Fisheries Science and Environmental Issues with Fishing

Chester Isbell
Russel Burnett

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Email: info@wtbooks.com

Table of Contents

Chapter 1

Fish Counter and Fish Measurement

Fish counter

Automatic **fish counters** are automatic devices for measuring the number of fish passing along a particular river in a particular period of time. Usually one particular species is of interest.

One important species studied by fish counters are Atlantic salmon. This species is of interest owing to its ecologically vulnerable status and anadromous lifestyles.

Methods of operation

Fish counters can be divided into three principal types: resistive counters, optical counters, and hydroacoustic counters.

Resistive counters

A resistive counter is associated with an in-river structure, such as a Crump weir. The resistivity of a fish is lower than that of water. So, as fish cross this barrier, they pass embedded electrodes, and the difference in resistivity disturbs the field established in the vicinity of the electrodes, altering inter-electrode resistance. With three electrodes these disturbances can then be measured by a Wheatstone bridge, or other means, to detect the size and direction of travel of the fish.

Fish counters of this type are used widely in Scotland to census populations of Atlantic salmon, where comparison with closed circuit television shows around a 97% detection rate.

Optical counters

An optical counter is also associated with an in-river structure. However, rather than pass electrodes, in an optical counter the fish interrupt some of a number of vertically arranged beams of light. The pattern of beam-breaks can be used to determine the size, profile, and direction of motion of the fish.

The performance of optical counters has been determined by studies, under various conditions, to be greater than 90%. Optical counters can also distinguish the size of fish more accurately than other counter types and so are particularly useful where a mixture of species inhabit a river (for example rivers where salmon mix with sea trout).

The key disadvantage of optical counters is the small penetration of the beams through the water, restricting their use to narrow river features or in-river structures, such as fish ladders.

Hydroacoustic counters

Hydroacoustic counters operate using the principles of sonar. A fish is insonified by a sound source, and reflections from the fish are detected by an underwater microphone. The reflection occurs because of the sudden change in impedance to sound waves within the fish, particularly at the swimbladder (90% of the reflection).

Hydroacoustic counters do not require in-river structures, but require skilled installation and operators. Without skilled installation at ideal sites hydroacoustic counters can be inaccurate. Studies typically indicate detection rates of 50% to 80%, though one study found detection rates as low as 3%. Careful planning and pre-siting study must be used to determine effectiveness.

The lack of a requirement for any in-river structure makes the counters an attractive proposition. Generally used for short-term or seasonal studies, some situations require a long-term count which is accurate in absolute terms, not only in relative change (for example, no hydroacoustic sensors are routinely used in the detection of Scottish Atlantic salmon). In these instances resistivity or optical sensors tend to be preferred. Such methods usually require significant habitat modification, such as construction of a weir to funnel the fish through the counter.

Recent advances in automated hydroacoustic monitoring systems has allowed continuous monitoring for periods exceeding 18 months. These systems include intelligent monitoring and real-time data processing, ensuring proper operation and publication of status and results (e.g. fish counts) on a routine basis.

Siting counters

In river structures

Resistivity and (particularly) optical fish counters require in-river structures to direct the fish through the detection aperture of the counter. Fish ladders and Borland fish passes are effective structures for this purpose and occasionally a natural restriction within the river may be used for a similar purpose. However for most counters a custom in-river structure will be required. One of the most effective such structures is the Crump weir, a triangular profile weir designed to ensure rapid planar flow over the detector.

Siting within the river system

When monitoring anadromous fish such as the Atlantic salmon it is important to remember that a species may return to a particular breeding ground throughout its life. This means that within the larger rivers a number of quite distinct populations may cross a counter together, in aggregate. A population which uses a particular tributary may collapse whilst the overall numbers are not clearly affected. Issues with the management of that particular tributary and population therefore go unnoticed. It is important in these situations, therefore, that counters are placed to count individual populations, rather than the species in aggregate, in order that population collapses and recoveries can be detected.

Alternative methods

The results of automatic fish counters can be supplemented, confirmed, or replaced by a number of alternative techniques, varying in accuracy, cost, complexity, and skew effects.

- Electrofishing
- Traps
- Net and rod counts
- Redd counts (disturbances in gravel caused by mating activities of some fish)
- Closed circuit television

Fish measurement

Fish measurement refers to the measuring of the length of individual fish and of various parts of their anatomy. These data are used in many areas of ichthyology, including taxonomy and fisheries biology.

Overall length

- **Standard length** (**SL**) refers to the length of a fish measured from the tip of the snout to the posterior end of the last vertebra or to the posterior end of the midlateral portion of the hypural plate. Simply put, this measurement excludes the length of the caudal fin.

- **Total length** (**TL**) refers to the length from the tip of the snout to the tip of the longer lobe of the caudal fin, usually measured with the lobes compressed along the midline. It is a straight-line measure, not measured over the curve of the body.

Standard length measurements are used with Teleostei (most bony fish), while total length measurements are used with Myxini (hagfish), Petromyzontiformes (lampreys), and (usually) Elasmobranchii (sharks and rays), as well as some other fishes.

In addition, fishery biologists often use a third measure, **fork length** (**FL**), in fishes with forked tails. This measure is the length from the tip of the snout to the end of the middle caudal fin rays and is used in fishes in which it is difficult to tell where the vertebral column ends.

Other measurements

Other measurements that may be taken include the lengths of various fins, the lengths of fin bases, the length from the snout to various points on the body, and the diameter of the eye.

Chapter 2

Fish Mortality and Fish Stock

Fish mortality

Fish mortality is a term widely used in fisheries science that denotes the loss of fish from a stock through death. The term is also commonly used in British English as a synonym for fish kill. Fish mortality can be divided into two types:

- Natural mortality: the removal of fish from the stock due to causes not associated with fishing. Such causes can include disease, competition, cannibalism, old age, predation, pollution or any other natural factor that causes the death of fish. In fisheries population dynamics natural mortality is denoted by (M).

- Fishing mortality: the removal of fish from the stock due to fishing activities using any fishing gear. It is denoted by (F) in fisheries models. (M) and (F) are additive instantaneous rates that sum up to (Z), the instantaneous total mortality coefficient; that is, Z=M+F. These rates are usually calculated on an annual basis.

Estimates of fish mortality rates are often included in mathematical yield models to predict yield levels obtained under various exploitation scenarios. These are used as resource management indices or in bioeconomic studies of fisheries.

Estimating mortality

Natural

Estimating *natural mortality* (M) is one of the most difficult and critical elements of a stock assessment (Hewitt et al. 2007). There are two basic approaches used to estimate natural mortality: *tagging studies* and *growth parameters*. Tagging studies are used in the *Brownies Model*, where multiyear tagging studies are used to estimate natural mortality based on recaptures:

$$fi = ri(1 - Si)$$

The *Paulys Model* (using growth parameters) is an indirect way of estimating natural mortality. It assumes that there is a relationship between size and natural mortality. Pauly's original method was based on the correlation of M with von Bertalanffy growth parameters (K and L∞) and temperature (Gunderson 2002):

$$N0 = N\ 1*e(-Z*\Delta t)$$

In the *Hoenigs method*, M was inversely correlated with longevity across a wide variety of taxa (Hewitt and Hoenig 2005):

$$Ln(M) = 1.44-0.982*ln(tmax)$$

Fishing

Fishing mortality (F) can be estimated by dividing the *catch* by the mean stock size. The catch includes annual commercial and recreational landings, along with dead discards. Bycatch discards would be estimated by estimating the percent of fish that are captured in a certain gear and the mortality associated with being captured in this gear. These mortality studies are generally done by using cages for a certain period of time following capture to determine the percentage of fish that die during being held in holding cages. These deaths are assumed to be associated with physical injury or physiological stress from being captured in the gear used during capture.

Why estimating mortality is important

Mortality estimates are important to managers. Determining mortality rates are critical for determining abundance of fish populations. Using the model Z=M+F with M being Natural mortality and F being Fishing mortality (combined mortality from landings plus discard mortality) you can estimate the trend of a population. The mortality rates give you the total deaths of a population when you compare these to the total births or recruits to the population, you can determine if a population is increasing or decreasing. Knowing these rates can help managers to set harvest limits to (MSY) maximum sustainable yield or (OSY) optimum sustainable yield to give the maximum benefit to the stakeholders of the resource.

Fish stock

Fish stocks are subpopulations of a particular species of fish, for which intrinsic parameters (growth, recruitment, mortality and fishing mortality) are the only significant factors in determining population dynamics, while extrinsic factors (immigration and emigration) are considered to be insignificant.

The stock concept

All species have geographic limits to their distribution. which are determined by their tolerance to environmental conditions, and their ability to compete successfully with other species. In marine environments this may be less evident than on land because there are fewer topographical boundaries, however, discontinuities still exist, produced for example by mesoscale and sub-mesoscale circulations that minimize long-distance dispersal of fish larvae .

For fishes, it is rare for an individual to reproduce randomly with all other individuals of that species within its biological range. There is a tendency to form a structured series of discrete populations which have a degree of reproductive isolation from each other in space, in time, or in both. This isolation is reflected in the development between sub-populations of genetic differences, morphological variations and exposure to different chemical regimes and parasitic species. Sub-populations also respond to fishing in such a way that fishing on one population appears to have no effect on the population dynamics of a neighbouring population.

The currently accepted definition of a stock in fisheries science, is that of Begg et al. (1999), *"...[a "stock"] describes characteristics of semi-discrete groups of fish with some definable attributes which are of interest to fishery managers."*.

Stock identification is a field of fisheries science which aims to identify these subpopulations, based on a number of techniques.

Straddling stock

The United Nations defines straddling stocks as "stocks of fish such as pollock, which migrate between, or occur in both, the economic exclusion zone (EEZ) of one or more states and the high seas". Sovereign responsibility must be worked out in collaboration with neighbouring coastal states and fishing entities. Usually this is done through the medium of an intergovernmental regional organisation set up for the purpose of coordinating the management of that stock.

Straddling stocks are usually pelagic, rather than demersal. Demersal species move less than pelagic species, since they tend to relate to bottom topography. Pelagic species are more mobile, their movements influenced by ocean temperatures and the availability of zooplankton as food. Example pelagic fish are capelin, herring, whiting, mackerel and redfish, There are, however, a few demersal species that are straddling, such as the Greenland halibut migrates in feeding/spawning migrations to Greenland in the west and to the Faeroes in the east.

Straddling stock can be compared with transboundary stock. Straddling stock range both within an EEZ as well as in the high seas. Transboundary stock range in the EEZs of at least two countries. A stock can be both transboundary and straddling.

Chapter 3

Fisheries Management

Fisheries management draws on fisheries science in order to find ways to protect fishery resources so sustainable exploitation is possible. Modern fisheries management is often referred to as a governmental system of appropriate management rules based on defined objectives and a mix of management means to implement the rules, which are put in place by a system of monitoring control and surveillance.

History

Fisheries have been explicitly managed in some places for hundreds of years. For example, the Māori people, New Zealand residents for about 700 years, had prohibitions against taking more than could be eaten and about giving back the first fish caught as an offering to sea god Tangaroa. Starting in the 18th century attempts were made to regulate fishing in the North Norwegian fishery. This resulted in the enactment of a law in 1816 on the Lofoten fishery, which established in some measure what has come to be known as territorial use rights.

"The fishing banks were divided into areas belonging to the nearest fishing base on land and further subdivided into fields where the boats were allowed to fish. The allocation of the fishing fields was in the hands of local governing committees, usually headed by the owner of the onshore facilities which the fishermen had to rent for accommodation and for drying the fish."

Governmental resource protection-based fisheries management is a relatively new idea, first developed for North European fisheries after the first Overfishing Conference held in London in 1936. In 1957 British fisheries researchers Ray Beverton and Sidney Holt published a seminal work on North Sea commercial fisheries dynamics. In the 1960s the work became the theoretical platform for North European management schemes.

After some years away from the field of fisheries management, Beverton criticized his earlier work in a paper given at the first World Fisheries Congress in Athens in 1992. "The Dynamics of Exploited Fish Populations" expressed his concerns, including the way his and Sydney Holt's work had been misinterpreted and misused by fishery biologists and managers during the previous 30 years. Nevertheless, the institutional foundation for modern fishery management had been laid.

Political objectives

According to the FAO, fisheries management should be based explicitly on political objectives, ideally with transparent priorities. Typical political objectives when exploiting a fish resource are to:

- maximize sustainable biomass yield
- maximize sustainable economic yield
- secure and increase employment
- secure protein production and food supplies
- increase export income

Such political goals can also be a weak part of fisheries management, since the objectives can conflict with each other.

International objectives

Fisheries objectives need to be expressed in concrete management rules. In most countries fisheries management rules should be based on the internationally agreed, though non-binding, Code of Conduct for Responsible Fisheries, agreed at a meeting of the U.N.'s Fish and Agriculture Organization FAO session in 1995. The precautionary approach it prescribes is typically implemented in concrete management rules as minimum spawning biomass, maximum fishing mortality rates, etc. In 2005 the Fisheries Centre at the University of British Columbia comprehensively reviewed the performance of the world's major fishing nations against the Code.

International agreements are required in order to regulate fisheries in international waters. The desire for agreement on this and other maritime issues led to three conferences on the Law of the Sea, and ultimately to the treaty known as the United Nations Convention on the Law of the Sea (UNCLOS). Concepts such as exclusive economic zones (EEZ, extending 200 nautical miles (370 km) from a nation's coasts) allocate certain sovereign rights and responsibilities for resource management to individual countries.

Other situations need additional intergovernmental coordination. For example, in the Mediterranean Sea and other relatively narrow bodies of water, EEZ of 200 nautical miles (370 km) are irrelevant. International waters beyond 12-nautical-mile (22 km) from shore require explicit agreements.

Straddling fish stocks, which migrate through more than one EEZ also present challenges. Here sovereign responsibility must be agreed with neighbouring coastal states and fishing entities. Usually this is done through the medium of an regional organisation set up for the purpose of coordinating the management of that stock.

UNCLOS does not prescribe precisely how fisheries confined only to international waters should be managed. Several new fisheries (such as high seas bottom trawling fisheries) are not (yet) subject to international agreement across their entire range. In November 2004 the UN General Assembly issued a resolution on Fisheries that prepared for further development of international fisheries management law.

Management mechanisms

Many countries have set up Ministries/Government Departments, named "Ministry of Fisheries" or similar, controlling aspects of fisheries within their exclusive economic zones. Four categories of management means have been devised, regulating either input/investment, or output, and operating either directly or indirectly:

	Inputs	**Outputs**
Indirect	Vessel licensing	Catching techniques
Direct	Limited entry	Catch quota and technical regulation

Technical means may include:

- prohibiting devices such as bows and arrows, and spears, or firearms
- prohibiting nets
- limiting the average potential catch of a vessel in the fleet (vessel and crew size, gear, electronic gear and other physical "inputs".
- prohibiting bait
- snagging
- limits on fish traps
- limiting the number of poles or lines per fisherman
- restricting the number of simultaneous fishing vessels
- limiting a vessel's average operational intensity per unit time at sea
- limiting average time at sea

Catch quotas

Systems that use *individual transferable quotas* (ITQ), also called individual fishing quota limit the total catch and allocate shares of that quota among the fishers who work that fishery. Fishers can buy/sell/trade shares as they choose.

A large scale study in 2008 provided strong evidence that ITQ's can help to prevent fishery collapse and even restore fisheries that appear to be in decline.

Population dynamics

Population dynamics describes the growth and decline of a given fishery stock over time, as controlled by birth, death and migration. It is the basis for understanding changing fishery patterns and issues such as habitat destruction, predation and optimal harvesting rates. The population dynamics of fisheries has been traditionally used by fisheries scientists to determine sustainable yields.

The basic accounting relation for population dynamics is the BIDE model:

$$N_1 = N_0 + B - D + I - E$$

where N_1 is the number of individuals at time 1, N_0 is the number of individuals at time 0, B is the number of individuals born, D the number that died, I the number that immigrated, and E the number that emigrated between time 0 and time 1. While immigration and emigration can be present in wild fisheries, they are usually not measured.

Care is needed when applying population dynamics to real world fisheries. In the past, over-simplistic modelling, such as ignoring the size, age and reproductive status of the fish, focusing solely on a single species, ignoring bycatch and physical damage to the ecosystem, has accelerated the collapse of key stocks.

Ecosystem based fisheries

According to marine ecologist Chris Frid, the fishing industry points to pollution and global warming as the causes of unprecedentedly low fish stocks in recent years, writing, "Everybody would like to see the rebuilding of fish stocks and this can only be achieved if we understand all of the influences, human and natural, on fish dynamics." Overfishing has also had an effect. Frid adds, “Fish communities can be altered in a number of ways, for example they can decrease if particular sized individuals of a species are targeted, as this affects predator and prey dynamics. Fishing, however, is not the sole perpetrator of changes to marine life - pollution is another example [...] No one factor operates in isolation and components of the ecosystem respond differently to each individual factor."

In contrast to the traditional approach of focusing on a single species, the ecosystem-based approach is organized in terms of ecosystem services. Ecosystem-based fishery concepts have been implemented in some regions. In 2007 a group of scientists offered the following *ten commandments*

“

- Keep a perspective that is holistic, risk-adverse and adaptive.
- Maintain an “old growth” structure in fish populations, since big, old and fat female fish have been shown to be the best spawners, but are also susceptible to overfishing.
- Characterize and maintain the natural spatial structure of fish stocks, so that management boundaries match natural boundaries in the sea.
- Monitor and maintain seafloor habitats to make sure fish have food and shelter.
- Maintain resilient ecosystems that are able to withstand

”

occasional shocks.

- Identify and maintain critical food-web connections, including predators and forage species.
- Adapt to ecosystem changes through time, both short-term and on longer cycles of decades or centuries, including global climate change.
- Account for evolutionary changes caused by fishing, which tends to remove large, older fish.
- Include the actions of humans and their social and economic systems in all ecological equations.

Elderly maternal fish

Old fat female rockfish are the best producers

Traditional management practices aim to reduce the number of old, slow-growing fish, leaving more room and resources for younger, faster-growing fish. Most marine fish produce huge numbers of eggs. The assumption was that younger spawners would produce plenty of viable larvae.

However, 2005 research on rockfish shows that large, elderly females are far more important than younger fish in maintaining productive fisheries. The larvae produced by these older maternal fish grow faster, survive starvation better, and are much more likely to survive than the offspring of younger fish. Failure to account for the role of older fish may help explain recent collapses of some major US West Coast fisheries. Recovery of some stocks is expected to take decades. One way to prevent such collapses is to establish marine reserves, where fishing is not allowed and fish populations age naturally.

Data quality

According to fisheries scientist Milo Adkison, the primary limitation in fisheries management decisions is the absence of quality data. Fisheries management decisions are often based on population models, but the models need quality data to be effective. He asserts that scientists and fishery managers would be better served with simpler models and improved data.

The most reliable source for summary statistics is the FAO Fisheries Department.

Ecopath

Ecopath, with Ecosim (EwE), is an ecosystem modelling software suite. It was initially a NOAA initiative led by Jeffrey Polovina, later primarily developed at the Fisheries Centre of the University of British Columbia. In 2007, it was named as one of the ten biggest scientific breakthroughs in NOAA's 200-year history. The citation states that Ecopath "revolutionized scientists' ability worldwide to understand complex marine ecosystems". Behind this lies two decades of development work by Villy Christensen, Carl Walters, Daniel Pauly, and other fisheries scientists. As of 2010 there are 6000 registered users in 155 countries. Ecopath is widely used in fisheries management as a tool for modelling and visualising the complex relationships that exist in real world marine ecosystems.

Human factors

Managing fisheries is about managing people and businesses, and not about managing fish. Fish populations are managed by regulating the actions of people. If fisheries management is to be successful, then associated human factors, such as the reactions of fishermen, are of key importance, and need to be understood.

Management regulations must also consider the implications for stakeholders. Commercial fishermen rely on catches to provide for their families just as farmers rely on crops. Commercial fishing can be a traditional trade passed down from generation to generation. Most commercial fishing is based in towns built around the fishing industry; regulation changes can impact an entire town's economy. Cuts in harvest quotas can have adverse affects on the ability of fishermen to compete with the tourism industry.

Performance

The biomass of global fish stocks have been allowed to run down to the point where it is no longer possible to catch the amount of fish that could be caught. According to a 2008

UN report, titled *The Sunken Billions: The Economic Justification for Fisheries Reform*, the world's fishing fleets incur a "$US 50 billion annual economic loss" through depleted stocks and poor fisheries management. The report, produced jointly by the World Bank and the UN Food and Agriculture Organization (FAO), asserts that half the world's fishing fleet could be scrapped with no change in catch.

"By improving governance of marine fisheries, society could capture a substantial part of this $50 billion annual economic loss. Through comprehensive reform, the fisheries sector could become a basis for economic growth and the creation of alternative livelihoods in many countries. At the same time, a nation's natural capital in the form of fish stocks could be greatly increased and the negative impacts of the fisheries on the marine environment reduced."

Chapter 4

Monitoring Control and Surveillance

Monitoring, control and surveillance (MCS), in the context of fisheries, is defined by the Food and Agriculture Organization (FAO) of the United Nations as a broadening of traditional enforcing national rules over fishing, to the support of the broader problem of fisheries management.

Internationally, the basis of law for fisheries management comes from the 1982 United Nations Convention on the Law of the Sea (UNCLOS). Further definition was in the Declaration of Cancun This is complemented by the work of a variety of regional organizations that cover high seas fishing areas. A key concept in international fishing laws is that of the Exclusive Economic Zone, which extends 200 miles (370 km) from the coast of nations bordering on the oceans. EEZ is not a meaningful concept in relatively small seas such as the Mediterranean and Baltic, so those areas tend to have regional agreements for MCS of international waters within those seas.

Components and related activities

MCS has aspects distinct from **fisheries management**, although there is overlap. According to the 2003 FAO paper on Recent Trends, fisheries management consists of:

- Data collection and analysis
- Participatory management planning
- Establishing a regulatory framework
    - Input controls
    - Operational and output controls
- Implementation

While MCS, in the basic FAO definitions, does not include enforcement, that category will be included here as part of the means of implementing MCS operations. In MCS discussions, there is a strong emphasis that the success of MCS is not to be measured in number of arrests, but in the level of compliance with presumably reasonable frameworks (i.e., the "control" part of MCS). If a sense of participation in the development of controls, as well as peer pressure, leads to meeting the fisheries management controls without a single arrest, the MCS program is successful.

Monitoring

A 1981 Conference of Experts defined **monitoring** as " the continuous requirement for the measurement of fishing effort characteristics and resource yields." This was expanded, in a 1993 workshop, to include the measurement of:

- catch
- species composition
- fishing effort
- bycatch (i.e., species other than the targeted one incidentally captured by the primary effort)
- area of operations

Control

According to the 1981 Conference of Experts, **control** are the "regulatory conditions under which the exploitation of the resource may be conducted." This is usually considered to consist of legislation, regulations, and international agreements. Each of these should describe the management measures required and the requirements that will be enforced. The actual enforcement mechanisms are not part of control.

Management criteria include:

- Establishing designated fishing areas in which no fishing, fishing by vessels with permits, or open fishing is allowed.
- Restrictions on fishing gear, including the banning of certain types on vessels in give areas, or controls on such parameters as the mesh size of fishing nets. These restrictions can be enforced only by physical inspection at sea or at dockside.
- Catch and quota controls, by species or total take
    - Days at sea
    - Daily time at sea
    - Seasonal catch limits
    - Per-trip catch limits
    - Limits on catch within certain areas
    - Individual (vessel) transferable quotas
    - Minimum or maximum fish sizes
    - Bycatch
- Vessel movement controls
    - Into areas
    - Exiting areas
    - Sightings in areas
- Onboard observers
- Licensing

Vessel inspections

Surveillance

Surveillance, according to the 1981 Conference of Experts, are "the degree and types of observations required to maintain compliance with the regulatory controls imposed on fishing activities." The Ghana workshop termed it the "regulation and supervision of fishing activity..." This definition does not clearly include enforcement.

Through surveillance, overfishing by authorized fishers and poaching by unauthorized fishers can be detected. Many systems are involved in the technical process of surveillance. Radar, including coastal, airborne, and spaceborne systems, may be intended for national security or law enforcement, but can simultaneously provide information to fisheries management and environmental protection authorities. Vessel monitoring system principally intended for fisheries surveillance can provide critical information to search and rescue (SAR) under the International Convention for the Safety of Life at Sea (SOLAS) and its associated Global Maritime Distress Safety System (GMDSS).

Enforcement

Enforcement ranges from self-regulation to onboard observers to patrol platforms (vessels and aircraft) to law enforcement activity.

Spatial Components

MCS implementation has sea, land, and aerospace aspects. Monitoring systems, such as Vessel monitoring system, may operate in all three of these regimes. These aspects also affect other maritime systems that can cooperate with VMS, such as Automatic Identification Systems (AIS) with their specialized Vessel Traffic Services (VTS), radar surveillance of the seas, and pollution tracking mechanisms.

Sea components

Perhaps the most basic component, aboard fishing vessels, are the logs and catch reporting completed by the fishers themselves. Closely associated are reports prepared by onboard observers.

Also on the fishing vessel can be the shipboard components of vessel monitoring system (VMS). These can be independent systems involving navigational and time input, embedded and dedicated computer, and radio transmission of reports. The transmission is usually via satellite, but some countries are using coastal VHF repeater systems.

VMS components can also integrate with other shipboard electronics. For example, if the report generation component is on a general-purpose personal computer, that computer may also run a chartplotter and various catch planning applications. The chart plotter function may be a general-purpose graphic display, presenting radar or bottom sounder/fish finder data, perhaps merged with electronic charts.

Surface components

Catch inspectors, as well as electronic or hard copy filings of catch and other reports, are basic land components of MCS. Fisheries management authorities who make real-time decisions about opening or closing restricted fishing areas are usually on land, and will communicate their decisions on paper, using websites or electronic mail, and by voice radio.

Within a vessel monitoring system (VMS), the Fisheries Management Center (FMC) components are on land. Minimally, this is a regional or national center of the nation in whose waters the fishing is happening. Under the Flag Principle, the VMS of a vessel registered in a nation other than the coastal or EEZ nation of the fishing area will transmit to its national FMC, which will then relay the information to the FMC where the vessel is operating.

Patrol vessels may do visual or electronic surveillance of fishing vessels at sea, or may board them for spot inspections. Fisheries management vessels also may independently monitor fish densities in the areas of interest, water conditions, or other observations of interest for operations or research.

Aerospace components

Low-flying aircraft can visually identify fishing vessels, and, with reasonable navigational skills, determine whether a given craft is in an authorized area. This is aided if the fishing craft display distinctive identifiers.

Higher-flying aircraft using radar and other sensors can determine which vessels are in a designated open or closed fishing area, and the ashore FMC can correlate these observations with VMS data.

Communications satellites, in both low earth orbit and geosynchronous orbit are the backbone of VMS communications with FMCs. Radar satellites can locate vessels in a far larger area than can aircraft, but have little or no ability to characterize the vessel.

Chapter 5

Population Dynamics of Fisheries

Predator bluefin trevally sizing up schooling anchovies, in the Maldives

A fishery is an area with an associated fish or aquatic population which is harvested for its commercial or recreational value. Fisheries can be wild or farmed. Population dynamics describes the ways in which a given population grows and shrinks over time, as controlled by birth, death, and emigration or immigration. It is the basis for understanding changing fishery patterns and issues such as habitat destruction, predation and optimal harvesting rates. The population dynamics of fisheries is used by fisheries scientists to determine sustainable yields.

The basic accounting relation for population dynamics is the BIDE model:

$$N_1 = N_0 + B - D + I - E$$

where N_1 is the number of individuals at time 1, N_0 is the number of individuals at time 0, B is the number of individuals born, D the number that died, I the number that immigrated, and E the number that emigrated between time 0 and time 1. While immigration and emigration can be present in wild fisheries, they are usually not measured.

A fishery population is affected by three dynamic rate functions:

- Birth rate or **recruitment**. Recruitment means reaching a certain size or reproductive stage. With fisheries, recruitment usually refers to the age a fish can be caught and counted in nets.

- Growth rate. This measures the growth of individuals in size and length. This is important in fisheries where the population is often measured in terms of biomass.

- Mortality. This includes harvest mortality and natural mortality. Natural mortality includes non-human predation, disease and old age.

If these rates are measured over different time intervals, the **harvestable surplus** of a fishery can be determined. The harvestable surplus is the number of individuals that can be harvested from the population without affecting long term stability (average population size). The harvest within the harvestable surplus is called **compensatory mortality**, where the harvest deaths are substituting for the deaths that would otherwise occur naturally. Harvest beyond that is **additive mortality**, harvest in addition to all the animals that would have died naturally.

Care is needed when applying population dynamics to real world fisheries. Over-simplistic modelling of fisheries has resulted in the collapse of key stocks.

History

The first principle of population dynamics is widely regarded as the exponential law of Malthus, as modelled by the Malthusian growth model. The early period was dominated by demographic studies such as the work of Benjamin Gompertz and Pierre François Verhulst in the early 19th century, who refined and adjusted the Malthusian demographic model. A more general model formulation was proposed by F.J. Richards in 1959, by which the models of Gompertz, Verhulst and also Ludwig von Bertalanffy are covered as special cases of the general formulation.

Population size

The population size (usually denoted by *N*) is the number of individual organisms in a population.

The effective population size (N_e) was defined by Sewall Wright, who wrote two landmark papers on it (Wright 1931, 1938). He defined it as "the number of breeding individuals in an idealized population that would show the same amount of dispersion of allele frequencies under random genetic drift or the same amount of inbreeding as the population under consideration". It is a basic parameter in many models in population genetics. N_e is usually less than *N* (the absolute population size).

Small population size results in increased genetic drift. Population bottlenecks are when population size reduces for a short period of time.

Overpopulation may indicate any case in which the population of any species of animal may exceed the carrying capacity of its ecological niche.

Virtual population analysis

Virtual population analysis (VPA) is a modelling technique commonly used in fisheries science for reconstructing historical fish numbers using information on death of individuals each year. This death is usually partitioned into catch by fisheries and natural mortality.

VPA is the most commonly used term to refer to cohort reconstruction techniques used in fisheries. It is virtual in the sense that the population size is not observed or measured directly but is inferred or back-calculated to have been a certain size in the past in order to support the observed fish catches and an assumed death rate owing to non-fishery related causes.

Minimum viable population

The minimum viable population (MVP) is a lower bound on the population of a species, such that it can survive in the wild. More specifically MVP is the smallest possible size at which a biological population can exist without facing extinction from natural disasters or demographic, environmental, or genetic stochasticity. The term "population" refers to the population of a species in the wild.

As a reference standard, MVP is usually given with a population survival probability of somewhere between ninety and ninety-five percent and calculated for between one hundred and one thousand years into the future.

The MVP can be calculated using computer simulations known as population viability analyses (PVA), where populations are modelled and future population dynamics are projected.

Maximum sustainable yield

In population ecology and economics, the maximum sustainable yield or **MSY** is, theoretically, the largest catch that can be taken from a fishery stock over an indefinite period. Under the assumption of logistic growth, the MSY will be exactly at half the carrying capacity of a species, as this is the stage at when population growth is highest. The maximum sustainable yield is usually higher than the optimum sustainable yield.

This logistic model of growth is produced by a population introduced to a new habitat or with very poor numbers going through a lag phase of slow growth at first. Once it reaches a foothold population it will go through a rapid growth rate that will start to level off once the species approaches carrying capacity. The idea of maximum sustained yield is to decrease population density to the point of highest growth rate possible. This changes the number of the population, but the new number can be maintained indefinitely, ideally.

MSY is extensively used for fisheries management. Unlike the logistic (Schaefer) model, MSY in most modern fisheries models occurs at around 30% of the unexploited population size. This fraction differs among populations depending on the life history of the species and the age-specific selectivity of the fishing method.

However, the approach has been widely criticized as ignoring several key factors involved in fisheries management and has led to the devastating collapse of many fisheries. As a simple calculation, it ignores the size and age of the animal being taken, its reproductive status, and it focuses solely on the species in question, ignoring the damage to the ecosystem caused by the designated level of exploitation and the issue of bycatch. Among conservation biologists it is widely regarded as dangerous and misused.

