Fisheries Science

Chester Isbell

First Edition, 2012

ISBN 978-81-323-4139-0

Table of Contents

Introduction

Fisheries scientists sorting a catch of small fish and langoustine.

Fisheries science is the academic discipline of managing and understanding fisheries. It is a multidisciplinary science, which draws on the disciplines of oceanography, marine biology, marine conservation, ecology, population dynamics, economics and management to attempt to provide an integrated picture of fisheries. In some cases new disciplines have emerged, as in the case of bioeconomics.

Fisheries science is typically taught in a university setting, and can be the focus of an undergraduate, master's or Ph.D. program. Some universities offer fully integrated programs in fisheries science.

Notable contributors

- Spencer F. Baird, founding scientist of the United States Fish Commission
- Ludwig von Bertalanffy, an Austrian-born biologist and a founder of general systems theory
- Raymond Beverton was an English fisheries biologist; known for the Beverton–Holt model (with Sidney Holt), credited with being one of the founders of fisheries science
- Villy Christensen is a fisheries scientist and ecosystem modeler, known for his work on the development of Ecopath
- John N. Cobb, founder of the first college of fisheries in the United States, the University of Washington College of Fisheries, in 1919
- David Cushing was an English born fisheries biologist, who is credited with the development of the match/mismatch hypothesis
- Gotthilf Hempel, a German marine biologist and oceanographer, and co-founder of the Alfred Wegener Institute for Polar and Marine Research
- Walther Herwig, a Prussian lawyer and promoter of high seas fishing and research
- Ray Hilborn, a Canadian-born fisheries biologist, with strong contributions towards fisheries management
- Johan Hjort, a Norwegian fisheries biologist, marine zoologist, and oceanographer
- Bruno Hofer, a German fishery scientist, credited with being the founder of fish pathology
- Sidney Holt, an English fisheries biologist; known for the Beverton–Holt model (with Ray Beverton), credited with being one of the founders of fisheries science
- Uwe Kils, a German marine biologist specializing in planktology. Inventor of the ecoSCOPE.
- Leo Margolis, a Canadian parasitologist and head of the Pacific Biological Station in Nanaimo, British Columbia
- R. J. McKay, an Australian-born biologist and a specialist in translocated freshwater fishes
- Ransom A. Myers, a Canadian marine biologist and conservationist.
- Daniel Pauly, prominent French-born fisheries scientist, known for his work studying human impacts on global fisheries
- Tony J. Pitcher, known for work on the impacts of fishing, management appraisals and the shoaling behavior of fish
- Michael A. Rice, an American known for work on molluscan fisheries.
- Bill Ricker, a Canadian fisheries biologist, known for the Ricker model, credited with being one of the founders of fisheries science
- Ed Ricketts, a colourful American marine biologist and philosopher who introduced ecology to fisheries science.
- Callum Roberts, a British marine conservation biologist, known for his work on the role marine reserves play in protecting marine ecosystems
- Harald Rosenthal, a German hydrobiologist known for his work in fish farming and ecology
- Carl Safina, author of several writings on marine ecology and the ocean.

- Georg Sars, a Norwegian marine biologist credited with the discovery of a number of new species and known for his analysis of cod fisheries
- Tore Schweder, a Norwegian statistician whose work includes the assessment of marine resources
- Milner Baily Schaefer is notable for his work on the population dynamics of fisheries.
- Ussif Rashid Sumaila, noted for his analysis of the economic aspects of fisheries.
- Fred Utter, noted as the founding father of the field of fishery genetics
- Carl Walters is an American born biologist known for his work involving fisheries stock assessments, the adaptive management concept, and ecosystem modeling
- Boris Worm has made contributions to marine ecology and fisheries conservation. He was a student of the late Ransom Myers and now leads Myer's lab at Dalhousie.

Ransom A. Myers

Daniel Pauly

Professional societies

- World Council of Fisheries Societies
- American Fisheries Society
- The Fisheries Society of the British Isles
- The Japanese Society of Fisheries Science
- The Australian Society for Fish Biology

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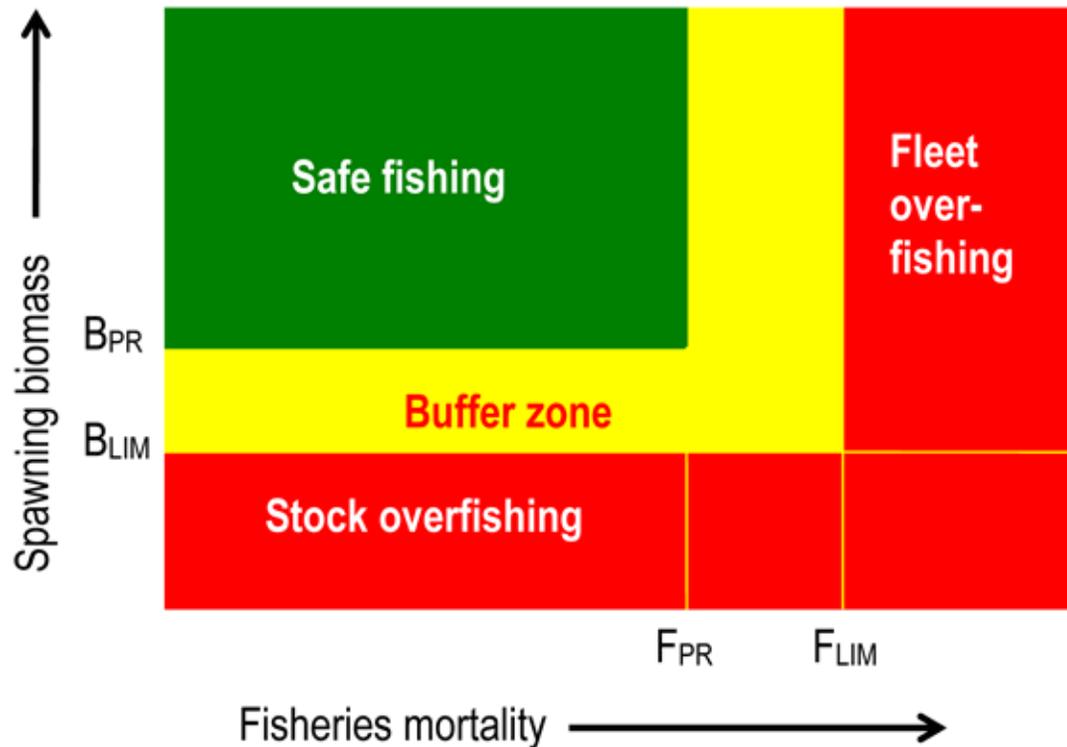
The Traffic Light colour convention, showing the concept of Harvest Control Rule (HCR), specifying when a rebuilding plan is mandatory in terms of precautionary and limit reference points for spawning biomass and fishing mortality rate.

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.
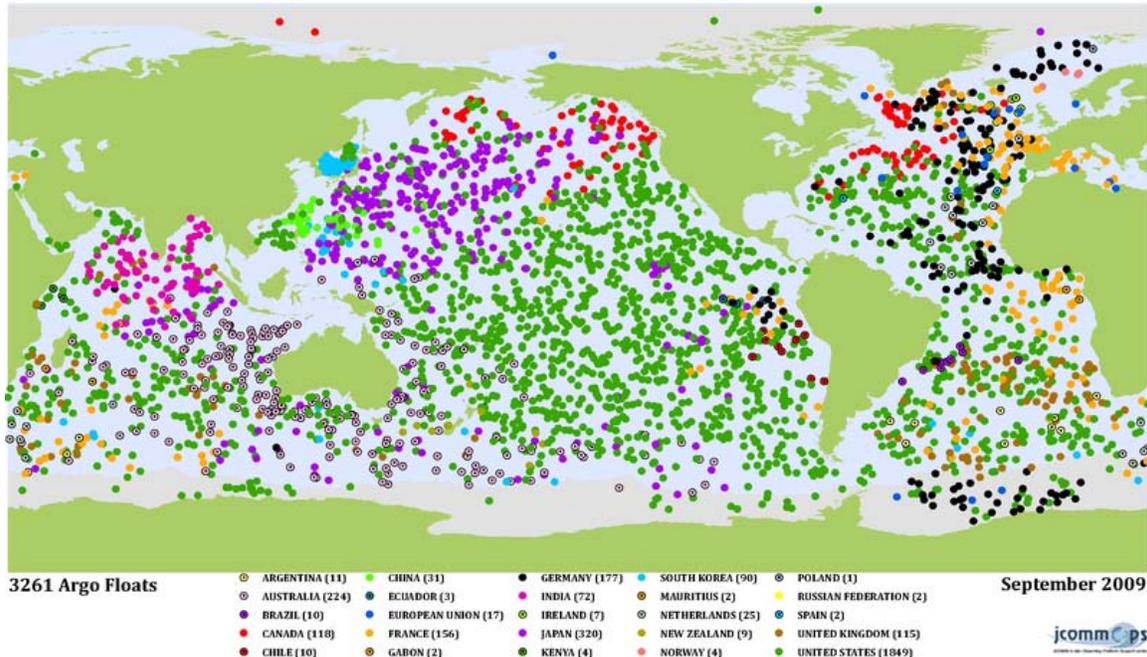
Map of the Argo float network as of September 2009

