# ICES Insight

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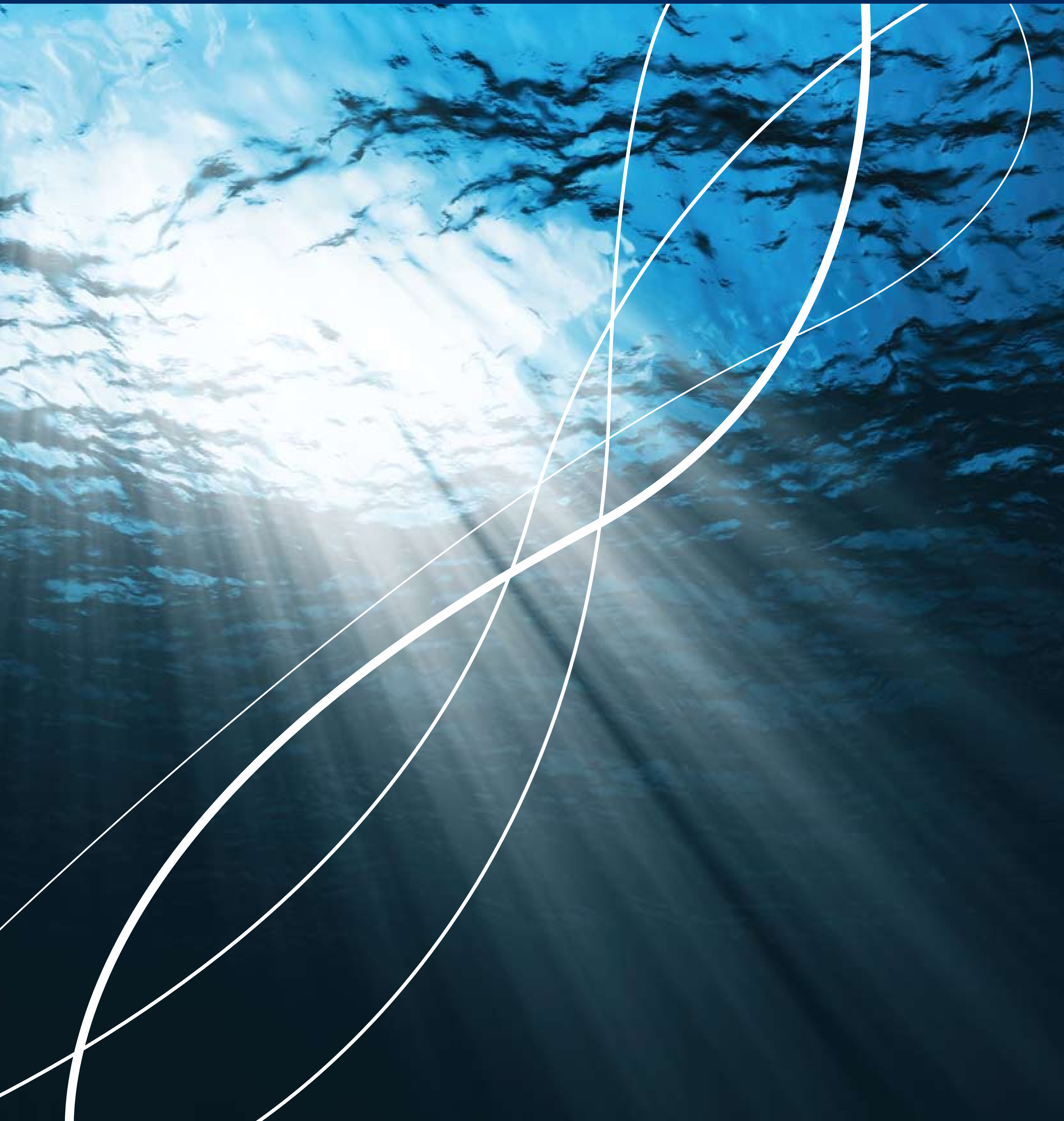


# I'll never forget what's-his-name.

Too often the details of an organization's history fall between the cracks of memory and disappear. The wide range and diversity of ICES work intensify the danger that the minutiae of ICES history will be forgotten.