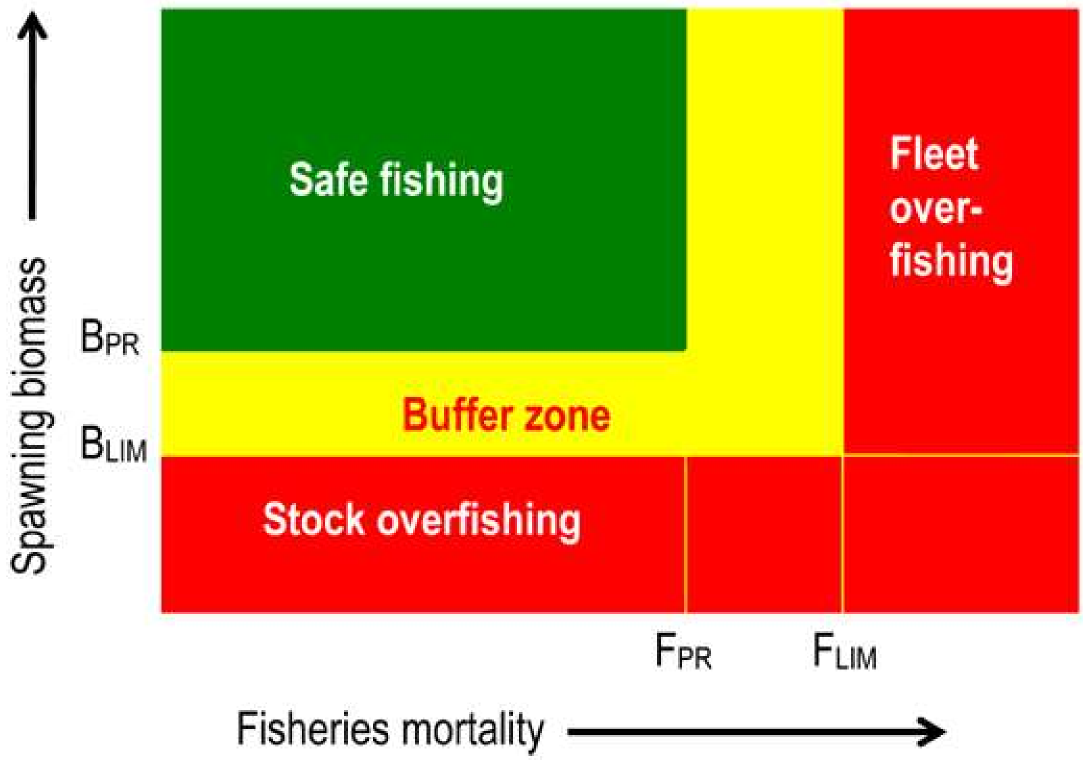
Recruitment

Recruitment is the number of new young fish that enter a population in a given year. The size of fish populations can fluctuate by orders of magnitude over time, and five to 10-fold variations in abundance are usual. This variability applies across time spans ranging from a year to hundreds of years. Year to year fluctuations in the abundance of short lived forage fish can be nearly as great as the fluctuations that occur over decades or centuries. This suggests that fluctuations in reproductive and recruitment success are prime factors behind fluctuations in abundance. Annual fluctuations often seem random, and recruitment success often has a poor relationship to adult stock levels and fishing effort. This makes prediction difficult.

The recruitment problem is the problem of predicting the number of fish larvae in one season that will survive and become juvenile fish in the next season. It has been called "the central problem of fish population dynamics" and “the major problem in fisheries science". Fish produce huge volumes of larvae, but the volumes are very variable and mortality is high. This makes good predictions difficult.

According to Daniel Pauly, the definitive study was made in 1999 by Ransom Myers. Myers solved the problem "by assembling a large base of stock data and developing a complex mathematical model to sort it out. Out of that came the conclusion that a female in general produced three to five recruits per year for most fish."

Overfishing



The Traffic Light colour convention, showing the concept of Harvest Control Rule (HCR), specifying when a rebuilding plan is mandatory in terms of precautionary and limit reference points for spawning biomass and fishing mortality rate.

The notion of overfishing hinges on what is meant by an **acceptable level** of fishing.

A current operational model used by some fisheries for predicting acceptable levels is the **Harvest Control Rule** (HCR). This formalizes and summarizes a management strategy which can actively adapt to subsequent feedback. The HCR is a variable over which the management has some direct control and describes how the harvest is intended to be controlled by management in relation to the state of some indicator of stock status. For example, a harvest control rule can describe the various values of fishing mortality which will be aimed at for various values of the stock abundance. Constant catch and constant fishing mortality are two types of simple harvest control rules.

- **Biological overfishing** occurs when fishing mortality has reached a level where the stock biomass has negative marginal growth (slowing down biomass growth), as indicated by the red area in the figure. Fish are being taken out of the water so quickly that the replenishment of stock by breeding slows down. If the replenishment continues to slow down for long enough, replenishment will go into reverse and the population will decrease.

- **Economic** or **bioeconomic overfishing** additionally considers the cost of fishing and defines overfishing as a situation of negative marginal growth of resource rent. Fish are being taken out of the water so quickly that the growth in the profitability of fishing slows down. If this continues for long enough, profitability will decrease.

Metapopulation

A metapopulation is a group of spatially separated populations of the same species which interact at some level. The term was coined by Richard Levins in 1969. The idea has been most broadly applied to species in naturally or artificially fragmented habitats. In Levins' own words, it consists of "a population of populations".

A metapopulation generally consists of several distinct populations together with areas of suitable habitat which are currently unoccupied. Each population cycles in relative independence of the other populations and eventually goes extinct as a consequence of demographic stochasticity (fluctuations in population size due to random demographic events); the smaller the population, the more prone it is to extinction.

Although individual populations have finite life-spans, the population as a whole is often stable because immigrants from one population (which may, for example, be experiencing a population boom) are likely to re-colonize habitat which has been left open by the extinction of another population. They may also emigrate to a small population and rescue that population from extinction (called the *rescue effect*).

Malthus

BENJAMIN GOMPERTZ

Gompertz

Verhulst

Age class structure

Age can be determined by counting growth rings in fish scales, otoliths, cross-sections of fin spines for species with thick spines such as triggerfish, or teeth for a few species. Each method has its merits and drawbacks. Fish scales are easiest to obtain, but may be unreliable if scales have fallen off of the fish and new ones grown in their places. Fin spines may be unreliable for the same reason, and most fish do not have spines of sufficient thickness for clear rings to be visible. Otoliths will have stayed with the fish throughout its life history, but obtaining them requires killing the fish. Also, otoliths often require more preparation before ageing can occur.

An age class structure with gaps in it, for instance a regular bell curve for the population of 1-5 year-old fish, excepting a very low population for the 3-year-olds, implies a bad spawning year 3 years ago in that species.

Often fish in younger age class structures have very low numbers because they were small enough to slip through the sampling nets, and may in fact have a very healthy population.

Population cycle

A population cycle occurs where populations rise and fall over a predictable period of time. There are some species where population numbers have reasonably predictable patterns of change although the full reasons for population cycles is one of the major unsolved ecological problems. There are a number of factors which influence population change such as availability of food, predators, diseases and climate.

Trophic cascades

Trophic cascades occur when predators in a food chain suppress the abundance of their prey, thereby releasing the next lower trophic level from predation (or herbivory if the intermediate trophic level is an herbivore). For example, if the abundance of large piscivorous fish is increased in a lake, the abundance of their prey, zooplanktivorous fish, should decrease, large zooplankton abundance should increase, and phytoplankton biomass should decrease. This theory has stimulated new research in many areas of ecology. Trophic cascades may also be important for understanding the effects of removing top predators from food webs, as humans have done in many places through hunting and fishing activities.

Classic examples

1. In lakes, piscivorous fish can dramatically reduce populations of zooplanktivorous fish, zooplanktivorous fish can dramatically alter freshwater zooplankton communities, and zooplankton grazing can in turn have large impacts on phytoplankton communities. Removal of piscivorous fish can change lake water from clear to green by allowing phytoplankton to flourish.
2. In the Eel River, in Northern California, fish (steelhead and roach) consume fish larvae and predatory insects. These smaller predators prey on midge larvae, which feed on algae. Removal of the larger fish increases the abundance of algae.
3. In Pacific kelp forests, sea otters feed on sea urchins. In areas where sea otters have been hunted to extinction, sea urchins increase in abundance and decimate kelp

A recent theory, the mesopredator release hypothesis, states that the decline of top predators in an ecosystem results in increased populations of medium-sized predators (mesopredators).

Basic models

- The classic population equilibrium model is Verhulst's 1838 growth model:

  $$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

  where $N(t)$ represents number of individuals at time t, r the intrinsic growth rate and K is the carrying capacity, or the maximum number of individuals that the environment can support.

- The individual growth model, published by von Bertalanffy in 1934, can be used to model the rate at which fish grow. It exists in a number of versions, but in its simplest form it is expressed as a differential equation of length (L) over time (t):

  $$L'(t) = r_B\left(L_\infty - L(t)\right)$$

  where r_B is the von Bertalanffy growth rate and L_∞ the ultimate length of the individual.

- Schaefer published a fishery equilibrium model based on the Verhulst model with an assumption of a bi-linear catch equation, often referred to as the Schaefer short-term catch equation:

  $$H(E, X) = qEX$$

  where the variables are; H, referring to catch (harvest) over a given period of time (e.g. a year); E, the fishing effort over the given period; X, the fish stock biomass at the beginning of the period (or the average biomass), and the parameter q represents the catchability of the stock.
  Assuming the catch to equal the net natural growth in the population over the same period ($\dot{X} = 0$), the equilibrium catch is a function of the long term fishing effort E:

  $$H(E) = qKE\left(1 - \frac{qE}{r}\right)$$

  r and K being biological parameters representing intrinsic growth rate and natural equilibrium biomass respectively.

- The Ricker model is a classic discrete population model which gives the expected number (or density) of individuals N_{t+1} in generation $t + 1$ as a function of the number of individuals in the previous generation,

  $$N_{t+1} = N_t e^{r\left(1 - \frac{N_t}{k}\right)}$$

  Here r is interpreted as an intrinsic growth rate and k as the carrying capacity of the environment. The Ricker model was introduced in the context of the fisheries by Ricker (1954).

- The Beverton–Holt model, introduced in the context of fisheries in 1957, is a classic discrete-time population model which gives the expected number n_{t+1} (or density) of individuals in generation $t + 1$ as a function of the number of individuals in the previous generation,

  $$n_{t+1} = \frac{R_0 n_t}{1 + n_t/M}.$$

  Here R_0 is interpreted as the proliferation rate per generation and $K = (R_0 - 1) M$ is the carrying capacity of the environment.

- Nurgaliev's law says

  $$\frac{dN}{dt} = aN^2 - bN$$

  where N is the size of a population, a is a half of the average probability of a birth of a male (the same for females) of a potential arbitrary parents pair within a year, and b is an average probability of a death of a fish within a year.

Predator-prey equations

The classic predator-prey equations are a pair of first order, non-linear, differential equations used to describe the dynamics of biological systems in which two species interact, one a predator and one its prey. They were proposed independently by Alfred J. Lotka in 1925 and Vito Volterra in 1926.

An extension to these are the competitive Lotka-Volterra equations, which provide a simple model of the population dynamics of species competing for some common resource.

In the 1930s Alexander Nicholson and Victor Bailey developed a model to describe the population dynamics of a coupled predator-prey system. The model assumes that predators search for prey at random, and that both predators and prey are assumed to be distributed in a non-contiguous ("clumped") fashion in the environment.

Chapter 6

Stock Assessment

Stock assessments provide fisheries managers with the information that is used in the regulation of a fish stock. Biological and fisheries data are collected in a stock assessment.

A wide array of biological data may be collected for an assessment. These include details on the age structure of the stock, age at first spawning, fecundity, ratio of males to females in the stock, natural mortality (M), fishing mortality (F), growth rate of the fish, spawning behavior, critical habitats, migratory habits, food preferences, and an estimate of either the total population or total biomass of the stock.

The following data regarding fisheries activities is collected: the kinds of fisherman in the fishery, commercial versus recreational, and the gear that is used (longline, rod and reel, nets, etc), pounds of fish caught by each type of fisherman, the fishing effort each kind of fisherman expends, the age structure of the fish harvested by each group of fisherman, the ratio of males to females that are captured, how the fish are marketed, the value of the fish to the different fisherman groups, and the time and geographic location of the best catches. Also in the assessment, geographical boundaries of different stocks or populations are defined. From the combined biological and fisheries data, the current status and condition of the stock is defined and managers use this assessment to predict how in the future, stocks will respond to varying levels of fishing pressure. Ultimately managers want to reduce the levels of overfishing that occurs and restore stocks that have been overfished.

Defining stock

In fisheries management, stock refers to a harvested or managed unit of a fish. Typically stocks are divided based on geographical location and not based on individual population. Spanish mackerel are distributed from Maine to the Yucatan Peninsula in Mexico. They are divided into two stocks, based on whether they migrate northward along the eastern United States coast or if they migrate into the Gulf of Mexico. Each stock of Spanish mackerel does not represent discrete populations. Stocks are not always composed of a single species. Stocks can be composed of multiple species due to their being harvested together or as a form of convenience for managers. An example of a multispecies stock is river herring. Alewives and blueback herring are labeled as river herring for management purposes due to their similar physical appearances and being harvested together. Individuals within a stock are subdivided into cohorts. A cohort is a group of fish born in the same year within a population or stock.

Gathering data

Data used in stock assessments can be classified as fishery-dependent data or fishery-independent data. Fishery-dependent data is collected from the fishery itself, using both commercial and recreational sources. There are a variety of methods for obtaining fishery-dependent data. The most common approach is to use recorded landings. Landings are a record of the amount of fish sold and the numbers are typically reported in total weight. Another common mode for acquiring fishery-dependent data is through portside sampling of the catch of both recreational and commercial fisherman to obtain age and length information on the stock. Other less common methods for obtaining data is through the use of onboard observers, self-reporting, telephone surveys, and vessel-monitoring surveys.

Fishery-independent data is obtained in the absence of any fishing activity. The majority of this data is collected by state and federal agencies. A wide variety of methods and gear types are used to acquire fishery-independent data. Sampling equipment can include trawls, seines, acoustic and/or video surveys. The study may focus on a single species, multiple species, or a specific age range or cohort. Regardless of the method or approach, these surveys provide managers with an estimate of abundance. Mark and recapture studies are commonly used to estimate movement, migration, growth rate, natural mortality, and discard mortality. Stock assessments are often completed using both fishery-dependent and fishery-independent data.

Overfished versus overfishing

Overfished refers to the number of fish in the stock. Typically a stock is described as being overfished when current biomass of a stock is lower than what is required to support the maximum sustainable yield. Overfishing describes the rate of removal from a stock and can be categorized as two different types: recruitment and economic. Recruitment overfishing is when fishing pressure is too heavy to allow a fish population to replace itself. Economic overfishing occurs when the level of fish harvesting that is higher than that of economic efficiency and more fish are harvested than necessary to have maximum profits for the fishery.

Biological reference points

Biological reference points are the primary output of stock assessments and fishing regulations are set to meet these biological benchmarks. There are several types of benchmarks are used depending on the preference of the regulating agency. The benchmarks are used to control different aspects of the fishery or population. Benchmarks that regulate fishing mortality include Fcurr, Fmsy, Emsy, and MFMT.

Fcurr is the current level of fishing mortality, Fmsy is the fishing mortality that produces the maximum sustainable yield, and Emsy is the expected level of fishing that will produce the maximum sustainable yield. SSBcurr, SSBmsy, and MSST are used in the regulation of biomass levels. SSBcurr stands for the current spawning stock biomass, SSBmsy is the amount of spawning stock biomass needed to produce the maximum sustainable yield, and MSST is the minimum standing stock threshold. The amount that is available to be harvested is controlled by the benchmarks MSY and OY. MSY is the maximum sustainable yield and OY is the optimum yield of a stock. The main difference between MSY and OY is that MSY considers only the biology of the fish while the OY considers the economic aspect of the harvest.

Some of these benchmarks are combined in the form of ratios in order to better understand the status of the stock. A Fcurr/Fmsy ratio greater than one indicates that overfishing is occurring. When SSBcurr/SSBmsy is greater than one, the MSY will be produced, but if it is less than one it means that the stock is overfished. MFMT and MSST are used as limit reference points. When MFMT is exceeded or the spawning stock size dips below MSST the fishery is shut down. A benchmark that is currently gaining in popularity is SPR, spawning potential ratio. The SPR is the average fecundity of a recruit over its lifetime when the stock is fished divided by the average fecundity of a recruit over its lifetime when the stock is unfished. The SPR is based on the principle that certain levels of fish have to survive in order to spawn and replenish the stock at a sustainable level.

Catch curve

A catch curve is a descriptive figure that describes catch by age and length. A catch curve only reflects fish that have recruited to a fishery and does not reflect the full age structure of a stock. A catch curve illustrates the proportions that different age and size classes are harvested by a fishery.

Assessment models

The mathematical and statistical techniques used to complete a stock assessment are referred to as assessment models. Three commonly used models are surplus production models, statistical catch at age models, and virtual population analysis models. Of these models, surplus production models are the least complex and require the least amount of data. This model describes the stock solely in regards of biomass and the only used total catch and effort data. These are most commonly used in situations limited data is available on a stock. Statistical catch at age models are based on the age structure of a fished population. These models use the proportional catch-at-age to predict the relative abundance of each age class. These calculated relative abundances are then used to estimate future abundances of the stock and harvest regulations are set based on the predicted future abundances. In virtual population analysis models, catch-at-age data is used to estimate historical stock abundance. From this analysis, the manager then determines if overfishing is occurring. The type of model used depends on the data that is available. Modern stock assessment methods use statistical approaches to "integrate" multiple sources of information to estimate management quantities and their associated uncertainty.

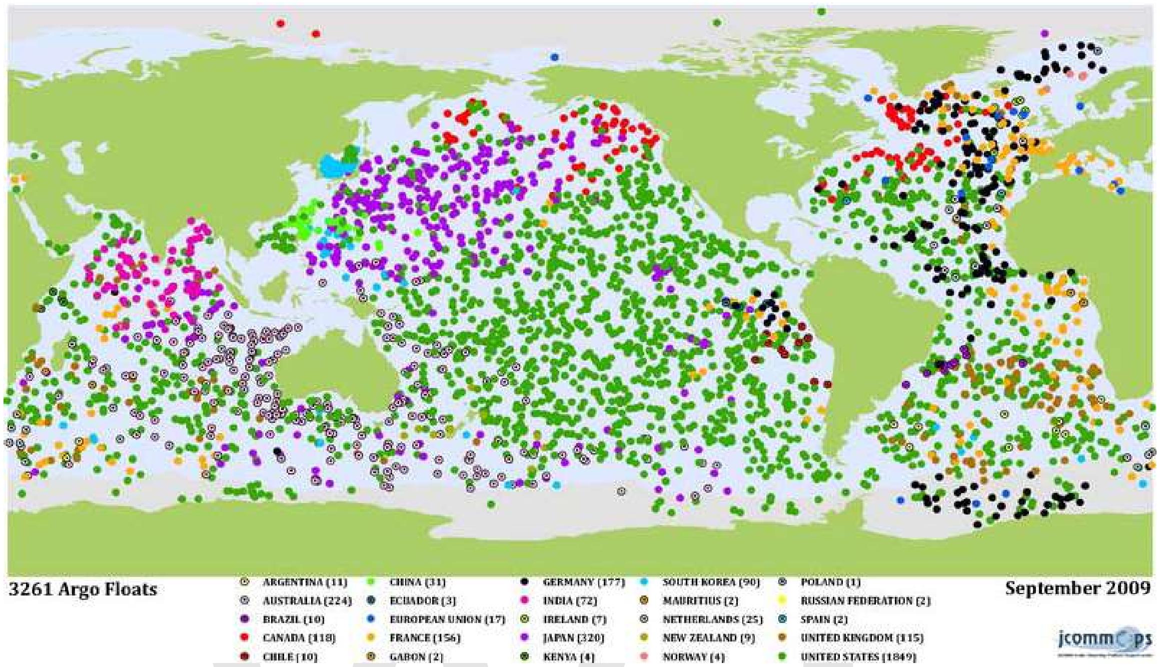
After a stock assessment

After a stock assessment is completed, the findings are provided to regional fishery management councils. The council identifies stocks that are endanger of or currently undergoing overfishing and then develops fishery management plans and regulations. Fishery management plans (FMP) must protect fishery resources while maintaining opportunities for domestic recreational and commercial fishing at sustainable levels of effort and yield. If a stock already has a FMP, the stock assessment is used to modify the FMP in response to current conditions. The public are also encouraged to participate in the management process and public hearings are held to allow for comment before the new management policies are enforced.

Chapter 7

Argo (Oceanography)

Argo is an observation system for the Earth's oceans that provides real-time data for use in climate, weather, oceanographic and fisheries research. Argo consists of a large collection of small, drifting oceanic robotic probes deployed worldwide. The probes float as deep as 2 km. Once every 10 days, the probes surface, measuring conductivity and temperature profiles to the surface. From these, salinity and density can be calculated. The data are transmitted to scientists on shore via satellite. The data collected are freely available to everyone, without restrictions. The initial project goal was to deploy 3,000 probes, completed in November 2007.



Map of the Argo float network as of September 2009

International collaboration

The Argo program is a collaboration between 50 research and operational agencies from 26 countries, with the United States contributing over half the total funding (as of December 2004). Argo is a component of the Integrated Ocean Observing System.

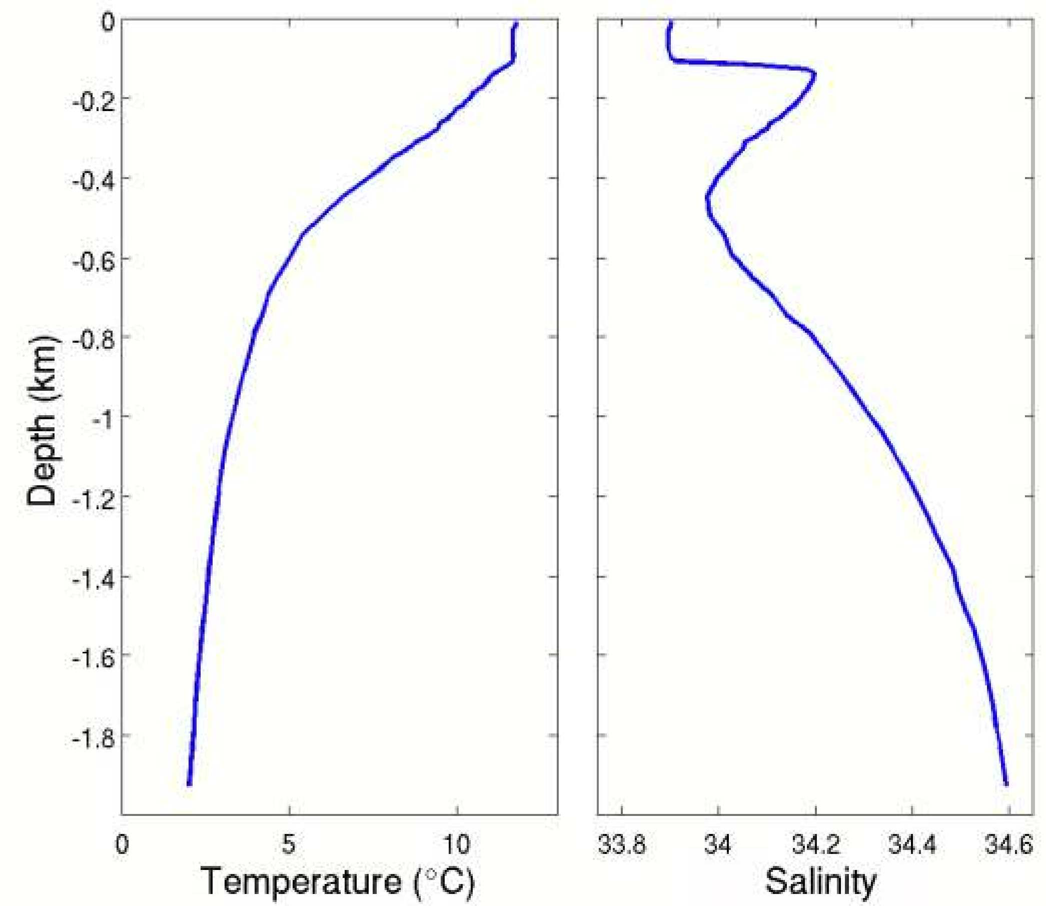
Float operation

The Argo program was designed to operate on the same 10-day duty cycle to match the existing satellite measurements of the ocean's sea surface. These satellites, called Topex/Poseidon and Jason 1, measure changes in the surface topography of the ocean. With such measurements, information about temperature, mass redistribution, or surface currents can be inferred. The Argo floats measure *subsurface* changes in temperature and salinity, hence the float measurements are complementary to the altimetry.

Argo is named after the Greek mythical ship Argo which Jason and the Argonauts use on their quest for the Golden Fleece. The name was chosen to emphasize the complementary relationship of the project with the Jason-1 satellite altimeter.

Although drifting floats had been deployed during the World Ocean Circulation Experiment in the 1990s, Argo floats began to be deployed in earnest in the early 2000s. The target number of 3,000 deployed floats was reached during 2006–2007. The number of floats is continually changing as floats are lost or expire, while others are deployed. Nominally, some 750 floats are deployed each year to sustain the system. The floats have a nominal 300-km spacing, although the exact separations depend on the randomness of the float drift.

The Argo temperature and salinity measurements are yielding valuable information about the large-scale water properties and currents of the ocean, including the variability of these properties over time scales from seasonal to decadal.



Example profiles of temperature and salinity obtained from an Argo float in the central North Pacific (38.4°N, 155.3°W) on April 8, 2005.

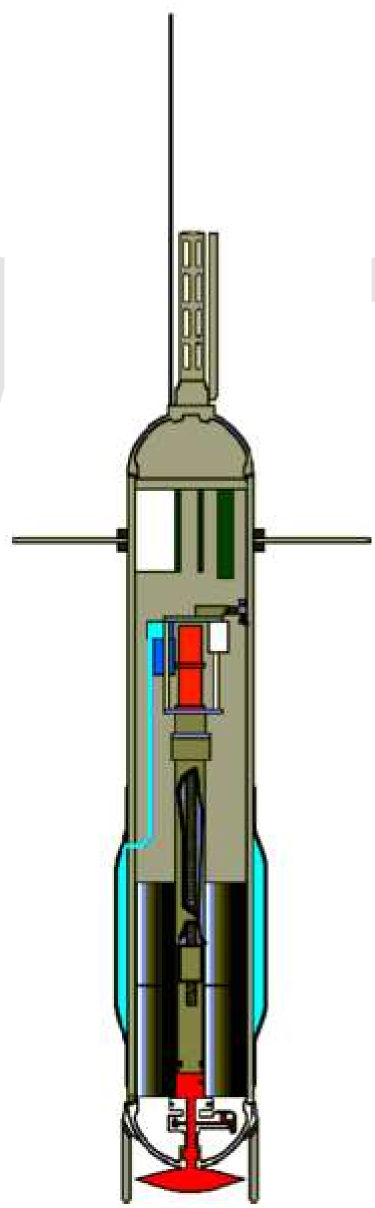
Profiling

Argo floats drift at a fixed pressure (usually around 1,000 metres depth) for 10 days. After this period, within the relatively short time of around two hours, the floats move to a profiling pressure (usually 2,000 metres deep) then rise, collecting instantaneous profiles of pressure, temperature, and salinity data on their way to the surface. Once at the surface, the floats remain there for under a day, transmitting the data collected via a satellite link back to a ground station and allowing the satellite to determine their surface drift. The floats then sink again and repeat their mission.

Data communication

Most of the floats use the Argos System of satellites to recover data, though a few are using the newer Iridium satellite constellation. The Iridium system offers significant advantages associated with the much faster data transfer. Since an Iridium float spends only 3 minutes at the sea surface, the opportunity to observe surface currents by tracking the movements of the floats is lost but the trajectories of the floats become more representative of the flow at their parking depth.

Float design



Cutaway diagram of an Argo float. The height of the float is about 2 m. The antenna and sensors are mounted at the top of the buoy.

A critical capability of an Argo float is its ability to rise and descend in the ocean on a programmed schedule. The floats do this by changing their effective density. The density of any object is given by its mass divided by its volume. The Argo float keeps its mass constant, but by altering its volume, it changes its density. To do this, a hydraulic piston is used to push mineral oil out of the float and expand a rubber bladder at the bottom end of the float. As the bladder expands, the float becomes less dense than seawater and rises to the surface. Upon finishing its tasks at the surface, the float withdraws the piston and descends again.

An increasing number of the floats also carry other sensors, such as for measuring dissolved oxygen.

The antenna for satellite communications is mounted at the top of the float. Once the float reaches the surface, the float is essentially a spar buoy, allowing the antenna to poke above the sea surface for communication. The ocean is saline, hence an electric conductor, so that radio communications from under the sea surface are difficult.

The nominal life span of an Argo float is five years. After the internal batteries expire, the floats are allowed to sink to the ocean floor or wash ashore.

Data access

Argo is unique among research programs in that the real-time data are freely offered to anyone. The data collected by the network are made available with no constraint on use of the data, and most data are available for download within 24 hours of a float measurement. Data can be downloaded over the world wide web from one of two global data servers (OPeNDAP servers).

Data format

Even though data are supplied by 24 national programs, all data are available in near real-time in a single format. Argo data are in the native import format of the Ocean Data View (ODV) suite of programs. Ocean Data View (ODV) is proprietary but freely available software created by Reiner Schlitzer that offers flexible ways of displaying oceanographic data. Data in other formats are also available, e.g., netCDF. A careful study of the manuals before starting to use the data is essential.

Data results

It is not yet possible to use Argo data to detect global change signals.

Data results from year 2006 with undetected errors

The Argo Network has shown a continuous declining trend in ocean temperatures. The trend was overstated in media reports because of published data with undetected errors in year 2006. In March 2008, Josh Willis of NASA's Jet Propulsion Laboratory did report that the Argo system show no ocean warming since it started in 2003. "There has been a very slight cooling, but not anything really significant," Willis has stated. A lot of media has reported the uncorrected data results and even though the revised corrected data appeared in 2008, many articles and arguments still use and promote the uncorrected data results from 2006.

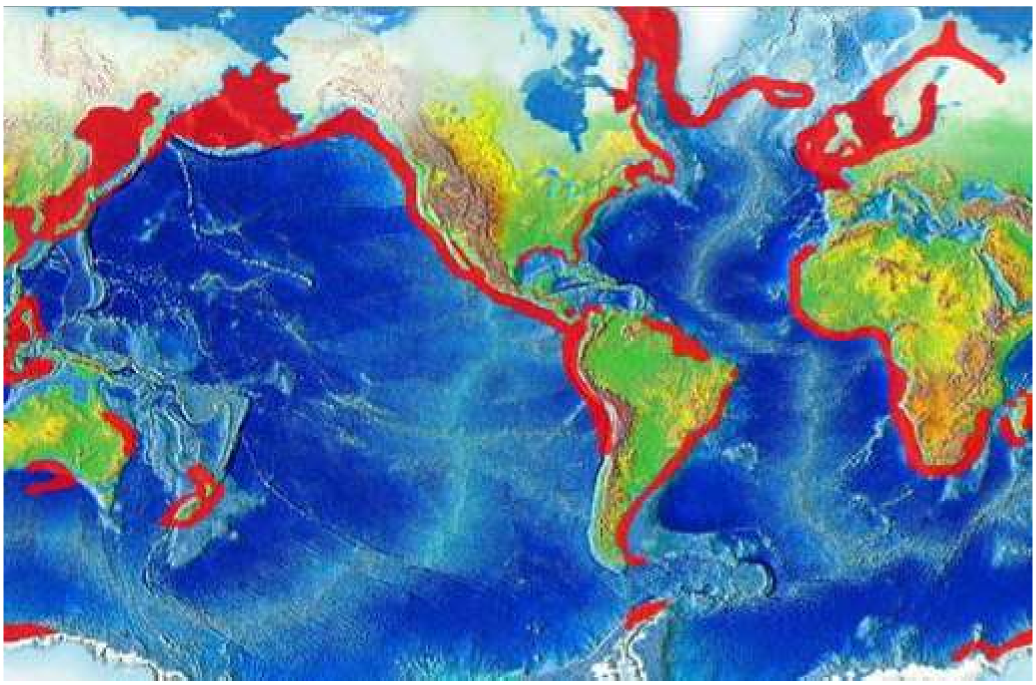
Data results from year 2008 and after

In an article from November 5, 2008, Josh Willis states that the world ocean actually has been warming since 2003 after removing Argo measurement errors from the data and adjusting the measured temperatures with a computer model his team developed.

Here is a graph with the 2008/2009 Argo network data included.