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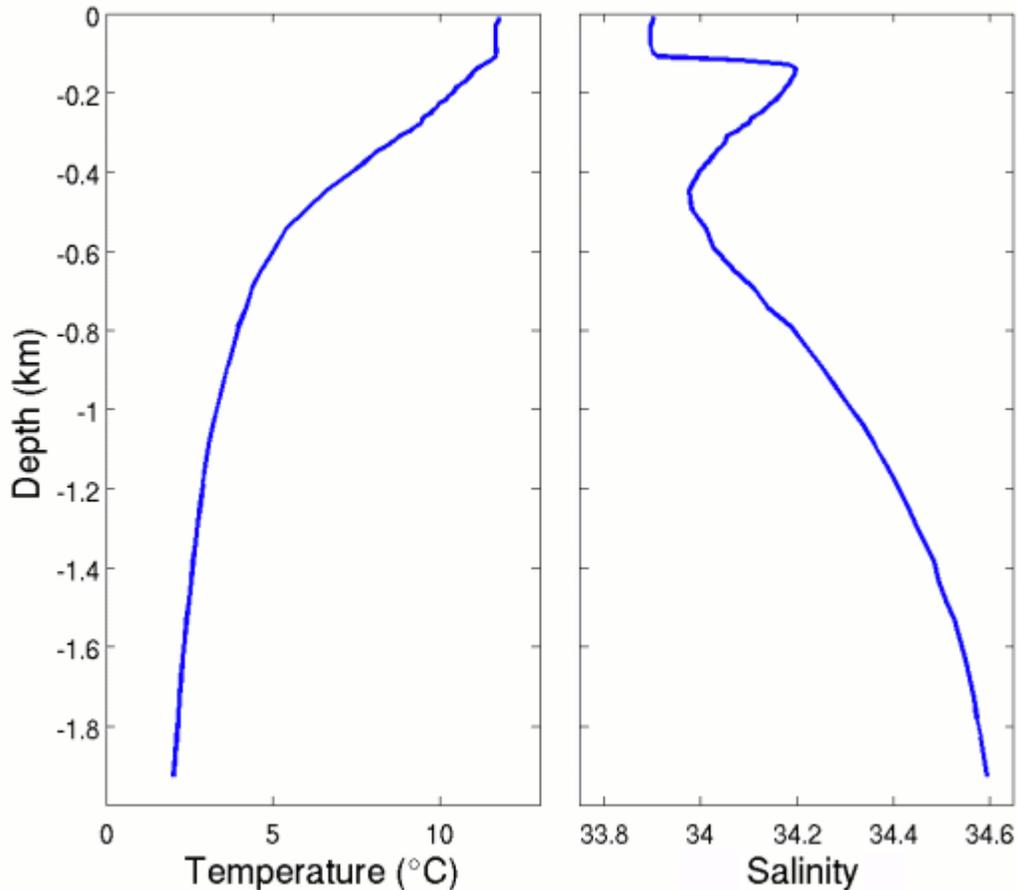
Example profiles of temperature and salinity obtained from an Argo float in the central North Pacific (38.4°N, 155.3°W) on April 8, 2005.

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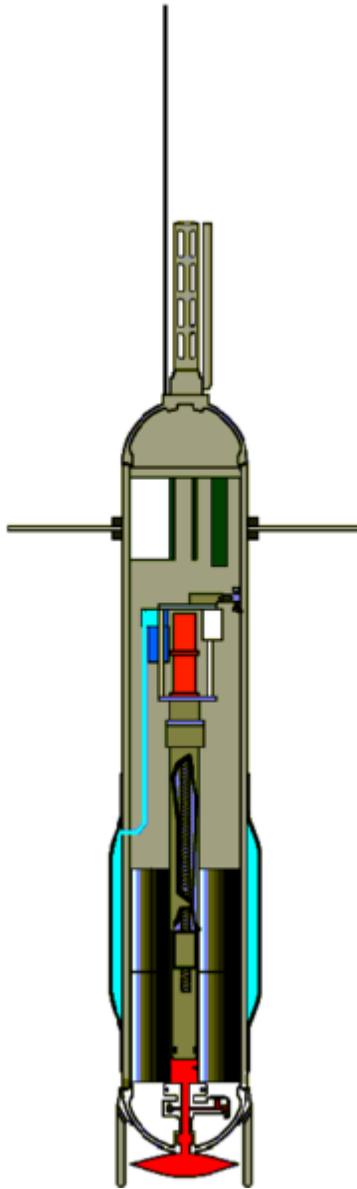
Cutaway diagram of an Argo float. The height of the float is about 2 m. The antenna and sensors are mounted at the top of the buoy.

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
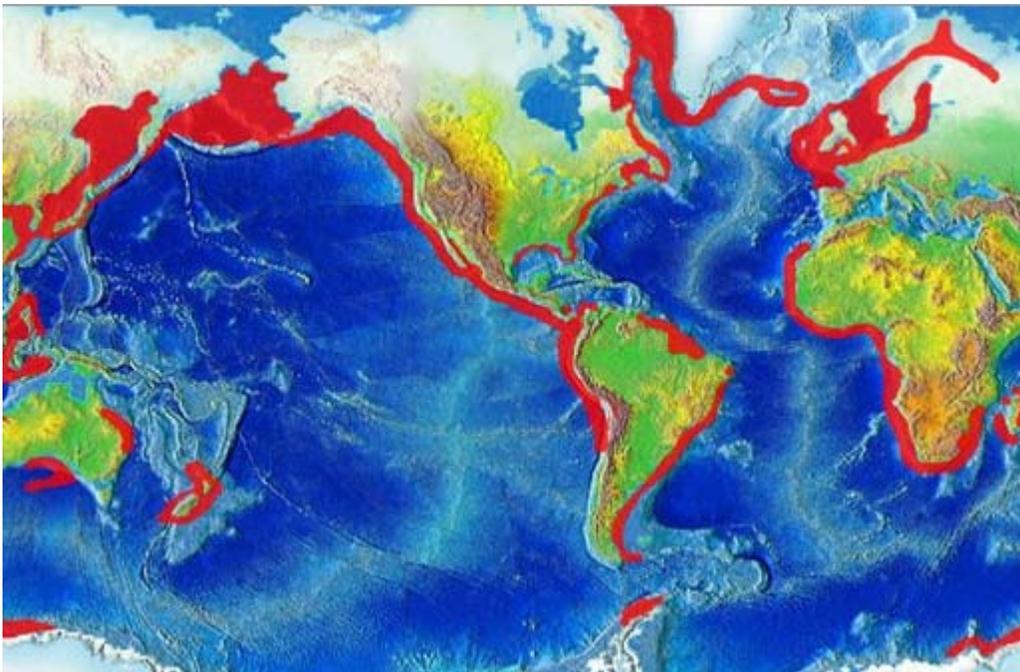
Areas of upwelling in red.

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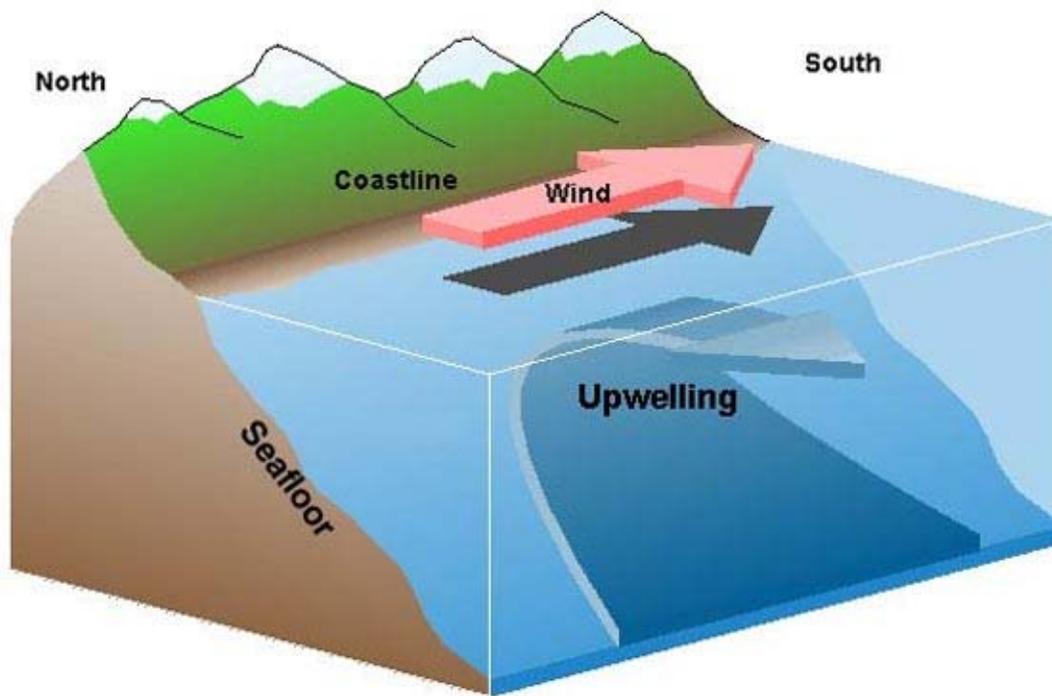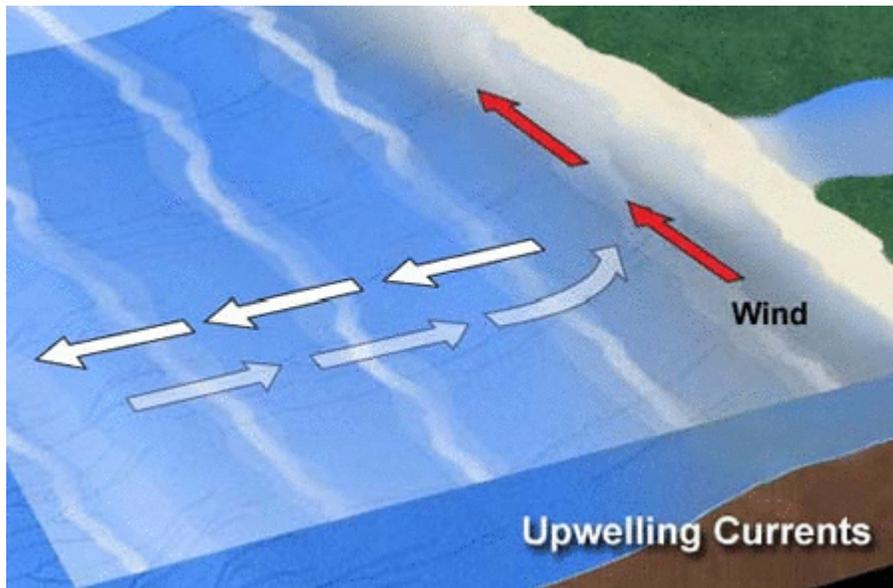
Upwelling near the coast due to Ekman transport perpendicular to the wind in the northern hemisphere.

