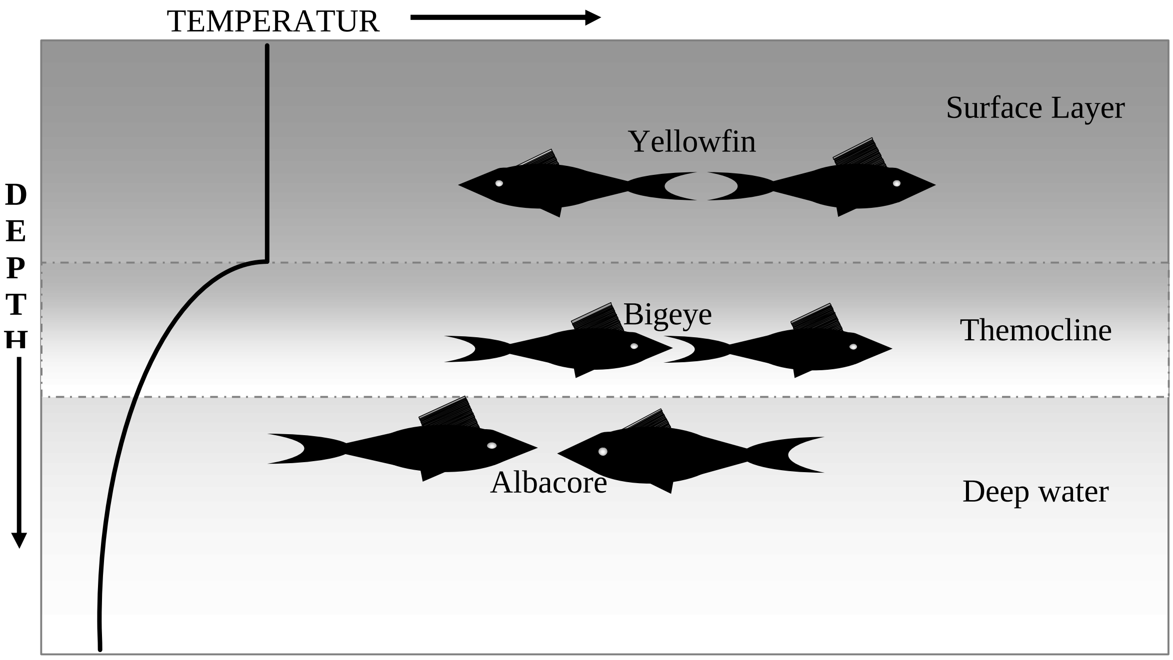
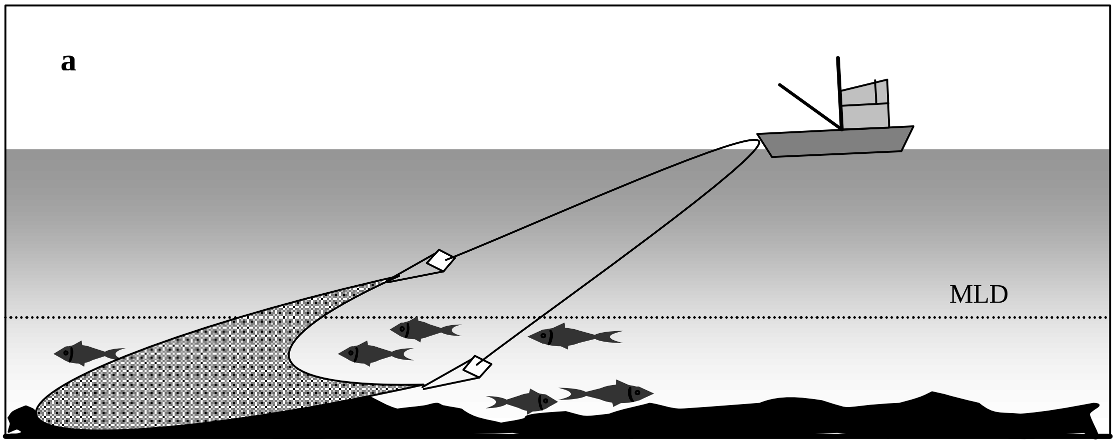


Figure-2. Schematic representation of temperature preference by different species of tuna in tropics (*Adapted from*: *Laevastu & Hela, 1970).*



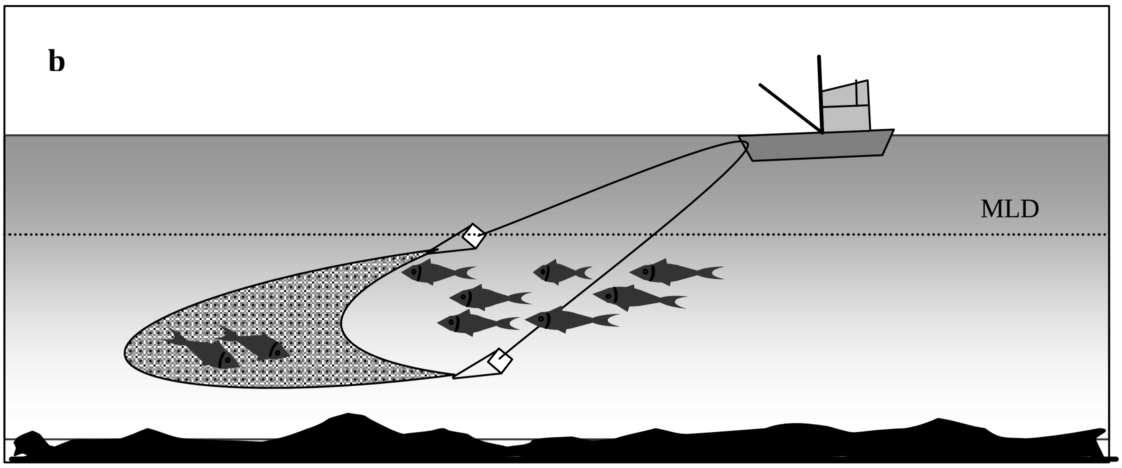


Figure.3. Fish behaviour and Trawling. (a) Deep MLD, fish schools too close to bottom, not favourable for mid water trawling, but may be good for bottom trawling; (b) Normal MLD, Fish schools (herring) below it good for mid water trawling (*Adapted from*: *Laevastu & Hela, 1970)*