Chapter 8

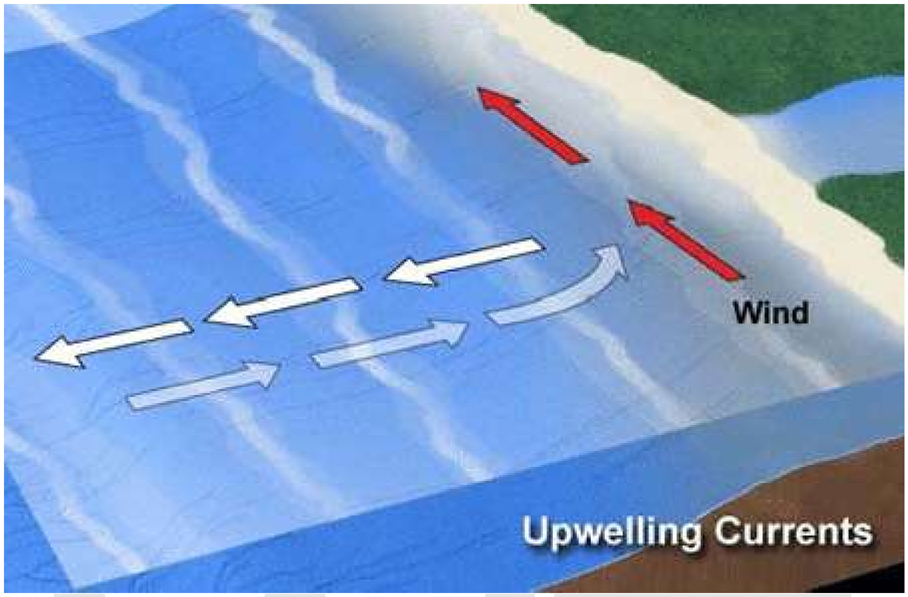
Upwelling

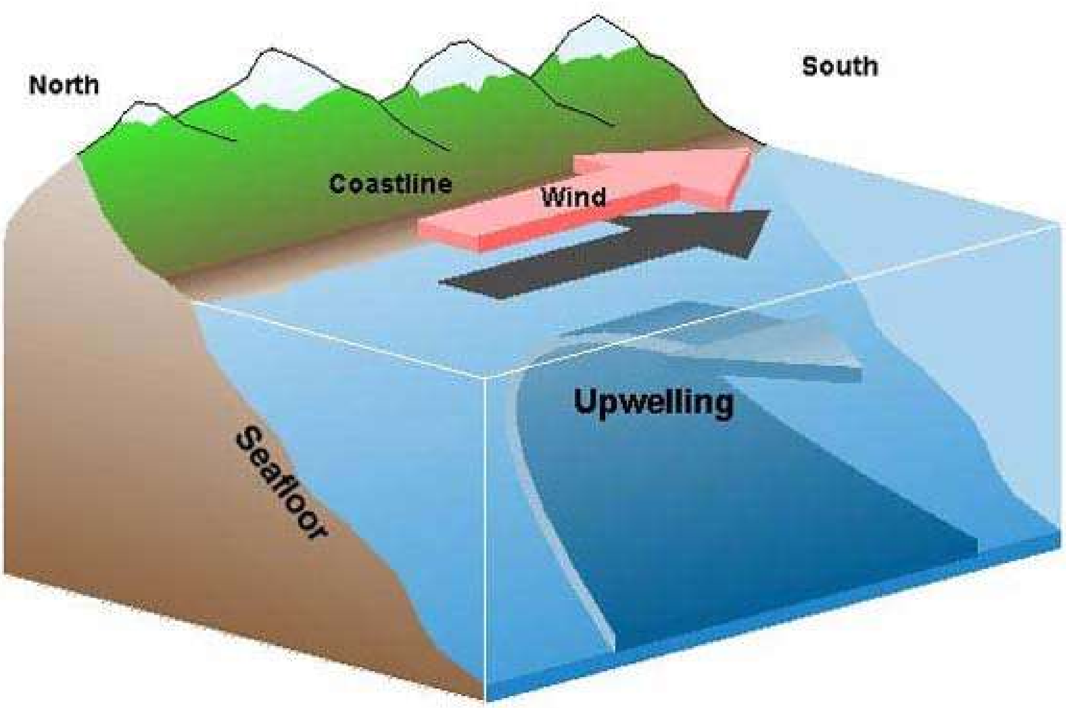


Areas of upwelling in red.

Upwelling is an oceanographic phenomenon that involves wind-driven motion of dense, cooler, and usually nutrient-rich water towards the ocean surface, replacing the warmer, usually nutrient-depleted surface water. The increased availability in upwelling regions results in high levels of primary productivity and thus fishery production. Approximately 25% of the total global marine fish catches come from five upwellings that occupy only 5% of the total ocean area. Upwellings that are driven by coastal currents or diverging open ocean have the greatest impact on nutrient-enriched waters and global fishery yields.

Types





Upwelling near the coast due to Ekman transport perpendicular to the wind in the northern hemisphere.

The major upwellings in the ocean are associated with the divergence of currents that bring deeper, colder, nutrient rich waters to the surface. There are at least five types of upwelling: coastal upwelling, large-scale wind-driven upwelling in the ocean interior, upwelling associated with eddies, topographically-associated upwelling, and broad-diffusive upwelling in the ocean interior.

Coastal

Coastal upwelling is the best known type of upwelling, and the most closely related to human activities as it supports some of the most productive fisheries in the world. Wind-driven currents are diverted to the right of the winds in the Northern Hemisphere and to the left in the Southern Hemisphere due to the Coriolis effect. The result is a net movement of surface water at right angles to the direction of the wind, known as the Ekman transport. When Ekman transport is occurring away from the coast, surface waters moving away are replaced by deeper, colder, and denser water.

Deep waters are rich in nutrients, including nitrate and phosphate, themselves the result of decomposition of sinking organic matter (dead/detrital plankton) from surface waters. When brought to the surface, these nutrients are utilized by phytoplankton, along with dissolved CO_2 (carbon dioxide) and light energy from the sun, to produce organic compounds, through the process of photosynthesis. Upwelling regions therefore result in very high levels of primary production (the amount of carbon fixed by phytoplankton) in comparison to other areas of the ocean. High primary production propagates up the food chain because phytoplankton are at the base of the oceanic food chain.

The food chain follows the course of:

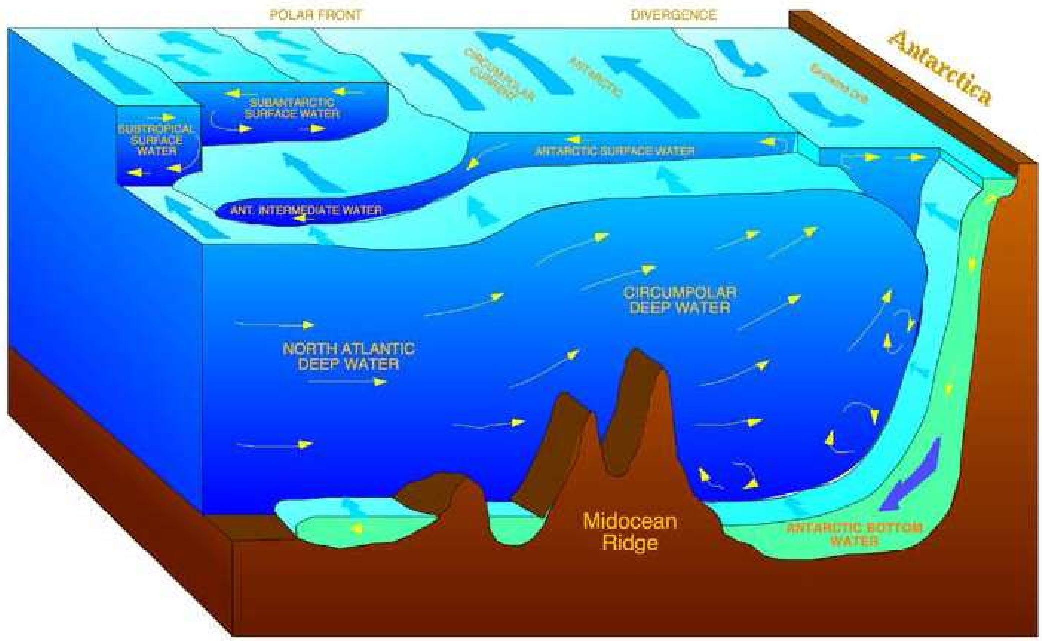
- Phytoplankton → Zooplankton → Predatory zooplankton → Filter feeders → Predatory fish

Worldwide, there are five major coastal currents associated with upwelling areas: the Canary Current (off Northwest Africa), the Benguela Current (off southern Africa), the California Current (off California and Oregon), the Humboldt Current (off Peru and Chile), and the Somali Current (off Western India). All of these currents support major fisheries. It also occurs in southeastern Brazil, more precisely in Arraial do Cabo.

Equatorial

Upwelling at the equator is associated with the Intertropical Convergence Zone (ITCZ) which actually moves, and consequently, is often located north or south of the equator. Easterly (westward) winds blowing along the ITCZ in both the Pacific and Atlantic Basins drive water to the right (northwards) in the Northern Hemisphere and to the left (southwards) in the Southern Hemisphere. If the ITCZ is displaced above the equator, the wind south of it becomes a southwesterly wind which drives water to its right or southeasterly, away from the ITCZ. Whatever its location, this results in a divergence, with denser, nutrient-rich water being upwelled from below, and results in the remarkable fact that the equatorial region in the Pacific can be detected from space as a broad line of high phytoplankton concentration.

Southern Ocean



Upwelling in the Southern Ocean

Large-scale upwelling is also found in the Southern Ocean. Here, strong westerly (eastward) winds blow around Antarctica, driving a significant flow of water northwards. This is actually a type of coastal upwelling. Since there are no continents in a band of open latitudes between South America and the tip of the Antarctic Peninsula, some of this water is drawn up from great depths. In many numerical models and observational syntheses, the Southern Ocean upwelling represents the primary means by which deep dense water is brought to the surface. Shallower, wind-driven upwelling is also found in off the west coasts of North and South America, northwest and southwest Africa, and southwest Australia, all associated with oceanic subtropical high pressure circulations.

Some models of the ocean circulation suggest that broad-scale upwelling occurs in the tropics, as pressure driven flows converge water toward the low latitudes where it is diffusively warmed from above. The required diffusion coefficients, however, appear to be larger than are observed in the real ocean. Nonetheless, some diffusive upwelling does probably occur.

Other sources

- Local and intermittent upwellings may occur when offshore islands, ridges, or seamounts cause a deflection of deep currents, providing a nutrient rich area in otherwise low productivity ocean areas. Examples include upwellings around the Galapagos Islands and the Seychelles Islands, which have major pelagic fisheries.
- Upwelling can also occur when a tropical cyclone transits an area, usually when moving at speeds of less than 5 mph (8 km/h). The churning of a cyclone eventually draws up cooler water from lower layers of the ocean. This causes the cyclone to weaken.
- Artificial upwelling is produced by devices that use ocean wave energy or ocean thermal energy conversion to pump water to the surface. Ocean wind turbines are also known to produce upwellings. Ocean wave devices have been shown to produce plankton blooms.

Variations

Upwelling intensity depends on wind strength and seasonal variability, as well as the vertical structure of the water, variations in the bottom bathymetry, and instabilities in the currents.

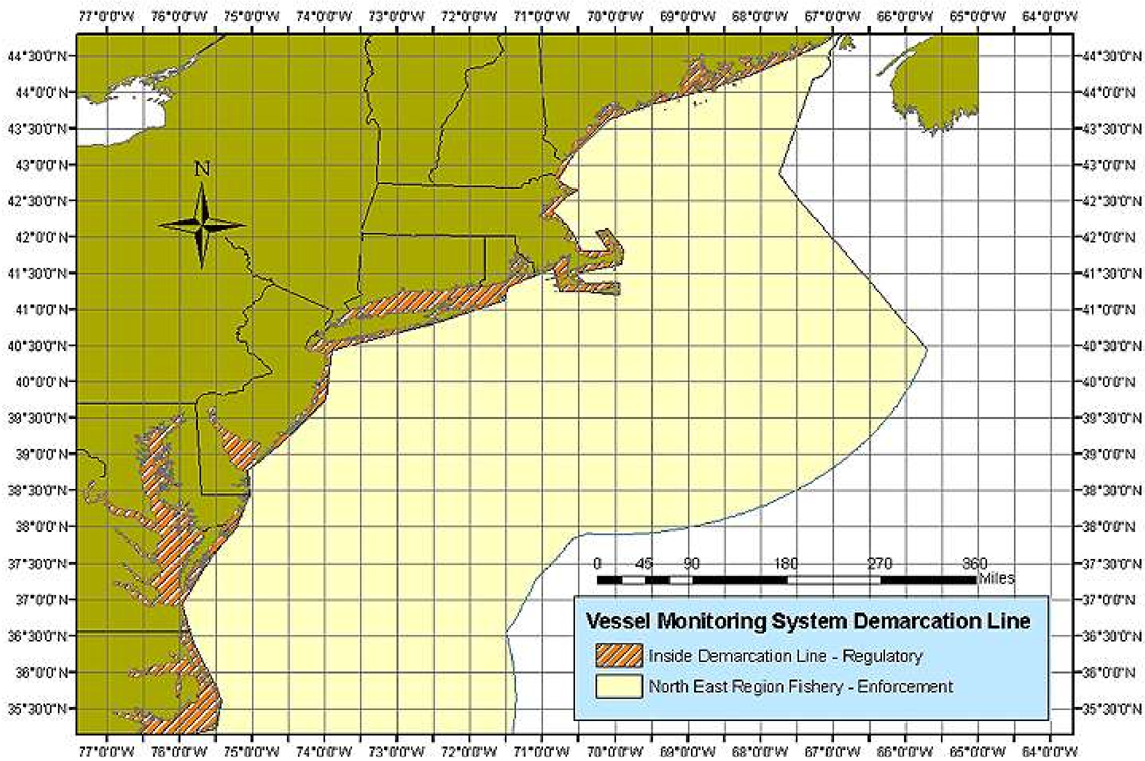
In some areas, upwelling is a seasonal event leading to periodic bursts of productivity similar to spring blooms in coastal waters. Wind-induced upwelling is generated by temperature differences between the warm, light air above the land and the cooler denser air over the sea. In temperate latitudes, the temperature contrast is greatly seasonably variable, creating periods of strong upwelling in the spring and summer, to weak or no upwelling in the winter. For example, off the coast of Oregon, there are four or five strong upwelling events separated by periods of little to no upwelling during the six month season of upwelling. In contrast, tropical latitudes have a more constant temperature contrast, creating constant upwelling throughout the year. The Peruvian upwelling, for instance, occurs throughout most of the year, resulting in one of the world's largest marine fisheries for sardines and anchovies.

In anomalous years when the trade winds weaken or reverse, the water that is upwelled is much warmer and low in nutrients, resulting in a sharp reduction in the biomass and phytoplankton productivity. This event is known as the El Nino-Southern Oscillation (ENSO) event. The Peruvian upwelling system is particularly vulnerable to ENSO events, and can cause extreme interannual variability in productivity.

Changes in bathymetry can affect the strength of an upwelling. For example, a submarine ridge that extends out from the coast will produce more favorable upwelling conditions than neighboring regions. Upwelling typically begins at such ridges and remains strongest at the ridge even after developing in other locations.

Chapter 9

Vessel Monitoring System



Vessel monitoring systems (VMS) are used in commercial fishing to allow environmental and fisheries regulatory organizations to monitor, minimally, the position, time at a position, and course and speed of fishing vessels. They are a key part of monitoring control and surveillance (MCS) programs at the national and international levels. VMS may be used to monitor vessels in the territorial waters of a country or a subdivision of a country, or in the Exclusive Economic Zones (EEZ) that extend 200 nautical miles (370.4 km) from the coasts of many countries.

Detail of VMS approved equipment and operational use will vary with the requirements of the nation of the vessel's registry, and the regional or national water in which the vessel is operating. Fisheries followed by VMS fall into two main categories:

- Local/regional fish such as scallops in the Northeast U.S., anchovies in Peruvian waters, or rock shrimp in the Gulf of Mexico
- Highly migratory species (HMS) such as tuna and billfish, or Patagonian toothfish (*Dissostichus eleginoides*) in the Antarctic. which can be caught in multiple regions

In this discussion, VMS relates specifically to fisheries management systems. VMS is sometimes used as an informal synonym for other such things as the Automatic Identification System (AIS) or Vessel Traffic Service (VTS). AIS and VTS are quite different from VMS, although they may be complementary may apply to marine oversight and sensing programs that deal with the safety of navigation, hazardous material spills, and environmental threats such as algal blooms. VMS uses different radio technologies, is long-range, and handles commercially sensitive information.

Since VMS components are expensive, most countries subsidize the purchase of equipment, although the vessel owner may have to pay for installation, maintenance, and continuing communications costs. The communications service used can optionally support other functions such as voice, electronic mail, and other applications over which the communications cost can be amortized. VMS cost is a significant obstacle to its use in developing countries, but there are a number of subsidy programs to encourage VMS use. VMS from marine electronics suppliers may also offer a variety of other optional functions that can help in navigation, economic analysis, safety, and finding fish to harvest.

Applications

VMS is intended principally for fisheries management, but the country using it may use the data for other purposes.

Fisheries management

Among the most basic purposes is to monitor the movement of VMS-equipped vessels with respect to restricted fishing areas. A given vessel may have approval to fish in a restricted area, to transit through it without fishing, or it may not be allowed in the area.

Catch reporting

Not all VMS systems have the software to record and transmit catch reports. On the systems with separate PCs, it is reasonably easy to distribute separate software, although the fishermen may or may not be able to install it without assistance. For VMS with dedicated PCs, additional software can be made part of software support with established channels. There is a distinct trend to making catch reporting part of an overall MCS program, although current VMS systems rarely integrate this capability with position reporting. Under the European Union scheme, vessels are generally required to report

- Catch on entry
- Weekly catch
- Transshipment
- Port of landing
- Catch on exit

A number of programs require tracking of days at sea (DAS) for a given vessel. They may require tracking the total cumulative catch of a given fishery.

Fisheries research & analysis

VMS is a planning and analysis tool as well as an aid to operations. Treated as a research database, the cumulative position reports gives an analysis of fishing vessel tracks in search of fish. Coupled with species-specific fishing licenses and catch reports, fisheries managers can estimate the amount of a given fish in an area, the amount taken by fishing vessels, and project overfishing before it happens.

Safety

VMS itself can help in search and rescue (SAR), especially when the SAR organization participates in the Global Maritime Distress Safety System(GMDSS). Some VMS have built-in Emergency Position-Indicating Radio Beacons (EPIRB), although a dedicated VMS unit may not be able to have an emergency beacon that automatically floats to the surface and starts transmitting when it detects it is in salt water. At the very least, the SAR agency can get a last reported location of the vessel, and perhaps its course, from the FMC.

Enforcement

VMS obviously is part of fisheries enforcement, but, along with other systems, it can be part of overall sea surveillance. When a radar or other sensor detects a given vessel, VMS can tell the center that monitors the radar whether the radar target is a known fishing vessel. There may be correlation between AIS/VTS and VMS.

Technologies and components

VMS involves technology on the vessel, ashore, and communications between them. In addition, there may be additional communications from the Fisheries Management Center (FMC) of the vessel's country of registry, and regional or national FMCs of the waters in which the vessel is fishing.

Functions aboard the vessel

The most basic function of a VMS is to determine the vessel's location at a given time, and periodically send this information, usually by satellite, to a monitoring station ashore.

VMS components on the vessel sometimes are called VMS, or sometimes Automatic Location Communicators (ALC). These minimally include a GPS antenna and receiver, a computer (which may be embedded or user-supplied), and a transmitter and antenna appropriate for the communications that links the vessel to the flag center.

In practice, many of the VMS components also have applicability, along with non-VMS marine electronics, to a wide range of functions aboard a fishing vessel. These include navigation, finding fish, collision avoidance, routine voice and email communications, etc.

Selecting a VMS system is most dependent on what vendors and models have been approved by the fishing vessel's state of registry. If there is a choice, then consider that the greatest flexibility to add components is with a system that does not have an embedded computer. If there is not an embedded computer, however, the vessel's owners will have to take more responsibility, perhaps through a contractor or installer, for keeping the software updated and integrating new software components without interfering with VMS functionality.

Especially when the user supplies the computer (i.e., the VMS consists of the radio gear and software only), VMS often have, in addition to the pure location transmission function, some level of fusing the various data sources with electronic charts.

VMS software and devices for the fishing vessel include:

- Absolute Software
- AMS
- Argos CLS
- AST Ltd
- Bluefinger/Thales
- Boatracs
- Faria
- Skymate
- Thrane & Thrane
- vTrack VMS
- Satamatics
- BlueTraker
- Free Port - Eye from a sky

Communications

VMS units principally rely on GPS for position and time information. LORAN may be a backup or complementary technology. They report data to monitoring systems generally using satellite systems from Inmarsat, Iridium, Argos, ORBCOMM or Qualcomm. Some nations, such as Iceland, are experimenting with coastal VHF repeaters for VMS communications.

- Operated by Inmarsat plc, originally founded by governments but now commercial, Inmarsat has a constellation of geosynchronous communications satellites.
- Iridium uses a constellation of 66 Low Earth Orbit satellites to provide complete global coverage (including all ocean regions and both poles) with real time coverage.
- Argos uses Low Earth Orbit European and US satellites in polar orbit, which is an especially appropriate orbit for vessels operating in high latitudes.
- Skymate uses Orbcomm LEO satellites, which is optimized for machine-to-machine communications, potentially at lower cost than voice-capable satellite systems. They operate in the VHF and UHF bands, and have demonstrated an AIS capability.
- Qualcomm provides access to the Iridium satellite systems.
- BlueTraker uses both GPRS and Iridium constellation to provide the biggest flexibility and the lowest communication costs. The BlueTraker is a stand alone device fully integrated including the antennas, the communication modules and a back-up battery. It is also e-logbook ready.

VMS/ALC Vendor	Product type	Communications	Communications type
Applied Satellite Technology	Dedicated computer with voice and email	Inmarsat-C	Geosynchronous satellite
Bluefinger/Thales	GPS & uplink antenna; PC software for VMS, log	Inmarsat	Geosynchronous satellite
Blue Oceans Satellite Systems	GPS; duplex communication; Web-based monitoring interface	Iridium and Globalstar	Low-earth orbiting (LEO), cross-linked satellites operating as a fully meshed network and supported by multiple in-orbit spares.
Boatracs	Dedicated with phone, fax, email	Qualcomm	LEO L-band uplink
CLS America	GPS with uplink	Argos	Polar LEO
Satrax ETS-1000	Dedicated computer with telephone	Iridium	Polar LEO with satellite-to-satellite
Satrax ETS-250	Dedicated computer	Orbcomm	Polar LEO with satellite-to-satellite
Skymate	GPS & uplink antenna; PC software for VMS, weather, fish prices, surface temperature, log	Orbcomm	LEO VHF Uplink
Thrane & Thrane	Dedicated computer with voice and email	Inmarsat-C	Geosynchronous satellite

Satamatics or Skywave	Low-cost, small transceivers with integrated GPS	Inmarsat-D+	Geosynchronous satellite
EMA - BlueTraker	all-integrated Hybrid device (GPRS and satellite communications)with internal back-up battery, antennas and e-logbook capabilities	GPRS & Iridium	Polar LEO with satellite-to-satellite
Free Port - Eye from a sky (Maestral 2009)	integrated black-box device (GPS positioning, GPRS/EDGE and satellite communications) with internal back-up battery, external antenna and PC software for monitoring, surveillance, communication and data gathering	GPRS/EDGE & Iridium	Polar LEO with satellite-to-satellite

Fisheries management center of the vessel's nation

Software at the fisheries management organization looks for several pieces of information:

- location vis-a-vis restricted area
- time at sea
- time in restricted area, possibly separating fishing and transit time by speed

A restricted area may be closed for all purposes, open to transit, open to fishing for a specific period, or open to designated vessels only. Vessel speed is often the way its status is determined in lieu of direct observation. Some VMS directly report speed, or speed can be calculated by FMS software based on the time stamps of different position reports. A rule of thumb in scallop fisheries, for example, is that the vessel cannot be dredging for scallops if its speed is greater than 5 knots (9 km/h).

FMC software can note the time a vessel leaves and returns to port, and the time it is inside or outside designated areas. There may be restrictions on trip length, time in an area, etc., which can be calculated directly from VMS data. Other observations may require correlation of catch reports with the vessel's presence in given areas. Presence in other areas may require an onboard observer.

Individual regional, national, and international FMCs have different levels of software intelligence, which can detect patterns of interest to SAR, fisheries management, or law enforcement.

Fisheries monitoring center of the waters being fished

Countries with registered fishing vessels that employ VMS generally agree to set up a Fisheries Monitoring Center (FMC), which connects via data network to the FMCs of other states. The flag state principle requires all vessels, registered in a given state, to transmit their positions automatically to that state's FMC. When the vessel enters the waters of a different state, the home FMC must forward the report of the vessel's entry into those waters. Until the vessel leaves the foreign state's coastal area, the home FMC must forward, to the FMC of the foreign state, position, speed, and course reports at least every two hours.

If position details are not received from a vessel that has been sending them, the FMC for the ocean area. from which the last signal was received, must attempt to contact the vessel. must contact the vessel or the flag state FMC without delay. Since VMS reports are sent automatically, it is possible that there is nothing wrong with the vessel itself, only the VMS. Full SAR, therefore, should not be launched simply because a VMS report does not arrive, although it is reasonable to inform sea surveillance assets, such as radars, that might be able to find the vessel. Fishing vessel crews should check the VMS at reasonable intervals, and confirm it is working.

While the procedure will vary with the jurisdiction, if an at-sea vessel finds their VMS is not working and they cannot fix it, they may be able to contact the FMC and get permission to continue the voyage. If they do get such authorization, they may get an inspection when they return to port. The FMC may also order them back to port. It is unlikely they will be allowed to leave port again without the VMS being repaired, so that they may need 24/7 VMS technical services at their home port.

Position reports received by the FMC should be forwarded automatically to the FMC of the vessel's registry. FMCs and other organizations, such as SAR and research, which receive VMS data must comply with confidentiality agreements. All recipients of data are also in accordance with agreements obliged to handle the data they receive in a responsible manner.

Catch documentation scheme

Catch reports are not themselves part of VMS, but often will be correlated with VMS data as part of an overall fisheries MCS program.

AIS, VTS and GMDSS

These safety and traffic management systems are not interoperable with VMS. VMS has privacy requirements they do not, and uses different technical standards. Nevertheless, a vessel required to have some or all of these capabilities may share some onboard equipment, such as computers, displays, or antennas. SAR and other safety agencies that can protect VMS data may combine data received by an FMC with their own information systems. Law enforcement organizations can combine VMS data with their own sensors and intelligence when a fishing violation is within their authority.

International programs

Given that fish exist in food chains, it is worth nothing that the United Nations is at the logical top of the VMS chain, under the authority of the United Nations Convention on Law of the Sea (UNCLOS). While it does not contain any provisions that are directly related to the use of VMS, it establishes a number of important principles of relevance for this study, relating to the conservation and management of living resources, both within national jurisdictions and on the high seas. UN fisheries operations are under the Food and Agricultural Organization.

Antarctic

Under the Commission for the Conservation of Antarctic Living Marine resources (CCAMLR), a number of member states monitor agreed-to conservation measures and research information. The major emphasis is on the *Dissostichus* sp. catch (i.e., Patagonian and Atlantic toothfish, Chilean sea bass) Realtime VMS is required for most exploratory VMS, with delayed reporting for other longline fisheries and for finfish trawling. The flag state VMS architecture is used, where the national FMCs of vessel registry, starting in 2005, transmit to the CCAMLR regional FMC.

Member states under the agreement are Argentina, Australia, Belgium, Brazil, Chile, European Community, France, Germany, India, Italy, Japan, Republic of Korea, Namibia, New Zealand, Norway, Poland, Russian Federation, South Africa, Spain, Sweden, Ukraine, United Kingdom of Great Britain and Northern Ireland, United States of America, and Uruguay. In addition, Bulgaria, Canada, Finland, Greece, Netherlands, Peru,and Vanuatu accede to the convention. In practice, up to 50 vessels are expected to be monitored, and about 15 of the convention states actually fish in the area. The longline vessels range from 349 to 2,203 long tons (355 to 2,238 t).

Depending on the latitude, satellite communications may require polar-orbiting satellites, or the vessel may be in line of sight of a geosynchronous satellite.

Europe

Under the European Union legislation, VMS is a legal requirement for vessels in excess of 15 metres. By 1999, Europe had 7000 vessels, in excess of 15 meters, under VMS. Since 2005, all Community vessels automatically transmit vessel identification, date, time, position, course and speed either hourly or every 2 hours (if the responsible Fisheries Monitoring Centre can request positions). The only exception is for vessels that operate only inside home waters, and are used exclusively for aquaculture.

One of the challenges for European MCS is that the idea of a 200-nautical-mile (370 km) EEZ is meaningless for nations with coasts in small seas such as the Mediterranean or

Baltic. In such circumstances, appropriate international agreements need to be developed to govern fishing beyond the territorial limit and thus on the high seas, but high seas that would have overlapping jurisdiction in an EEZ-based model.

There are precedents where maritime pollution already is handled on a basin basis, which might provide a framework for fisheries enforcement in international waters of a small sea:

- Mediterranean (Barcelona Convention)
- Baltic (Helsinki Convention)
- North Sea (Bonn Agreement)

A recent IMO regulation requires AIS transponders aboard vessels, which transmit identifier, name and position of vessels not limited to fishing. Another approach might involve either AIS, or the more finely grained VTS, agreements that use coastal radar to monitor ships in and beyond coastal waters. This allows a transport vessel, for example, to be tracked in the small sea.

Another cross-check could involve current EU RADARSAT ScanSAR imagery, correlated with transponder information, such that only radar images of ships without active transponders display to enforcement personnel. At present, however, inspectors on aircraft or surface patrol vessels may not have real-time access to satellite imagery. Currently, the fusion of VMS, radar (satellite, aircraft, or coastal) has to be done at an operations center ashore. Another complication is that enforcement organizations for such things as spill monitoring are not concerned with issues such as illegal fishing.

Northwest Atlantic

The Northwest Atlantic Fisheries Organization is composed of Canada, Cuba, Denmark (in respect of the Faroe Islands and Greenland), European Union, France (in respect of St Pierre et Miquelon), Iceland, Japan, Republic of Korea, Norway, Russian Federation, Ukraine, United States of America.

Under this agreement are all fisheries, principally trawl and longline, except crab, lobster, salmon, sedentary species, whale and tuna. Approximately 135 vessels are monitored, the majority of which are trawlers with a few longline, ranging from 500 to over 2000 gross weight tons (GWT).

The VMS software used is vTrack.

Northeast Atlantic

Under the Northeast Atlantic Fisheries Commission (NEAFC), Denmark (in respect of the Faroe Islands and Greenland), European Union, Iceland, Norway, Poland, Russian Federation.

This agreement covers all fisheries in the high seas of the regulated area, including trawlers, purse seiners, longliners, and gill netters. In 2004, 1473 vessels were monitored, with 800 authorized to fish for regulated species.

VMS is required for any vessel of 24 meters or longer overall length. NEAFC is a secondary user of data from flag state FMCs; the regional FMC connects to national Germany, Denmark, Spain, Estonia, France, Faroe Islands, United Kingdom, Greenland, Ireland, Iceland, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Russian Federation, Sweden, and, occasionally in the past, Japan and New Zealand. It also connects to the European Commission FMC.

Fisheries surveillance vessels will transmit, to the FMC, information on their operations with respect to VMS-equipped vessels, including:

- surveillance entry
- observations
- prepare for inspection
- surveillance exit

NEAFC participated as an observer in, a project funded by the EU to use satellite radar images to validate VMS information and to complement and optimise surveillance tasks. NEAFC decided, based on the results of the EU-funded IMPAST (Improving Fisheries Monitoring By Integrating Passive and Active Satellite Technologies), to deploy a Vessel Detection System (VDS) in several coastal states.

NEAFC is also participating in the EU-funded SHEEL (Secure and Harmonized European Electronic Logbook) and CEDER (Catch, Effort and Discard Estimate in Real-time) projects, which may lead to direct electronic reporting of real-time catch data.

Pacific Islands

The FFA has 16 country members and one territory member from the western and central Pacific region. It is based in Honiara, Solomon Islands. While the FFA proper was formed over 20 years ago, VMS operation began in late 1997, covering the EEZs of 16 South Pacific countries.

FFA VMS is expected to cover 2000+ vessels, transmitting via Inmarsat-C and reporting every 4 hours.

Southern Africa

Fisheries are a major component of the economies of the coastal member states of the SADC (Angola, Namibia, South Africa, Mozambique, Tanzania, Mauritius and Seychelles).