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.
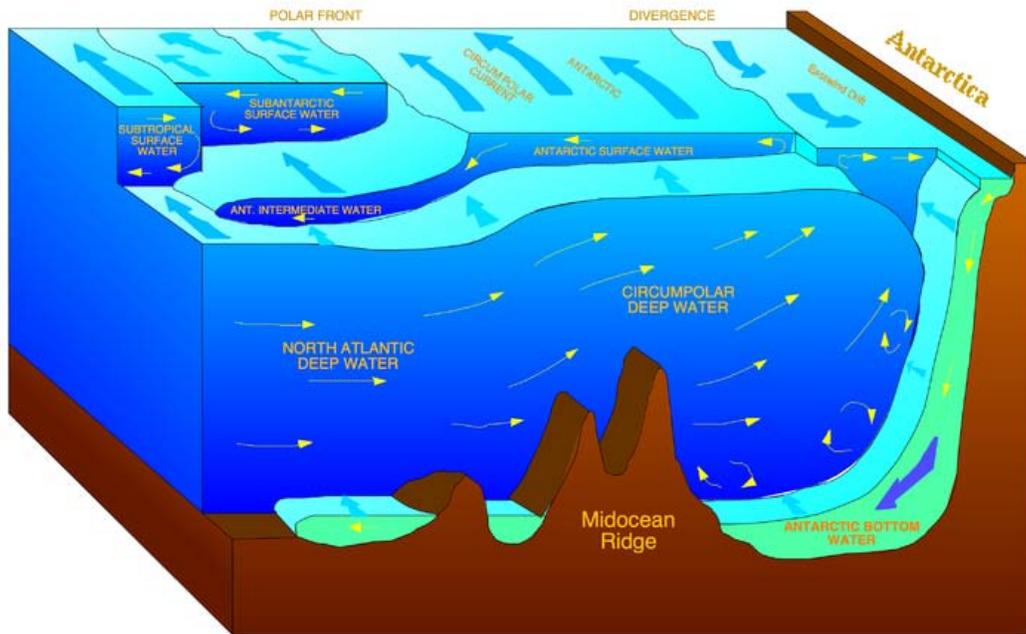
The food chain follows the course of:

- 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

POLAR FRONT   DIVERGENCE

Antarctica

SUBANTARCTIC SURFACE WATER

SUBTROPICAL SURFACE WATER

ANTARCTIC SURFACE WATER

ANT. INTERMEDIATE WATER

CIRCUMPOLAR DEEP WATER

NORTH ATLANTIC DEEP WATER

Midocean Ridge

ANTARCTIC BOTTOM WATER

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
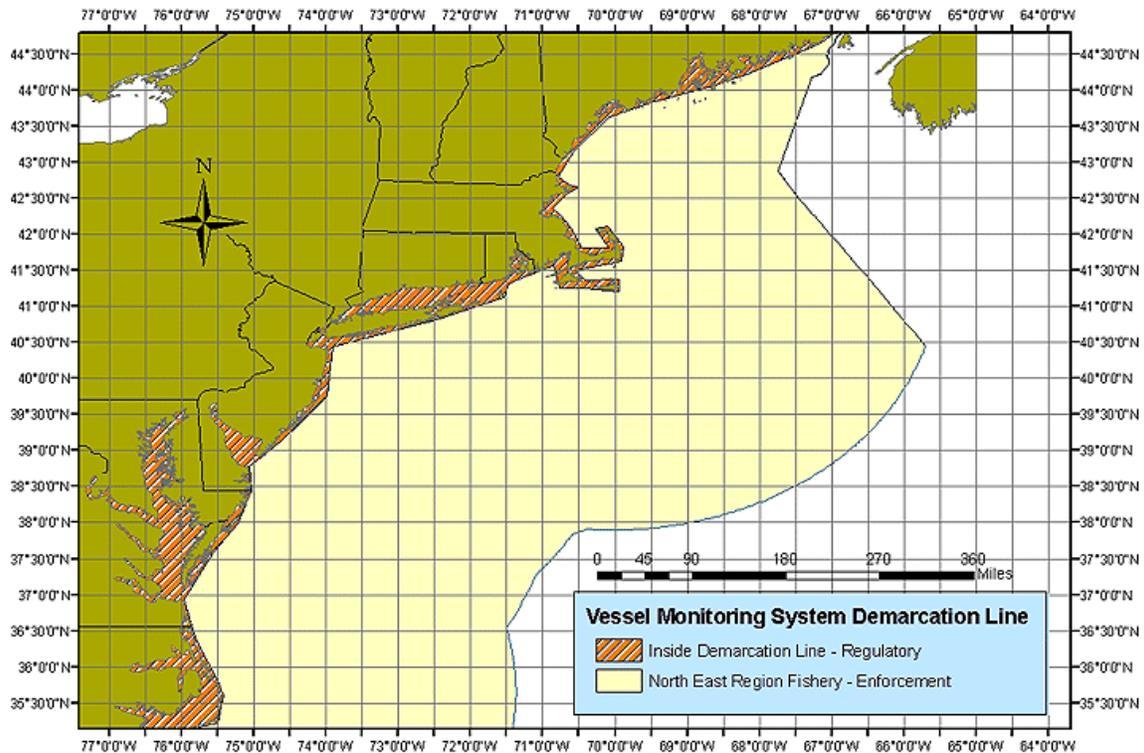
Vessel monitoring systems (VMS) are used in commercial fishing to allow environmental and fisheries regulatory organizations to monitor, minimally, the position, time at a position, and course and speed of fishing vessels. They are a key part of monitoring control and surveillance (MCS) programs at the 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

Maximum Sustainable Yield

In population ecology and economics, **maximum sustainable yield** or **MSY** is, theoretically, the largest yield (or catch) that can be taken from a species' stock over an indefinite period. Fundamental to the notion of sustainable harvest, the concept of MSY aims to maintain the population size at the point of maximum growth rate by harvesting the individuals that would normally be added to the population, allowing the population to continue to be productive indefinitely. Under the assumption of logistic growth, resource limitation does not constrain individuals' reproductive rates when populations are small, but because there are few individuals, the overall yield is small. At intermediate population densities, also represented by half the carrying capacity, individuals are able to breed to their maximum rate. At this point, called the maximum sustainable yield, there is a surplus of individuals that can be harvested because growth of the population is at its maximum point due to the large number reproducing individuals. Above this point, density dependent factors increasingly limit breeding until the population reaches carrying capacity. At this point, there are no surplus individuals to be harvested and yield drops to zero. The maximum sustainable yield is usually higher than the optimum sustainable yield and maximum economic yield.

MSY is extensively used for fisheries management. Unlike the logistic (Schaefer) model, MSY has been refined in most modern fisheries models and 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.

History

The concept of MSY as a fisheries management strategy developed in the early 1930s. It increased in popularity in the 1950s with the advent of surplus-production models with

explicitly estimate MSY. As an apparently simple and logical management goal, combined with the lack of other simple management goals of the time, MSY was adopted as the primary management goal by several international organizations (e.g., IWC, IATTC, ICCAT, ICNAF), and individual countries.

Between 1949 and 1955, the U.S. maneuvered to have MSY declared the goal of international fisheries management (Johnson 2007). The international MSY treaty that was eventually adopted in 1955 gave foreign fleets the right to fish off any coast. Nations that wanted to exclude foreign boats had to first prove that its fish were overfished.

As experience was gained with the model, it became apparent to some researchers that it lacked the capability to deal with the real world operational complexities and the influence of trophic and other interactions. In 1977, Larkin wrote its epitaph, challenging the goal of maximum sustained yield on several grounds: It put populations at too much risk; it did not account for spatial variability in productivity; it did not account for species other than the focus of the fishery; it considered only the benefits, not the costs, of fishing; and it was sensitive to political pressure. In fact, none of these criticisms was aimed at sustainability as a goal. The first one noted that seeking the absolute MSY with uncertain parameters was risky. The rest point out that the goal of MSY was not holistic; it left out too many relevant features.

Some managers began to use more conservative quota recommendations, but the influence of the MSY model for fisheries management still prevailed. Even while the scientific community was beginning to question the appropriateness and effectiveness of MSY as a management goal, it was incorporated into the 1982 United Nations Convention for the Law of the Sea, thus ensuring its integration into national and international fisheries acts and laws. According to Walters and Maguire, an ''institutional juggernaut had been set in motion'', climaxing in the early 1990s with the collapse of northern cod.

Modelling MSY

Population growth

The key assumption behind all sustainable harvesting models such as MSY is that populations of organisms grow and replace themselves – that is, they are renewable resources. Additionally it is assumed that because the growth rates, survival rates, and reproductive rates increase when harvesting reduces population density, they produce a surplus of biomass that can be harvested. Otherwise, sustainable harvest would not be possible.

Another assumption of renewable resource harvesting is that populations of organisms do not continue to grow indefinitely; they reach an equilibrium population size, which occurs when the number of individuals matches the resources available to the population (i.e., assume classic logistic growth). At this equilibrium population size, called the carrying capacity, the population remains at a stable size.
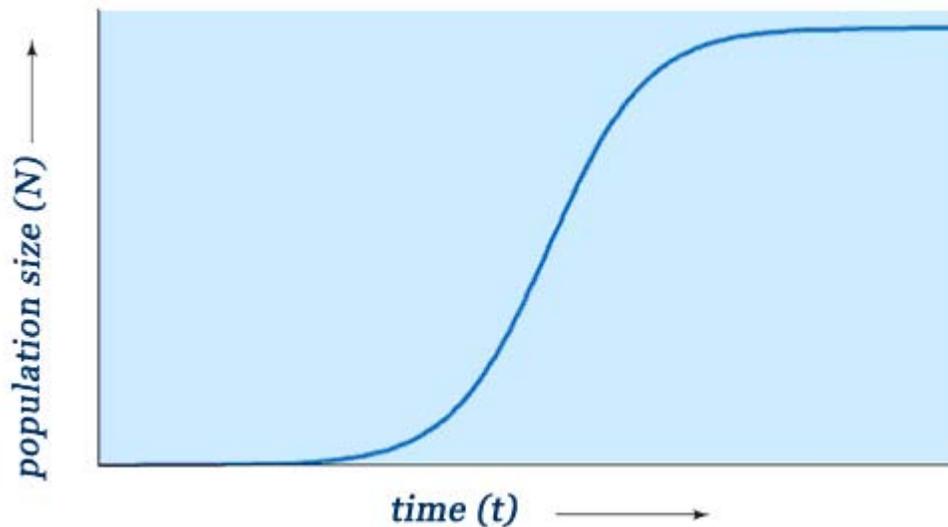
Figure 1

The logistic model (or logistic function) is a function that is used to describe bounded population growth under the previous two assumptions. The logistic function is bounded at both extremes: when there are not individuals to reproduce, and when there is an equilibrium number of individuals (i.e., at carrying capacity). Under the logistic model, population growth rate between these two limits is most often assumed to be sigmoidal (Figure 1). There is scientific evidence that some populations do grow in a logistic fashion towards a stable equilibrium – a commonly cited example is the logistic growth of yeast.

