FINFISH FISHERIES AND TOOLS FOR ASSESSING FISH BIOLOGY

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Introduction

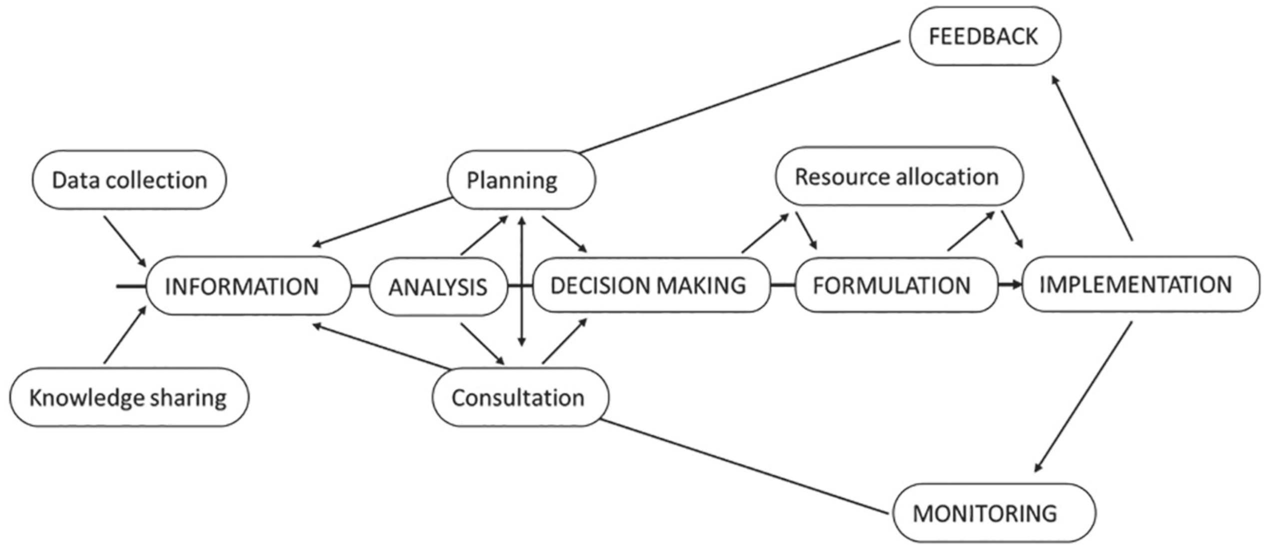
'Fisheries' in the broad sense refers to an activity leading to the harvest of fish, mostly from the capture of wild fish but may also include steady harvest of a fish species from aquaculture systems. The study of 'Fisheries" essentially includes a comprehensive dissection of the human, biological and ecological components of a fish harvest system. The key participants of a fishery are the fish and their associated network partners within the trophic web of the ecosystem they inhabit, and the human stakeholder groups including the fishers, traders, processors, exporters, consumers, researchers, policymakers and managers. Fisheries science is a study of fisheries through a mathematical and statistical approach, the results of which are used for stock status assessments that ultimately direct Fisheries Management.

Status of world fisheries

Fish production from global marine capture fisheries was reported to be 84.4 million t in 2018 (FAO 2020). Pauly & Zeller (2016) estimated a decline of about 1.2 million tonnes per year, and from the early 2000s, the global marine capture fish production hovered around the 80 million tonne mark indicating a likely plateauing. The health of marine fish stocks has also seen a significant decline globally, with an estimated 31% of marine fish species indicated as being overfished (FAO 2016). In 2017, it was estimated that only 65.8% of assessed stocks were being fished within biologically sustainable levels, declining considerably from 90% in 1974 (FAO, 2020). Harvesting of fish stocks at levels that risk their long-term sustainability has the potential to catastrophically impact food security, livelihoods, economy and ultimately regional stability (Karim et al. 2020).

In several instances across the globe fisheries which are managed effectively, have shown increases in biomass while those which have less-developed management systems are in poor shape (FAO, 2020). Fisheries Management (FM) thus assumes a crucial role in stabilizing global marine capture fish production. Fisheries Management (FM) seeks to evolve suitable regulatory policies to ensure the sustained productivity of fishery resources from within a geographically defined ecological sphere, which will hold good for a good measure of time and will, at the same time provide scope for flexibility following the changes reflected in the system because of extraneous forces of natural or anthropogenic origin. The Technical Guidelines on FM (FAO, 1997) describe a management plan as *a formal or informal arrangement between a fisheries management authority and interested parties which identifies the partners in the fishery and their respective roles, details the agreed objectives for the fishery and specifies the management rules and regulations which apply to it and provides other details about the fishery which are relevant to the task of the management authority*.