Due to limited resources, there is little VMS beyond experiments in Namibia and South Africa. There is a European Union funded project to improve monitoring.

West Africa

The Sub-Regional Fisheries Commission (SRFC) based at Dakar, Senegal is made up of west African States, namely Cape Verde, The Gambia, Guinea, Guinea-Bissau, Mauritania, Sierra Leone and Senegal. Its role is to promote fisheries cooperation between its member States.

The donor is the Grand Duchy of Luxembourg and the executing agency is the FAO and Lux-Development. Participating countries are These countries are members of the Sub-Regional Fisheries Commission (CRSP) with the addition of Sierra Leone. The project proposed is a continuation and extension of the AFR/101 Project (FAO), which may add VMS to supplement the present air surveillance.

National

This section deals with the specifics of national use of VMS, rather than their overall approach to fisheries management.

Albania

Albania is currently implementing a VMS for its 220 vessels fishing fleet, combining satellite and GPRS communications channels. The BlueTraker VMS solution, which is E-Logbook ready, is supplied EMA.

Argentina

The Commission for the Conservation of Antarctic Marine Living Resources demands the consensus of its 24 member countries for any proposals to be implemented. At its annual meeting in Hobart over the past two weeks, Argentina could not be persuaded to approve the adoption of a centralised system to monitor pirate ships.

The Parliamentary Secretary to the Minister for Environment, Sharman Stone, says Argentina was suspicious of the technology. "Argentina was concerned that we couldn't guarantee the confidentiality of any system, now the technical requirements of such a system were agreed that this wasn't beyond anyone's technical ability and capacity, but unfortunately Argentina remained concerned about the confidentiality of the data," she said.

However, the commission has agreed that Australia and the United States will head up a trial of the centralised vessel monitoring system over the coming season.

Australia

Australia has both national and state programs. The national-level program is run by the Australian Government agency, the Australian Fisheries Management Authority (AFMA). VMS runs on about 500 (growth expected to 800) vessels from small 10-meter scallop boats to 850-meter deep sea trawlers.

Fisheries of interest include orange roughy, scallops, prawns, tuna and billfish. Fishers must use AFMA-approved VMS devices.

Southern Australia

There is a regional organization of Southern Australian states which monitors rock lobster, giant crab, and, on a sampling basis, aquaculture.

Canada

Since 2001, Canada has mandated VMS, for vessels of certain sizes, to fish for specific species in designated areas. The underlying MCS strategies, while differing in specific fisheries, are based on limited entry licensing, with restrictions on vessel and gear types. Canada expects VMS reports every two hours.

Canadian activities involving VMS are joint between the Department of Fisheries & Oceans (DFO) and the Department of National Defense (DND). DND is the lead department for an inter-Departmental web-based mapping application, supported by positional information from DFO.

DND provides non-VMS surveillance data to a DND-operated data base available to DFO for fisheries management. Aerial surveillance, using a variety of sensors, monitors freighters, tankers, bulk carriers and container ships as well as fishing vessels.

Canada intends to provide, in real time, VMS data, correlated with other sensors and database information, to patrol vessels and aircraft. Electronic logs, two-way communication with fishing vessels, issuing orders, and possibly placing video and other sensors on fishing.

Chile

Chile has VMS aboard approximately 500 vessels, each vessel being associated with one fishery.

Marimsys built the Chilean VMS, but that system was be replaced in 2007 with a new one provided by CLS.

Chile went from a government-specified VMS to a type-approval system for VMS units in an open market, which drove down costs.

Monitored industrial fishing boats limit fishing activities to—generally—5 nautical miles (9 km) from the coast of Chile. This leaves the 5 nm zone for "artisanal" or smaller fishing boats and limits excessive fishing effort being applied to inshore waters.

Chile also pioneered in the emission of reports at short intervals. Prior systems had focussed on "where is the vessel" with the provision of hourly reporting. The Chilean system, by dropping the minimum report interval to 8 minutes is capable of determining "what" the vessel is doing. When you see a series of circular positions, they are all at speeds of below 2 knots (4 km/h) and reflect the drift of the current—there is no question, that vessel was purse seining, and the printout of the chart can be shown to the court to demonstrate the fact.

Chile is currently the world's largest producer of farmed salmon and has a burgeoning mussel culture industry that is supplying a growing world market. Other fisheries of interest include alfonsino, anchovies, cod, cuttlefish, hake, mackerel, ray, sardines, sea bream, squid, and swordfish.

The system is also used to monitor foreign vessels entering and leaving both the EEZ and Chilean ports.

China

China has national and provincial VMS programs, the most active being for Taiwan. It uses both Inmarsat-C and Argos to monitor up to 1200 vessels.

Croatia

Croatia has implemented its VMS on 256 vessels in 2007. The BlueTraker VMS solution, supplied by EMA, enables utilization of both satellite and GPRS communication channels.

Denmark

Denmark has a nation-wide VMS based on Inmarsat-C transceivers owned and maintained by the authorities. The VMS software is vTrack. The system monitors 600 vessels.

Ecuador

Ecuador uses VMS for tuna, under the Association of Tuna Fishing Companies of Ecuador (ATUNEC).

Estonia

Estonia has a nation-wide VMS based on Inmarsat-C hardware and vTrack software. The system monitors 50 vessels. The Estonian VMS system is operated by the Estonian Environmental Inspectorate.

Falklands Islands

The Falklands have a VMS program for approximately 30 vessels worldwide. There is a monitoring requirement for all vessels in the squid fishery.

Faeroe Islands

Faeroe Islands has a nation-wide VMS based on Inmarsat-C hardware and vTrack software. The system monitors 150 vessels.

France

Implementing its FMC at the CROSS sea rescue center at Etel, France uses the flag state principle described under Norway. The MAR-GE unit is a self-contained GPS and Argos device. France expects 2-hour reporting.

Germany

The German VMS is based on Inmarsat-C transceivers. The VMS software is vTrack. The system monitors 300 vessels.

Greenland

Greenland VMS is based on Argos/CLS and Inmarsat-C transceivers. The VMS software is vTrack. The system monitors 100 vessels.

Iceland

Iceland uses VMS for both safety and fisheries compliance, monitoring with Inmarsat-C or a coastal VHF repeater system. Approximately 1600 vessels of all sizes are monitored. Thales VMS has been approved.

India

India is introducing VMS for its EEZ, along with a system of permits to control capacity.

Indonesia

The Indonesian Ministry of Maritime Affairs and Fisheries selected Argos for their VMS. Indonesia's VMS system is the largest, or among the largest, in the world. 1500 fishing vessels initially with VMS, with three ashore FMCs. A distinctive feature of the Indonesian system is that an initial 15 patrol boats can directly receive VMS information.

Ireland

The Irish VMS system is operated by the Irish Naval Service, based in County Cork. As well as monitoring Irish vessels, the VMS exchanges data with VMS systems operated by other EU states.

Japan

A framework for groundfish fisheries in the Northwest Pacific's high seas was established in January 2007 in a consultation involving Japan, Russia, South Korea and the United States. VMS will be used to collect data.

Lithuania

Lithuania has a nation-wide VMS based on Inmarsat-C hardware and vTrack software. The system monitors 50 vessels.

Malaysia

Malaysia uses VMS on its Malaysian Maritime Enforcement Agency patrol boats and also on larger fishing vessels, through the Fisheries Department.

Malta

Malta monitors approximately 60 vessels.

Mexico

Under current Mexican law, it is illegal for commercial boats like longliners and drift gillnetters,to take fish reserved for sports fishing within fifty miles (93 km) of the coast in the Sea of Cortez, and any fish within 12 nautical miles (22 km) of the Revillagigedo Islands. VMS is seen as the only way Mexico will to enforce controls on areas in its EEZ.

Morocco

Morocco are currently implementing a VMS system combining satellite tracking and radar correlation, supplied primarily by BlueFinger Ltd.

Namibia

The fisheries in Namibia are among the largest in Africa, with some of the most sophisticated MCS systems.

VMS is fully operational and has been implemented across many fishing fleets. Following an EU funded MCS program for the SADC region, Namibia has facilities to integrate its VMS data with that of other SADC partners so that information can be shared regarding vessels that operate across the border in another SADC states waters. Similarly, Namibia can receive VMS information from its SADC partners when a vessel from another SADC state enters its waters.

The observer program has been effective. Nevertheless, it may be appropriate, initially for the orange roughy fishery.

Nauru

All foreign vessels licenced to fish or support fishing operations in Nauru waters are required to use an Automatic Location Communicator and be compatible and registered with the Regional Vessel Monitoring Systems at the Forum Fisheries Agency and the Western and Central Pacific Fisheries Commission. Nauru has VMS data-sharing agreements with several other FFA member countries. A list of vessels licenced to fish in Nauru fisheries waters can be found on the Nauru Fisheries and Marine Resources Authority website

Netherlands

The Netherlands has a nation-wide VMS based on Inmarsat-C hardware and vTrack software. The system monitors 500 vessels.

New Zealand

New Zealand has been running VMS since April 1994, with coverage out to the EEZ border under national and state agencies, with a target of 1000 vessels reporting every 2 hours. National & State Fisheries Agencies are responsible for the management of Fisheries located within its EEZ. Vessels use either Argos or Inmarsat-C to report position every 2 hours

Norway

Norway requires VMS aboard all of its fishing vessels longer than 24 meters. Norway has established such a centre at the Directorate of Fisheries in Bergen. Norway currently has mutual tracking agreements with the EU, Russia, Iceland, the Faeroe Islands and Greenland.

Panama

When Panama joined the International Commission for the Conservation of Atlantic Tunas (ICCAT) in 1998, in response to an ICCAT embargo on bluefin tuna, it committed to require licensing and equipping deep sea fishing vessels aith the Argo ELSA VMS.

Peru

Peru uses VMS to manage its anchovy fishery. For Peru fishing is a prime source of foreign exchange, second only to mining. Over 1000 fishing vessels are tracked in Peruvian waters by Argos. The Peruvian government implemented a national fishing Vessel Monitoring System (VMS) in 1998 to monitor and track all fishing vessels in its Exclusive Economic Zone. One of the first major VMS system's in the world, the system continues to operate today and is a reference for other countries wishing to implement similar fisheries management capabilities.

The country's anchovy fishing fleet, which seeks the Peruvian anchovy *Engraulis ringens*, is the world's largest single-species fishery, with an average of 8% of global landings.

For research, safety and monitoring purposes, vessels have the statutory obligation to use VMS, with industrial-scale fishing prohibited within 5 nautical miles (9 km) from the coast.

Poland

Poland has a nation-wide VMS based on Inmarsat-C hardware and vTrack software.

Russia

The Russian Federation has an integrated system called SSM, for fisheries resource monitoring and has implemented a sectoral system for monitoring of the aquatic living resources, and for surveillance and control over the activities of the fishing vessels (SSM). SSM includes VMS monitoring of vessel positions.

SSM headquarters is in Moscow, with regional monitoring centers in Murmansk and Petropavlovsk-Kamchatskiy. The national system covers approximately 3800 vessels. Bilateral agreements exist with Faroes, Greenland Iceland, Japan, and Norway. Russia participates in the NAFO, NEAFC, and CCALMR multinational agreements. It regards SSM as integral to safety of navigation and SOLAS. Russia has bilateral agreements with Japan. AMS builds a Russian VMS.

Kamchatka Region

This covers the Pacific Ocean and the eastern Arctic Sector.

Murmansk Region

The Murmansk region covers Russian vessels in the Atlantic Ocean, the Azov, Black and Caspian Sea regions, and the western Arctic Sector/

Slovenia

Slovenia has a nation-wide VMS based on Inmarsat-C hardware and vTrack software. The system monitors 7 vessels.

South Africa

Fisheries management, including limited VMS, is under the Marine and Coastal Management (MCM) organization in the Department of Environmental Affairs and Tourism. Hake *Merluccius spp.*) trawl fishery is the mainstay of South Africa's fishing industry, and the center of regulatory efforts. On-board observers had been the mainstay of monitoring, rather than VMS.

VMS is aboard many vessels with reporting to an FMC in Cape Town that is equipped with BlueFinger's VMS software. Additional VMS will go onto vessels into more distant waters, such as hake longliners. VMS is seen as a management, a research, and a safety tool. South Africa is exploring correlating its VMS with:

- RadarSat off Prince Edward Island, possibly in lieu of patrol vessels there,
- Airborne Synthetic Aperture Radar for quick-look surveillance and coverage out to the edge of the EEZ.
- Coastrad, a system of linked coastal radars for monitoring specific vessels, as verifying that foreign fishing vessels conducting innocent passage do that, rather than fish
- Patrol vessels to back up all other sensors.

South Korea

The Korean Squid Fishing Association has 102 fishing veesels which are to be equipped with an Argos satellite transmitter for their fishing campaigns in Russia.

Suriname

CLS/Argos is under the Ministry of Agriculture, Farming and Fisheries, and was initially deployed on over 80 vessels.

United Kingdom

The Marine Management Organisation (England & Wales), Marine Scotland (Scotland) and Department of Agriculture and Rural Development (Northern Ireland) jointly direct

VMS, currently using the BlueFinger VMS supporting mostly Thrane & Thrane compliant transponders supplied by Applied Satellite for:

1. Hake *Merluccius hubbsi* on the continental shelf of the Uruguayan-Argentine Common Fishing Zone in depth more than 50 meters
2. white croaker *Micropogonias furnieri* and sea trout *Cynoscion guatucupa*, fishing in the coastal zone less than 50 meters depth in the La Plata River and the Uruguayan-Argentine common fishing zone
3. Various vessels different from 1 and 2, that can fish in Uruguayan waters.
4. Various vessels that fish in international waters. At present these vessels are fishing in FAO statistical area 41, CCAMLR 88.1 and 48.3, and the Pacific Ocean.

Chapter 10

Blast Fishing

Dead fish and damaged coral as the result of blast fishing

Blast fishing or **dynamite fishing** is the practice of using explosives to stun or kill schools of fish for easy collection. This often illegal practice can be extremely destructive to the surrounding ecosystem, as the explosion often destroys the underlying habitat (such as coral reefs) that supports the fish. The frequently improvised nature of the explosives used also means danger for the fishermen as well, with accidents and injuries.

Although outlawed, the practice remains widespread in Southeast Asia, as well as in the Aegean Sea and coastal Africa. In the Philippines, where the practice has been well documented, blast fishing dates back to even before World War I, as this activity is mentioned by Ernst Jünger in his book *Storm of Steel*. One 1999 report estimated that some 70,000 fishermen (12% of the Philippines' total fishermen) engaged in the practice.

Extensive hard-to-patrol coastlines, the lure of lucrative, easy catches and in some cases outright apathy or corruption on the part of local officials make enforcement of blast fishing bans an ongoing challenge for authorities.

Commercial dynamite or, more commonly, homemade bombs constructed using a glass bottle with layers of powdered potassium nitrate and pebbles or an ammonium nitrate and kerosene mixture are often employed. Such devices, though, may explode prematurely without warning and have been known to injure or kill the person using them, or innocent bystanders.

Underwater shock waves produced by the explosion stun the fish and cause their swim bladders to rupture. This rupturing causes an abrupt loss of buoyancy; a small number of fish float to the surface, but most sink to the sea floor. The explosions indiscriminately kill large numbers of fish and other marine organisms in the vicinity and can damage or destroy the physical environment, including extensive damage to coral reefs.

Impact on coral reefs

Researchers believe that destructive fishing practices like blast fishing to be the biggest threat to the coral reef ecosystems. Blown up coral reefs are no more than rubble fields. The long-term impact associated with blast fishing is that there is no natural recovery of the reefs. Coral reefs are less likely to recover from constant disturbance such as blast fishing than from small disturbance that does not change the physical environment. Blast fishing destroys the calcium carbonate coral skeletons and is one of the continual disruptions of coral reefs. In the Indo-Pacific, the practice of blast fishing is a main cause of coral reef degradation. As a result, weakened rubble fields are formed and fish habitat is reduced.

The damaged coral reefs from blast fishing lead to instant declines in fish species wealth and quantity. Explosives used in blast fishing not only kill fish but also destroy coral skeletons, creating unbalanced coral rubble. The elimination of the fish also eliminates the resilience of the coral reefs to climate change, further hindering their recovery. Single blasts cause reefs to recover over 5–10 years, while widespread blasting, as often practiced, transforms these biodiverse ecosystems into continuous unstable rubble.

Strategies to control blast fishing

Community-based Enforcement

In Tanzania, one of the few methods to help manage blast fishing is a joint approach between fisheries officers and village committees. Working together, they help the enforcement agencies recognize offenders by patrolling the sea as well as providing information collected in the local villages. As a result, this has assisted the enforcement agencies to reduce the occurrence of fish blasting from an average of 8 per day to zero. It has also provided sustainable funding to continue the efficient patrols, a certified planning institution and suitable training and information to prosecutors and judges.

Similar patrols employed in Indonesia and Philippines have reduced the amount of blast fishing occurrences there. Based on dialogue with stakeholder groups in Southeast Asia and people of Tanzania and Philippines, it is evident that firmer enforcement is an effective strategy in managing blast fishing. Many countries have laws regarding blast fishing, but they are not fully implemented. Effective management of Marine Protected Areas (MPAs) is key in the patrolling of illegal fishing areas.

Blast Detection System

This method involves a triangulation system of hydrophones one meter apart that is capable of detecting blast events and at the same time eliminating other sources of underwater noise. The goal of the system is to improve and assist the effectiveness of fisheries patrol. Based on tests performed in Malaysia from 7 to 15 July 2002, a total of 13 blasts were recorded with a directional uncertainty of 0.2°. An electronic compass would limit the bearing uncertainty to 0.2° while correcting for the local magnetic effects of ferrous metals, therefore making sure the precision of the system is high.

Similar triangulation systems of hydrophones can potentially locate single blast events within 30 m at a range of 10 km. The detector system can be mounted on a patrol boat to help locate a probable range of blasts. Two or more patrol boats would permit accurate triangulation of blast events. Such a method is also beneficial enforcement agencies, as it offers stronger evidence to support convictions related to blast fishing.

Countries

Tanzania

In northern Tanzania, blast fishing, which is illegal, has re-emerged in recent years as a key danger to its coral reefs. This has occurred even though major institutions like local communities and the district government have been put in place for enhanced fisheries management. The damage of blast fishing in the area has contributed to unstable coral reefs, discouragement of tourism investors and a threat to the habitat of coelacanths in the region. Other impacts of blast fishing in the area include reports that citizens have died or lost limbs due to the blasting. The northern part of the country has many beautiful beaches and uninhabited islands. However, many investors feel and tourists are discouraged due to the fish blasting.

In Tanzania, coral reefs are essential for both ecological and socio-economic reasons. They are full of fish, lobsters, prawns, crabs, octopuses, mollusks and sea cucumbers. In addition, coral reefs are one of the major tourist attractions in Tanzania. The coastal tourism provides a living for the people as well as foreign currency for the country. However, there has been an increase in the people living along the coast which has led to a large demand for fisheries. It has led to overexploitation and destructive fishing practices. Blast fishing has been practised in Tanzania since the 1960s. It was during the 1980s and 1990s that blast fishing was at its peak in Tanzania. For example, in Mnazi bay, Mtwara, 441 blasts were recorded in two months in 1996 and 100 blasts were witnessed through one 6 hour period in Mpovi reef.

Indonesia

Blast fishing in Indonesia has been around for over 50 years. The use of bombs made with kerosene and fertilizer is very popular in the region. In the market in the city of Makassar, an estimated 10 to 40 percent of the fish are caught in this manner. The local fishermen find the technique to be easier and more productive than traditional methods. The goal for the country has been to implement stricter polices and fisheries management programs to limit the killing of the fish as well as the destruction to the marine ecosystem. Forty years ago, blast fishing was practiced with dynamite which was in plentiful supply after World War II. Today, fishermen mostly use homemade bombs that are made from bottles filled with an explosive mixture; weights are also added to make the bottle sink faster underwater. After the bomb explodes, the fish killed or stunned by the shock wave from the explosion are collected.

Chapter 11

Bottom Trawling

The *Celtic Explorer*, a research vessel engaged in bottom trawling

Bottom trawling is trawling (towing a **trawl**, which is a fishing net) along the sea floor. The scientific community divides bottom trawling into benthic trawling and demersal trawling. Benthic trawling is towing a net at the very bottom of the ocean and demersal trawling is towing a net just above the benthic zone.

Bottom trawling can be contrasted with midwater trawling (also known as pelagic trawling), where a net is towed higher in the water column. Midwater trawling catches pelagic fish such as anchovies, tuna and mackerel, whereas bottom trawling targets both bottom living fish (groundfish) and semi-pelagic species such as cod, squid, shrimp and rockfish.

Trawling is done by a trawler, which can be a small open boat with only 30 hp or a large factory trawler with 10,000 hp (7,500 kW). Bottom trawling can be carried out by one trawler or by two trawlers fishing cooperatively (pair trawling).

History

An early reference to fishery conservation measures comes from a complaint about a form of trawling dating from the 14th century, during the reign of Edward III. A petition was presented to Parliament in 1376 calling for the prohibition of a "subtlety contrived instrument called the *wondyrchoum*". This was an early beam trawl with a wooden beam and consisted of a net 6 m (18 ft) long and 3 m (10 ft) wide,

"of so small a mesh, no manner of fish, however small, entering within it can pass out and is compelled to remain therein and be taken...by means of which instrument the fishermen aforesaid take so great abundance of small fish aforesaid, that they know not what to do with them, but feed and fatten the pigs with them, to the great damage of the whole commons of the kingdom and the destruction of the fisheries in like places, for which they pray remedy."

Another source describes the wondyrchoun as

"three fathom long and ten mens' feet wide and that it had a beam ten feet long, at the end of which were two frames formed like a colerake, that a leaded rope weighted with a great many stones was fixed on the lower part of the net between the two frames and that another rope was fixed with nails on the upper part of the beam, so that the fish entering the space between the beam and the lower net were caught. The net had maskes of the length and breadth of two men's thumbs"

The response from the Crown was to "let Commission be made by qualified persons to inquire and certify on the truth of this allegation and thereon let right be done in the Court of Chancery". Thus, already back in the Middle Ages, basic arguments about three of the most sensitive current issues surrounding trawling - the effect of trawling on the wider environment, the use of small mesh size and of industrial fishing for animal feed - were already being raised.

Until the late 18th century sailing vessels were only capable of towing small trawls. However, in the closing years of that century a type of vessel emerged that was capable of towing a large trawl, in deeper waters. The development of this type of craft, the sailing trawler, is credited to the fishermen of Brixham in Devon. The new method proved to be far more efficient than traditional long-lining. At first its use was confined to the western half of the English Channel, but as the Brixham men extended their range to the North Sea and Irish Sea it became the norm there too.

By the end of the 19th century there were more than 3,000 sailing trawlers in commission in UK waters and the practice had spread to neighbouring European countries. Despite the availability of steam, trawling under sail continued to be economically efficient and sailing trawlers continued to be built until the middle of the 1920s. Some were still operating in UK waters until the outbreak of World War II and in Scandinaia and the Faroe Islands until the 1950s.

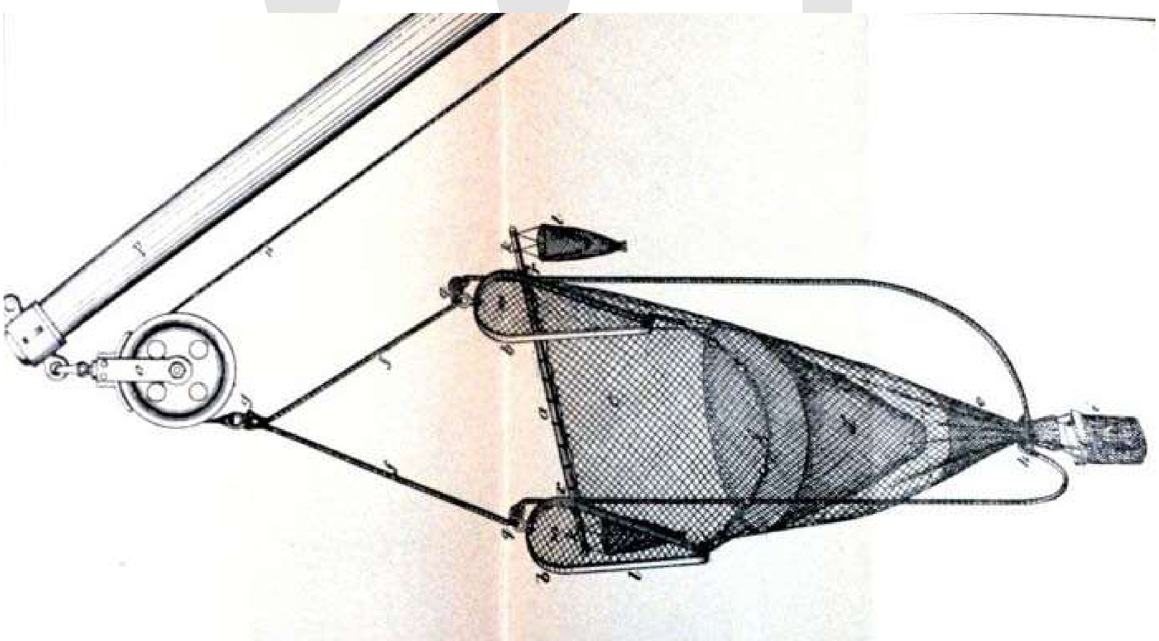
English commissions in the 19th century determined that there should be no limitation on trawling. They believed that bottom trawling, like tilling of land, actually increased production. As evidence, they noted that a second trawler would often follow a first trawler and that the second trawler would often harvest even more fish than the first. The reason for this peculiarity is that the destruction caused by the first trawl resulted in many dead and dying organisms, which temporarily attracted a large number of additional species to feed on this moribund mass.

Bottom trawling has been widely implicated in the population collapse of a variety of fish species, locally and worldwide, including orange roughy, barndoor skate, shark and many others.

Fishing gear

The design requirements of a bottom trawl are relatively simple, a mechanism for keeping the mouth of the net open in horizontal and vertical dimensions, a "body" of net which guides fish inwards and a "cod-end" of a suitable mesh size, where the fish are collected. The size and design of net used is determined by the species being targeted, the engine power and design of the fishing vessel and locally enforced regulations.

Beam trawling



Design of an early beam trawl

The simplest method of bottom trawling, the mouth of the net is held open by a solid metal beam, attached to two "shoes", which are solid metal plates, welded to the ends of the beam, which slide over and disturb the seabed. This method is mainly used on smaller vessels, fishing for flatfish or prawns, relatively close inshore.

Otter trawling

Otter trawling derives its name from the large rectangular **otter boards** which are used to keep the mouth of the trawl net open. Otter boards are made of timber or steel and are positioned in such a way that the hydrodynamic forces, acting on them when the net is towed along the seabed, pushes them outwards and prevents the mouth of the net from closing. They also act like a plough, digging up to 15 cm into the seabed, creating a turbid cloud and scaring fish towards the net mouth. The net is held open vertically on an otter trawl by floats and/or kites attached to the "headline" (the rope which runs along the upper mouth of the net) and weighted "bobbins" attached to the "foot rope" (the rope which runs along the lower mouth of the net). These bobbins vary in their design depending on the roughness of the sea bed which is being fished, varying from small rubber discs for very smooth, sandy ground, to large metal balls, up to 0.5 m in diameter for very rough ground. These bobbins can also be designed to lift the net off the seabed when they hit an obstacle. These are known as "rock-hopper" gears.

Bobbins (lower left) and floats (lower right - upper right) on a trawl net

Body of the trawl

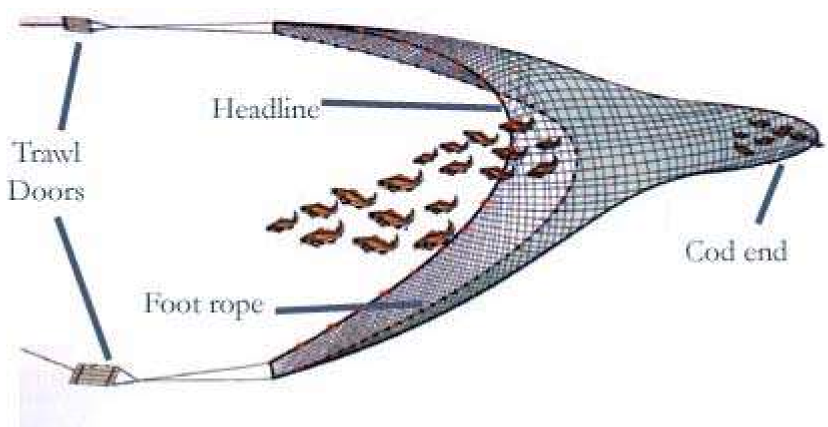
The body of the trawl is funnel-like, wide at its "mouth" and narrowing towards the cod end and usually is fitted with wings of netting at the both sides of the mouth. It is long enough to assure adequate flow of water and prevent fish from escaping the net, after having been caught. It is made of diamond-meshed netting, the size of the meshes decreasing from the front of the net towards the codend. Into the body, fish and turtle escape devices can be fitted. These can be simple structures like "square mesh panels", which are easier for smaller fish to pass through, or more complicated devices, such as bycatch grills.

Cod end

The cod end is the trailing end of the net where fish are finally "caught". The size of mesh in the cod end is a determinant of the size of fish which the net catches. Consequently, regulation of mesh size is a common way of managing mortality of juvenile fishes in trawl nets.

How trawls work

The idea that fish are passively "scooped up" is commonly held and has been since trawling was first developed, but has been revealed to be erroneous. Since the development of scuba diving equipment and cheap video cameras it has been possible to directly observe the processes that occur when a trawl is towed along the seabed.



Structure of a benthic otter trawl

The trawl doors disturb the sea bed, create a cloud of muddy water which hides the oncoming trawl net and generates a noise which attracts fish. The fish begin to swim in front of the net mouth, but do not seem to be distressed by it. As the trawl continues along the seabed, fish begin to tire and slip backwards into the net. Finally, the fish become exhausted and drop back, into the "cod end" and are caught. The speed that the trawl is towed at depends on the swimming speed of the species which is being targeted and the exact gear that is being used, but for most demersal species, a speed of around 4 knots (7 km/h) is appropriate.

Environmental impacts

Bottom fishing has operated for over a century on heavily fished grounds such as the North Sea and Grand Banks. Although overfishing has caused huge ecological changes to the fish community on the Grand Banks, concern has been raised recently about the damage which benthic trawling inflicts upon seabed communities. A species of particular concern is the slow growing, deep water coral *Lophelia pertusa*. This species is home to a diverse community of deep sea organisms, but is easily damaged by fishing gear. On

November 17, 2004 the United Nations General Assembly urged nations to consider temporary bans on high seas bottom trawling.

Satellite image of trawler mud trails off Louisiana coast

Resuspension

Bottom trawling stirs up the sediment at the bottom of the sea. The suspended solid plumes can drift with the current for tens of kilometres from the source of the trawling. These plumes introduce a turbidity which decreases light levels at the bottom and can affect kelp reproduction.

Ocean sediments are the sink for many persistent organic pollutants, usually lipophilic pollutants like DDT, PCB and PAH. Bottom trawling mixes these pollutants into the plankton ecology where they can move back up the food chain and into our food supply.

Phosphorus is often found in high concentration in soft shallow sediments. Resuspending nutrient solids like these can introduce oxygen demand into the water column and result in oxygen deficient dead zones.

Even in areas where the bottom sediments are ancient, bottom trawling, by reintroducing the sediment into the water column, can create harmful algae blooms. More suspended solids are introduced into the oceans from bottom trawling than any other man-made source.

Deep sea impacts

The UN Secretary General reported in 2006 that 95 percent of damage to seamount ecosystems worldwide is caused by deep sea bottom trawling.

Current restrictions

Today, some countries regulate bottom trawling within their jurisdictions:

• The United States National Oceanic and Atmospheric Administration banned bottom trawling off most of its Pacific coast in early 2006 and has restricted the practice severely off its other coasts as well. This Federal regulation affects areas between 3–300 miles from the coast (areas within 3 miles (4.8 km) of the coast are State regulated).

• The Council of the European Union in 2004 applied “a precautionary approach” and closed the sensitive Darwin Mounds off Scotland to bottom trawling.

• In 2005, the FAO’s General Fisheries Commission for the Mediterranean (GFCM) banned bottom trawling below 1000 metres and, in January 2006, completely closed ecologically sensitive areas off Italy, Cyprus and Egypt to all bottom trawling.

• Norway first recognized in 1999 that trawling had caused significant damage to its cold-water lophelia corals. Norway has since established a program to determine the location of cold-water corals within its EEZ so as to quickly close those areas to bottom trawling.