The equation describing logistic growth is:

$$N_t = \frac{K}{1 + \frac{K - N_0}{N_0} e^{-rt}}$$ (equation 1.1)

The parameter values are:

N_t=The population size at time t
K=The carrying capacity of the population
N_0= The population size at time zero
r= the intrinsic rate of population increase (the rate at which the population grows when it is very small)

From the logistic function, the population size at any point can be calculated as long as r, K, and N_0 are known.
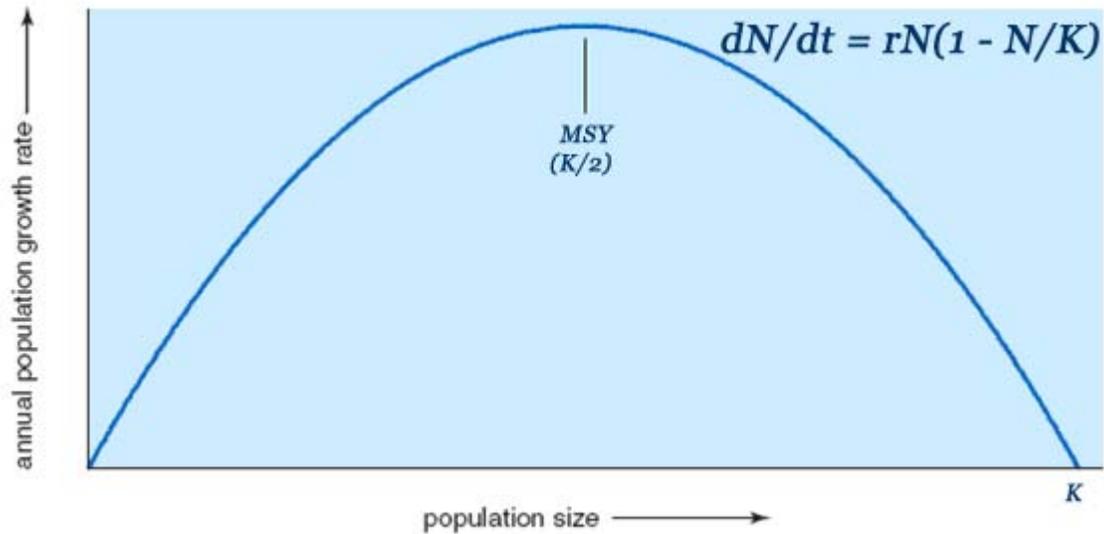
Figure 2

Differentiating equation 1.1 give an expression for how the rate of population increases as t increases. At first, the population growth rate is fast, but it begins to slow as times goes on, until it levels off to zero and then begins to decrease (figure 2).

The equation for figure 2 is the differential of equation 1.1 (Verhulst's 1838 growth model):

$$\frac{dN}{dt} = rN \left(1 - \frac{N}{K}\right)$$ (equation 1.2)

$\frac{dN}{dt}$ can be understood as the change in population (N) with respect to a change in time (t). Equation 1.2 is the usual way in which logistic growth is represented mathematically and has several important features. First, at very low population sizes, the value of $\frac{N}{K}$ is small, so the population growth rate is approximately equal to rN, meaning the population is growing exponentially at a rate r (the intrinsic rate of population increase). Despite this, the population growth rate is very low (low values on the y-axis of figure 2) because, even though each individual is reproducing at a high rate, there are few reproducing individuals present. Conversely, when the population is large the value of $\frac{N}{K}$ approaches 1 effectively reducing the terms inside the brackets of equation 1.2 to zero. The effect is that the population growth rate is again very low, because either each individual is hardly reproducing or mortality rates are high. As a result of these two

extremes, the population growth rate is maximum at an intermediate population or half the carrying capacity ($N = \dfrac{K}{2}$).
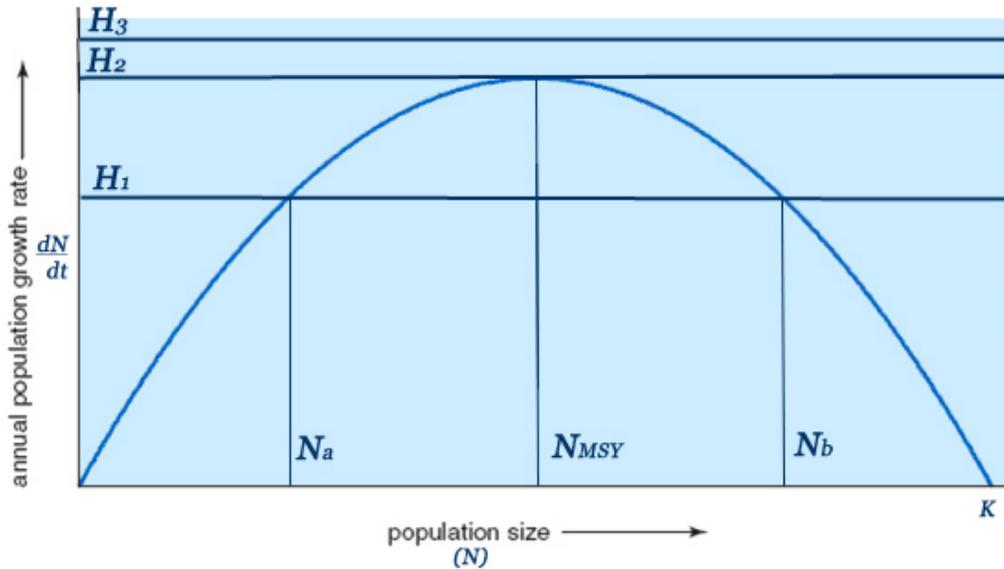
MSY model

Figure 3

The simplest way to model harvesting is to modify the logistic equation so that a certain number of individuals is continuously removed:

$$\frac{dN}{dt} = rN(1 - \frac{N}{K}) - H \quad \text{(equation 1.3)}$$

Where H represents the number of individuals being removed from the population – that is, the harvesting rate. When H is constant, the population will be at equilibrium when the number of individuals being removed is equal to the population growth rate (figure 3). The equilibrium population size under a particular harvesting regime can be found when the population is not growing – that is, when $\dfrac{dN}{dt} = 0$. This occurs when the population growth rate is the same as the harvest rate:

$$rN(1 - \frac{N}{K}) = H$$

Figure 3 shows how growth rate varies with population density. For low densities (far from carrying capacity), there is little addition (or "recruitment") to the population, simply because there are few organisms to give birth. At high densities, though, there is

intense competition for resources, and growth rate is again low because the death rate is high. In between these two extremes, the population growth rate rises to a maximum value (N_{MSY}). This maximum point represents the maximum number of individuals that can be added to a population by natural processes. If more individuals than this are removed from the population, the population is at risk for decline to extinction. The maximum number that can be harvested in a sustainable manner, called the maximum sustainable yield, is given by this maximum point.

Figure 3 also shows several possible values for the harvesting rate, H. At H_1, there are two possible population equilibrium points: a low population size (N_a) and a high one (N_b). At H_2, a slightly higher harvest rate, however there is only one equilibrium point (at N_{MSY}), which is the population size that produces the maximum growth rate. With logistic growth, this point, called the maximum sustainable yield, is where the population size is half the carrying capacity (or $N = \dfrac{K}{2}$). The maximum sustainable yield is the largest yield that can be taken from a population at equilibrium. In figure 3, if H is higher than H_2, the harvesting would exceed the population's capacity to replace itself at any population size (H_3 in figure 3). Because harvesting rate is higher than the population growth rate at all values of N, this rate of harvesting is not sustainable.

An important feature of the MSY model is how harvested populations respond to environmental fluctuations or illegal offtake. Consider a population at N_b harvested at a constant harvest level H_1. If the population falls (due to a bad winter or illegal harvest) this will ease density-dependent population regulation and increase yield, moving the population back to N_b, a stable equilibrium. In this case, a negative feedback loop creates stability. The lower equilibrium point for the constant harvest level H_1 is not stable however; a population crash or illegal harvesting will decrease population yield farther below the current harvest level, creating a positive feedback loop leading to extinction. Harvesting at N_{MSY} is also potentially unstable. A small decrease in the population can lead to a positive feedback loop and extinction if the harvesting regime (H_2) is not reduced. Thus, some consider harvesting at MSY to be unsafe on ecological and economic grounds. The MSY model itself can be modified to harvest a certain percentage of the population or with constant effort constraints rather than an actual number, thereby avoiding some of its instabilities.

The MSY equilibrium point is semi-stable – a small increase in population size is compensated for, a small decrease to extinction if H is not decreased. Harvesting at MSY is therefore dangerous because it is on a knife-edge – any small population decline leads to a positive feedback, with the population declining rapidly to extinction if the number of harvested stays the same.

The formula for maximum sustained harvest (H) is one-fourth the maximum population or carrying capacity (K) times the intrinsic rate of growth (r).

$$H = \frac{Kr}{4}$$

Implications of MSY model

Starting to harvest a previously unharvested population will always lead to a decrease in the population size. That is, it is impossible for a harvested population to remain at its original carrying capacity. Instead, the population will either stabilize at a new lower equilibrium size or, if the harvesting rate is too high, decline to zero.

The reason why populations can be sustainably harvested is that they exhibit a density-dependent response. This means that at any population size below K, the population is producing a surplus yield that is available for harvesting without reducing population size. Density dependence is the regulator process that allows the population to return to equilibrium after a perturbation. The logistic equation assumes that density dependence takes the form of negative feedback.

If a constant number of individuals is harvested from a population at a level greater than the MSY, the population will decline to extinction. Harvesting below the MSY level leads to a stable equilibrium population if the starting population is above the unstable equilibrium population size.

Uses of MSY

MSY has been especially influential in the management of renewable biological resources such as commercially important fish and wildlife. In fisheries terms, **maximum sustainable yield** (MSY) is the largest average catch that can be captured from a stock under existing environmental conditions. MSY aims at a balance between too much and too little harvest to keep the population at some intermediate abundance with a maximum replacement rate.

Relating to MSY, the maximum economic yield (MEY) is the level of catch that provides the maximum net economic benefits or profits to society. Like optimum sustainable yield, MEY is usually less than MSY.