It is important that the members of ICES understand the pioneering role in marine science that ICES has often played since its founding in 1902. It is also important to realize that our ancient-looking predecessors in yellowing photographs are not as different from ourselves as they might seem.

In this issue, we interview Jens Smed, who spent forty-five years in ICES Service Hydrographique, preserving hydrographical data and amassing a wealth of information about ICES history.

Darwin's ideas permeate the scientific and social air that we breathe, and we would be remiss if we didn't make an explicit nod to Darwin and the anniversary of *On the Origin of Species,* which was first published 24 November 1859. In that vein, we explore the evolutionary changes that are being induced by our fishing practices.

Speaking about ecosystems, we consider how the rise and fall of grey seal populations in the Baltic is affecting the ecosystem and whether or not the EC's Marine Strategy Framework Directive will lead to a practical application of an ecosystem-based approach to fisheries, as well as how Canadian mussel culture interacts with the ecosystem.

New ways of looking at and supplying vital information are examined in stories about how the Shelf Geology Explorer is making geological information available, and how the UNCOVER project is utilizing existing information to form a picture of the EU marine world.

This issue also includes articles about a software program that helps to identify priorities for preserving biodiversity when an oil spill threatens and a tagging programme that helps us to better understand the misunderstood Atlantic halibut.

The passing of Warren S. Wooster, eulogized by Gotthilf Hempel, reminds us that methods change, but goals, ideals, and problems are shared across the ICES generations.

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Send your comments or story ideas to info@ices.dk

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◀ ***Opposite top***. *Keynote speakers for the ICES Symposium "100 Years of Science under ICES", held in Helsinki from 1 to 4 August 2000, under the convenership of Emory Anderson. Front row, left to right: Michael Sinclair, Scott Parsons, Gotthilf Hempel, and Jake Rice. Middle row, left to right: John Ramster, Jens Smed, Jakob Jakobsson, Øyvind Ulltang, and Alasdair McIntyre. Back row, left to right: Warren Wooster, Katherine Richardson, Robert Dickson, David Griffith, Helen Rozwadowski, James Stewart, Tim Smith, and Jens Meincke.*


# Jens Smed: Bridges Made of Data

*William Anthony speaks with Jens Smed, a man who, for forty-five years, helped to form the way that ICES communicates with the world, all through its hydrographic data.*

From its inception, ICES has published hydrographic data collected by Member Country research vessels, and has been a pioneer in the collection, standardization, and sharing of that data. Ninety-five-year-old Jens Smed served ICES as caretaker of its hydrographic data for forty-five years while working on the staff of the ICES Secretariat, initially as Hydrographical Assistant and seven years later as Hydrographer. In addition, he made important contributions to the subject of hydrobiological variability in the sea, by his painstaking development of long time-series, and (perhaps even more importantly) by his establishment of a sound and comprehensive international dataset on which other studies of environmental variation could be based.

**Jens Smed served ICES as the caretaker of its hydrographic data for forty-five years.**

For nearly half a century, despite his assertion that “data centre work is not very dramatic”, he was a driving force behind the work that advanced the handling of hydrographic data worldwide. He speaks with typical Danish modesty and good humour, but even at the age of ninety-five, he retains a firm, unapologetic grasp of the millions of facts that have crossed his desk.

Pinning down an exact definition of hydrography is not a simple matter. Smed says, “What we in ICES called hydrography is now called physical and chemical oceanography. Of course, hydrography in the English-speaking countries, that's quite another thing. It includes sounding of the depths and all that. When I was in America, my friend told me I had better call myself an oceanographer. All of these words can really be problematic. In Russia, I think it's called oceanology, and then we have hydrology and the many variants. I believe that the librarian at the Musée Océanographique de Monaco is trying to collect all of the terms in a paper, and that would be a good thing, but I don't think it's come out yet”.