Cochrane (2002) defines FM as *the integrated process of information gathering, analysis, planning,* *consultation, decision-making, allocation of resources and formulation and implementation, with enforcement as necessary, of regulations or rules which govern fisheries activities to ensure the continued productivity of the resources and the accomplishment of other fisheries objectives*. This can be visualized through a simple flow diagram –



Adapting a simpler definition from FAO, FM can be defined as an integrated process that aims to improve the benefits that society receives from harvesting fish while ensuring the sustainability of the resource.

Measures of performance of a fishery form the primary platform for FM projections – these measures are in turn a reflection of the data assimilated on a particular fishery over a period, spanning different variables of eco-biology, technology, climate, season, economy, social bands, and market trends. FM is thus, a process of considering the following components to make decisions and implement actions to achieve goals –

- Biological considerations focus on the resource, its abundance, availability, sustainability status, resilience capacity etc.
- Ecological and Environmental considerations – focussing on the repercussions of a fishery on the ecosystem balance (based on prey-predator relationships) and the impact on the habitat health (eg., the impact of bottom trawling on the sea beds and the life sustained therein).
- Technological considerations focus on the use of advanced, eco-friendly, green fishing technologies.
- Social and Cultural considerations focussing on the impact of a fishery, and therefore its regulation, on the livelihood and traditions of the stakeholder communities involved.
- Economic considerations focus on the economic output of a fishery through domestic and international trade.
- Considerations imposed by other parties focus on external influences on a fishery, and therefore its regulations. These can be local (eg., negative impacts of certain anthropogenic activities like industrial pollution and release of effluents into aquatic bodies) or of a global nature (eg. regulating fisheries following global conservation protocols and streamlining aquaculture systems to meet health standards specified by global import markets).

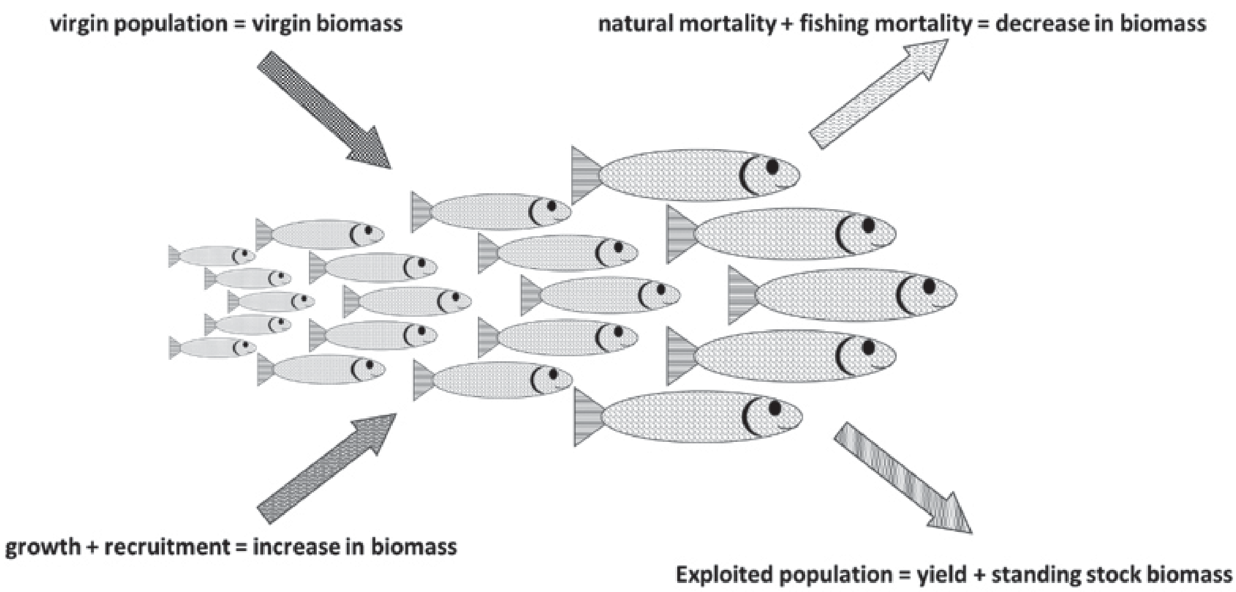
Principles of fisheries management

Fisheries managers work on certain assumptions and conclusions drawn from past experience. The seven basic principles that form the baseline for a fishery management protocol are as follows.