Limitations of MSY approach

Although it is widely practiced by state and federal government agencies regulating wildlife, forests, and fishing, MSY has come under heavy criticism by ecologists and others from both theoretical and practical reasons. The concept of maximum sustainable yield is not always easy to apply in practice. Estimation problems arise due to poor assumptions in some models and lack of reliability of the data. Biologists, for example, do not always have enough data to make a clear determination of the population's size and growth rate. Calculating the point at which a population begins to slow from competition is also very difficult. The concept of MSY also tends to treats all individuals

in the population as identical, thereby ignoring all aspects of population structure such as size or age classes and their differential rates of growth, survival, and reproduction.

As a management goal, the static interpretation of MSY (i.e., MSY as a fixed catch that can be taken year after year) is generally not appropriate because it ignores the fact that fish populations undergo natural fluctuations (i.e., MSY treats the environment as unvarying) in abundance and will usually ultimately become severely depleted under a constant-catch strategy. Thus, most fisheries scientists now interpret MSY in a more dynamic sense as the maximum average yield (MAY) obtained by applying a specific harvesting strategy to a fluctuating resource.

Orange roughy

An example of errors in estimating the population dynamics of a species occurred with in the New Zealand Orange roughy fishery. Early quotas were based on an assumption that the orange roughy had a fairly short lifespan and bred relatively quickly. However, it was later discovered that the orange roughy lived a long time and had bred slowly (~30 years). By this stage stocks had been largely depleted.

Overfishing

All around the world, from the arctic to the tropics, there is a crisis in the world's fisheries. Until fairly recently it was assumed that our marine resources were limitless.

In recent years however, an accelerating decline has been observed in the productivity of many important fisheries. Fisheries which have been devastated in recent times include (but are not limited too) the great whale fisheries, the Grand Bank fisheries of the western Atlantic, and the Peruvian anchovy fishery. Recent assessments by the United Nations Food and Agriculture Organization (FAO) of the state of the world's fisheries indicate a levelling off of landings in the 1990s, at about 100 million tons.

In addition, the composition of global catches has changed. As fishers deplete larger, long-lived predatory fish species such as cod, tuna, shark, and snapper, they move down to the next level – to species that tend to be smaller, shorter-lived, and less valuable.

Overfishing is a classic example of the tragedy of the commons.

Optimum sustainable yield

In population ecology and economics, **optimum sustainable yield** is the level of effort (LOE) that maximizes the difference between total revenue and total cost. Or, where marginal revenue equals marginal cost. This level of effort maximizes the economic profit, or rent, of the resource being utilized. It usually corresponds to an effort level lower than that of maximum sustainable yield. In environmental science, **optimum sustainable yield** is the largest economical yield of a renewable resource achievable over

a long time period without decreasing the ability of the population or its environment to support the continuation of this level of yield.

Chapter 11

Reef Aquarium

Marine aquaria include "fish only" tanks, "fish only with live rock" (FOWLR) tanks, and "reef tanks". Fish only tanks often showcase large or aggressive marine fish species and generally rely on mechanical and chemical filtration. FOWLR and reef tanks use live rock, a material composed of coral skeletons harboring beneficial nitrogen waste metabolizing bacteria, as a means of more natural biological filtration. A **reef aquarium** or **reef tank** is an aquarium that prominently displays live corals and other marine invertebrates as well as fish that play a role in maintaining the coral reef environment. A reef aquarium requires appropriately intense lighting, turbulent water movement, and more stable water chemistry than fish-only marine aquaria, and careful consideration is given to which reef animals are appropriate and compatible with each other.

Components

Reef aquariums consist of a number of components, in addition to the livestock, including:

Display tank: The primary tank in which the livestock are kept and shown.

Stand: A stand allows for placement of the display tank at eye level and provides space for storage of the accessory components.

Sump: An accessory tank in which mechanical equipment is kept. A remote sump allows for a clutter-free display tank.

Refugium: An accessory tank dedicated to the cultivation of beneficial macroalgae and microflora/fauna. The refugium and sump are often housed in a single tank with a system of dividers to separate the compartments.

Lighting: Several lighting options are available for the reef-keeper and are tailored to the types of coral kept.

Canopy: The canopy houses the light fixtures and provides access to the tank for feeding and maintenance.

Filtration and water movement: A variety of filtration and water movement strategies are employed in reef aquaria. Bulky equipment is often relegated to the sump.

Display Tank

fig 1
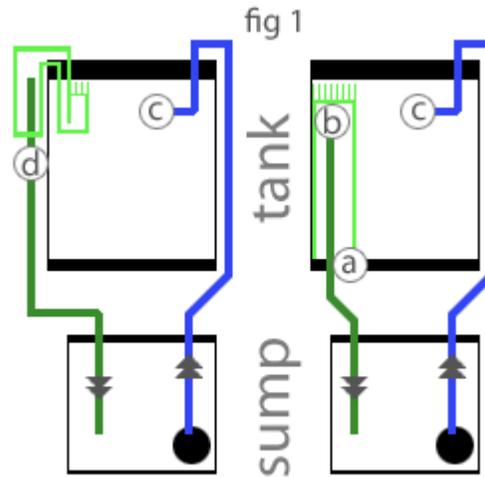
A "reef ready" or simply "drilled" tank is often used. This style of tank has holes drilled into the rear pane allowing water to drain into the sump or refugium. These drains are usually housed in an internal overflow aparatus made of plastic or glass which encloses a drain standpipe and a water return line (See fig 1, a). The surface water pours over the overflow, down the standpipe (See fig 1, b), through PVC piping, into the sump. After transiting the sump, water is pushed by a return water pump through the second hole and into the aquarium (See fig 1, c). Alternatively, standard non-drilled aquariums employ an external "hang-on" overflow that feeds water via continuous siphon to the sump (See fig 1 d). The tanks are usually constructed from either glass or acrylic. Acrylic has the advantage of optical clarity, lightness, and ease of drilling. Drawbacks include a tendency to scratch easily, bowing, and often limited access from above due to top bracing. Glass aquariums are heavier but harder to scratch. Other materials such as epoxy coated plywood have been used by industrious DIY'ers.

Filtration

The primary biological filtration for reef aquariums usually comes from the use of live rock which come from various tropical zones around existing reefs, or more recently aquacultured rock from Florida. Some Reefkeepers also use what is called Deep sand beds (DSB). These are often employed to augment this biological filtration by aiding in the reduction of nitrate (waste). Deep sand bed opponents may prefer a "bare bottom" or "suspended reef" which allows for easier removal of accumulated detritus to remove nitrate. This biologic filtration is usually supplemented by protein skimmers. Protein skimmers use the foam fractionation process wherein air is introduced into a water stream creating microbubbles. Organic waste adheres to the surface of these microbubbles and is removed as it accumulates at the reactor surface. When this group of elements listed are used in conjunction, it is referred to as the Berlin Method which first came from

Germany. In recent years the Berlin Method is being supplemented with a refugium. A refugum serves many benefits, which include nitrate reduction, as well as providing a natural food source. It preferably houses mainly two species of macroalgae, including *Caulerpa Prolifera* or *chaetomorphae* or both (because these two strains are known to not "Spore" but grow by "rooting" to propagate). Macroalgae is used for two reasons, 1) To remove from the water excess nutrients such as nitrate, phosphate, and iron., and 2) To support beneficial microflora and fauna (zooplankton) as well as small invertebrates (copepods and amphipods) are provided a space free of predation to grow and, when returned to the display tank, serve as food for corals and fish. Conventional combined mechanical/biological filtration used in fish only systems is avoided because these filters trap detritus and produce nitrate which may stunt the growth or even kill many delicate corals. Chemical filtration in the form of activated carbon is used when needed to remove discoloration of the water, or to remove dissolved matter (organic or otherwise) to help purify the water in the reef system.

Water movement
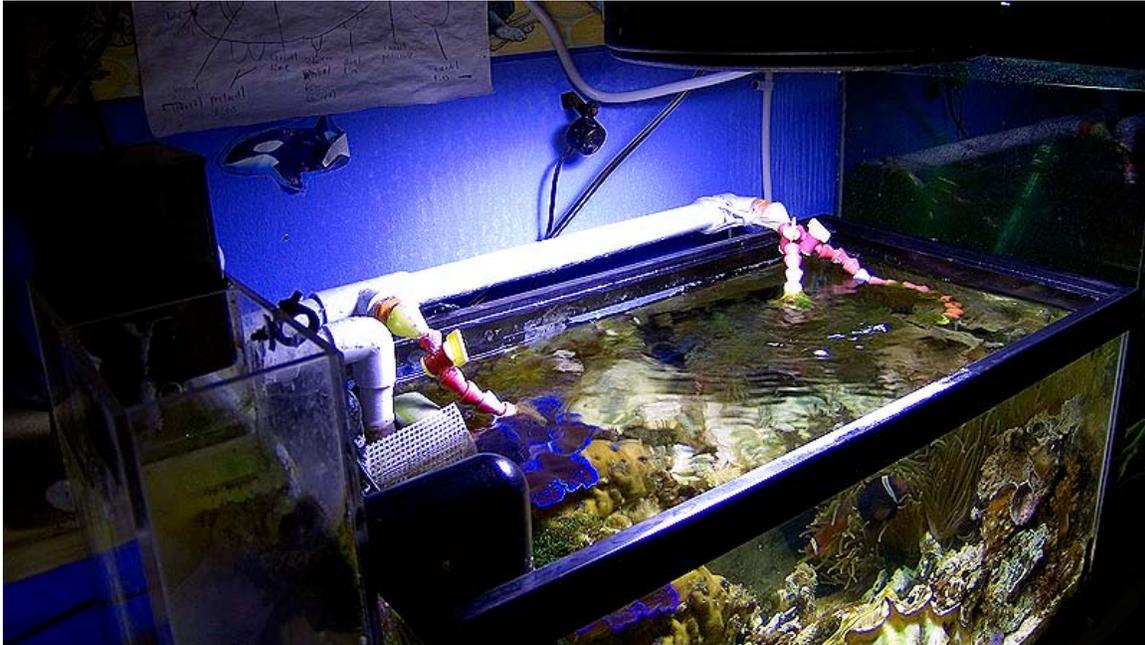
An example of a closed loop water circulation system

Water movement is important in the reef aquarium with different types of coral requiring different flow rates. At present, many hobbyists advocate a water turnover rate of 10x: 10 x aquarium capacity in gallons = required flow in gallons per hour. This is a general rule with many exceptions. For instance, Mushroom Coral requires little flow and is commonly found in crevices near the base of the reef. Species such as Acropora and Montipora thrive under much more turbulent conditions in the range of 30 to 40 times more flow, which imitates breaking waves in shallow water near the tip of the reef. The directions which water pumps are pointed within an aquarium will have a large effect on

flow speeds. Many corals will gradually move themselves to a different area of the tank if the water movement in its current area is not satisfactory.