It is said that, in Denmark, you’re never more than fifty kilometres from the sea. It would seem that every Dane must have a special relationship with the sea, but actually, there are two kinds of Danes: those who live from the land and those who live from the sea. Strangely perhaps, in view of the trajectory of his career, Smed started out deeply rooted in the land.

Jens Smed was born on 20 March 1914, the son of a farmer, and grew up in eastern Jutland in Vinterslev, a village, he says, that doesn’t exist any more.“It has been swallowed up by the expanding cities. It was a wonderful way to grow up, one that hardly exists today”.


▲ ***Top left.*** *Jens Smed attending a meeting in Geneva in 1951.*
***Top middle.*** *Jens Smed attending an FAO meeting in Rome in 1971.*
***Top right.*** *Jens Smed assisting in the production of standard seawater. Between 1936 and 1974, standard seawater was produced by ICES in the basement of Charlottenlund Castle.*

"We had about forty acres. It would have been natural if I had taken over the farm, but after completing the village school, I thought it would be more interesting to continue my education. So I made my way to the Aarhus Cathedral School and later read physics at the University of Copenhagen".

**"Actually, the job was offered first to one of my university colleagues…"**

He distinguished himself academically, completing his master's degree, then winning a gold medal in physics. He was well on the way to becoming a high-school teacher, having already been promised a place on the faculty of one of Denmark's best schools, but then the call came from ICES in 1939.

"Actually, the job was offered first to one of my university colleagues, but he wasn't interested because he wanted to do experimental physics and the job was too theoretical. I was a theoretical physicist, but had no particular relationship with the sea. They knew they couldn't expect to find anyone trained in hydrography, so they were willing to hire someone and train him".

After an interview with Martin Knudsen, the long-serving Chef du Service of the Council's Service Hydrographique, Smed joined the small staff at the ICES Secretariat.

"I must say that we never called it 'ICES'. We always spoke of the 'Council'. 'ICES' is one of those acronyms that came up in the middle of the 1950s. Before that time it was the 'Council'".

Martin Knudsen suggested a salary of 4000 kroner a year, but the Administrative Secretary Wilhelm Nellemose protested. "I think he got more or less furious, because there had been a Council meeting a couple of months before, and the cost of my salary had not been mentioned. He contacted President Johan Hjort in Oslo, who agreed with Nellemose. So, Knudsen offered me 3000 kroner. I accepted it, which really surprised Knudsen".

**"Knudsen could never really be replaced. He was a very kind man. I liked him very much".**

Smed formally joined the Service Hydrographique as assistant to the Council's Hydrographer Jacob P. Jacobsen on 1 August 1939, "but then came the war, of course, and nobody knew what would happen".

The Secretariat managed to remain open for the duration of the war, and although Denmark was spared the destruction of its cities, it was a time bristling with danger and doubt about the future survival of ICES.

With no new data arriving, the staff could only evaluate data that had already been submitted, and Smed was mainly employed editing the *Bulletin Hydrographique*. Jacobsen was able to carry out work on a 1939 proposal to study the variation in the inflow of Atlantic water through the Faroe–Shetland Channel. This is a very important region because of the inflow of surface water from the Atlantic and the inflow of cold bottom water from the north. Smed recalls, "I was assisting Jacobsen, and I came across a certain variation in the salinities, and I wrote a small paper about that".

**He has worked steadily since retiring, turning out a stream of historical papers that continues unabated to this day.**

It was during the war that Smed had his first serious experience at sea, aboard the Danish research vessel "Biologen", which belonged to the Danish Biological Station but had been borrowed for the cruise by the nautical section of the Danish Meteorological Office. The stated purpose of the cruise was to make hydrographical observations in the Limfjord in northern Jutland. Smed laughs, "I think it was arranged so the Germans couldn't get their hands on the vessel. I was aboard for a month. There wasn't much to do in the Limfjord".