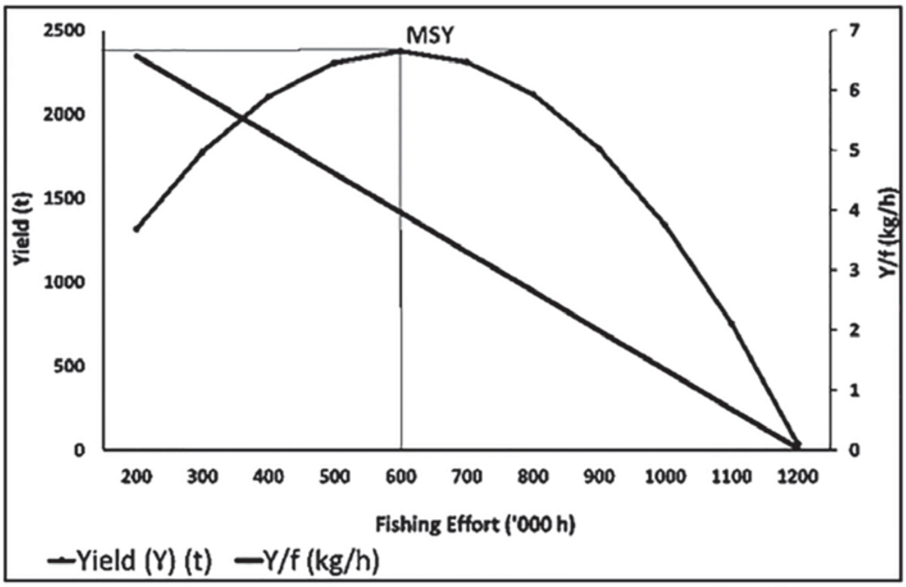
1. Fish resources are a common property resource.
2. Sustainability is paramount and ecological impacts must be considered.
3. Decisions must be made on the best available information but the absence of, or any uncertainty in, information should not be used as a reason for delaying or failing to make a decision.
4. A harvest level for each fishery should be determined.
5. The total harvest across all sectors should not exceed the allowable harvest level.
6. If this occurs, steps consistent with the impacts of each sector should be taken to reduce the removal.
7. Management decisions should aim to achieve the optimal benefit to the community and take account of economic, social, cultural and environmental factors.

Fish stock assessment for fisheries management

A fish stock is the primary unit for species assessment and fishery management frameworks backed by scientific data. Single species stock assessments are primarily based on the assumption that the unit stock is representative of the population in a particular ecosystem, and management is aimed at sustaining the exploited population that thrives after the constant addition to (through growth and reproduction) and removal from (through natural and fishing mortalities) the virgin population.



Fisheries management frameworks usually focus on target species and their stock assessment, being, at the same time, single sector-specific, i.e., considering only fisheries and not any interactions the sector has. Management measures are, by and large, related to fishing regulations (e.g. gear restrictions and closed zones or seasons) and are usually evolved with the primary goal of maximizing production. The Maximum Sustainable Yield (MSY) is one of the focal points of fishing regulations, the idea being that effort input has to be maintained at a level which yields the maximum resource output from the stock, beyond which the stock biomass in the ecosystem will decline.



Fisheries assessments are highly sophisticated scientific exercises calling for a variety of skills, a sound knowledge of the biology of the system and a good understanding of the fishing operations and the industry. The researcher often faces the problem of lack of information, or even if information is available, it is either inadequate or cannot be processed in time. Stock assessment studies rely on the quantity and quality of the data assimilated. Trends in fisheries and assessment of stock parameters, which are the two main aims of fishery statistical computations, require a good representation of data spread over a sufficiently long time, and including well-defined extreme limits of measures. For instance, catch and effort data should be representative of a continuous and sufficiently long duration, say a minimum of five years for single species stock assessment using prediction models and twenty years or more for holistic models. Similarly, biological data on a species must be representative of the entire length range of both sexes of the species which contribute even minimally to the fishery and should be indicative of trends and changes that recur on a seasonal basis.

However, "The absence of scientific data shall not be used as a reason for postponing or failing to take conservation and management measures" (UN, 1995).