• Canada has acted to protect vulnerable coral reef ecosystems from bottom trawling off Nova Scotia. The Northeast Channel was protected by a fisheries closure in 2002 and the Gully area was protected by its designation as a Marine Protected Area (MPA) in 2004.

• Australia in 1999 established the Tasmanian Seamounts Marine Reserve to prohibit bottom trawling in the south Tasman Sea. Australia also prohibits bottom trawling in The Great Australian Bight Marine Park near Ceduna off South Australia. In 2004, Australia established the world’s largest marine protected area in the Great Barrier Reef Marine Park where fishing and other extractive activities are prohibited.

• New Zealand in 2001 closed 19 seamounts within its EEZ to bottom trawling, including in the Chatham Rise, sub-Antarctic waters and off the east and west coasts of the North

Island. New Zealand Fisheries Minister Jim Anderton announced on 14 February 2006 that a draft agreement had been reached with fishing companies to ban bottom trawling in 30 percent of New Zealand's exclusive economic zone, an area of about 1.2 million km² reaching from sub-Antarctic waters to sub-tropical ones. But only a small fraction of the area proposed for protection will cover areas actually vulnerable to bottom trawling.

• Palau has banned all bottom trawling within its jurisdiction and by any Palauan or Palauan corporation anywhere in the world.

• The President of Kiribati, Anote Tong, announced in early 2006 the formation of the world's first deep sea marine reserve area. This measure—the Phoenix Islands Protected Area—creates the world's third largest marine protected area and may protect deep sea corals, fish and seamounts from bottom trawling. However, the actual boundaries of this reserve and what harvest limitations may occur therein have not been detailed. Moreover, Kiribati currently has only 1 patrol boat to monitor this proposed region.

Lack of regulation

Beyond national jurisdictions, most bottom trawling is unregulated either because there is no Regional Fisheries Management Organization (RFMO) with competence to regulate, or else what RFMOs that do exist have not actually regulated. The major exception to this is in the Antarctic region, where the Convention for the Conservation of Antarctic Marine Living Resources regime has instituted extensive bottom trawling restrictions. The North East Atlantic Fisheries Commission (NEAFC) also recently closed four seamounts and part of the mid-Atlantic Ridge from all fishing, including bottom trawling, for three years. This still leaves most of international waters completely without bottom trawl regulation.

As of May 2007 the area managed under the South Pacific Regional Fisheries Management Organisation (SPRFMO) has gained a new level of protection. All countries fishing in the region (accounting for about 25 percent of the global ocean) agreed to exclude bottom trawling on high seas areas where vulnerable ecosystems are likely or known to occur until a specific impact assessment is undertaken and precautionary measures have been are implemented. Also observers will be required on all high seas bottom trawlers to ensure enforcement of the regulations.

Failed United Nations ban

Palau President Tommy Remengesau has called for a ban on destructive and unregulated bottom trawling beyond national jurisdictions and Palau has led the effort at the United Nations and in the Pacific to achieve a consensus by countries to take this action at an international level. Palau has been joined by the Federated States of Micronesia, the Republic of the Marshall Islands and Tuvalu in supporting an interim bottom trawling ban at the United Nations. The proposal for this ban did not result in any actual legislation and was blocked.

In 2006, New Zealand Fisheries Minister Jim Anderton promised to support a global ban on bottom trawling if there was sufficient support to make that a practical option. Bottom Trawling has been banned in 1/3 of New Zealand's waters (although a large percentage of these areas were not viable for bottom trawling in the first place)

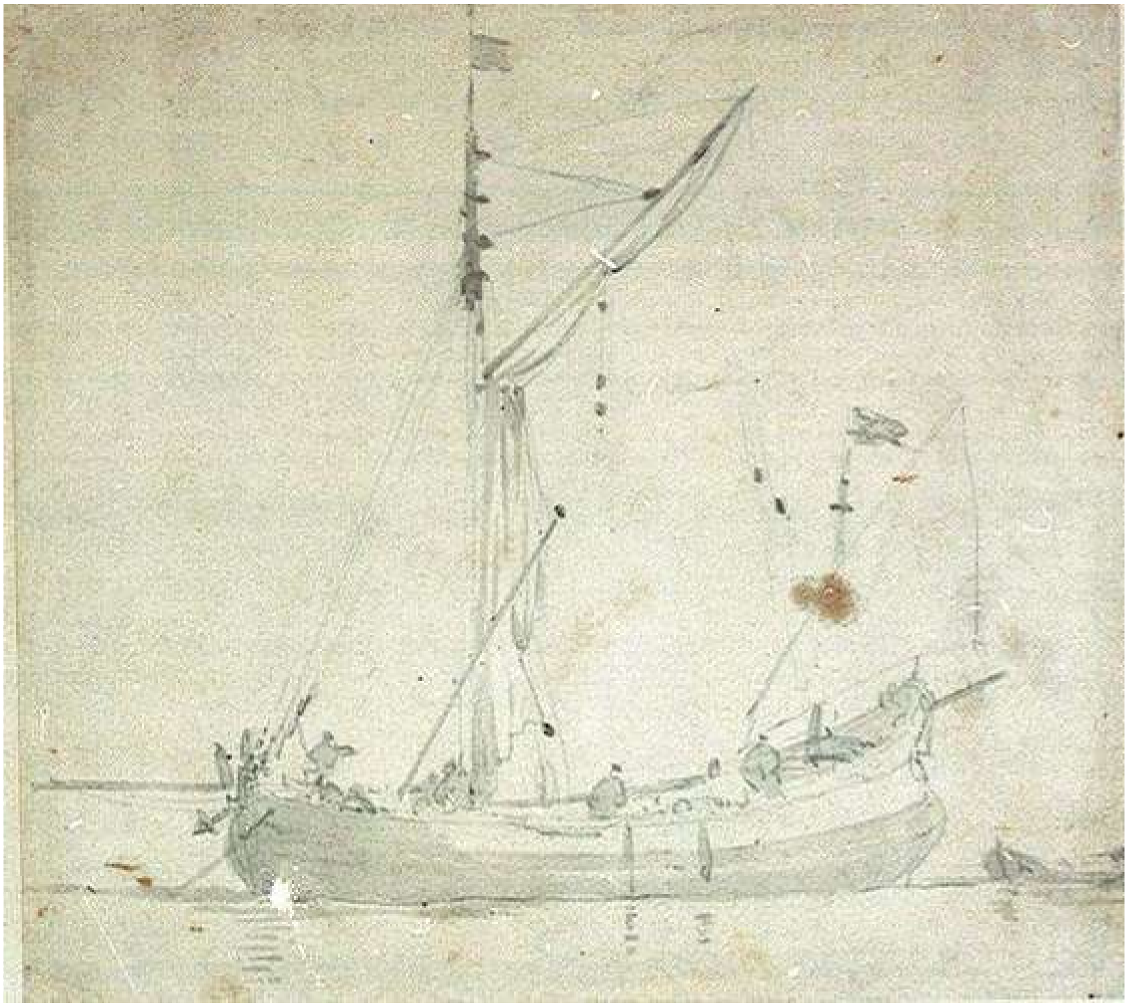
Fishing trawler

The Irish RSW tank trawler *Brendelen* in Skagen harbour

A **fishing trawler** is a commercial fishing vessel designed to operate fishing trawls. Trawling is a method of fishing that involves actively pulling a trawl through the water behind one or more trawlers. Trawls are fishing nets that are dragged along the bottom of the sea or in midwater at a specified depth. A trawler may also operate two or more trawl nets simultaneously (double-rig and multi-rig).

There are many variants of trawling gear. They vary according to local traditions, bottom conditions and how large and powerful the trawling boats are. A trawling boat can be a small open boat with only 30 hp or a large factory ship with 10,000 hp. Trawl variants include beam trawls, large-opening midwater trawls and large bottom trawls, such as "rock hoppers" that are rigged with heavy rubber wheels that let the net crawl over rocky bottom.

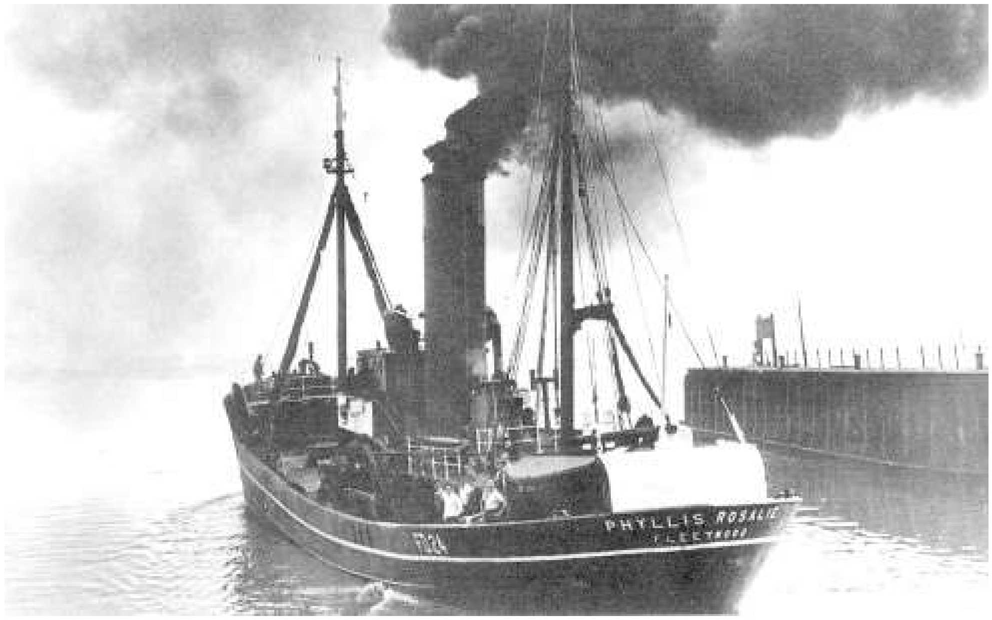
History



A Dogger, an early sailing trawler, c. 1675 by Willem van de Velde the Younger

During the 17th century, the British developed the Dogger, an early type of sailing trawler commonly operated in the North Sea. The Dogger takes its name from the Dutch word *dogger*, meaning a fishing vessel which tows a trawl. Dutch trawling boats were common in the North Sea and the word *dogger* was given to the area where they often fished, which became known as the Dogger Bank. Doggers were slow but sturdy, capable of fishing in the rough conditions of the North Sea.

In the Middle Ages, Brixham was a fishing port and at one time it was the greatest in England. Brixham is famous for being the town where the fishing trawler was improved in the 19th century. Known as the "Mother of Deep-Sea Fisheries", the design of her elegant wooden boats spread across the world, influencing fishing fleets everywhere. Their distinctive sails inspired the song Red Sails in the Sunset which was written aboard a Brixham sailing trawler called the *Torbay Lass*. In the 1890s there were about 300 trawling vessels there, each usually owned by the skipper of the boat. Several of these old sailing trawlers have been preserved.



English steam trawler, ST *Phyllis Rosalie*

Trawler designs adapted as the way they were powered changed from sail to coal-fired steam by World War I to diesel and turbines by the end of World War II. During World War I and World War II, many fishing trawlers were commissioned as naval trawlers to be used as minesweepers, the activities being similar, with the crew and layout already suited to the task. Since World War II, commercial fishing vessels have been increasingly equipped with electronic aids, such as radio navigation aids and fish finders. During the Cold War, some countries fitted fishing trawlers with additional electronic gear so they could be used as spy ships to monitor the activities of other countries.

The town of Grimsby on Lincolnshire's east coast once laid claim to the title of the 'largest fishing port in the world', Its fleet of over 700 trawlers and the rail links from the town to London's Billingsgate Fish Market allowed Grimsby fish to be renowned nationwide. Today Grimsby's fish docks are virtually deserted, though the towns port is still a hive of activity for cargo vessels. The glory days of fishing in the town are remembered at the town's Fishing Heritage Centre (previously the National Fishing Heritage Centre) where the preserved trawler Ross Tiger provides a unique glimpse into the lost lives of the 1950's trawlerman.

The largest fishing port in Europe from the 1970s onwards has been Peterhead in the North-East corner of Scotland. In its prime in the 1980s Peterhead had over 500 trawlers staying at sea for a week each trip. Peterhead has seen a significant decline in the number of vessels and the value of fish landed has been reduced due to several decades of overfishing which in turn has reduced fishing quotas.

Modern trawlers

Modern trawlers are usually decked vessels. Their superstructure (wheelhouse and accommodation) can be forward, midship or aft. Motorised winches, electronic navigation and sonar systems are usually installed. Fishing equipment varies in sophistication depending on the size of the vessel and the technology used. Design features for modern fishing trawlers vary substantially, as many national maritime jurisdictions do not impose compulsory vessel inspection standards for smaller commercial fishing vessels.

Mechanised hauling

Mechanised hauling devices are used on modern trawlers. Trawl winches, such as Gilson winches, net drums and other auxiliary winches are installed on deck to control the towing warps (trawling wires) and store them when not in use.

Electronics

Depth sounder on the bridge of this (rather dated) trawler

Modern trawlers make extensive use of contemporary electronics, including navigation and communication equipment, fish detection devices and equipment to control and monitor gear. Just which equipment will be installed depends on the size and type of the trawler.

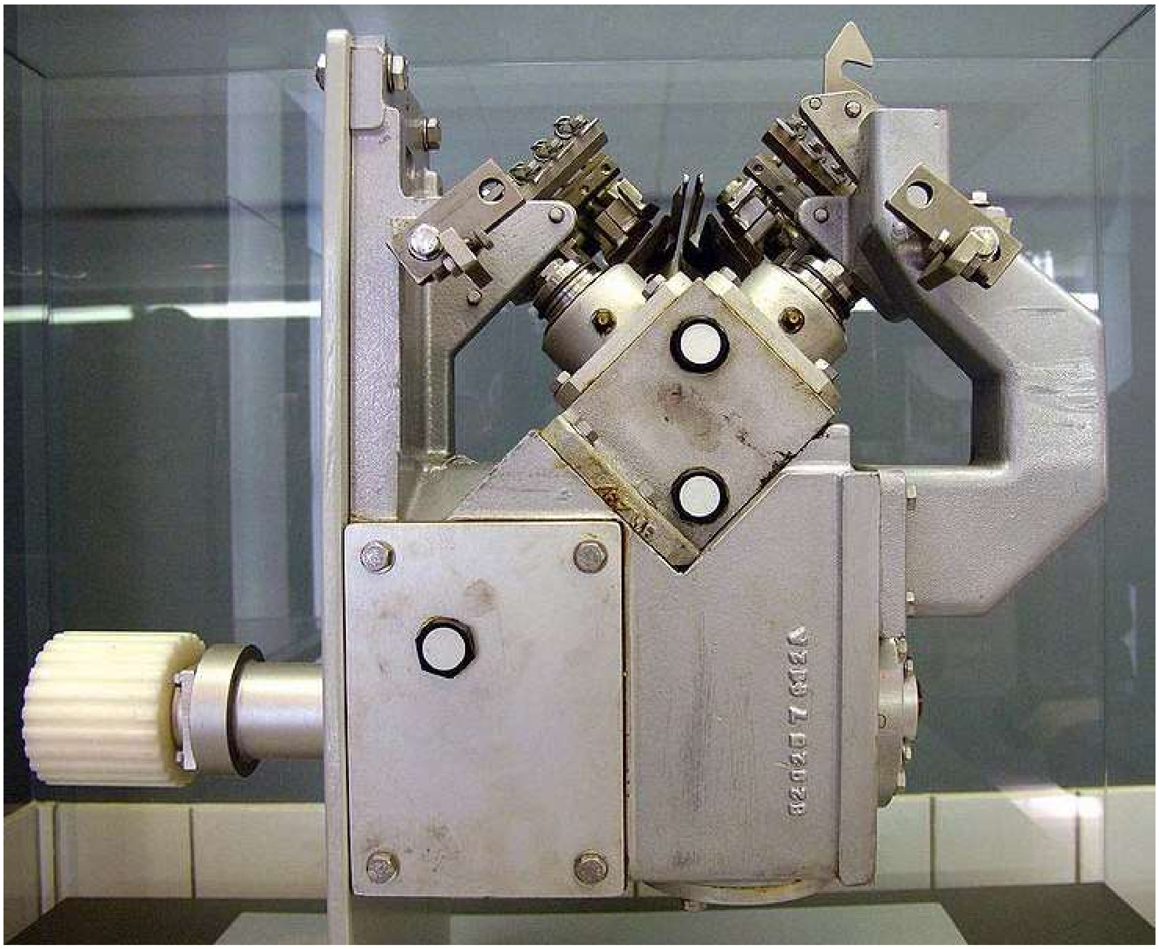
Much of this equipment can be controlled from the wheelhouse or bridge. Smaller trawlers have wheelhouses, where electronic equipment for navigation, communications, fish detection and trawl sensors are typically arranged about the skipper's chair. Larger vessels have a bridge, with a command console at the centre and an further co-pilot chair. Modern consoles display all the key information on an integrated display. Less frequently used sensors and monitors may be mounted on the deckhead.

Navigational instruments, such as an autopilot and GPS, are used for manoeuvering the vessel in harbour and at sea. Radar can be used, for example, when pair trawling to keep the correct distance between the two vessels. Communication instruments range from basic radio devices to maritime distress systems and EPIRBs, as well as devices for communicating with the crew. Fish detection devices, such as echosounders and sonar, are used to locate fish.

A net mensurations system using acoustic sensors which measure the depth and opening of the trawl net

During trawling operations, a range of trawl sensors may be used to assist with controlling and monitoring gear.

- net sounders (trawl eyes) give information about the concentration of fish around the opening to the trawl, as well as the clearances around the opening and the bottom of the trawl
- catch sensors give information about the rate at which the cod end is filling.
- symmetry sensors give information about the optimal geometry of the trawls.
- tension sensors give information about how much tension is in the warps and sweeps.



Automatic knives for filleting fish

Fish storage and processing

Modern trawlers store the fish they catch in some form of chilled condition. At the least, the fish will be stored in boxes covered with ice or stored with ice in the fish hold. In general, the fish are kept fresh by chilling them with ice or refrigerated sea water, or freezing them in blocks. Also, many trawlers carry out some measure of onboard fish processing and the larger the vessel, the more likely it is to include fish processing facilities. For example, the catch can undergo some preliminary processing by being passed through sorting and washing devices. At a further stage, the fish might be mechanically gutted and filleted. Factory trawlers may process fish oil and fish meal and may include canning plants.

Other design features

Crew quarters are usually below the wheelhouse and may include bunks, with cot sides to stop the occupant from rolling out in heavy weather. The need for drying sea clothes is shown by a notice in at least one steam trawler's boiler room saying "*Do not dry oil frocks over the boiler*".

Trawler types

Trawlers can be classified by their architecture, the type of fish they catch, the fishing method used, or geographical origin. The classification used below follows the FAO, who classify trawlers by the gear they use.

Outrigger trawlers

Outrigger trawlers use outriggers, or booms, to tow the trawl. These outriggers are usually fastened to, or at the foot of the mast and extend out over the sides of the vessel during fishing operations. Each side can deploy a twin trawl or a single otter trawl. Outrigger trawlers may have the superstructure forward or aft. Warp winches with capstans are installed on the deck to haul the catch.

This small shrimp trawler uses outriggers, with a forward deckhouse and aft working deck.

- Outrigger trawlers with a forward superstructure and aft working deck are widely used to target shrimp. The towing winch is usually located to the rear of the superstructure so warps from the drums feed to bollards on the cap rail and then to towing blocks on the outriggers.

- Outrigger trawlers with aft superstructure and midship working deck are usually beam trawlers (see below). These use large beams to rig the trawls.

Outrigger trawlers use vertical fish finders of different kinds, according to their size. Drawing (FAO)

Beam trawlers

Beam trawlers are a type of outrigger trawler (above), with the superstructure aft and the working deck amidships. They use a very strong outrigger boom on each side, each towing a beam trawl, with the warps going through blocks at the end of the boom. This arrangement makes it easier to stow and handle the large beams. The outriggers are controlled from a midship A-frame or mast. The towing winch is forward of the superstructure, with the towing warps passed through deck bollards and then out to the towing blocks on the booms.

Beam trawling is used in the flatfish fisheries in the North Sea. They are equipped with equipment for hauling the net and stowing it aboard. Typically an echosounder and sonar is used for finding fish.

They are medium sized and high powered vessels, towing gear at speeds up to 8 knots. To avoid the boat capsizing if the trawl snags on the sea floor, winch brakes can be installed, along with safety release systems in the boom stays. The engine power of bottom trawlers is restricted to 2000 HP (1472 KW) for further safety.

Otter trawlers

Otter trawlers deploy one or more parallel trawls kept apart horizontally using otter boards. These trawls can be towed in midwater or along the bottom. Otter trawlers range in size from sailing canoes to supertrawlers.

Otter trawlers usually have two gallows at the stern with towing blocks. The towing warps run through these, each regulated by its own winch. Medium and large trawlers usually have a stern ramp for hauling the trawl onto the deck. Some trawlers tow twin parallel trawls, using three warps, each warp with its own winch. Some otter trawlers are also outrigger trawlers (above), using outriggers to tow one or two otter trawls from each side.

Usually otter trawlers have the superstructure forward, though it can be aft or amidship. Gallows are on the stern quarters or there is a stern gantry for operating the otter boards. Pelagic trawlers can use fish pumps to empty the cod end.

Pair trawlers

Pair trawlers are trawlers which operate together towing a single trawl. They keep the trawl open horizontally by keeping their distance when towing. Otter boards are not used. Pair trawlers operate both midwater and bottom trawls.

The superstructure is forward or midships and the working deck aft. Pelagic trawlers can have fish pumps to empty the codend.

Side trawlers

Side trawlers have the trawl deployed over the side with the trawl warps passing through blocks suspended from a forward gallow and another aft gallow. Usually the superstructure is towards the stern, the fish hold amidships and the transversal trawl winch forward of the superstructure. A derrick may be a boom rigged to the foremast to help shoot the codend from the side. Until the late sixties, side trawlers were the most common deep sea boat used in North Atlantic fisheries. The 1950's side trawler, *Ross Tiger* is preserved in Grimsby. These trawlers were used for a longer period than other kinds of trawlers, but are now being replaced by stern trawlers. Some side trawlers still in use have been equipped with net drums. Drawing (FAO)

Stern trawlers

An Icelandic stern trawler

RV *Celtic Explorer*, a bottom trawler used for research

Stern trawlers have trawls which are deployed and retrieved from the stern. Larger stern trawlers often have a ramp, though pelagic and small stern trawlers are often designed without a ramp. Stern trawlers are designed to operate in most weather conditions. They can work alone when midwater or bottom trawling, or two can work together as pair trawlers. The superstructure is forward with an aft working deck. At the stern are gallows or a gantry for operating otter boards.

Any fish processing usually occurs in deck houses or below deck. A wet fish stern trawler stores the fish in ice or sea water which has been refrigerated. A freezer stern trawler stores the fish in frozen boxes or blocks and a factory stern trawler processes the catch. A pelagic stern trawler may use fish pumps to empty the codend.

Freezer trawlers

The majority of trawlers operating on the high seas are freezer trawlers. They have facilities for preserving fish by freezing. They are medium to large size trawlers, with the same general arrangement as stern or side trawlers. Drawing (FAO)

Wet fish trawlers

Wet fish trawlers are trawlers where the fish is kept in the hold in a fresh/wet condition, in boxes covered with ice or with ice in the fish hold. They must operate in areas close to their landing place and the time such a vessel can spend fishing is limited. Drawing (FAO)

Trawler/purse seiners

Trawler/purse seiners are designed so the deck equipment, including an appropriate combination winch, can be rearranged and used for both methods. Blocks, purse davits, trawl gallows and rollers need to be arranged so they control the pursing lines and warp leads and in such a way as to reduce the time required to convert from one arrangement to the other. These vessels are usually classified as trawlers, since the power requirement for trawling is higher.

Naval trawlers

During both World Wars some countries created small warships by converting and arming existing trawlers or building new vessels to standard trawler designs. They were typically armed with a small naval gun and sometimes depth charges and were used for patrolling, escorting other vessels and minesweeping.

Images

Images on board 1950's trawler *Ross Tiger* (before her 2010 renovations), now in National Fishing Heritage Centre museum, Grimsby. It is about 126 feet long.

On deck

On deck again

Bridge of trawler

Trawler galley, with clamps to stop cooking pots from falling off in rough weather

Chapter 12

Bycatch

Shrimp bycatch

The term **bycatch** is usually used for fish caught unintentionally in a fishery while intending to catch other fish. It may however also indicate untargeted catch in other forms of animal harvesting or collecting. Bycatch are either of a different species, sublegal, or juveniles of the target species.

The OECD (1997) defines bycatch as "total fishing mortality excluding that accounted directly by the retained catch of target species". bycatch is contributory to fishery decline and is a mechanism of overfishing for unintentional catch.

There are at least four different ways the word *bycatch* is used in fisheries:

- Catch which is retained and sold but which is not the target species for the fishery
- Species/sizes/sexes of fish which fishermen discard
- Non-target fish whether retained and sold or discarded
- Unwanted invertebrate species such as echinoderms and non-commercial crustaceans

Examples

Shrimp trawling

Double-rigged shrimp trawler hauling in the nets

Shrimp bycatch

The highest rates of incidental catch of non-target species are associated with shrimp trawling. In 1997, the FAO documented the estimated bycatch and discard levels from shrimp fisheries around the world. They found discard rates (bycatch to catch ratios) as high as 20:1 with a world average of 5.7:1.

Shrimp trawl fisheries catch two percent of the world total catch of all fish by weight, but produce over one third of the world total bycatch. US shrimp trawlers produce bycatch ratios between 3:1 and 15:1.

Trawl nets in general and shrimp trawls in particular, have been identified as sources of mortality for cetacean and finfish species. When bycatch is discarded (returned to the sea) it is often dead or dying.

Recent sampling in the South Atlantic rock shrimp fishery found 166 species of finfish, 37 crustacean species and 29 other species of invertebrate among the bycatch in the trawls. Another sampling of the same fishery over a two year period found that rock shrimp amounted to only 10% of total catch weight. Iridescent swimming crab, dusky flounder, inshore lizardfish, spot, brown shrimp, longspine swimming crabs and other bycatch made up the rest.

Despite the use of bycatch reduction devices, the shrimp fishery in the Gulf of Mexico removes about 25-45 million red snapper annually as bycatch, nearly one half the amount taken in directed recreational and commercial snapper fisheries.

Cetacean

Group of Fraser's dolphins

Cetaceans, such as dolphins, porpoises and whales, can be seriously affected by entanglement in fishing nets and lines, or direct capture by hooks or in trawl nets. Cetacean bycatch is increasing in intensity and frequency. In some fisheries, cetaceans are captured as bycatch but then retained because of their value as food or bait. In this fashion, cetaceans can become a target of fisheries.

A Dall's Porpoise caught in a fishing net

One example of bycatch is dolphins caught in tuna nets. As dolphins are mammals and do not have gills they may drown while stuck in nets underwater. This bycatch issue has been one of the reasons of the growing ecolabelling industry, where fish producers mark their packagings with something like "Dolphin Friendly" to reassure buyers. However, "dolphin friendly" does not mean that dolphins were not killed in the production of a particular tin of tuna, but that the fleet which caught the tuna did not *specifically* target a feeding pod of dolphins, but relied on other methods to spot tuna schools.

Albatross

This Black-browed Albatross has been hooked on a long-line

Of the 21 albatross species recognised by IUCN on their Red List, 19 are threatened and the other two are *near threatened*. Two species are considered critically endangered: the Amsterdam Albatross and the Chatham Albatross. One of the main threats is commercial long-line fishing, because the albatrosses and other seabirds which readily feed on offal are attracted to the set bait, become hooked on the lines and drown. An estimated 100,000 albatross per year are killed in this fashion. Unregulated pirate fisheries exacerbate the problem.

Sea turtles

Loggerhead Sea Turtle

Sea turtles, already critically endangered, have been killed in large numbers in shrimp trawl nets. Estimates indicate that thousands of Kemp's Ridley, loggerhead, green and leatherback sea turtles are caught in shrimp trawl fisheries in the Gulf of Mexico and the US Atlantic annually

Sea turtles can sometimes escape from the trawls. In the Gulf of Mexico, the Kemp’s Ridley turtles recorded most interactions, followed in order by loggerhead, green and leatherback sea turtles. In the US Atlantic, the interactions were greatest for loggerheads, followed in order by Kemp’s Ridley, leatherback and green sea turtles.

Mitigation

A turtle excluder device

Concern about bycatch led fishermen and scientists to find ways of reducing unwanted catch. There are two main approaches.

One approach is to ban fishing in areas where bycatch is unacceptably high. Such area closures can be permanent, seasonal, or for a specific period when a bycatch problem is registered. Temporary area closures are common in some bottom-trawl fisheries where under-sized fish or non-target species are caught unpredictably. In some cases fishermen are required to relocate when a bycatch problem occurs.

The other approach is alternative fishing gear. A technically simple solution is to use nets with a larger mesh size, allowing smaller species and smaller individuals to escape. However, this usually requires replacing the existing gear. In other cases, it is possible to modify gear. The "bycatch reduction device" (BRD) and the Nordmore grate are net modifications that help fish escape from shrimp nets.

BRDs allow many commercial finfish species to escape. The US government has approved BRDs that reduce finfish bycatch by 30%. Spanish mackerel and weakfish bycatch in the South Atlantic was reduced by 40%. However, recent surveys suggest BRDs may be less effective than previously thought. A rock shrimp fishery off Florida found the devices did not exclude 166 species of fish, 37 crustacean species and 29 species of other invertebrates.

In 1978, the National Marine Fisheries Service (NMFS) started to develop turtle excluder devices (TEDs). A TED uses a grid which deflects turtles and other big animals, so they exit from the trawl net through an opening above the grid. US shrimp trawlers and foreign fleets which market shrimp in the US are required to use TEDs. Not all nations enforce the use of TEDs.

For the most part, when they are used, TEDs have been successful reducing sea turtle bycatch. However, they are not completely effective and some turtles are still captured.

NMFS certifies TED designs if they are 97% effective. In heavily trawled areas, the same sea turtle may pass repeatedly through TEDs. Recent studies indicate recapture rates of twenty percent or more, but it is not clear how many turtles survive the escape process.

The size selectivity of trawl nets is controlled by the size of the net openings, especially in the "cod end". The larger the openings, the more easily small fish can escape. The development and testing of modifications to fishing gear to improve selectivity and decrease impact is called "conservation engineering."

Seabirds with longline fishing vessel

Longline fishing is controversial in some areas because of by-catch. Mitigation methods have been successfully implemented in some fisheries. These include:

- weights to sink the lines quickly
- streamer lines to scare birds away from baited hooks while deploying the lines
- setting lines only at night with minimal ship lighting (to avoid attracting birds)
- limiting fishing seasons to the southern winter (when most seabirds are not feeding young)
- and not discharging offal while setting lines.

However, gear modifications do not eliminate by-catch of many species. In March 2006, the Hawaiʻi longline swordfish fishing season was closed due to excessive loggerhead sea turtle by-catch after being open only a few months, despite using modified circle hooks.

Alternative to release

Some fisheries retain bycatch, rather than throwing the fish back into the ocean. Bycatch can be converted into fish hydrolysate for use as a soil amendment in organic agriculture. However, if bycatch is quickly released, predators and scavengers may consume its biomass.

Non-fisheries bycatch

The term "bycatch" is used also in contexts other than fisheries. Examples are insect collecting with pitfall traps or Flight Interception Traps for either financial, controlling or scientific purposes (where the bycatch may either be small vertebrates or untargeted insects) and control of introduced vertebrates which have become pest species like the muskrat in Europe (where the bycatch in traps may be e.g. European mink or waterfowl).

Chapter 13

Cetacean Bycatch

Group of Fraser's dolphins

Cetacean bycatch is the incidental capture of non-target cetacean species by fisheries. Species which are seriously affected by this include dolphins, porpoises and whales. Bycatch can be caused by entanglement in fishing nets and lines, or direct capture by hooks or in trawl nets.

Cetacean bycatch is increasing in intensity and frequency. This is a trend that is likely to continue because of increasing human population growth and demand for marine food sources, as well as industrialization of fisheries which are expanding into new areas. These fisheries come into direct and indirect contact with cetaceans. An example of direct contact is the physical contact of cetaceans with fishing nets. Indirect contact is through marine trophic pathways where fisheries are severely reducing fish stocks that cetaceans rely on for food. In some fisheries, cetaceans are captured as bycatch but then retained because of their value as food or bait. In this fashion, cetaceans can become a target of fisheries.