During the war, Smed familiarized himself with the Council's hydrographical card index. The card index was the brain-child of Wilhelm Nellemose, a former commander in the Danish navy, who had been forced to take early retirement as the result of an injury. He joined the Council as Administrative Secretary[1] and developed the two-type card system that recorded observations of temperature and salinity simultaneously. This was used

▲ *Martin Hans Christian Knudsen, Danish Delegate 1899 and 1901–1949, and ICES Bureau member 1932–1946.*

to store information about the North Atlantic, the Norwegian, Baltic, and North seas, and the Transition Area (between the Baltic and North seas).

Two types of cards were used: surface cards, for surface observations, and station cards, for observations at a series of depths at a station. Each card included details of the year, date, position, temperature, and salinity. The station cards also indicate the depths at which the recorded temperatures and salinities were recorded, and the bottom depth.

The end of the war saw the revival of projects that had been interrupted and, in that release of energy, information began to flood the data centre. "As time went on, there were so many data coming in that we couldn't publish them all". With Jacobsen's passing in 1946, Smed assumed the post of Hydrographer, and when Knudsen retired two years later, he became Chef du Service Hydrographique. Smed comments with typical understatement, "I was fairly young but nevertheless they trusted me. I was aware that I could never replace Knudsen".

Smed remembers Knudsen. "He was a very kind man. I liked him very much. Perhaps that was partly because we shared similar backgrounds. We were both raised on farms and received our elementary education in country schools. He was, of course, very important in many respects, a professor at the university and the technical high school, and a great thinker and inventor in many fields besides marine science. He was nominated several times for the Nobel prize in physics".

[1] *The title Administrative Secretary was given to Knud Schøning (1927–1932), Wilhelm Nellemose (1932–1944), and Ebba Brønniche (1944–1945) instead of General Secretary. According to Arthur Went (1972) in* Seventy Years Agrowing, *the Council "invited Captain Schøning to become, not General Secretary but, as Maurice says 'in a less independent but still in a responsible position'". This title was used until 1945, when Harald Blegvad was appointed General Secretary.*

The post-war period was one of expanding international cooperation and developments in hydrographic equipment.

A tribute to Smed, published at the time of his retirement (ICES, 1984), sums up the ICES-related achievements by Knudsen, Jacobsen, and Smed. "Knudsen established an international reputation for his work on the determination of salinity and his studies relating to the equation of state of seawater, and Jacobsen was best known for his development of the temperature–salinity (T–S) diagram as a tool in water mass analysis, whereas Jens Smed has become internationally recognized, first, for the development of ICES as a regional oceanographic data centre and, second, for his work on long time-series of T–S data. Under him the Service Hydrographique has played a vital role in the quality-control, exchange, promulgation, and archiving of hydrographic data collected by ICES Member Countries".

The post-war period was one of expanding international cooperation and developments in hydrographic equipment that allowed more accurate and varied measurements to be taken. Under Smed, the Council established important links with the World Data Centres for Oceanography in Washington, DC and in Moscow. He was instrumental in developing relationships with the various national data centres and with marine and fishery science laboratories in Member Countries. The connections created on the Council's behalf served as new channels for the flow of data and information between the marine science communities in Europe and North America, amplifying the work that the Council had pioneered.

Both before and during Smed's time, the work was done by a minimal but extremely dedicated staff that has been compared, more than once, to a family. Smed and his "ladies", Inger Bondorff, Poula Holm, Birthe Knudsen, and Ruth Larsen, processed the vast number of hydrographic observations submitted to the Council. The metaphor of a family was quite genuine because Inger Bondorff was Martin Knudsen's daughter, and Birthe Knudsen was his daughter-in-law.