"Since flow speed is the critical measure for determining the rate of gas exchange, turnover does little to convey how fast a coral will respire and photosynthesize."

Reef ready tanks obtain at least a portion of the required water motion from the pump that returns water from the sump. This flow usually is augmented by other strategies. A popular strategy is placement within the display tank of multiple powerheads. Powerheads are simply small submersible water pumps that produce a laminar or narrow, unidirectional water stream. If the presence of the powerhead in the tank does not fit with the aesthetics of the display, small holes may be drilled in an overflow of a tank and the bulk of the powerhead can be hidden, leaving only the small funnel spout visible in the tank. The pumps may be alternately switched on and off using a wave timer and aimed at one another or at the aquarium glass to create turbulent flow in the tank. Drawbacks to the use of these powerheads include their capacity to clutter the display tank, propensity for excess heat production, and the laminar quality of water flow often produced. Another method is the closed loop in which water is pulled from the main tank into a pump which returns the water back into the aquarium via one or more returns to create water turbulence. Newer submersible propeller pumps are gaining popularity and are able to generate large volumes of turbulent water flow without the intensely directed laminar force of a power head. Propeller pumps are more energy-efficient than powerheads, but require a higher initial investment.

Another recent method is the gyre tank. A gyre tank encourages a maximum amount of water momentum through a divider in the center of the aquarium. The divider leaves an open, unobstructed space which provides a region with little friction against water movement. Building water momentum using a gyre is an efficient method to increase flow, thus benefiting coral respiration and photosynthesis.

Water flow is important to bring food to corals, since no coral fully relies on photosynthesis for food. Gas exchange occurs as water flows over a coral, bringing oxygen and removing gases and shedding material. Water flow assists in reducing the risk of thermal shock and damage by reducing the coral's surface temperature. The surface temperature of a coral living near the water's surface can be significantly higher than the surrounding water due to infrared radiation.

Lighting

With the advent of newer and better technologies, increasing intensities and a growing spectrum, there are many options to consider.

Many, if not most aquarium corals contain within their tissue the symbiotic algae called zooxanthellae. It is these zooxanthellae that require light to perform photosynthesis and in turn produce simple sugars that the corals utilize for food. The challenge for the hobbyist is to provide enough light to allow photosynthesis to maintain a thriving

population of zooxanthellae in a coral tissue. Though this may seem simple enough, in reality this can prove to be a very complex task.

Some corals such as mushroom corals and polyp corals require very little light to thrive. Conversely, large-polyp stony corals such as brain coral, bubble coral, elegance coral, cup coral, torch coral, and trumpet coral require moderate amounts of light, and small polyp stony corals such as *Acropora*, *Montipora*, *Porites*, and *Pocillopora* require high intensity lighting.

Of the various types, most popular aquarium lighting comes from metal halide, very high output or VHO, compact fluorescent and T5 high output lighting systems. Although they were once widely used, many reef tank aquarists have abandoned T12 and T8 fluorescent lamps due to their poor intensity, and mercury vapor due to its production of a limited light spectrum.

Recent advances in lighting technology have also made available a completely new technology for aquarium lighting: lightemitting diodes (LEDs). Although LEDs themselves are not new, the technology has only recently been adapted to produce systems with qualities that allow them to be considered viable alternatives to gas- and filament-based aquarium lighting systems. The newness of the technology does cause them to be relatively expensive, but these systems bring several advantages over traditional lighting. Although their initial cost is much higher, they tend to be economical in the long run because they consume less power and have far longer lifespans than other systems. Also, because LED systems are made of hundreds of very small bulbs, a microcomputer can control their output can be controlled to simulate daybreak and sunset. Some systems also have the ability to simulate moonlight and the phases of the moon, as well as vary the color temperature of the light produced.

The choices for aquarium lighting are made complicated by variables such as color temperature, (measured in kelvins), color rendering index (CRI), photosynthetically active radiation (PAR) and lumens. Power output available to the hobbyist can range from a meager 9 W fluorescent lamp to a blinding 1000 W metal halide. Lighting systems also vary in the light output produced by each bulb type—listed in order of weakest to strongest they would be: T8/12 or normal output lamps, compact fluorescent and T5 high output, VHO, and metal halide lamps. To further complicate matters, there are several types of ballasts available: electric ballast, magnetic ballast, and pulse start ballast.

Heating and cooling

Reef tanks are usually kept at a temperature between 25 and 28 °C (75-82 °F). Radical temperature shifts should be avoided as these can be particularly harmful to reef invertebrates and fish. Depending on the location of the tank and the conditions therein (i.e. heat/air conditioning), one may install a heater and/or a chiller for the tank. Heaters are relatively inexpensive and readily available at any local fish store. Aquarists frequently use the sump to hide unsightly equipment such as heaters. Chillers, on the other hand, are expensive and are more difficult to locate. For many aquarists, installing

surface fans and running home air conditioning suffice in place of a chiller. Fans cool the tank via evaporative cooling and require more frequent top-off of the aquarium water.

Water chemistry

Stony corals, which are defined by their calcerous calcium carbonate skeletons ($CaCO_3$), are the focus of many advanced reef keepers. These corals require additional attention to water chemistry, especially maintenance of stable and optimal calcium, carbonate, and pH levels. These parameters may be tracked and adjusted with test kits and frequent manual dosing of calcium and pH buffer additives requiring no additional equipment. Alternatively, automated methods employing small dedicated computers with electronic water quality monitoring capabilities are often used to control water chemistry parameters via several components including calcium reactors and kalkwasser reactors. Calcium reactors are canisters filled with crushed coral skeletons. Carbon dioxide is injected into the canister acidifying the water and dissolving the coral skeletons. The acidified and $CaCO_3$ rich solution is then pumped into the sump. The excess CO_2 then diffuses out of the water and into the air leaving behind the $CaCO_3$. Kalkwasser is an aqueous solution of calcium hydroxide, $Ca(OH)_2$. The kalk reactor stirs the solution, preventing precipitation, and dispenses the solution into the sump where the $Ca(OH)_2$ combines with dissolved CO_2 to produce $CaCO_3$. These components must be controlled by a computer to prevent dangerous changes in pH due to the acidic calcium reactor effluent or alkaline kalkwasser effluent.

Safety

Large volumes of highly conductive salt water, complex plumbing, and numerous electrical appliances housed in close proximity certainly pose a significant risk of damage to both person and property and require close attention to safety. All equipment should be used according to manufacturer instructions. Electrical equipment should be placed above water level whenever possible, and drip loops should always be used. Circuit limits should never be exceeded and all appliances should be plugged into ground fault circuit interrupter (GFCI) outlets. These can be purchased at any hardware store and are relatively easy to install. Plug in GFCI power strips are also readily available. Home monitoring equipment with water sensors can also be adapted for the home aquarist and used to alert the owner of power outages or water overflows. This equipment can allow for timely intervention in a potential disaster and provides an added sense of security for frequent travelers.

Nano reefs

14 litre (3 gallon) nano reef containing small and large polyped stony corals

A **nano reef** is a type of marine aquarium that is typically less than 140 litres (30 gallons). The exact limit that distinguishes a nano reef from a regular reef is somewhat ill-defined (some claim that anything less than 180 litres/40 gallons would qualify), but 140 litres (30 gallons) seems to be the generally accepted limit. Nano reefs have become quite popular in recent years among fish keeping hobbyists, primarily because of their smaller size, maintainability, and the possibility of lower costs. The burgeoning interest in this niche of marine aquarium science has fostered several notable contributions ranging from specific consumer products such as specialized aquarium filters, compact high intensity lighting systems and smaller circulation pumps. Such equipment allows the aquarist to maintain an environment wherein many marine organisms are capable of thriving.

Nano reefs are very commonly sold as complete kits which contain the tank, stand, power compact T5, T8, PL lamps or Metal Halide lighting, protein skimmer, UV steriliser, 3 or more stage filtration, a heater and a water pump or powerhead. However, many nano reefkeepers decide to upgrade their aquariums with better quality equipment such as a more powerful protein skimmer or lighting.

Pico reefs

Another term gaining popularity is *pico reef*, which is used to refer to the smallest of nano reef aquariums. Most online forum polls set the range of approximately 2.5 gallons and below as pico reefs. These tiny tanks require even more diligence with regard to

water changes and attention to water chemistry because the small water volume provides little room for error. Care must be exercised when stocking these tiny tanks because too many inhabitants can easily overload the tank's ability to process wastes effectively. For the smallest of pico reefs, even the presence of a single fish is discouraged. Pico reefs often consist of live rock, hardy corals, and small invertebrates such as hermit crabs and marine snails. The keeping of pico reef aquariums has tested the extent of allelopathy, the chemical and physical means by which corals compete for space. Before the advent of these concentrated environments, it was thought to be impossible for corals of even a few mixed genera to occupy such a small shared water volume.

Challenges associated with small reef aquariums

Because of the small water volume, nano reef aquariums require extra attention to water quality compared to aquariums of larger water volumes. Many experienced reef aquarists recommend testing the water twice weekly, with water changes at least every week. In particular, ammonia, nitrite, nitrate, pH, salinity, alkalinity, calcium and phosphate levels should be monitored closely. When it comes to nano reefs, even minute changes in water conditions such as mild temperature fluctuations can be problematic, whereas the greater water volume of larger aquariums provides a more stable and flexible environment.

Nano reefs also require extra care in the selection of occupants. There are two major factors to be considered: biological load, i.e. the ability of the tank to process the wastes produced by the occupants, and species compatibility. These issues, though present in larger tanks, are magnified in the nano tank. Species considered reef safe and able to coexist in larger tanks may not do well in a nano tank due to their close physical proximity. For this reason, smaller species of fish such as gobies and clownfish are popular choices due to their relatively small size and ability to coexist peacefully with other tank inhabitants.