Bycatch trends

A Dall's Porpoise caught in a fishing net

Generally cetacean bycatch is on the increase. Most of the world's cetacean bycatch occurs in gillnet fisheries. The mean annual bycatch in the U.S. alone from 1990–1999 was 6,215 marine mammals, with dolphins and porpoises being the primary cetaceans caught in gillnets. A study by Read et al. estimated global bycatch through observation of U.S. fisheries and came to the conclusion that an annual estimate of 653,365 marine mammals, comprising 307,753 cetaceans and 345,611 pinnipeds were caught from 1990–1994.

While gillnets are a principal concern, other types of nets also pose a problem: trawl nets, purse seines, beach seines, longline gear and driftnets. Driftnets are known for high rates of bycatch and they affect all cetaceans and other marine species. They are fatal for small toothed whales (*Odontocetes*) and sperm whales, as well as other marine mammals and fish such as sharks, sea birds and sea turtles. Many fisheries routinely use driftnets exceeding the EU size limit of 2.5 km/boat. This illegal drift-netting is a major issue, especially in important feeding and breeding grounds for cetaceans.

However, the tuna industry has achieved successes in reversing cetacean bycatch trends. International recognition of the problem of cetacean bycatch in tuna fishing led to the Agreement on the International Dolphin Conservation Program in 1999 and overall there has been a dramatic reduction in death rates. In particular, dolphin bycatch in tuna fishing in the East Tropical Pacific has dropped from 500,000 per year in 1970 to 100,000 per year in 1990 to 3,000 per year in 1999 to 1,000 per year in 2006.

Cetaceans at risk

Bycatch is recognized as a primary threat to all cetaceans. The following cetaceans are at high risk for entanglement in gillnets:

Atlantic humpback dolphins

The Atlantic humpback dolphin (*Sousa teuszii*) is endemic to West Africa. Several stocks have been identified with numbers ranging from tens to a few hundred. Abundance estimates are lacking. Gaps in the species range and hence distribution is evident. Bycatch is only documented in a few West African countries. Surveys and evaluations need to be conducted to determine the presence/ absence of humpback dolphins in their historical range. Conservation measures need to be implemented to save this species. Because many people live off the sea, it is not feasible to have complete gillnet closures. Some areas may be designated as off-limits to gillnet fisheries. Eco-tourism may be implemented successfully because of high species diversity.

Baleen whales

North Atlantic Right Whale mother and calf

Baleen whales, *Mysticeti*, are often taken in gill-nets and in fisheries that use vertical lines to mark traps and pots. Large cetaceans such as humpback and right whales may carry off gear after entanglement. This explains the large scars borne by whales along the U.S. Atlantic coast. Analyses show that 50-70% of Gulf of Maine humpback whales, *Megaptera novaeangliae* and North Atlantic Right Whale, *Eubalaena glacialis*, have been entangled at least once in their lifetime. The north Atlantic right whale is one of the most endangered large cetaceans and only 300-350 individuals remain. Minke Whales, *Balaenoptera acutorostrata*, are also at risk.

Burmeister’s porpoises

The Burmeister's porpoise (*Phocoena spinipinnis*) is one of three cetaceans that are most often bycaught in Peru and Chile. Several thousand porpoises are caught each year in Peru alone. Bycatch is a frequent occurrence for this species because of the inability to detect them in the water. Surveys have shown that bycatch remains a concern in that area today and it is unknown whether or not the population is declining. Data, conservation measures and awareness are lacking. These porpoises are cryptic making surveying a challenge. It is also difficult to estimate bycatch because the sale of porpoise meat is no longer available at markets.

Commerson’s dolphins

A Commerson's Dolphin in an aquarium

The expanding trawl fisheries devastated the Commerson's dolphin (*Cephalorhynchus commersonii*) populations in Patagonia. Trawl fisheries greatly expanded for twenty years until they crashed in 1997. Pelagic squid fisheries took over which use pelagic trawls that are harmful to dusky, short-beaked common dolphins and Commerson’s dolphins. There are approximately 21,000 Commerson’s dolphins remaining today. Two stocks have been identified in the population but genetic information and bycatch levels are unknown. With anchovy fisheries expanding, it is imperative to assess the Commerson’s dolphin population before these fisheries grow. The seasonal operation of in-shore gillnet fisheries are known to involve bycatch of cetaceans. Presently, there are no known estimates of gillnet bycatch. The bycatch problem in Argentina is political in nature. Improvements in fishing technology, awareness and a large scale survey of Commerson’s dolphin populations and the impact of bycatch is essential.

La Plata dolphins

The La Plata or Franciscana dolphin (*Pontoporia blainvillei*) is the most threatened small cetacean in the southwest Atlantic Ocean due to bycatch. They are only found in the coastal waters of Argentina, Brazil and Uruguay. This species has been divided into four ranges (FMU's: Franciscana Management Units) for management and conservation purposes. These populations are genetically different. Mortality rates are 1.6% for FMU 4 and 3.3% for FMU 3 but it is unknown whether these estimates are accurate. Aerial surveys have proven inconclusive so far as to the population numbers of franciscanas. To rectify this situation, more surveys are needed as well as political commitment, awareness campaigns and bycatch mitigation techniques.

Harbour porpoises

There is substantial incidental catches in fishing operations. Often, the Harbour Porpoise (*Phocoena phocoena*) is killed by incidental by-catch (10, 11, 12). Gillnets pose a serious threat to the harbour porpoise as they are extremely susceptible to entanglement. A study by Caswell et al. in the western North Atlantic combined the mean annual rate of increase of the harbour porpoise with the uncertainty of incidental mortality and population size. It was found that the incidental mortality exceeds critical values and therefore by-catch is a significant threat to the harbour porpoise. Harbour porpoises become entangled in nets due to their inability to detect the nets before collision. In 2001, 80 harbour porpoises were killed in salmon gillnet fisheries in British Columbia, Canada.

Hector's and Maui's dolphins

Hector's dolphins have a unique rounded dorsal fin

In New Zealand, these dolphins have a high rate of entanglement. Hector's dolphin (*Cephalorhynchus hectori*) is endemic to the coastal waters New Zealand and there are about 7,400 in abundance. A small population of Hector's dolphins is isolated on the west coast of the island and have been declared a subspecies called Maui's Dolphin. Maui's dolphins (*Cephalofhynchus hectori maui*) are often caught in set nets and pair trawlers resulting in less than 100 left in the wild. For protection, a section of the dolphin's range on the west coast has been closed to gillnet fisheries.

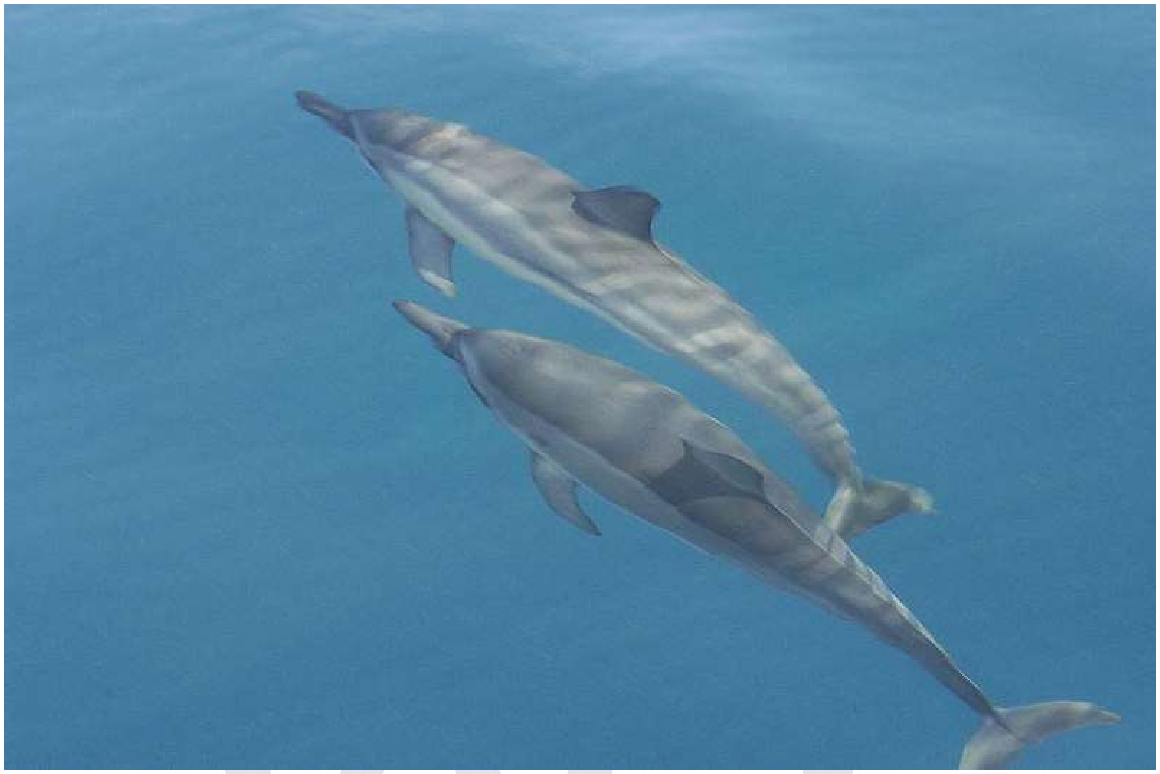
Indo-Pacific humpback and bottlenose dolphins

Drift and bottom-set gillnets are the biggest conservation threat to these dolphins in the Indian Ocean. There have only been assessments in some areas such as Zanzibar. Hunting up until 1996 reduced the population and contributed to their decline. Now hunting has been replaced with eco-tourism. It was estimated in 2001 that there are 161 bottlenose dolphins (*Tursiops aduncus*) and 71 Indo-Pacific Humpback Dolphin (*Sousa chinensis*) that are left based on photo-identification mark-recapture techniques. A study on bycatch revealed over 160 incidences of bycatch since 2000. Approximately 30% of bycatch is in drift and bottom-set gillnets. Mortality is about 8% and 5.6% for bottlenose and humpback dolphins respectfully. The mitigation of bycatch is imperative for these species and eco-tourism.

Irrawaddy dolphins

Based on a survey in 2001, fewer than 70 Irrawaddy dolphins (*Orcaella brevirostris*) left in the upper region of the Malampaya Sound in the Philippines and 69 individuals in the Mekong River. They have been severely impacted by lift nets and crab gear and they are critically endangered. It is estimated that mortality from bycatch may be greater than 4.5% in Malampaya Sound and 5.8% in the Mekong River. The population is declining dramatically. Current bycatch levels are unsustainable and bycatch reduction measures as well as long-term systematic monitoring are urgently required. The elimination of gillnets from areas of high use is needed and economic incentives need to be provided to the local people.

Spinner and Fraser's dolphins



Spinner dolphins

In the Philippines, tuna driftnet fisheries have a substantial impact on the populations. One tuna fishery alone kills 400 Spinner Dolphin (*Stenella longirostris*) and Fraser's dolphins (*Lagenodelphis hosei*) each year. Round-haul nets are an even greater concern with a bycatch of up to 3000 dolphins per year. Dolphins that are bycaught often end up as shark bait for longline fisheries. There is not enough data to conclude total bycatch for the Philippines. Initial assessment indicates that bycatch is not sustainable. Monitoring of dolphin populations and fisheries is urgently needed.

Yangtze River dolphins and finless porpoises

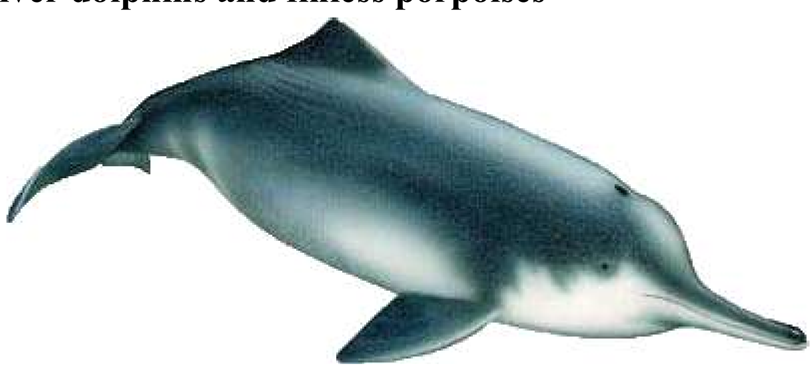


Illustration of a Baiji dolphin

The Yangtze River or Baiji dolphin (*Lipotes vexillifer*) is the most endangered cetacean and is only found in the Yangtze River, China. A survey conducted in 1997 found only thirteen dolphins. The Yangtze River finless porpoise (*Neophocaena phocaenoides asiaeorientalis*) also lives in the Yangtze River. Abundance has declined and there are fewer than 2000 dolphins left. This may be due, in part, to the construction of the Three Gorges Dam which covers a significant amount of the dolphin's habitat. Both species are often subject to entanglement in gillnets.

Vaquita

The vaquita (*Phocoena sinus*) is highly endangered and is endemic to the upper Gulf of California, Mexico. They are killed in both gillnets and trawl nets from commercial and artisanal fishing. There are presently less than 600 vaquitas left in the Gulf of California.

Mitigating bycatch

Acoustic deterrent devices

The use of acoustic alarms to mitigate by-catch and also to protect aquaculture sites has been proposed but has advantages and risks associated with the alarms. Acoustic deterrent devices, or pingers, have reduced the number of cetaceans caught in gill nets. Harbour porpoises have been effectively excluded from bottom-set gill nets during many experiments for instance in the Gulf of Maine, along the Olympic Peninsula, in the Bay of Fundy and in the North Sea. All of these studies show up to a 90% decrease in harbour porpoise bycatch. Pingers work because they produce a sound that is aversive (20; 15). There has been a recent re-evaluation of the potential of pingers and their use in other fisheries due to their growing success. An experiment on the California drift gill net fishery demonstrated how acoustic pingers reduce marine mammal bycatch. It was shown that bycatch was significantly reduced for common dolphins and sea lions. Bycatch rates were also lower for other cetacean species like the Northern right whale dolphin, Pacific white-sided dolphin, Risso's dolphin and Dall's Porpoise. It is agreed upon that the more pingers on a net, the less bycatch. There was a 12-fold decrease in common dolphin entanglement using a net with 40 pingers. However, the widespread use of pingers along coastlines effectively excludes cetaceans such as porpoises from prime habitat and resources. Cetaceans which are extremely sensitive to noise are effectively being driven from their preferred coastal habitats by the use of acoustic devices. In poorer quality habitat, harbour porpoises are subjected to increased competition for resources. This situation is recognized as range contraction which can be a result of climate change, anthropogenic activity, or population decline. Large scale range contractions are considered indicative of impending extinction. A similar form of deterrent is noise pollution originating from vessel traffic.

Barium sulfate

A promising gillnet that is effective in reducing bycatch for harbor porpoises contains barium sulfate. These nets are detected at a greater distance than conventional nets because the barium sulfate reflects the echolocation signal and also renders the nets more visible. Barium sulfate makes the nets stiffer if it is added at high concentration. All three factors: echo reflectivity, stiffness and visibility may be important in reducing bycatch. Fish takes in the Bay of Fundy were normal, except for haddock takes, which were down by 3-5%. The advantage of this approach is that it is passive and thus does not require batteries and there is no “dinner bell” effect. The potential advantage of these nets is greatest in the artisanal fishery. NOAA would like further testing to verify the effectiveness of the nets.

Fishing regulations and management

Management and regulation are lacking in many fisheries today. Management measures are urgently needed to monitor fisheries (and illegal fisheries) to protect cetaceans. Efforts to document bycatch should focus on gill-net fisheries because cetaceans are more likely to be caught in gill-nets. Conservation efforts should be directed to areas where marine mammal bycatch is high but where no infrastructure exists to assess the impact. There is a lack of reporting on a global scale of cetacean bycatch.

In the U.S. the Marine Mammal Protection Act prohibits the use and sale of marine mammals captured by fisheries. Similar legislation prohibits the use and sale of marine mammals in other countries. A marine mammal mortality monitoring program for commercial fisheries occurs in the U.S. where “Take Reduction Teams” observe the extent of bycatch and then formulate strategies to reduce bycatch and Take Reduction Plans are put into place.

Temporary closure

Temporary closure of fisheries during the short period of the year when cetaceans are migrating through the area would decrease bycatch significantly.

Observers on boat

Observers on boats should be present on fishing vessels to spot cetaceans in the water so that they can be avoided.

Other Ways of Mitigating Bycatch

- Choose only fish that are caught using cetacean friendly fishing gear.
- Buy food that has a “dolphin safe” label.
- Read The sustainable seafood guide for information on seafood that is produced sustainably.
- Volunteer locally.
- Raise awareness for cetacean bycatch.

Fish caught in nets that are designed not to harm dolphins is marketed as "dolphin safe", though this label may not be truly indicative of the harm done to dolphins in that fishery.

Chapter 14

Illegal, Unreported and Unregulated Fishing

Illegal fishing takes place where vessels operate in violation of the laws of a fishery. This can apply to fisheries that are under the jurisdiction of a coastal state or to high seas fisheries regulated by regional organisations.

Unreported fishing is fishing that has been unreported or misreported to the relevant national authority or regional organisation, in contravention of applicable laws and regulations.

Unregulated fishing generally refers to fishing by vessels without nationality, or vessels flying the flag of a country not party to the regional organisation governing that fishing area or species.

The drivers behind **illegal, unreported and unregulated (IUU) fishing** are clear enough and similar to those behind many other types of international environmental crime. Most obviously, pirate fishers have a strong economic incentive: many species of fish, particularly those that have been over-exploited and are thus in short supply, are of high value.

Such IUU activity may then show a high chance of success – i.e. a high rate of return – from the failure of governments to regulate adequately (e.g. inadequate coverage of international agreements), or to enforce national or international laws (e.g. because of lack of capacity, or poor levels of governance). A particular driver behind IUU fishing is the failure of a number of flag states to exercise any effective regulation over ships on their registers—which in turn creates an incentive for ships to register under these flags of convenience.

Since no-one is reporting catches made by pirates, their level of fishing cannot be accurately quantified. However, industry observers think that IUU occurs in most fisheries and accounts for up to 30% of total catches in some important fisheries.

Economic and environmental impacts

The most obvious **economic impact** of illegal, unreported and unregulated (IUU) fishing on developing countries is the direct loss of the value of the catches that could be taken by local fishermen if the IUU fishing was not taking place. Available estimates place the economic loss of illegal fishing to be between $10 billion to $23 billion annually.

These losses include not only the loss to GNP, but revenue from landing fees, licence fees and taxes payable by legal fishing operators. In addition, there are indirect impacts in terms of loss of income and employment in related industries; any loss in income will also have impacts on the consumer demands of families working in the fishing industry.

Illegal, unreported and unregulated (IUU) fishing usually has a significant impact on the sustainability of both the targeted species and the ecosystem.

Fishing generally has the capacity to **damage fragile marine ecosystems and vulnerable species** such as coral reefs, turtles and seabirds. In fact, all eight sea turtle species are now endangered and illegal fishing and hunting are two major reasons for their destruction. Regulating legitimate fisheries is aimed at mitigating such impacts, but IUU fishers rarely comply with regulations. This is likely to reduce productivity and biodiversity and create imbalances in the ecosystem.

This in turn may lead to reduced food security in communities heavily dependent on fish as a source of animal protein.

Certification

Mandatory product certification and catch documentation are increasingly used as a natural extension of normal monitoring and enforcement in fisheries and as a means of excluding IUU products from consumer markets and therefore rewarding responsible fishing with protected markets. The concept is increasingly common in other markets, including those for timber and for diamonds.

The use of certification or catch document schemes is encouraged in the FAO's International Plan of Action on IUU Fishing. Several RFMOs include them, including CCAMLR's Catch Documentation Scheme for Toothfish, CCSBT's Trade Information Scheme for Southern Bluefin Tuna and ICCAT's Bluefin Tuna Statistical Document Programme. Similar systems are applied at a national level, including the USA's Certification of Origin of Tuna and Tuna Tracking and Verification Systems, Japan's reporting requirements (including area of capture) for all imports or transportation of tunas into Japan by boat and the EU’s labelling of all fish products (including area of capture).

Marine Stewardship Council

The Marine Stewardship Council (MSC) is an international non-profit organization that runs a certification and ecolabelling program for traceable, sustainable seafood.

To achieve certification as sustainable a fishery must meet a standard based on three principles:

1. ensuring healthy fish stocks
2. minimal impact on the marine ecosystem
3. effective management (which includes ensuring the fishery operates within national and international laws).

Fisheries that meet the MSC standard for a sustainable fishery can use the blue MSC ecolabel on their seafood products.

The second element of the program is a certification for seafood traceability. This is called MSC Chain of Custody. From the fishery, every company in the supply chain that handles the certified fish is checked to ensure the MSC label is only applied to fish products that come from a certified fishery. This requires effective record-keeping and storage procedures. This traceability element of the program helps to keep illegally fished seafood out of the supply chain by linking seafood sold in shops and restaurants to a certified sustainable fishery.

The MSC ecolabel enables consumers to easily identify sustainable seafood when shopping or dining out. As of April 2010, there are nearly 4,000 MSC-labelled seafood products sold in over 60 countries around the world. The MSC website lists outlets selling MSC-certified seafood.

The MSC-certified South Georgia Patagonian toothfish fishery provides a good example of how good fisheries management can reverse the trend of illegal fishing. The fishery took significant steps to exclude illegal vessels from its waters:

- Strict vessel licensing system is rigorously enforced with limited landing points, controlled by the port authorities.

- No transshipment is allowed.

- Every pound of fish landed is monitored through tamper-proof satellite surveillance of on-board weighing scales and GPS locations of vessels.

- On landing, boxed product is applied with a barcode label to ensure there is no introduction of illegal fish into the supply chain.

These are only some of the measures taken by the fishery to achieve MSC certification in March 2004.

The Responsible Fishing Scheme

The Responsible Fishing Scheme was launched in May 2006. It is an independent, audited assessment of the application of good practice by a vessel skipper and crew in their fishing operations. It has been developed to raise standards in the catching sector and demonstrate a vessel operates to industry good practice guidelines. The scheme helps to meet the needs of the seafood supply chain. The sector needs to provide tangible evidence and a practical demonstration of their commitment to the responsible sourcing of seafood. This scheme does just that. A vessel's certification to the scheme is an assurance that the fish landed by that vessel has been caught responsibly. It will also give the vessel a tool to allow them to positively position itself in the global marketplace.

Based on a Publicly Available Specification developed by Seafish in collaboration with the British Standards Institution (BSI), the Responsible Fishing Scheme is a means of recognising responsible fishing practices for individual vessels operating in a diverse range of fisheries under international agreements. It covers five key areas, namely: environmental issues, fishing practices, crew competence, vessel criteria and record maintenance. Ultimately it is designed to promote and recognise good practice. As of March 2009 the scheme boasts 585 vessels in various stages of assessment with over 300 certified.

Enforcement

Illegal and unreported fishing (two of the three components of IUU fishing) essentially arise from a failure to adequately enforce existing national and international laws. There are, however, many factors underlying enforcement failure, including, notably, poor levels of national governance.

There are obvious problems with enforcing fisheries regulations on the high seas, including locating and apprehending the pirate ships, but solutions are available, chiefly through improved monitoring and surveillance systems.

MSC systems are similarly of value within exclusive economic zones, including, for example, offshore patrols and licensing schemes.

Political processes

EU Action Plan

The EU played an active role in drawing up the FAO's international plan of action to prevent, deter and eliminate IUU fishing, endorsed by the FAO Council in June 2001.

The EU then proceeded to develop its own plan to implement the commitments agreed at international level and the European Commission's action plan for the eradication of IUU fishing was published in May 2002. It is intended to be implemented at four levels:

At the EU level, more responsibility will be requested with regard to member state nationals acting under a flag of convenience. Moreover, market measures concerning fisheries products caught in violation of the international agreements will be adopted. In addition, information actions addressed to the fishing industry, consumers and the public will be launched to raise their awareness.

In the framework of Regional Fisheries Organisations, control and inspection plans would be adopted as well as specific conservation and management measures. In addition IUU vessels would be identified and monitored and their catches would be quantified.

At the international level, concepts like genuine link would be defined and a number of rights and obligations of the port state would be established. Moreover, the exchange of information on IUU activities and the international co-operation would be strengthened.

In partnership with developing countries, the necessary means would be provided to enable them to effectively control fishing activities undertaken in waters under their jurisdiction.

High Seas Task Force

The High Seas Task Force comprises a group of fisheries ministers and international NGOs working together to develop an action plan designed to combat IUU fishing on the high seas.

Launched in 2003, the Task Force includes fisheries ministers from Australia, Canada, Chile, Namibia, New Zealand and the UK, together with the Earth Institute, IUCN-World Conservation Union, WWF International and the Marine Stewardship Council.

The goal of the Task Force is to set priorities among a series of practical proposals for confronting the challenge of IUU fishing on the high seas. A series of expert panels have been convened to identify the legal, economic, scientific and enforcement factors that permit IUU activity to thrive and then determine key points of leverage that can brought to bear at national, regional and global levels to minimise the incentives to carry out IUU fishing on the high seas. The completed action plan, published on 3 March 2006, will be placed by ministerial members of the Task Force directly in the hands of other ministers.

Regional Fisheries Management Organisations (RFMOs)

Regional Fisheries Management Organisations (RFMOs) are affiliations of nations that co-ordinate efforts to manage fisheries in a particular region.

RFMOs may focus on certain species of fish (e.g. the Commission for the Conservation of Southern bluefin tuna) or have a wider remit related to living marine resources in general within a region (e.g. the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)). This wide diversity of mandates and areas of application and also effective implementation of regulations, opens up opportunities for IUU vessels. Learn more here.

UN High Seas Processes

The present system of high seas governance has evolved over a period of several hundred years, the end result being a patchwork quilt of measures in the form of binding and non-binding instruments with different geographical and legal reaches and different levels of participation.

Most legal instruments build on the foundation established by the UN Convention on the Law of the Sea, which was agreed in 1982 and entered into force in 1992.

The UN Fish Stocks Agreement, which entered into force in 2001, sets out principles for the conservation and management of fish stocks and establishes that such management must be based on the precautionary approach and the best available scientific information. The Agreement provides a framework for cooperation on conservation and management, but since only about a third of the parties to the Law of the Sea Convention have ratified it, its impact is inevitably limited.

The UN Food and Agriculture Organisation (FAO) carries out much of the technical work on international fisheries management and provides a forum for the negotiation of agreements and codes of conduct. In 1995 the FAO agreed its Code of Conduct for Responsible Fisheries to promote long-term sustainable management.

In 2001, the FAO adopted the International Plan of Action (IPOA) on IUU Fishing. The aim of this voluntary instrument is to prevent, deter and eliminate IUU fishing by providing all states with comprehensive, effective and transparent measures by which to act, including through appropriate regional fisheries management organisations established in accordance with international law.

The FAO Compliance Agreement, which entered into force in 2003, is designed to close a major loophole in international fisheries management, that of the circumvention of fisheries regulations by ‘re-flagging‘ vessels under the flags of states that are unable or unwilling to enforce such measures.

In 2009, the FAO brokered a treaty between 92 nations (The agreement on port state measures to prevent, deter and eliminate illegal, unreported and unregulated fishing) that would close ports to vessels suspected of illegal fishing. The treaty would require vessels request permission to dock and to inform the port details of its fishing operations. Permission to dock could be denied if unregulated fishing was occurring. The measure would help block illegally caught fish from entering the marketplace. Other measures in the treaty include inspections of equipment, paperwork, catches and ship's records. Though the treaty does not compel countries to apply these measures to ships under its own flag, they are free to include them under the agreement.

Poaching

Poaching is the illegal taking of wild plants or animals contrary to local and international conservation and wildlife management laws. Violations of hunting laws and regulations are normally punishable by law and, collectively, such violations are known as poaching.

It may be illegal and in violation because

- The game or fish is not in season; usually the breeding season is declared as the closed season when wildlife species are protected by law.
- The poacher does not possess a valid permit.
- The poacher is illegally selling the animal, animal parts or plant for a profit.
- The animal is being hunted outside of legal hours.
- The hunter used an illegal weapon for that animal.
- The animal or plant is on restricted land.
- The right to hunt this animal is claimed by somebody.
- The type of bait is inhumane. (e.g. food unsuitable for an animal's health)
- The means used are illegal (for example, baiting a field while hunting quail or other animals, using spotlights to stun or paralyze deer, or hunting from a moving vehicle, watercraft, or aircraft).
- The animal or plant is protected by law or that it has been listed as extinct or endangered.
- The animal or plant has been tagged by a researcher.

Note that only wild animals can be poached. Stealing or killing domestic animals is considered to be theft ("cattle rustling"), not poaching.

Plant poaching is also on the rise. A prominent example is the removal of ginseng growing in the Great Smoky Mountains National Park. It is estimated that wild ginseng plants are worth more than $260–365 per pound (*dried*) on the black market.

Traditional medicine

The American paddlefish is poached for its eggs

A seashell vendor in Tanzania sells to tourists seashells which have been taken from the sea alive, killing the animal inside.

Traditional Chinese medicine often incorporates ingredients from all parts of plants, the leaf, stem, flower, root and also ingredients from animals and minerals. The use of parts of endangered species (such as seahorses, rhinoceros horns and tiger bones and claws) has created controversy and resulted in a black market of poachers who hunt restricted animals. Deep-seated cultural beliefs in the potency of tiger parts are so prevalent across Asia that laws protecting even critically endangered species such as the Sumatran tiger fail to stop the display and sale of these items in open markets, according to a 2008 report from TRAFFIC. Popular "medicinal" tiger parts from poached animals include tiger penis, believed to improve virility and tiger eyes.

Slips of Authority

There have been many national and international actions taken against certain kinds of poaching and hunting. Hunting for ivory was banned in 1989, but poaching of elephants continues in many parts of Africa stricken by economic decline. The Philippines have more than 400 endangered animals, all of which are illegal to poach.

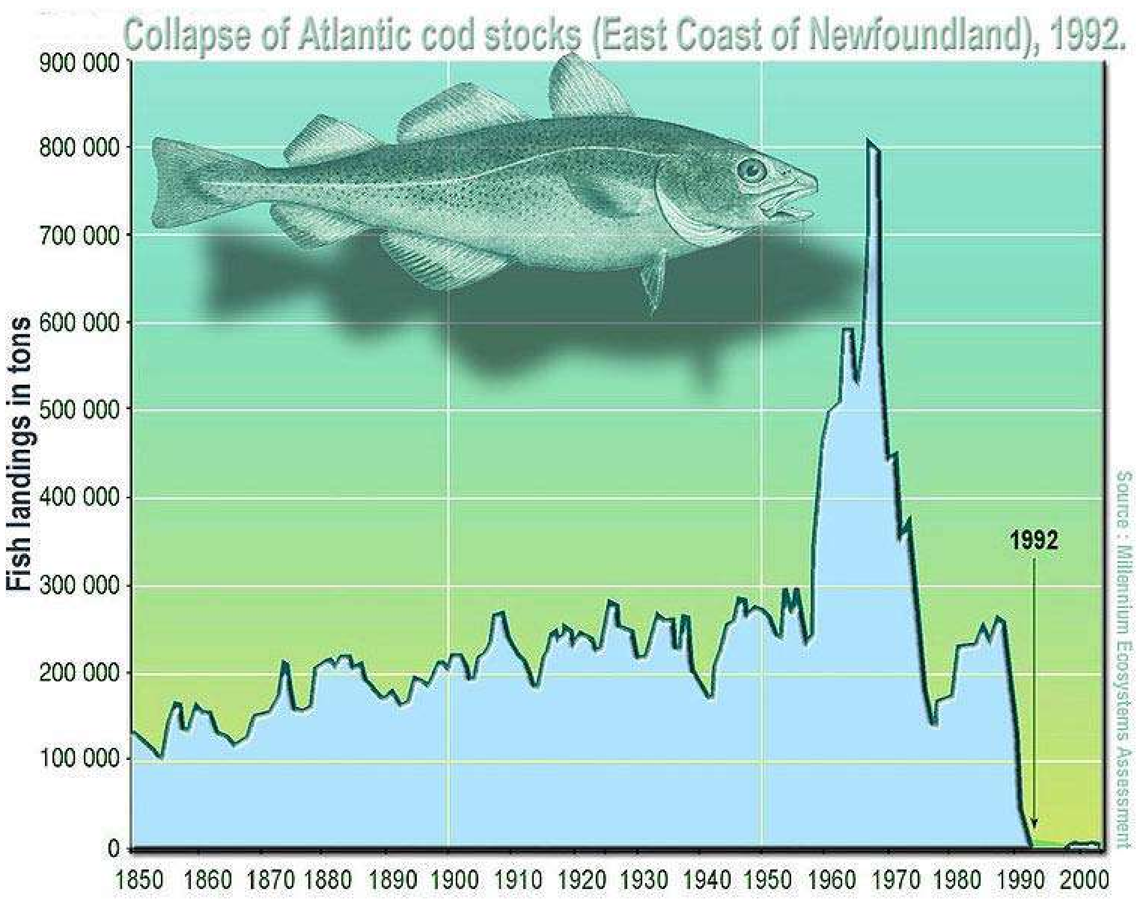
Some species, such as the sturgeon or paddlefish (aka **spoonbill catfish**) are listed as species of "special concern" by the U.S. Federal government, but are only banned from fishing in a few states such as Mississippi and Texas. The species, which is being overfished for its eggs to make caviar, is still allowed to be taken in all other states.