Basic fishery data

Fisheries research and fisheries management in most countries, particularly in the tropical belt, thrive upon data which are essentially fishery-dependent. Primary data from this sector often includes data on catch, effort, species diversity and market value. Add-ons to this data are in the form of biological data, environmental data and socio-economic data. These have been defined by the FAO as "general purpose datasets" that may be subsequently used for a variety of statistical applications to assess the health of the fishery.

Biological data

An aspect often overlooked, especially when fish stock assessment exercises are restricted to providing input length-frequency or catch and effort data for computer-based programs, is the fact that the subject in question is a biologically dynamic organism. While statisticians proceed to treat these organisms as rigid objects which must follow a normalized growth, distribution or recruitment pattern, biologists need to smooth the inferences drawn from rigorous computations, by allowing the maximum possible flexibility to the biological activity of the fish. A clear understanding of the biology of the fish and logical reasoning applied to statistical computations will help in drawing a better picture of the stock parameters of a particular resource. This, however, is a rarity in most research papers based on short-term single-species assessments. Knowledge of the biology of a fish is essential not only for stock status assessments in fisheries management but also for aiding husbandry practices in aquaculture.

Common methods and tools for assessing fish biology

While the study of the biology of a fish species encompasses analysis of many traits of the species that define its innate nature and its association within the ecological niche that it dwells in, classical FM requires the study of the following aspects –

- Morphometry
- Length-weight relationship and Condition factor
- Reproductive biology, which includes –
  - Gonadal maturation
  - Spawning season
  - Fecundity
  - Length at first maturity
- Age and growth assessments
- Food and feeding
- Trophic interactions

Morphometry

Morphometric and meristic traits are important in establishing the identity of a species and are very useful in fish taxonomy studies. Morphometric measurements are usually described as a proportion of the Total Length (TL) or Standard Length (SL) of a fish. The simplest method of recording linear measures is by placing the fish on a hard board fitted with a measuring scale. The snout of the must be at the zero mark. This enables reading the TL or SL easily. In some fishes, the Fork Length (FL) is taken instead. The unit of measurement is usually the centimetre, and the readings are taken up to 0.1 cm accuracy. For truss morphometric studies, the fish is usually placed on a graph sheet and important focal points for measurements are marked using pins. The fish is then removed and the points marked by pins are connected to obtain linear distances between them.

Length-weight Relationship & Condition factor

The Length-weight Relationship (LWR) in a fish is one of the most studied aspects of fish biology. The LWR finds wide application in understanding the health of a fish regarding its growth in weight vis-a-vis its increase in length. The LWR in fishes is defined by the hypothetical cube law $W = C*L^3$, where 'W' is the weight of the fish, 'L' is the length of the fish and 'C' is a constant. If the density and form of the fish remain constant irrespective of its growth, this formula can be considered to hold good. However, since this is not always the case, the value of the exponent in the formula may differ from 3 (Martin, 1949). The relationship is then better expressed as $W=a*L^b$, (Le Cren, 1951), where 'a' is a constant equivalent to 'C' in the isometric cube equation, and 'b' is another constant that needs to be calculated empirically (Martin, 1949). The growth is termed isometric when b = 3 and this is always the case in an ideal fish, which maintains its shape without any change (Allen, 1938). Beverton and Holt (1957) stated that significant variations from isometric growth are rare in fishes. However, the value of 'b' in fishes usually tends to vary between 2.5 and 4 (Hile, 1936; Martin 1949) and may also lie outside this range in some fishes at some stages of development. Analysis of covariance and Student's t-test (Snedecor and Cochran 1967) are conducted to assess significant variation in LWR between sexes and deviation of 'b' value from the isometric value of 3, respectively.

The LWR is also used indirectly to understand the health of the fish from the estimation of the relative condition factor 'Kn'. Condition factor, measured as the proportion of observed weight (estimated from LWR) in the expected weight under an isometric growth scenario (LWR with b=3) indicates the well-being of the fish. The condition factor can be influenced by biological factors such as sex, gonadal maturation, and spawning activity, and by certain external factors inducing stress, such as seasonal changes in the environment, water quality parameters and availability of food. High 'Kn' values indicate better health conditions of the fish.

Reproductive biology

Fishes most commonly exhibit sexual reproduction (with external or internal fertilization) with sexes being separate; morphological differentiation between sexes, however, is often not very discernible. Some fishes exhibit hermaphroditism and very rarely, some exhibit parthenogenesis. Most teleost fishes are oviparous while most chondrichthyans are ovoviviparous. Sexual dimorphism is seen in chondrichthyans where males are easily identified by the presence of claspers.