Filtration in nano reefs

Many nano reef aquarists prefer their nano reefs to be as natural-looking as possible, and therefore choose to use as few mechanical filtration methods as possible. The primary filtration method of choice in nano reefs is a good amount live rock and live sand, which are pieces of rock that have broken from the coral reef and are populated with millions of beneficial bacteria and organisms which aid in the dissolving of organic wastes produced by larger organisms in the nano reef. However, many other nano reef aquarists use devices such as protein skimmers to remove excess wastes from the aquarium, before it has a chance to be broken down in to nitrate. Removing the excess wastes mechanically can reduce the frequency of water changes needed to keep nitrate levels low, and delaying the action of the mechanical filters, such as by means of a day-night timer, can allow the invertebrates to filter-feed naturally on them for a long period first. A refugium may also be used to export nutrients. A refugium can be packed with macroalgae such as *Chaetomorpha*, and live rock. A DSB (Deep Sand Bed) filter is used as an efficient filtration method too.
Recently there have been several "natural" methods of processing waste in the aquarium

and specifically small environments as nano-reefs. The research on the encouragement of the development of different types of sponges and micro-organisms to process the pollutants in the aquarium, a matter that has been gaining popularity in the aquarium community.

Chapter 12

Whaling Controversy

The **whaling controversy** is the international environmental and ethical debate over whale hunting. The debate has focused on issues of sustainability and conservation as well as ownership and national sovereignty. Also raised in debates is the question of cetacean intelligence and the level of suffering which the animals undergo when caught and killed. Since the International Whaling Commission (IWC) 1986 moratorium on commercial whaling, the value of lethal sampling of whales for scientific research in order to establish catch quotas has also been debated. Finally, the value of whaling to fisheries as a method of controlling whales' perceived negative impact on fish stocks is another point of debate.

Conservation status
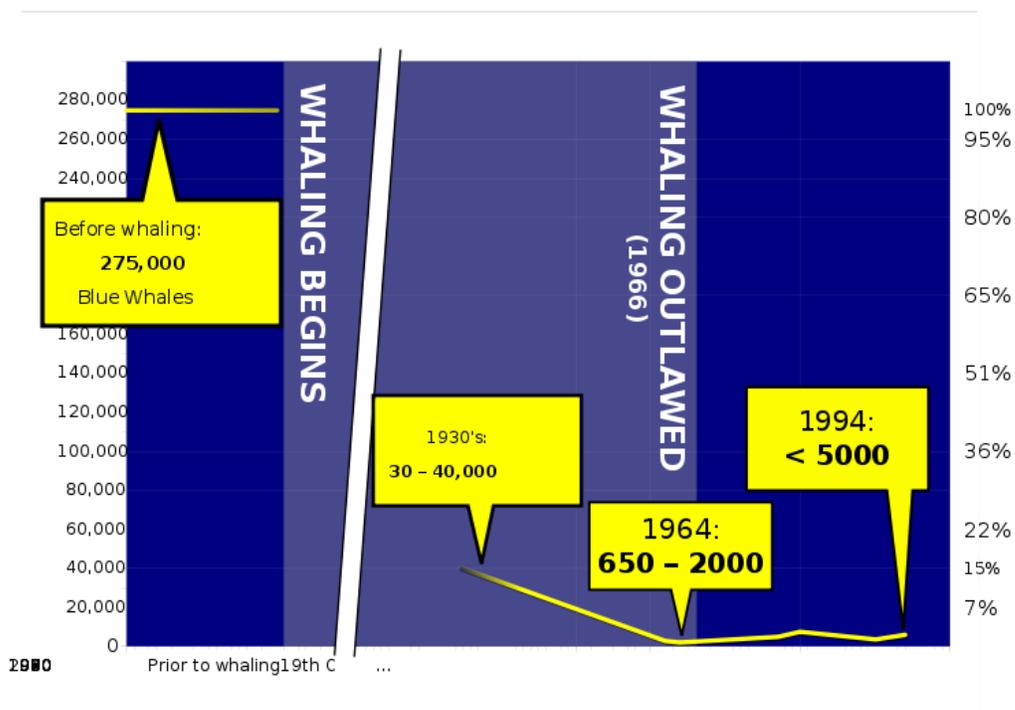
Blue whale populations have declined dramatically due to unregulated commercial whaling, putting them at risk of extinction.

Prior to the setting up of the IWC in 1946, unregulated whaling had depleted a number of whale populations to a significant extent, and several whales species were severely endangered. The IUCN notes that the Atlantic population of gray whales was made extinct around the turn of the eighteenth century. Examination of remains found in England and Sweden found evidence of a separate Atlantic population of gray whales existing up until 1675. Radiocarbon dating of subfossil remains has confirmed this, with whaling the possible cause. Whaling and other threats have led to at least five of the 13 great whales being listed as endangered. A past ban which was implemented around the 1960s has helped some of these species of whale to recover. According to IUCN's Cetacean Specialist Group (CSG), "Several populations of southern right whales, humpbacks in many areas, grey whales in the eastern North Pacific, and blue whales in both the eastern North Pacific and central North Atlantic have begun to show signs of recovery." Populations of many other whales species are also increasing.

Other whale species, however (in particular the minke whale) have never been considered endangered.

Despite this, opponents of whaling argue that a return to full-scale commercial whaling will lead to economic concerns overriding those of conservation, and there is a continuing battle between each side as to how to describe the current state of each species. For instance, conservationists are pleased that the sei whale continues to be listed as endangered, but Japan says that the species has swelled in number from 9,000 in 1978 to about 28,000 in 2002, so its catch of 50 sei whales per year is safe and the classification of endangered should be reconsidered for the North Pacific population.

Some North Atlantic states have recently argued that fin whales should not be listed as endangered anymore and criticize the list for being inaccurate. IUCN has recorded studies showing that more than 40,000 individuals are present in the North Atlantic Ocean around Greenland, Iceland, and Norway. There is no information about fin whales in areas outside of the Northern Atlantic, where they still hold the status of being endangered.

A complete list of whale conservation statuses as listed by The World Conservation Union (IUCN) is given below. Note that, in the case of the blue and gray whales, the IUCN distinguishes the statuses of various populations. These populations, while not regarded as separate species, are considered sufficiently important in terms of conservation.

Methods of whaling

Whaling harpoon

Whaling harpoon being used to kill a whale

Farming whales in captivity has never been attempted and would almost certainly be logistically impossible. Instead, whales are harvested at sea often using explosive harpoons, which puncture the skin of a whale and then explode inside its body. Anti-whaling groups say this method of hunting is cruel, particularly if carried out by inexperienced gunners, because a whale can take several minutes or even hours to die. In March 2003, Whalewatch, an umbrella group of 140 conservation and animal welfare groups from 55 countries, led by the World Society for the Protection of Animals (WSPA), published a report, *Troubled Waters*, whose main conclusion was that whales cannot be guaranteed to be harvested humanely and that all whaling should be stopped. The report quoted official figures that said 20% of Norwegian and 60% of Japanese-captured whales failed to die as soon as they had been harpooned. WSPA further released a report in 2008 entitled *Whaling: Defying international commitments to animal welfare?* in which the culling of whales is compared–unfavorably–with slaughter guidelines for farm animals from the World Organisation for Animal Health (OIE).

John Opdahl of the Norwegian embassy in London responded by saying that Norwegian authorities worked with the IWC to develop the most humane methods. He said that the average time taken for a whale to die after being shot was the same as or less than that of animals killed by big game hunters on safari. Pro-whalers also say that the free-roaming lifestyle of whales followed by a quick death is less cruel than the long-term suffering of factory-farmed animals.

In response to the UK's opposition to the resumption of commercial whaling on the grounds that no humane method of catching whales exists, or "is on the horizon", the pro-whaling High North Alliance points to apparent inconsistencies in the policies of some anti-whaling nations by drawing comparisons between commercial whaling and recreational hunting. For instance, the United Kingdom allows the commercial shooting

of deer without these shoots adhering to the standards of British slaughterhouses, but says that whalers must meet such standards as a pre-condition before they would support whaling. Moreover, fox hunting, in which foxes are mauled by dogs, is legal in many anti-whaling countries including Ireland, the United States, Portugal, Italy and France (although not in the United Kingdom) according to UK Government's Burns Inquiry (2000). Pro-whaling nations argue that they should not be expected to adhere to animal-welfare standards which anti-whaling countries do not themselves follow consistently, and draw the conclusion that the cruelty argument is a mere expression of cultural bigotry, similar to the Western attitude towards the eating of dog meat in several East Asian countries.

The economic argument
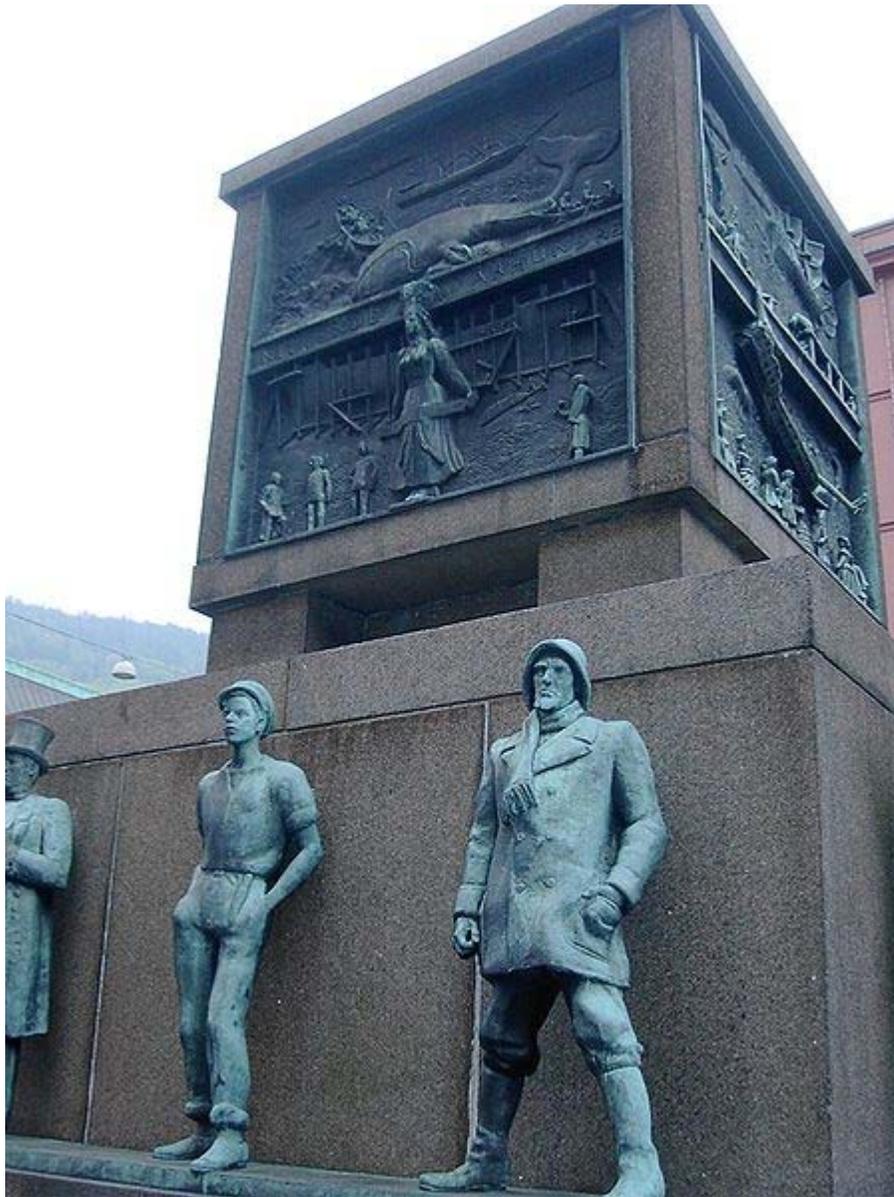
Sailors Monument, Bergen, Norway