Addressing the problem

Some game wardens have made use of robotic decoy animals placed in high visibility areas to draw out poachers for arrest after the "animals" get shot.

Chapter 15

Overfishing



Atlantic cod stocks were severely overfished in the 1970s and 1980s, leading to their abrupt collapse in 1992

Overfishing occurs when fishing activities reduce fish stocks below an acceptable level. This can occur in any body of water from a pond to the oceans.

Ultimately overfishing can lead to resource depletion in cases of subsidised fishing, low biological growth rates and critical low biomass levels (e.g. by critical depensation growth properties). For example, overfishing of sharks has led to the upset of entire marine ecosystems.

The ability of a fishery to recover after overfishing depends on whether the ecosystem conditions are suitable for the recovery. Dramatic changes in species composition can result in an ecosystem shift, where other equilibrium energy flows involve species compositions other than those that had been present before. For example, once trout have been overfished, carp might take over in a way that makes it impossible for the trout to re-establish a breeding population.

Types

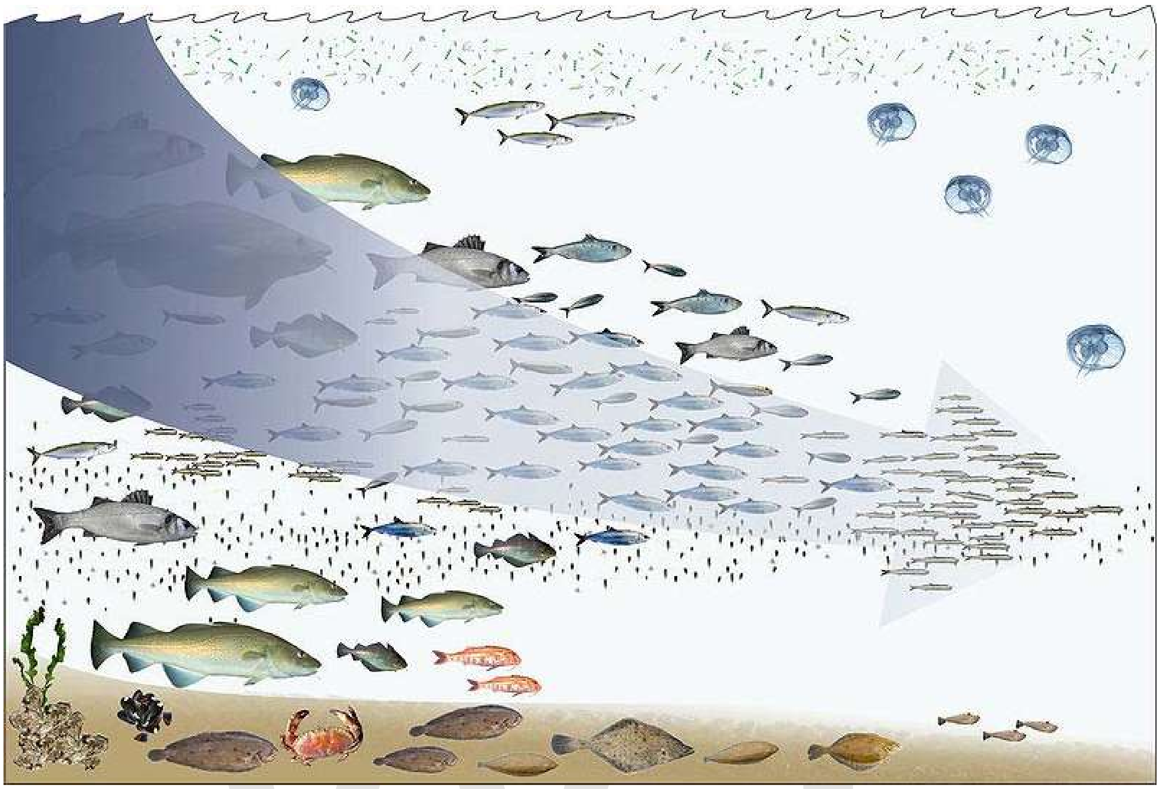
There are three recognized types of overfishing: growth overfishing, recruit overfishing and ecosystem overfishing.

- Growth overfishing – is when fish are harvested at an average size that is smaller than the size that would produce the maximum yield per recruit. This makes the total yield less than it would be if the fish were allowed to grow to a reasonable size. It can be countered by reducing fishing mortality to lower levels and increasing the average size of the fish harvested to a length that will allow maximum yield per recruit.

- Recruit overfishing – is when the mature adult (spawning biomass) population is depleted to a level where it no longer has the reproductive capacity to replenish itself. There are not enough adults to produce offspring. Increasing the spawning stock biomass to a target level is the approach taken by managers to restore an overfished population to sustainable levels. This is generally accomplished by placing moratoriums, quotas and minimum size limits on a fish population.

- Ecosystem overfishing – is when the balance of the ecosystem is altered due to overfishing. Declines in the abundances of large predatory species declines and in turn small forage type species increase in abundance, causing a shift in the balance of the ecosystem towards smaller species of fish.

Instances



Fishing down the food web

Examples of the outcomes from overfishing exist in areas such as the North Sea of Europe, the Grand Banks of North America and the East China Sea of Asia. In these locations, overfishing has not only proved disastrous to fish stocks but also to the fishing communities relying on the harvest. Like other extractive industries such as forestry and hunting, fishery is susceptible to economic interaction between ownership or stewardship and sustainability, otherwise known as the tragedy of the commons.

- The Peruvian coastal anchovy fisheries crashed in the 1970s after overfishing, following an El Niño season which largely depleted anchovies from its waters. Anchovies had previously been a major natural resource in Peru; indeed, 1971 alone yielded 10.2 million metric tons of anchovies. However, in the following year and the four after that, the Peruvian fleet's catch amounted to only about 4 million tons. This was a major loss to Peru's economy.

- The collapse of the cod fishery off Newfoundland and the 1992 decision by Canada to impose an indefinite moratorium on the Grand Banks, is a dramatic example of the consequences of overfishing.

- The sole fisheries in the Irish Sea, the west English Channel and other locations have become overfished to the point of virtual collapse, according to the UK government's official Biodiversity Action Plan. The United Kingdom has created elements within this plan to attempt to restore this fishery, but the expanding global human population and the expanding demand for fish has reached a point where demand for food threatens the stability of these fisheries, if not the species' survival.

- Many deep sea fish are at risk, such as orange roughy, Patagonian toothfish and sablefish. The deep sea is almost completely dark, near freezing and has little food. Deep sea fish grow slowly because of limited food, have slow metabolisms, low reproductive rates and many don't reach breeding maturity for 30 to 40 years. A fillet of orange roughy at the store is probably at least 50 years old. Most deep sea fish are in international waters, where there are no legal protections. Most of these fish are caught by deep trawlers near seamounts, where they congregate because of food. Flash freezing allows the trawlers to work for days at a time and modern fishfinders target the fish with ease.

Consequences

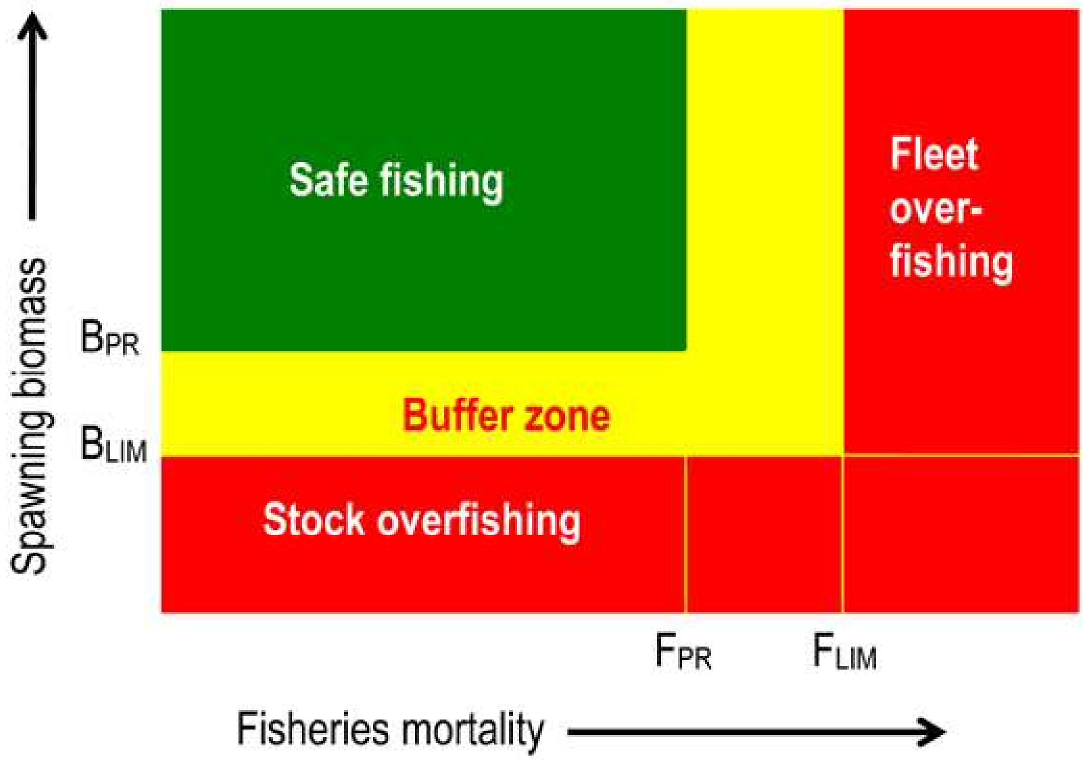
According to a 2008 UN report, the world's fishing fleets are losing $50 billion USD each year through depleted stocks and poor fisheries management. The report, produced jointly by the World Bank and the UN Food and Agriculture Organization (FAO), asserts that half the world's fishing fleet could be scrapped with no change in catch. In addition, the biomass of global fish stocks have been allowed to run down to the point where it is no longer possible to catch the amount of fish that could be caught. Increased incidence of schistosomiasis in Africa has been linked to declines of fish species that eat the snails carrying the disease-causing parasites. Massive growth of jellyfish populations threaten fish stocks, as they compete with fish for food, eat fish eggs and poison or swarm fish and can survive in oxygen depleted environments where fish cannot; they wreak massive havoc on commercial fisheries. Overfishing eliminates a major jellyfish competitor and predator exacerbating the jellyfish population explosion.

Acceptable levels

The notion of overfishing hinges on what is meant by an **acceptable level** of fishing. More precise biological and bioeconomic terms define acceptable level as follows:

- **Biological overfishing** occurs when fishing mortality has reached a level where the stock biomass has negative marginal growth (slowing down biomass growth), as indicated by the red area in the figure. (Fish are being taken out of the water so quickly that the replenishment of stock by breeding slows down. If the replenishment continues to slow down for long enough, replenishment will go into reverse and the population will decrease.)

- **Economic** or **bioeconomic overfishing** additionally considers the cost of fishing when determining acceptable catches. Under this framework a fishery is considered to be overfished when catches exceed maximum economic yield where resource rent is at its maximum. Fish are being removed from the fishery so quickly that the profitability of the fishery is sub-optimal. A more dynamic definition of **economic overfishing** also considers the present value of the fishery using a relevant discount rate to maximise the flow of resource rent over all future catches.



The Traffic Light colour convention, showing the concept of Harvest Control Rule (HCR), specifying when a rebuilding plan is mandatory in terms of precautionary and limit reference points for spawning biomass and fishing mortality rate.

Harvest control rule

A current model for predicting acceptable levels is the Harvest Control Rule (HCR), which is a variable over which management has some direct control as a function of some indicator of stock status. Constant catch and constant fishing mortality are two types of simple harvest control rules.

Input and output orientations

Fishing capacity can also be defined following an input or an output orientation.

- An input-oriented fishing capacity is defined as the maximum available capital stock in a fishery that is fully utilized at the maximum technical efficiency in a given time period, given resource and market conditions.

- An output-oriented fishing capacity is defined as the maximum catch a vessel (fleet) can produce if inputs are fully utilized given the biomass, the fixed inputs, the age structure of the fish stock and the present stage of technology.

Technical efficiency of each vessel of the fleet is assumed necessary to attain this maximum catch. The degree of capacity utilization results from the comparison of the actual level of output (input) and the capacity output (input) of a vessel or a fleet.

Mitigation

With present and forecast levels of the world population it is not possible to solve the overfishing issue; however, there are mitigation measures that can save selected fisheries and forestall the collapse of others.

In order to meet the problems of overfishing, a precautionary approach and Harvest Control Rule (HCR) management principles have been introduced in the main fisheries around the world. The Traffic Light colour convention introduces sets of rules based on predefined critical values, which could be adjusted as more information is gained.

The "United Nations Convention on the Law of the Sea" treaty deals with aspects of **overfishing** in articles 61, 62 and 65.

- Article 61 requires all coastal states to ensure that the maintenance of living resources in their exclusive economic zones is not endangered by over-exploitation. The same article addresses the maintenance or restoration of populations of species above levels at which their reproduction may become seriously threatened.

- Article 62 provides that coastal states: "shall promote the objective of optimum utilization of the living resources in the exclusive economic zone without prejudice to Article 61"
- Article 65 provides generally for the rights of, inter alia, coastal states to prohibit, limit, or regulate the exploitation of marine mammals.

Overfishing can be viewed as a case of the tragedy of the commons; in that sense, solutions would promote property rights, such as privatization and fish farming. Daniel K. Benjamin, in *Fisheries are Classic Example of the "Tragedy of the Commons"*, cites research by Grafton, Squires and Fox to support the idea that privatization can solve the overfishing problem:

According to recent research on the British Columbia halibut fishery, where the commons has been at least partly privatized, substantial ecological and economic benefits have resulted. There is less damage to fish stocks, the fishing is safer and fewer resources are needed to achieve a given harvest.

Another possible solution, at least for some areas, is fishing quotas, so fishermen can only legally take a certain amount of fish. A more radical possibility is declaring certain areas of the sea "no-go zones" and make fishing there strictly illegal, so the fish in that area have time to recover and repopulate.

Controlling consumer behavior and demand is a key in mitigating action. Worldwide a number of initiatives emerged to provide consumers with information regarding the conservation status of the seafood available to them. The Guide to Good Fish Guides lists a number of these.

Fishing quotas

A model of the interaction between fish and fishers showed that when an area is closed to fishers, but there are no catch regulations such as individual transferable quotas, fish catches are temporarily increased but overall fish biomass is reduced, resulting in the opposite outcome than the one desired for fisheries. Thus, a displacement of the fleet from one locality to another will generally have little effect if the same quota is taken. As a result, management measures such as temporary closures or establishing a Marine Protected Area of fishing areas are ineffective when not combined with individual fishing quotas. An inherent problem with quotas is that fish populations vary from year to year. A study has found that fish populations rise dramatically after stormy years due to more nutrients reaching the surface and therefore greater primary production. To fish sustainably quotas need to be changed each year to take account of the population of fish but this is difficult to do.

Individual transferable quotas

Individual transferable quotas (ITQs) are fishery rationalization instruments defined under the Magnuson-Stevens Fishery Conservation and Management Act as limited access permits to harvest quantities of fish. Fisheries scientists decide the optimal amount of fish (total allowable catch) to be harvested in a certain fishery, taking into account carrying capacity, regeneration rates and future values. Under ITQs, members of a fishery are granted rights to a percentage of the total allowable catch which can be harvested each year. These quotas can be fished, bought, sold, or leased allowing for the least cost vessels to be used. ITQs are used in New Zealand, Australia, Iceland, Canada and the United States. Only three ITQ programs have been implemented in the United States due to a moratorium supported by Ted Stevens.

In 2008 a large scale study of fisheries that used ITQ's and ones that didn't provided strong evidence that ITQ's can help to prevent collapses and restore fisheries that appear to be in decline.

Fishing suspension

China bans fishing in the South China Sea for a period each year.

Benefits of underfishing

Deliberately underfishing to increase long term fish stocks has been proposed as a way fisherman can maximize their yields in the long run.

Resistance from fishermen

There is always disagreement between fishermen and government scientists... Imagine an overfished area of the sea in the shape of a hockey field with nets at either end. The few fish left therein would gather around the goals because fish like structured habitats. Scientists would survey the entire field, make lots of unsuccessful hauls and conclude that it contains few fish. The fishermen would make a beeline to the goals, catch the fish around them and say the scientists do not know what they are talking about. The subjective impression the fishermen get is always that there's lots of fish - because they only go to places that still have them... fisheries scientists survey and compare entire areas, not only the productive fishing spots. – *Fisheries scientist Daniel Pauly*

- The fishing capacity problem is not only related to the conservation of fish stocks but also to the sustainability of fishing activity. Causes of the fishing problem can be found in property rights regime of fishing resources. Overexploitation and rent dissipation of fishermen arise in open-access fisheries as was shown in Gordon.

- In open-access resources like fish stocks, in the absence of a system like individual transferable quotas, the impossibility of excluding others provokes the fishermen who want to increase catch to do so effectively by taking someone else' share, intensifying competition. This tragedy of the commons provokes a capitalization process that leads them to increase their costs until they are equal to their revenue, dissipating their rent completely.

Removal of subsidies

Several scientists have called for an end to subsidies paid to deep sea fisheries. In international waters beyond the 200 nautical mile exclusive economic zones of coastal countries, many fisheries are unregulated and fishing fleets plunder the depths with state of the art technology. In a few hours, massive nets weighing up to 15 tons, dragged along the bottom by deep-water trawlers, can destroy deep-sea corals and sponge beds that have taken centuries or millennia to grow. The trawlers can target orange roughy, grenadiers or sharks. These fish are usually long-lived and late maturing and their populations take decades, even centuries to recover.

Fisheries scientist Daniel Pauly and economist Ussif Rashid Sumaila have examined subsidies paid to bottom trawl fleets around the world. They found that $152 million US per year are paid to deep-sea fisheries. Without these subsidies, global deep-sea fisheries would operate at a loss of $50 million a year. A great deal of the subsidies paid to deep-sea trawlers is to subsidize the large amount of fuel required to travel beyond the 200 mile limit and drag weighted nets.

- "There is surely a better way for governments to spend money than by paying subsidies to a fleet that burns 1.1 billion litres of fuel annually to maintain paltry catches of old growth fish from highly vulnerable stocks, while destroying their habitat in the process" – Pauly.
- "Eliminating global subsidies would render these fleets economically unviable and would relieve tremendous pressure on over-fishing and vulnerable deep-sea ecosystems" – Sumaila.

Consumer awareness

Sustainable seafood is a movement that has gained momentum as more people become aware about overfishing and environmentally destructive fishing methods. Sustainable seafood is seafood from either fished or farmed sources that can maintain or increase production in the future without jeopardizing the ecosystems from which it was acquired. In general, slow-growing fish that reproduce late in life, such as orange roughy, are vulnerable to overfishing. Seafood species that grow quickly and breed young, such as anchovies and sardines, are much more resistant to overfishing. Several organizations, including the Marine Stewardship Council (MSC) and Friend of the Sea, certify seafood fisheries as sustainable.

MSC ecolabel for sustainable seafood

The Marine Stewardship Council (MSC) has developed an environmental standard for sustainable and well-managed fisheries. Environmentally responsible fisheries management and practices are rewarded with the use of its blue product ecolabel.

Consumers concerned about overfishing and its consequences are increasingly able to choose seafood products which have been independently assessed against the MSC's environmental standard and labelled. This enables consumers to play a part in reversing the decline of fish stocks. As of April 2010, 69 fisheries around the world have been independently assessed and certified as meeting the MSC standard. Their where to buy page lists the currently available certified seafood - as of April 2010 nearly 4,000 MSC-labelled products are available in over 60 countries around the world. Fish & Kids is an MSC project to teach schoolchildren about marine environmental issues, including overfishing.

The Monterey Bay Aquarium's Seafood Watch Program, although not an official certifying body like the MSC, also provides guidance on the sustainability of certain fish species: Some seafood restaurants have begun to offer more sustainable seafood options. The Seafood Choices Alliance is an organization whose members include chefs that serve sustainable seafood at their establishments. In the US, the Sustainable Fisheries Act defines sustainable practices through national standards. Although there is no official certifying body like the MSC, the National Oceanic and Atmospheric Administration has created FishWatch to help guide concerned consumers to sustainable seafood choices.

Fish farming

In 2009, researchers in Australia managed for the first time to coax southern bluefin tuna to breed in landlocked tanks, opening up the possibility of using fish farming as a way to save the species from the problems of overfishing in the wild.

Addendum

Daniel Pauly, a fisheries scientist well-known for pioneering work on the human impacts on global fisheries, comments:

"It is almost as though we use our military to fight the animals in the ocean. We are gradually winning this war to exterminate them. And to see this destruction happen, for nothing really – for no reason – that is a bit frustrating. Strangely enough, these effects are all reversible, all the animals that have disappeared would reappear, all the animals that were small would grow, all the relationships that you can't see any more would re-establish themselves and the system would re-emerge. So that's one thing to be optimistic about. The oceans, much more so than the land, are reversible..."

Chapter 16

Marine Pollution

While marine pollution can be obvious, as with the marine debris shown above, it is often the pollutants that cannot be seen that cause most harm

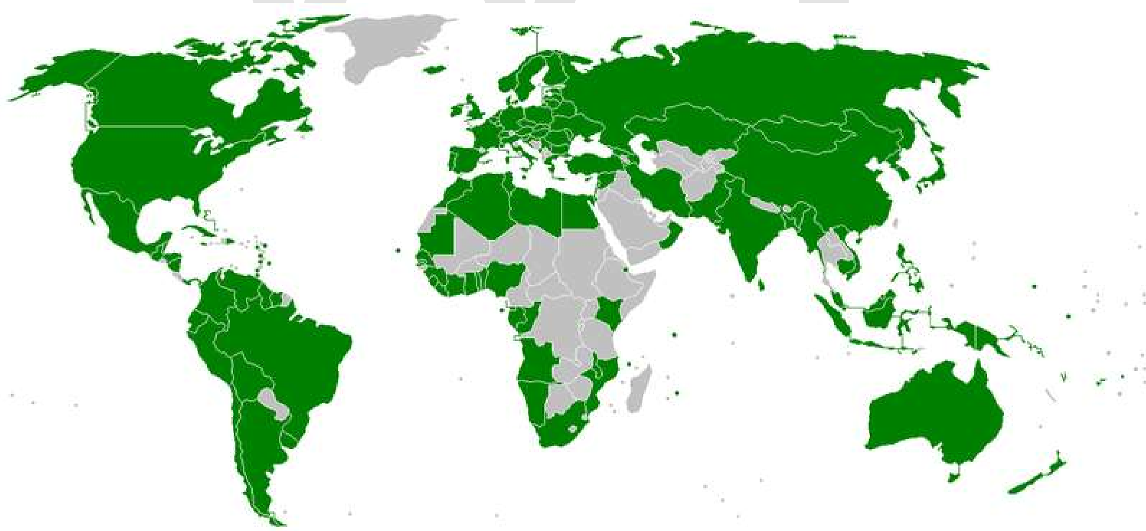
Marine pollution occurs when harmful effects, or potentially harmful effects, can result from the entry into the ocean of chemicals, particles, industrial, agricultural and residential waste, noise, or the spread of invasive organisms. Most sources of marine pollution are land based. The pollution often comes from nonpoint sources such as agricultural runoff and wind blown debris.

Many potentially toxic chemicals adhere to tiny particles which are then taken up by plankton and benthos animals, most of which are either deposit or filter feeders. In this way, the toxins are concentrated upward within ocean food chains. Many particles combine chemically in a manner highly depletive of oxygen, causing estuaries to become anoxic.

When pesticides are incorporated into the marine ecosystem, they quickly become absorbed into marine food webs. Once in the food webs, these pesticides can cause mutations, as well as diseases, which can be harmful to humans as well as the entire food web.

Toxic metals can also be introduced into marine food webs. These can cause a change to tissue matter, biochemistry, behaviour, reproduction and suppress growth in marine life. Also, many animal feeds have a high fish meal or fish hydrolysate content. In this way, marine toxins can be transferred to land animals and appear later in meat and dairy products.

History



Parties to the MARPOL 73/78 convention on marine pollution

Although marine pollution has a long history, significant international laws to counter it were enacted in the twentieth century. Marine pollution was a concern during several United Nations Conferences on the Law of the Sea beginning in the 1950s. Most scientists believed that the oceans were so vast that they had unlimited ability to dilute and thus render harmless, pollution. In the late 1950s and early 1960s, there were several controversies about dumping radioactive waste off the coasts of the United States by companies licensed by the Atomic Energy Commission, into the Irish Sea from the British reprocessing facility at Windscale and into the Mediterranean Sea by the French Commissariat à l'Energie Atomique. After the Mediterranean Sea controversy, for example, Jacques Cousteau became a worldwide figure in the campaign to stop marine pollution. Marine pollution made further international headlines after the 1967 crash of the oil tanker Torrey Canyon and after the 1969 Santa Barbara oil spill off the coast of California. Marine pollution was a major area of discussion during the 1972 United Nations Conference on the Human Environment, held in Stockholm. That year also saw the signing of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, sometimes called the London Convention. The London Convention did not ban marine pollution, but it established black and gray lists for substances to be banned (black) or regulated by national authorities (gray). Cyanide and high-level radioactive waste, for example, were put on the black list. The London Convention applied only to waste dumped from ships and thus did nothing to regulate waste discharged as liquids from pipelines.

Pathways of pollution

Septic river

There are many different ways to categorize and examine the inputs of pollution into our marine ecosystems. Patin (n.d.) notes that generally there are three main types of inputs of pollution into the ocean: direct discharge of waste into the oceans, runoff into the waters due to rain and pollutants that are released from the atmosphere.

One common path of entry by contaminants to the sea are rivers. The evaporation of water from oceans exceeds precipitation. The balance is restored by rain over the continents entering rivers and then being returned to the sea. The Hudson in New York State and the Raritan in New Jersey, which empty at the northern and southern ends of Staten Island, are a source of mercury contamination of zooplankton (copepods) in the open ocean. The highest concentration in the filter-feeding copepods is not at the mouths of these rivers but 70 miles south, nearer Atlantic City, because water flows close to the coast. It takes a few days before toxins are taken up by the plankton.

Pollution is often classed as point source or nonpoint source pollution. Point source pollution occurs when there is a single, identifiable and localized source of the pollution. An example is directly discharging sewage and industrial waste into the ocean. Pollution such as this occurs particularly in developing nations. Nonpoint source pollution occurs when the pollution comes from ill-defined and diffuse sources. These can be difficult to regulate. Agricultural runoff and wind blown debris are prime examples.

Direct discharge

Acid mine drainage in the Rio Tinto River

Pollutants enter rivers and the sea directly from urban sewerage and industrial waste discharges, sometimes in the form of hazardous and toxic wastes.

Inland mining for copper, gold. etc., is another source of marine pollution. Most of the pollution is simply soil, which ends up in rivers flowing to the sea. However, some minerals discharged in the course of the mining can cause problems, such as copper, a common industrial pollutant, which can interfere with the life history and development of coral polyps. Mining has a poor environmental track record. For example, according to the United States Environmental Protection Agency, mining has contaminated portions of the headwaters of over 40% of watersheds in the western continental US. Much of this pollution finishes up in the sea.

Land runoff

Surface runoff from farming, as well as urban runoff and runoff from the construction of roads, buildings, ports, channels and harbours, can carry soil and particles laden with carbon, nitrogen, phosphorus and minerals. This nutrient-rich water can cause fleshy algae and phytoplankton to thrive in coastal areas, known as algal blooms, which have the potential to create hypoxic conditions by using all available oxygen.

Polluted runoff from roads and highways can be a significant source of water pollution in coastal areas. About 75 percent of the toxic chemicals that flow into Puget Sound are carried by stormwater that runs off paved roads and driveways, rooftops, yards and other developed land.

Ship pollution

A cargo ship pumps ballast water over the side

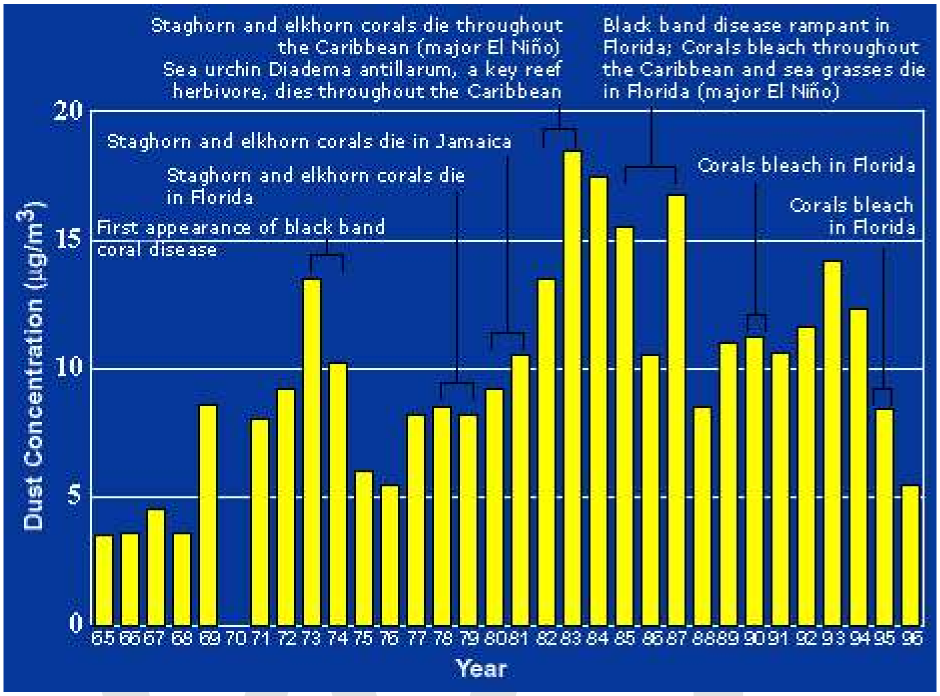
Ships can pollute waterways and oceans in many ways. Oil spills can have devastating effects. While being toxic to marine life, polycyclic aromatic hydrocarbons (PAHs), the components in crude oil, are very difficult to clean up and last for years in the sediment and marine environment.

Discharge of cargo residues from bulk carriers can pollute ports, waterways and oceans. In many instances vessels intentionally discharge illegal wastes despite foreign and domestic regulation prohibiting such actions. It has been estimated that container ships lose over 10,000 containers at sea each year (usually during storms). Ships also create noise pollution that disturbs natural wildlife and water from ballast tanks can spread harmful algae and other invasive species.

Ballast water taken up at sea and released in port is a major source of unwanted exotic marine life. The invasive freshwater zebra mussels, native to the Black, Caspian and Azov seas, were probably transported to the Great Lakes via ballast water from a transoceanic vessel. Meinesz believes that one of the worst cases of a single invasive species causing harm to an ecosystem can be attributed to a seemingly harmless jellyfish. *Mnemiopsis leidyi*, a species of comb jellyfish that spread so it now inhabits estuaries in many parts of the world. It was first introduced in 1982 and thought to have been transported to the Black Sea in a ship's ballast water. The population of the jellyfish shot up exponentially and, by 1988, it was wreaking havoc upon the local fishing industry. "The anchovy catch fell from 204,000 tons in 1984 to 200 tons in 1993; sprat from 24,600 tons in 1984 to 12,000 tons in 1993; horse mackerel from 4,000 tons in 1984 to zero in 1993." Now that the jellyfish have exhausted the zooplankton, including fish larvae, their numbers have fallen dramatically, yet they continue to maintain a stranglehold on the ecosystem.

Invasive species can take over once occupied areas, facilitate the spread of new diseases, introduce new genetic material, alter underwater seascapes and jeopardize the ability of native species to obtain food. Invasive species are responsible for about $138 billion annually in lost revenue and management costs in the US alone.