Sex ratio

The sex of the fish is determined from a macroscopic examination of the gonads. The sex ratio is calculated as the number of females for every male, i.e. M:F where M is taken as 1. Sex ratio is estimated month-wise and in many cases, within length groups, depending on the strength of the data collected. The estimated sex ratios are tested for significant deviation from the hypothetical ratio of 1:1 using the Chi-square test (Snedecor and Cochran 1967). This is done using the equation –

$$X^2 = \Sigma \frac{(O-E)^2}{E}$$

where 'O' and 'E' are the observed and expected numbers of males and females in each month or length group.

Gonadal maturity and spawning season

Gonadal maturity stages are assessed from macroscopic inspection of gonads, *i.e.,* based on size, colour pattern, distribution of blood vessels, visibility of ova in females and oozing milt in males, following the ICES scale (Lovern and Wood, 1937). Usually, VII stages are identified for females (I & II – immature, III – early maturing, IV – Late maturing, V – mature, ripe, VI – spawning and VII – spent, resting). For males, V stages are often recognized (I & II – immature, III – early maturing, IV – late maturing and V – mature, oozing). The actual stages may vary slightly from the general pattern depending on the type and biology of the fish (e.g., hermaphrodite fishes exhibiting sex reversal, elasmobranchs etc.) Confirmation of the stages is often done through histological examination of the gonads. The frequency distribution of different stages across months and years of sampling is taken to read spawning season and peak spawning months.

Gonadosomatic Index

Gonadosomatic Index (GSI) is a useful index to understand the maturation health of the gonad, relative to the body size. GSI is estimated using the equation –

$$GSI = \frac{\text{Weight of the gonad} \times 100}{\text{Weight of the fish}}$$

GSI estimates can be taken sex-wise and month-wise across length groups and annual patterns can be traced to understand spawning seasons and periodicity.

Fecundity

Fecundity is estimated from mature ovaries using the gravimetric method (Murua et al. 2003). The ovary sub-samples are obtained from the anterior, middle and posterior regions of the ovary of each female (James et al. 1978) and weighed separately. Then the total number of oocytes in each sub-sample is counted and sub-sample fecundities are estimated. Afterwards, the fecundity of each female fish is estimated by averaging the three sub-sample fecundities (Rahman et al. 2016). The relationships between fecundity vs. Total length, fecundity vs. Body weight and fecundity and gonad weight are determined by simple linear regression analyses based on natural-logarithmic transformations using the formula $\ln F_T = \ln m + n \times \ln TL$ and $\ln F_T = \ln m + n \times \ln BW$, respectively. The estimation of total fecundity is essential for a better understanding of fluctuations in reproductive output and for estimating the recruitment potential of the species. (Roff 1992; Kraus et al. 2002; Lambert 2008).

Length at first maturity

Length at maturity (L_m), defined as the length at which 50% of the individuals are mature, is estimated by fitting a logistic equation to the percentage distribution of mature individuals across each length group (King 2007). Females of maturity stage III and above in fishes are considered as mature and the proportions of mature females in each length group are used for the logistic regression (Ashton, 1972):

$$P = \frac{e^{a+bL}}{1+e^{a+bL}}$$

where 'P' is the predicted mature proportion, 'a' and 'b' are the estimated coefficients of the logistic equation and 'L' is the length. Information on reproductive biology is essential for the implementation of proper management intervention for the conservation of the commercially important fishes whose spawning aggregations are over-exploited (Hardie et al. 2007); for successful management of an exploited fishery, it is essential to know the size at first maturity of the target species and this value should be re-evaluated regularly (Watters and Hobday 1998).

Age and growth assessments

Growth in an organism is defined as a function of age (von Bertalanffy 1938) i.e., growth is defined by the change in measure of a body dimension concerning time. Growth studies in a fish species help to determine the quantum (in terms of weight) of fish that can be produced in a body of water concerning time (Qazim 1973). Estimates of growth parameters also aid in assessing the food consumption of fish populations (Palomares and Pauly 1989). The von Beratlanffy mathematical growth model (von Bertalanffy 1938) expressed length 'L' as a function of age 't'. Applying this to fishes, the growth curve of a fish can be traced using the von Bertalanffy growth equation –

$L_t = L_\alpha * (1 - e^{-K(t-t0)})$

where 'L_t' is length-at-age t, 'L_α' is asymptotic length, 'K' is the annual growth coefficient and 't_0' is the theoretical age at which L = 0.