The whale watching industry and anti-whaling advocates argue that whaling catches "friendly" whales that are curious about boats, as these whales are the easiest to catch. This analysis claims that once the economic benefits of hotels, restaurants and other tourist amenities are considered, hunting whales is a net economic loss. This argument is particularly contentious in Iceland, as it has among the most-developed whale-watching operations in the world and the hunting of minke whales resumed in August 2003. Brazil, Argentina and South Africa argue that whale watching is a growing billion-dollar industry that provides more revenue and more equitable distribution of profits than commercial whaling by pelagic fleets from far-away developed countries would provide. Peru, Uruguay, Australia, and New Zealand also support proposals to permanently forbid whaling South of the Equator, as Indonesia is the only country in the Southern Hemisphere with a whaling industry. Anti-whaling groups claim that developing countries which support a pro-whaling stance are damaging their economies by driving away anti-whaling tourists.

Pro-whaling advocates argue that the economic analysis assumes unsustainable whaling by arguing that whaling deprives the whale-watching industry of whales, and counter that if whales are hunted on a sustainable basis, there is no competition between the two industries. Furthermore, they point out that most whaling takes place outside of coastal areas where whale watching takes place, and communication between any whaling fleet and whale-watching boats would ensure that whaling and whale watching occurred in different areas. Pro-whaling advocates also argue that whaling continues to provide employment in the fishery, logistic and restaurant industries and that whale blubber can be converted into valuable oleochemicals while whale carcasses can be rendered into meat and bone meal. Poorer whaling nations argue that the need for resumption of whaling is pressing. Horace Walters, from the Eastern Caribbean Cetacean Commission stated, "We have islands which may want to start whaling again - it's expensive to import food from the developed world, and we believe there's a deliberate attempt to keep us away from our resources so we continue to develop those countries' economies by importing from them."

Intelligence

While whales possess the largest physical brains of any animal, there is no consensus about the existence, nature and magnitude of cetacean intelligence. This lack of knowledge is partly because of the cost and difficulty of carrying out research with marine mammals. Humpback whales have been found to have spindle neurons, a type of brain cell previously considered to exist only in dolphins, humans and other primates, and some species of whale are highly social.

There is an argument that whales should not be killed because of their alleged high intelligence. Pro-whalers counter that pigs, which also possess high intelligence, are routinely butchered and eaten, or indeed that intelligence should not be the determining factor of whether an animal is acceptable to eat or not.

Safety of eating whale meat

A dish of whale meat in Japan

Whale meat products from certain species have been shown to contain pollutants such as PCBs, mercury, and dioxins. Levels of pollutants in toothed-whale products are significantly higher than those of baleen whales, reflecting the fact that toothed whales feed at a higher trophic level than baleen whales in the food chain (other high-up animals such as sharks, swordfish and large tuna show similarly high levels of mercury contamination). Organochloride pesticides HCH and HCB are also at higher levels in toothed species, while minke whales show higher levels than most other baleens.

The red meat and blubber of (toothed) long-finned pilot whales in the Faroe Islands show high toxin levels, which has a detrimental effect on those who eat it. However, in Norway, only the red meat of minke whales is eaten and the levels of toxins conform to national limits, while Japanese health-ministry scientists have found that minke whale meat harvested from the Antarctic, which constitutes the vast majority of whale meat eaten in Japan is similarly within national standards for mercury and PCB levels.

Whale meat is very high in protein and very low in saturated fat.

Fishing

August 26, 2006 Hvalba, Faroe Islands

Whalers say that whaling is an essential condition for the successful operation of commercial fisheries, and thus the plentiful availability of food from the sea that consumers have become accustomed to. This argument is made particularly forcefully in Atlantic fisheries, for example the cod-capelin system in the Barents Sea. A minke whale's annual diet consists of 10 kilograms of fish per kilogram of body mass, which puts a heavy predatory pressure on commercial species of fish, thus whalers say that an annual cull of whales is needed in order for adequate amounts of fish to be available for humans. Anti-whaling campaigners say that the pro-whaling argument is inconsistent: if the catch of whales is small enough not to negatively affect whale stocks, it is also too small to positively affect fish stocks. To make more fish available, they say, more whales will have to be killed, putting populations at risk. Additionally, whale feeding grounds and commercial fisheries do not always overlap.

Professor Daniel Pauly, Director of the Fisheries Center at the University of British Columbia weighed into the debate in July 2004 when he presented a paper to the 2004 meeting of the IWC in Sorrento. Pauly's primary research is the decline of fish stocks in the Atlantic, under the auspices of the Sea Around Us Project. This report was commissioned by Humane Society International, an active anti-whaling lobby, and stated that although cetaceans and pinnipeds are estimated to eat 600 million tonnes of food per year, compared with just 150 million tonnes eaten by humans (although researchers at the Japanese Institute for Cetacean Research give figures of 90 million tonnes for humans

and 249-436 million tonnes for cetaceans), much of the food eaten by cetaceans (in particular, deep sea squid and krill) is not consumed by humans. However, Japanese do eat krill, and krill is also used in large quantities by fish farms as feed. Pauly's report also claims that the locations where whales and humans catch fish only overlap to a small degree, and he also considers more indirect effects of whales' diet on the availability of fish for fisheries. He concludes that whales are not a significant reason for diminished fish stocks.

More recent studies have also concluded that there are several factors contributing to the decline in fish stocks, such as pollution and habitat loss.

However, the dietary behaviour of whales differ among species as well as season, location and availability of prey. For example, sperm whales' prey primarily consists of mesopelagic squid. However, in Iceland, they are reported to consume mainly fish. In addition to krill, minke whales are known to eat a wide range of fish species including capelin, herring, sand lance, mackerel, gadoids, cod, saithe and haddock. Minke whales are estimated to consume 633,000 tons of Atlantic herring per year in part of Northeast Atlantic. In the Barents Sea, it is estimated that a [potential] net economic loss of five tons of cod and herring per fishery results from every additional minke whale in the population due the fish consumption of the single whale.

Value for research

Since the 1986 IWC ban on whaling, Japan has conducted its whaling by issuing scientific research permits. The value of "lethal sampling" of whales is a highly contentious issue. The stated aim of the Japanese JARPA research program is to establish sustainable whaling in the Antarctic Ocean. The selling of whale meat from the lethal sampling to fish markets is purportedly to help fund the research, a claim disputed by opponents as being a cover for illegal whaling. The IWC requires information on population structure, abundance and prior whaling history, which anti-whalers argue can be obtained through non-lethal means.

Lethal sampling is required to obtain age information and precise dietary composition. The age of a whale can be reliably gathered by examining the ear plug in the head of the dead animal, which accumulates as annual growth rings. Japan initially argued that simple population distribution of whale species is enough to determine the level of sustainability of the hunt and argued that certain species of whale, particularly minke whales, are in sufficient number to be hunted. The anti-whaling side countered by arguing that more accurate composition of population distribution in term of age and sex distribution is needed to determine the sustainability, which ironically provided the justification for the Japanese hunt under the scientific research exemption. According to lethal-sampling opponent Nick Gales, age data is not needed to establish a catch limit for whaling within the framework of the Revised Management Procedure (RMP) computer modeling, which is the stated goal of the Japanese research. However, deputy whaling commissioner, Joji Morishita, told BBC News that "The reason for the moratorium [on commercial whaling] was scientific uncertainty about the number of whales. ... It was a

moratorium for the sake of collecting data and that is why we started scientific whaling. We were asked to collect more data."

Dietary information is obtained with lethal sampling by cutting open the stomach of the animal. Opponents of lethal sampling state that dietary habits can be ascertained by biopsies as well as collecting feces from living whales. Proponents counter by stating that biopsies only reveal the type of food consumed (such as fish or krill) and not the exact type of fish, and that feces analysis does not provide as good of a quantitative estimation of dietary consumption.

Although lethal sampling is a heavily debated issue, the IWC Scientific Committee acknowledges the usefulness of the data from JARPA. In a November 2008 review of Japan's first 18 years of its scientific whaling program, the IWC stated that the panel was "very pleased with the data [that Japan] collected," and though "there was some advice on how these data could be further analyzed, or better analysed," that there "was general consensus about the high quality and the usefulness of the data."

Australian Prime Minister Kevin Rudd proposed to bring the issue to International Court of Justice in aim of stopping Japan from conducting scientific research.

Animal rights

The animal rights perspective states that environmental concerns, possible cetacean intelligence, and animal welfare concerns are irrelevant. The fundamental principle of the animal rights movement is that animals have basic interests that deserve recognition, consideration, and protection. In the view of animal rights advocates, these basic interests give the animals that have them both moral and legal rights. Thus, humans have a moral obligation to minimize or avoid causing animal suffering, just as they have an obligation to minimize or avoid causing the suffering of other humans, and should not use animals as food, clothing, research subjects, or entertainment.