Atmospheric pollution



Graph linking atmospheric dust to various coral deaths across the Caribbean Sea and Florida

Another pathway of pollution occurs through the atmosphere. Wind blown dust and debris, including plastic bags, are blown seaward from landfills and other areas. Dust from the Sahara moving around the southern periphery of the subtropical ridge moves into the Caribbean and Florida during the warm season as the ridge builds and moves northward through the subtropical Atlantic. Dust can also be attributed to a global transport from the Gobi and Taklamakan deserts across Korea, Japan and the Northern Pacific to the Hawaiian Islands. Since 1970, dust outbreaks have worsened due to periods of drought in Africa. There is a large variability in dust transport to the Caribbean and Florida from year to year; however, the flux is greater during positive phases of the North Atlantic Oscillation. The USGS links dust events to a decline in the health of coral reefs across the Caribbean and Florida, primarily since the 1970s.

Climate change is raising ocean temperatures and raising levels of carbon dioxide in the atmosphere. These rising levels of carbon dioxide are acidifying the oceans. This, in turn, is altering aquatic ecosystems and modifying fish distributions, with impacts on the sustainability of fisheries and the livelihoods of the communities that depend on them. Healthy ocean ecosystems are also important for the mitigation of climate change.

Deep sea mining

Deep sea mining is a relatively new mineral retrieval process that takes place on the ocean floor. Ocean mining sites are usually around large areas of polymetallic nodules or active and extinct hydrothermal vents at about 1,400 - 3,700 meters below the ocean's surface. The vents create sulfide deposits, which contain precious metals such as silver, gold, copper, manganese, cobalt and zinc. The deposits are mined using either hydraulic pumps or bucket systems that take ore to the surface to be processed. As with all mining operations, deep sea mining raises questions about environmental damages to the surrounding areas

Because deep sea mining is a relatively new field, the complete consequences of full scale mining operations are unknown. However, experts are certain that removal of parts of the sea floor will result in disturbances to the benthic layer, increased toxicity of the water column and sediment plumes from tailings. Removing parts of the sea floor disturbs the habitat of benthic organisms, possibly, depending on the type of mining and location, causing permanent disturbances. Aside from direct impact of mining the area, leakage, spills and corrosion would alter the mining area's chemical makeup.

Among the impacts of deep sea mining, sediment plumes could have the greatest impact. Plumes are caused when the tailings from mining (usually fine particles) are dumped back into the ocean, creating a cloud of particles floating in the water. Two types of plumes occur: near bottom plumes and surface plumes. Near bottom plumes occur when the tailings are pumped back down to the mining site. The floating particles increase the turbidity, or cloudiness, of the water, clogging filter-feeding apparatuses used by benthic organisms. Surface plumes cause a more serious problem. Depending on the size of the particles and water currents the plumes could spread over vast areas. The plumes could impact zooplankton and light penetration, in turn affecting the food web of the area.

Acidification

Island with fringing reef in the Maldives. Coral reefs are dying around the world

The oceans are normally a natural carbon sink, absorbing carbon dioxide from the atmosphere. Because the levels of atmospheric carbon dioxide are increasing, the oceans are becoming more acidic. The potential consequences of ocean acidification are not fully understood, but there are concerns that structures made of calcium carbonate may become vulnerable to dissolution, affecting corals and the ability of shellfish to form shells.

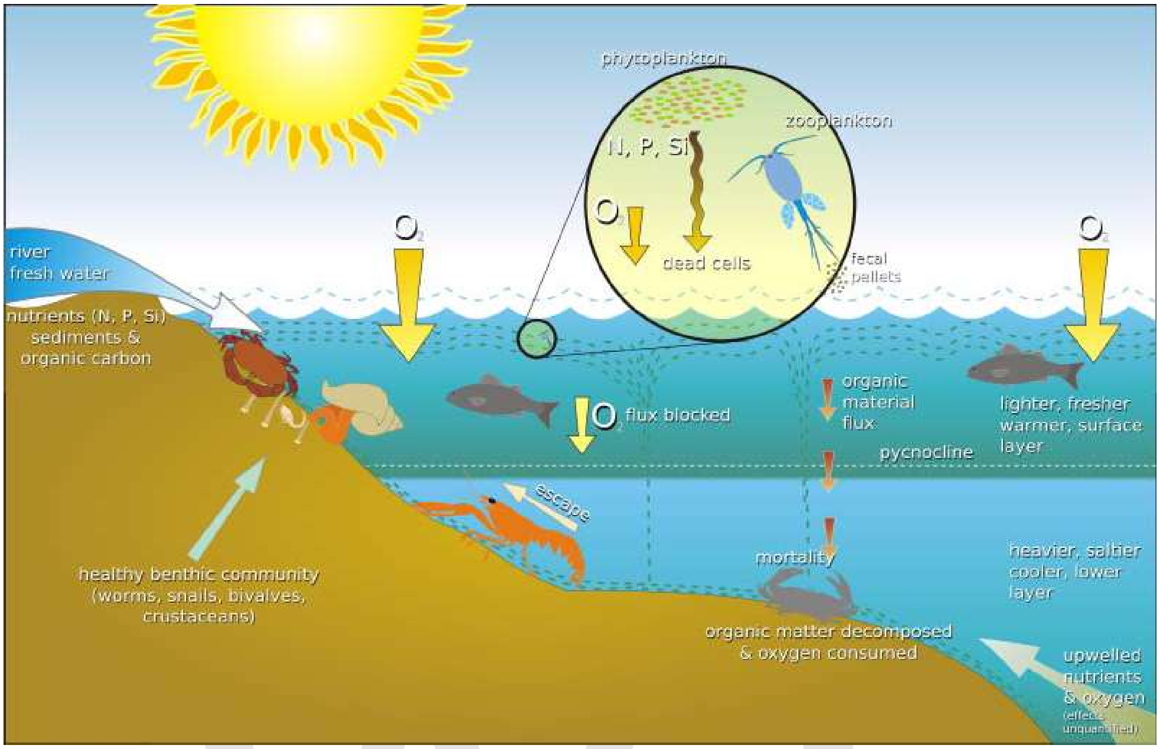
Oceans and coastal ecosystems play an important role in the global carbon cycle and have removed about 25% of the carbon dioxide emitted by human activities between 2000 and 2007 and about half the anthropogenic CO_2 released since the start of the industrial revolution. Rising ocean temperatures and ocean acidification means that the capacity of the ocean carbon sink will gradually get weaker, giving rise to global concerns expressed in the Monaco and Manado Declarations.

A report from NOAA scientists published in the journal Science in May 2008 found that large amounts of relatively acidified water are upwelling to within four miles of the Pacific continental shelf area of North America. This area is a critical zone where most local marine life lives or is born. While the paper dealt only with areas from Vancouver to northern California, other continental shelf areas may be experiencing similar effects.

A related issue is the methane clathrate reservoirs found under sediments on the ocean floors. These trap large amounts of the greenhouse gas methane, which ocean warming has the potential to release. In 2004 the global inventory of ocean methane clathrates was estimated to occupy between one and five million cubic kilometres. If all these clathrates were to be spread uniformly across the ocean floor, this would translate to a thickness between three and fourteen metres. This estimate corresponds to 500-2500 gigatonnes carbon (Gt C) and can be compared with the 5000 Gt C estimated for all other fossil fuel reserves.

Eutrophication

Polluted lagoon



Effect of eutrophication on marine benthic life

Eutrophication is an increase in chemical nutrients, typically compounds containing nitrogen or phosphorus, in an ecosystem. It can result in an increase in the ecosystem's primary productivity (excessive plant growth and decay) and further effects including lack of oxygen and severe reductions in water quality, fish and other animal populations.

The biggest culprit are rivers that empty into the ocean and with it the many chemicals used as fertilizers in agriculture as well as waste from livestock and humans. An excess of oxygen depleting chemicals in the water can lead to hypoxia and the creation of a dead zone.

Estuaries tend to be naturally eutrophic because land-derived nutrients are concentrated where runoff enters the marine environment in a confined channel. The World Resources Institute has identified 375 hypoxic coastal zones around the world, concentrated in coastal areas in Western Europe, the Eastern and Southern coasts of the US and East Asia, particularly in Japan. In the ocean, there are frequent red tide algae blooms that kill fish and marine mammals and cause respiratory problems in humans and some domestic animals when the blooms reach close to shore.

In addition to land runoff, atmospheric anthropogenic fixed nitrogen can enter the open ocean. A study in 2008 found that this could account for around one third of the ocean’s external (non-recycled) nitrogen supply and up to three per cent of the annual new marine biological production. It has been suggested that accumulating reactive nitrogen in the environment may have consequences as serious as putting carbon dioxide in the atmosphere.

Plastic debris

A mute swan builds a nest using plastic garbage

Marine debris is mainly discarded human rubbish which floats on, or is suspended in the ocean. Eighty percent of marine debris is plastic - a component that has been rapidly accumulating since the end of World War II. The mass of plastic in the oceans may be as high as one hundred million metric tons.

Discarded plastic bags, six pack rings and other forms of plastic waste which finish up in the ocean present dangers to wildlife and fisheries. Aquatic life can be threatened through entanglement, suffocation and ingestion. Fishing nets, usually made of plastic, can be left or lost in the ocean by fishermen. Known as ghost nets, these entangle fish, dolphins, sea turtles, sharks, dugongs, crocodiles, seabirds, crabs and other creatures, restricting movement, causing starvation, laceration and infection and, in those that need to return to the surface to breathe, suffocation.

Remains of an albatross containing ingested flotsam

Many animals that live on or in the sea consume flotsam by mistake, as it often looks similar to their natural prey. Plastic debris, when bulky or tangled, is difficult to pass and may become permanently lodged in the digestive tracts of these animals, blocking the passage of food and causing death through starvation or infection.

Plastics accumulate because they don't biodegrade in the way many other substances do. They will photodegrade on exposure to the sun, but they do so properly only under dry conditions and water inhibits this process. In marine environments, photodegraded plastic disintegrates into ever smaller pieces while remaining polymers, even down to the molecular level. When floating plastic particles photodegrade down to zooplankton sizes, jellyfish attempt to consume them and in this way the plastic enters the ocean food chain. Many of these long-lasting pieces end up in the stomachs of marine birds and animals, including sea turtles and black-footed albatross.

Marine debris on Kamilo Beach, Hawaii, washed up from the Great Pacific Garbage Patch

Plastic debris tends to accumulate at the centre of ocean gyres. In particular, the Great Pacific Garbage Patch has a very high level of plastic particulate suspended in the upper water column. In samples taken in 1999, the mass of plastic exceeded that of zooplankton (the dominant animal life in the area) by a factor of six. Midway Atoll, in common with all the Hawaiian Islands, receives substantial amounts of debris from the garbage patch. Ninety percent plastic, this debris accumulates on the beaches of Midway where it becomes a hazard to the bird population of the island. Midway Atoll is home to two-thirds (1.5 million) of the global population of Laysan Albatross. Nearly all of these albatross have plastic in their digestive system and one-third of their chicks die.

Toxic additives used in the manufacture of plastic materials can leach out into their surroundings when exposed to water. Waterborne hydrophobic pollutants collect and magnify on the surface of plastic debris, thus making plastic far more deadly in the ocean than it would be on land. Hydrophobic contaminants are also known to bioaccumulate in fatty tissues, biomagnifying up the food chain and putting pressure on apex predators. Some plastic additives are known to disrupt the endocrine system when consumed, others can suppress the immune system or decrease reproductive rates. Floating debris can also absorb persistent organic pollutants from seawater, including PCBs, DDT and PAHs.

Aside from toxic effects, when ingested some of these are mistaken by the animal brain for estradiol, causing hormone disruption in the affected wildlife.

Toxins

Apart from plastics, there are particular problems with other toxins that do not disintegrate rapidly in the marine environment. Examples of persistent toxins are PCBs, DDT, pesticides, furans, dioxins, phenols and radioactive waste. Heavy metals are metallic chemical elements that have a relatively high density and are toxic or poisonous at low concentrations. Examples are mercury, lead, nickel, arsenic and cadmium. Such toxins can accumulate in the tissues of many species of aquatic life in a process called bioaccumulation. They are also known to accumulate in benthic environments, such as estuaries and bay muds: a geological record of human activities of the last century.

Specific examples

- Chinese and Russian industrial pollution such as phenols and heavy metals in the Amur River have devastated fish stocks and damaged its estuary soil.

- Wabamun Lake in Alberta, Canada, once the best whitefish lake in the area, now has unacceptable levels of heavy metals in its sediment and fish.

- Acute and chronic pollution events have been shown to impact southern California kelp forests, though the intensity of the impact seems to depend on both the nature of the contaminants and duration of exposure.

- Due to their high position in the food chain and the subsequent accumulation of heavy metals from their diet, mercury levels can be high in larger species such as bluefin and albacore. As a result, in March 2004 the United States FDA issued guidelines recommending that pregnant women, nursing mothers and children limit their intake of tuna and other types of predatory fish.

- Some shellfish and crabs can survive polluted environments, accumulating heavy metals or toxins in their tissues. For example, mitten crabs have a remarkable ability to survive in highly modified aquatic habitats, including polluted waters. The farming and harvesting of such species needs careful management if they are to be used as a food.

- Surface runoff of pesticides can alter the gender of fish species genetically, transforming male into female fish.

- Heavy metals enter the environment through oil spills - such as the Prestige oil spill on the Galician coast - or from other natural or anthropogenic sources.

- In 2005, the 'Ndrangheta, an Italian mafia syndicate, was accused of sinking at least 30 ships loaded with toxic waste, much of it radioactive. This has led to widespread investigations into radioactive waste disposal rackets.

- Since the end of World War II, various nations, including the Soviet Union, the United Kingdom, the United States and Germany, have disposed of chemical weapons in the Baltic Sea, raising concerns of environmental contamination.

Noise pollution

Marine life can be susceptible to noise or sound pollution from sources such as passing ships, oil exploration seismic surveys and naval low-frequency active sonar. Sound travels more rapidly and over larger distances in the sea than in the atmosphere. Marine animals, such as cetaceans, often have weak eyesight and live in a world largely defined by acoustic information. This applies also to many deeper sea fish, who live in a world of darkness. Between 1950 and 1975, ambient noise in the ocean increased by about ten decibels (that is a ten-fold increase).

Noise also makes species communicate louder, which is called the Lombard vocal response. Whale songs are longer when submarine-detectors are on. If creatures don't "speak" loud enough, their voice can be masked by anthropogenic sounds. These unheard voices might be warnings, finding of prey, or preparations of net-bubbling. When one species begins speaking louder, it will mask other specie voices, causing the whole ecosystem to eventually speak louder.

According to the oceanographer Sylvia Earle, "Undersea noise pollution is like the death of a thousand cuts. Each sound in itself may not be a matter of critical concern, but taken all together, the noise from shipping, seismic surveys and military activity is creating a totally different environment than existed even 50 years ago. That high level of noise is bound to have a hard, sweeping impact on life in the sea."

Adaptation and mitigation

Aerosol can polluting a beach

Much anthropogenic pollution ends up in the ocean. Bjorn Jennssen (2003) notes in his article, “Anthropogenic pollution may reduce biodiversity and productivity of marine ecosystems, resulting in reduction and depletion of human marine food resources” (p. A198). There are two ways the overall level of this pollution can be mitigated: either the human population is reduced, or a way is found to reduce the ecological footprint left behind by the average human. If the second way is not adopted, then the first way may be imposed as world ecosystems falter.

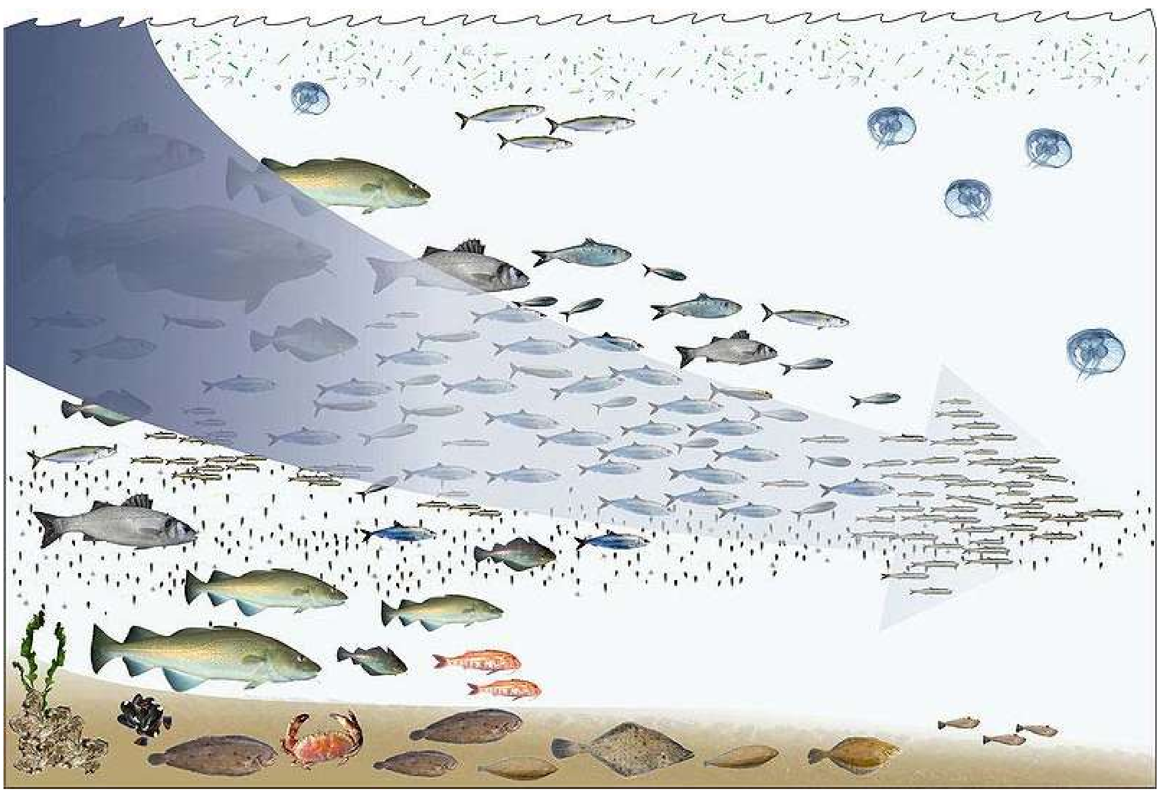
The second way is for humans, individually, to pollute less. That requires social and political will, together with a shift in awareness so more people respect the environment and are less disposed to abuse it. At an operational level, regulations and international government participation is needed. It is often very difficult to regulate marine pollution because pollution spreads over international barriers, thus making regulations hard to create as well as enforce.

Perhaps the most important strategy for reducing marine pollution is education. Most are unaware of the sources and harmful effects of marine pollution and therefore little is done to address the situation. In order to inform the population of all the facts, in depth research must be done to provide the full scale of the situation. Then this information must be made public.

As expressed in Daoji and Dag's research, one of the reasons why environmental concern is lacking among the Chinese is because the public awareness is low and therefore should be targeted. Likewise, regulation, based upon such in-depth research should be employed. In California, such regulations have already been put in place to protect Californian coastal waters from agricultural runoff. This includes the California Water Code, as well as several voluntary programs. Similarly, in India, several tactics have been employed that help reduce marine pollution, however, they do not significantly target the problem. In Chennai city, India, sewage has been dumped further into open waters. Due to the mass of waste being deposited, open-ocean is best for diluting and dispersing pollutants, thus making them less harmful to marine ecosystems.

Chapter 17

Environmental Effects of Fishing



Fishing down the foodweb

The **environmental effects of fishing** can be divided into issues that involve the availability of fish to be caught, such as overfishing, sustainable fisheries and fisheries management; and issues that involve the impact of fishing on the environment, such as by-catch.

These conservation issues are part of marine conservation and are addressed in fisheries science programs. There is a growing gap between how many fish are available to be caught and humanity's desire to catch them, a problem that gets worse as the world population grows.

Similar to other environmental issues, there can be conflict between the fishermen who depend on fishing for their livelihoods and fishery scientists who realise that if future fish populations are to be sustainable then some fisheries must reduce or even close.

The journal *Science* published a four-year study in November 2006, which predicted that, at prevailing trends, the world would run out of wild-caught seafood in 2048. The scientists stated that the decline was a result of overfishing, pollution and other environmental factors that were reducing the population of fisheries at the same time as their ecosystems were being degraded. Yet again the analysis has met criticism as being fundamentally flawed and many fishery management officials, industry representatives and scientists challenge the findings, although the debate continues. Many countries, such as Tonga, the United States, Australia and New Zealand and international management bodies have taken steps to appropriately manage marine resources.

Effects on habitat

Some fishing techniques also may cause habitat destruction. Dynamite fishing and cyanide fishing, which are illegal in many places, harm surrounding habitat. Bottom trawling, the practice of pulling a fishing net along the sea bottom behind trawlers, removes around 5 to 25% of an area's seabed life on a single run. A 2005 report of the UN Millennium Project, commissioned by UN Secretary-General Kofi Annan, recommended the elimination of bottom trawling on the high seas by 2006 to protect seamounts and other ecologically sensitive habitats.

In mid October 2006, U.S. President Bush joined other world leaders calling for a moratorium on deep-sea trawling, a practice shown to often have harmful effects on sea habitat and, hence, on fish populations.

Overfishing

Overfishing has also been widely reported due to increases in the volume of fishing hauls to feed a quickly growing number of consumers. This has led to the breakdown of some sea ecosystems and several fishing industries whose catch has been greatly diminished. The extinction of many species has also been reported. According to an FAO estimate, over 70% of the world's fish species are either fully exploited or depleted. According to Nitin Desai, Secretary General of the 2002 World Summit on Sustainable Development, "Overfishing cannot continue, the depletion of fisheries poses a major threat to the food supply of millions of people."

The cover story of the May 15, 2003 issue of the science journal *Nature* – with Dr. Ransom A. Myers, an internationally prominent fisheries biologist (Dalhousie University, Halifax, Canada) as the lead author – was devoted to a summary of the scientific information. The story asserted that, as compared with 1950 levels, only a remnant (in some instances, as little as 10%) of all large ocean-fish stocks are left in the seas. These large ocean fish are the species at the top of the food chains (e.g., tuna, cod, among others).

Ecological disruption

Fishing may disrupt food webs by targeting specific, in-demand species. There might be too much fishing of prey species such as sardines and anchovies, thus reducing the food supply for the predators. It may also cause the increase of prey species when the target fishes are predator species such as salmon and tuna. Fisheries can reduce fish stocks that cetaceans rely on for food.

By-catch

By-catch is the portion of the catch that is not the target species. These are either kept to be sold or discarded. In some instances the discarded portion is known as discards.

Possible remedies

Fisheries management draws on fisheries science in order to find ways to protect fishery resources so sustainable exploitation is possible. Modern fisheries management is often referred to as a governmental system of appropriate management rules based on defined objectives and a mix of management means to implement the rules, which are put in place by a system of monitoring control and surveillance.

History

Fisheries have been explicitly managed in some places for hundreds of years. For example, the Māori people, New Zealand residents for about 700 years, enforced strict prohibitions against taking more than could be eaten and about giving back the first fish caught as an offering to sea god Tangaroa.

Another example is the North Norwegian fishery by the Lofoten islands, where an eighteenth-century law limits fishing during periods when there were an unusually large number of fishers. To avoid taking too many fish out of any one area, gillnetters and longliners not allowed to fish in the same grounds south of Lofoten.

Governmental resource protection-based fisheries management is a relatively new idea, first developed for North European fisheries after the first Overfishing Conference held in London in 1936. In 1957 British fisheries researchers Ray Beverton and Sidney Holt published a seminal work on North Sea commercial fisheries dynamics. In the 1960s the work became the theoretical platform for North European management schemes.

After some years away from the field of fisheries management, Beverton criticized his earlier work in a paper given at the first World Fisheries Congress in Athens in 1992.

"The Dynamics of Exploited Fish Populations" expressed his concerns, including the way his and Sydney Holt's work had been misinterpreted and misused by fishery biologists and managers during the previous 30 years. Nevertheless, the institutional foundation for modern fishery management had been laid.

Political objectives

According to the FAO, fisheries management should be based explicitly on political objectives, ideally with transparent priorities. Typical political objectives when exploiting a fish resource are to:

- maximize sustainable biomass yield
- maximize sustainable economic yield
- secure and increase employment
- secure protein production and food supplies
- increase export income

Such political goals can also be a weak part of fisheries management, since the objectives can conflict with each other.

International objectives

Fisheries objectives need to be expressed in concrete management rules. In most countries fisheries management rules should be based on the internationally agreed, though non-binding, Code of Conduct for Responsible Fisheries, agreed at a meeting of the U.N.'s Fish and Agriculture Organization FAO session in 1995. The precautionary approach it prescribes is typically implemented in concrete management rules as minimum spawning biomass, maximum fishing mortality rates, etc. In 2005 theFisheries Centre at the University of British Columbia comprehensively reviewed the performance of the world's major fishing nations against the Code.

International agreements are required in order to regulate fisheries in international waters. The desire for agreement on this and other maritime issues led to three conferences on the Law of the Sea and ultimately to the treaty known as the United Nations Convention on the Law of the Sea (UNCLOS). Concepts such as exclusive economic zones (EEZ, extending 200 nautical miles (370 km) from a nation's coasts) allocate certain sovereign rights and responsibilities for resource management to individual countries.

Other situations need additional intergovernmental coordination. For example, in the Mediterranean Sea and other relatively narrow bodies of water, EEZ of 200 nautical miles (370 km) are irrelevant. International waters beyond 12-nautical-mile (22 km) from shore require explicit agreements.

Straddling fish stocks, which migrate through more than one EEZ also present challenges. Here sovereign responsibility must be agreed with neighbouring coastal states and fishing entities. Usually this is done through the medium of an regional organisation set up for the purpose of coordinating the management of that stock.

UNCLOS does not prescribe precisely how fisheries confined only to international waters should be managed. Several new fisheries (such as high seas bottom trawling fisheries) are not (yet) subject to international agreement across their entire range. In November 2004 the UN General Assembly issued a resolution on Fisheries that prepared for further development of international fisheries management law.

Management mechanisms

Many countries have set up Ministries/Government Departments, named "Ministry of Fisheries" or similar, controlling aspects of fisheries within their exclusive economic zones. Four categories of management means have been devised, regulating either input/investment, or output and operating either directly or indirectly:

	Inputs	**Outputs**
Indirect	Vessel licensing	Catching techniques
Direct	Limited entry	Catch quota and technical regulation

Technical means may include:

- prohibiting devices such as bows and arrows and spears, or firearms
- prohibiting nets
- limiting the average potential catch of a vessel in the fleet (vessel and crew size, gear, electronic gear and other physical "inputs".
- prohibiting bait
- snagging
- limits on fish traps
- limiting the number of poles or lines per fisherman
- restricting the number of simultaneous fishing vessels
- limiting a vessel's average operational intensity per unit time at sea
- limiting average time at sea

Catch quotas

Systems that use *individual transferable quotas* (ITQ), also called individual fishing quota limit the total catch and allocate shares of that quota among the fishers who work that fishery. Fishers can buy/sell/trade shares as they choose.

A large scale study in 2008 provided strong evidence that ITQ's can help to prevent fishery collapse and even restore fisheries that appear to be in decline.

Population dynamics

Population dynamics describes the growth and decline of a given fishery stock over time, as controlled by birth, death and migration. It is the basis for understanding changing fishery patterns and issues such as habitat destruction, predation and optimal harvesting rates. The population dynamics of fisheries has been traditionally used by fisheries scientists to determine sustainable yields.

The basic accounting relation for population dynamics is the BIDE model:

$$N_1 = N_0 + B - D + I - E$$

where N_1 is the number of individuals at time 1, N_0 is the number of individuals at time 0, B is the number of individuals born, D the number that died, I the number that immigrated and E the number that emigrated between time 0 and time 1. While immigration and emigration can be present in wild fisheries, they are usually not measured.

Care is needed when applying population dynamics to real world fisheries. In the past, over-simplistic modelling, such as ignoring the size, age and reproductive status of the fish, focusing solely on a single species, ignoring bycatch and physical damage to the ecosystem, has accelerated the collapse of key stocks.

Ecosystem based fisheries

According to marine ecologist Chris Frid, the fishing industry points to pollution and global warming as the causes of unprecedentedly low fish stocks in recent years, writing, "Everybody would like to see the rebuilding of fish stocks and this can only be achieved if we understand all of the influences, human and natural, on fish dynamics." Overfishing has also had an effect. Frid adds, “Fish communities can be altered in a number of ways, for example they can decrease if particular sized individuals of a species are targeted, as this affects predator and prey dynamics. Fishing, however, is not the sole perpetrator of changes to marine life - pollution is another example [...] No one factor operates in isolation and components of the ecosystem respond differently to each individual factor."

In contrast to the traditional approach of focusing on a single species, the ecosystem-based approach is organized in terms of ecosystem services. Ecosystem-based fishery concepts have been implemented in some regions. In 2007 a group of scientists offered the following *ten commandments*

> “
> - Keep a perspective that is holistic, risk-adverse and adaptive.
> - Maintain an “old growth” structure in fish populations, since big, old and fat female fish have been shown to be the best spawners, but are also susceptible to overfishing.
> - Characterize and maintain the natural spatial structure of fish stocks,
>
> ”

so that management boundaries match natural boundaries in the sea.

- Monitor and maintain seafloor habitats to make sure fish have food and shelter.
- Maintain resilient ecosystems that are able to withstand occasional shocks.
- Identify and maintain critical food-web connections, including predators and forage species.
- Adapt to ecosystem changes through time, both short-term and on longer cycles of decades or centuries, including global climate change.
- Account for evolutionary changes caused by fishing, which tends to remove large, older fish.
- Include the actions of humans and their social and economic systems in all ecological equations.

Elderly maternal fish

Old fat female rockfish are the best producers

Traditional management practices aim to reduce the number of old, slow-growing fish, leaving more room and resources for younger, faster-growing fish. Most marine fish produce huge numbers of eggs. The assumption was that younger spawners would produce plenty of viable larvae.

However, 2005 research on rockfish shows that large, elderly females are far more important than younger fish in maintaining productive fisheries. The larvae produced by these older maternal fish grow faster, survive starvation better and are much more likely to survive than the offspring of younger fish. Failure to account for the role of older fish may help explain recent collapses of some major US West Coast fisheries. Recovery of some stocks is expected to take decades. One way to prevent such collapses is to establish marine reserves, where fishing is not allowed and fish populations age naturally.

Data quality

According to fisheries scientist Milo Adkison, the primary limitation in fisheries management decisions is the absence of quality data. Fisheries management decisions are often based on population models, but the models need quality data to be effective. He asserts that scientists and fishery managers would be better served with simpler models and improved data.

The most reliable source for summary statistics is the FAO Fisheries Department.

Ecopath

Ecopath, with Ecosim (EwE), is an ecosystem modelling software suite. It was initially a NOAA initiative led by Jeffrey Polovina, later primarily developed at the Fisheries Centre of the University of British Columbia. In 2007, it was named as one of the ten biggest scientific breakthroughs in NOAA's 200-year history. The citation states that Ecopath "revolutionized scientists' ability worldwide to understand complex marine ecosystems". Behind this lies two decades of development work by Villy Christensen, Carl Walters, Daniel Pauly and other fisheries scientists. As of 2010 there are 6000 registered users in 155 countries. Ecopath is widely used in fisheries management as a tool for modelling and visualising the complex relationships that exist in real world marine ecosystems.

Human factors

Managing fisheries is about managing people and businesses and not about managing fish. Fish populations are managed by regulating the actions of people. If fisheries management is to be successful, then associated human factors, such as the reactions of fishermen, are of key importance and need to be understood.

Management regulations must also consider the implications for stakeholders. Commercial fishermen rely on catches to provide for their families just as farmers rely on crops. Commercial fishing can be a traditional trade passed down from generation to generation. Most commercial fishing is based in towns built around the fishing industry; regulation changes can impact an entire town's economy. Cuts in harvest quotas can have adverse affects on the ability of fishermen to compete with the tourism industry.

Performance

The biomass of global fish stocks have been allowed to run down to the point where it is no longer possible to catch the amount of fish that could be caught. According to a 2008 UN report, titled *The Sunken Billions: The Economic Justification for Fisheries Reform*, the world's fishing fleets incur a "$US 50 billion annual economic loss" through depleted stocks and poor fisheries management. The report, produced jointly by the World Bank and the UN Food and Agriculture Organization (FAO), asserts that half the world's fishing fleet could be scrapped with no change in catch.

"By improving governance of marine fisheries, society could capture a substantial part of this $50 billion annual economic loss. Through comprehensive reform, the fisheries sector could become a basis for economic growth and the creation of alternative livelihoods in many countries. At the same time, a nation's natural capital in the form of fish stocks could be greatly increased and the negative impacts of the fisheries on the marine environment reduced."