Growth assessments in tropical waters are commonly done using length-based models with the basic data input being the monthly length frequency of the fish species in the fishery/experimental surveys across a period ranging from 3 to 5 or more years (depending on the life span of the species). Such length-frequency data should ideally be representative of all lengths ranging from the smallest recruit into the fishery to the oldest. The data should also be continuous with good sample sizes across all the months.

Age and growth assessments are usually done using the FISAT software – FAO-ICLARM Fish Stock Assessment Tools (Gayanilo and Pauly 1997) which has modules for computing the length-at-age data through Modal Progression Analysis and tracing the growth curve through ELEFAN – Electronic Length Frequency Analysis. Age and growth assessments provide the primary inputs for species-specific fish stock assessment in tropical waters (Sparre and Venema 1992).

Growth in fishes can be also determined by counting annual or daily rings that are formed on hard parts such as scales, otolith, vertebrae etc. Such growth rings are well-defined in temperate waters where clear seasonal distinctions exist since growth is impacted by variations in the environment and availability of food.

Another method of directly recording the growth of fishes in the wild is by tagging and recapturing, but this is an expensive method and recapture of the tagged fishes in open water bodies is not easy.

Food and feeding

Food and feeding assessments in capture fisheries research are conventionally done through observations of the gut state and contents in sampled fishes. Knowledge of the gut contents enables a better understanding of the role of the fish species in the trophic network and can thus be an important contributor to management frameworks for multi-species fisheries. Knowledge of the diet preferences of cultivable fish species also helps in establishing natural and formulated feeds for captive rearing of the species.

The state of fullness of the stomach is defined as 'gorged', 'full', 'three-fourth full', 'half-full', quarter-full, 'trace' and 'empty'. The month-wise frequency distribution of the fullness states across sexes and length groups indicates sex-wise, ontogenetic and seasonal variations in feeding behaviour.

Gut content analysis is done in either fresh or preserved conditions. The gut contents are subjected to 'qualitative' analysis, wherein the contents are identified to the lowest possible taxonomic level (family, genus, or species) depending on the state of the contents. The gut contents are also subjected to 'quantitative' analysis, wherein the contents are quantified in terms of number (numerical method) weight (gravimetric method) and volume (volumetric method).

The most common index of diet preference is the 'Index of preponderance' (Natarajan and Jhingran 1961) which is estimated using the formula

$$I = \frac{V_i O_i \times 100}{\Sigma(V_i O_i)}$$

where V_i and O_i are the volume and occurrence indices of each food item.

The Index of Relative Importance (IRI) proposed by Pinkas et al. (1971) is considered a better Index of diet preference as it integrates and evaluates the relative importance of each food item in terms of number, volume, and frequency of occurrence in the observed stomachs/guts.

$$IRI = (\%N + \%V) * \%F$$

where N is the numerical percentage, V is a volumetric percentage and F is the frequency of occurrence percentage of the prey.

Trophic interactions

The study of stomach/gut contents provides insight into the marine food chain given the competition between species and helps evaluate predator-prey relationships. To study the trophic interactions between different species inhabiting an ecosystem, a diet matrix is developed by grouping different fish species and other associated resources into groups based on their diet and ecological preferences, such as predatory mammals, large pelagic carnivores, medium pelagic carnivores, large benthic carnivores, small benthic carnivores etc. These groupings are used as inputs in the ECOPATH/ECOSIM software (https://ecopath.org), together with gear-wise catch/landing data of the resources to derive the trophic interactions within the ecosystem.

Use of genetic tools

The use of genetic tools in fish biology studies and fisheries management has revolutionized our understanding of aquatic ecosystems and improved the sustainable management of fish populations. Genetic techniques, such as DNA analysis and molecular markers, play a crucial role in identifying and characterizing fish species, populations, and their genetic diversity. These tools enable researchers to study the population structure, migration patterns, and gene flow among fish populations, providing valuable insights into the dynamics of aquatic ecosystems. DNA analysis is also being applied in diet studies. In fisheries management, by understanding the genetic structure of fish populations, managers can make informed decisions about conservation measures, sustainable harvesting, and habitat restoration. Genetic tools also contribute to the implementation of effective stock enhancement programs, ensuring the long-term viability of fisheries resources.

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