Helen M. Rozwadowski (2002) describes the devotion with which Smed and his staff personally reviewed all incoming data. "Oceanographers who submitted

▲ *ICES hydrographic scientists at a meeting. Left to right: Jan Szaron, Jens Smed, Dieter Kohnke, and Tom Dalzeil. In addition to the purely scientific work carried out in the meetings, Jens Smed claims that the bonds formed during the many hydrographic social events helped to promote the exchange of scientific ideas. Former General Secretary Emory Anderson remembers, "The hydrographers' parties hosted by Smed during the annual Statutory Meetings were famous. There was always a lot of hard drinking and singing, inducing some non-hydrographers to try to wrangle an invitation".*

Smed was responsible for implementing the resolutions of the Hydrography Committee and providing secretarial support.

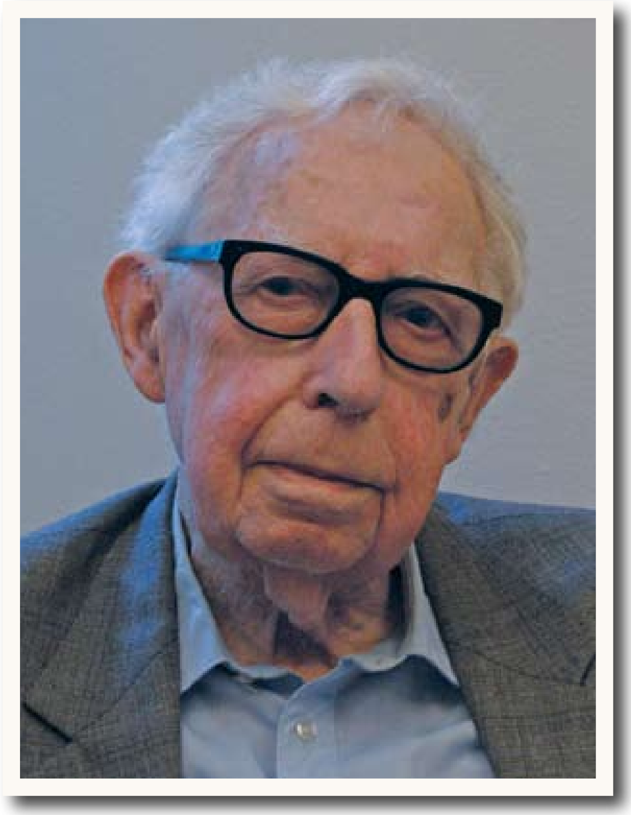
data from national cruises regularly received letters or phone calls politely informing them that 'this station is in the middle of Sweden,' as Swedish oceanographer Stig Fonselius recalled. 'You understood they [the staff of Service Hydrographique] sat there looking at every [observation],' marvelled fellow Swede Artur Svansson".

In 1957, anticipating an influx of data from the International Geophysical Year and future projects, the Service Hydrographique replaced its index-card system with the technologically more advanced system of punch cards, which allowed the mechanical reading of the cards and automatic preparation of *ICES Oceanographic Data Lists*, the series that replaced the *Bulletin*. In addition to promoting the compatibility of the Council's system with the systems used by other institutions, such as the US Hydrographic Office, it served as a model for national data centres in ICES Member Countries.

Smed was responsible for implementing the resolutions of the Hydrography Committee and providing secretarial support, but he made his own contributions to the field of data management, synoptic charts, fishery hydrography, and the study of climatic fluctuations.

As other organizations began to establish data centres in earnest, often under the aegis of UNESCO's Intergovernmental Oceanographic Commission after 1961, ICES decided to continue the Service Hydrographique as a regional centre, reflecting its continued utility for ICES Member Countries, as well as for the World Data Centers. One investigation revealed that the Service Hydrographique provided 87% of the data forms held in World Data Center A in Washington, DC. The computerization of ICES work was introduced at the very end of Smed's forty-five-year tenure, and once again, ICES became a major provider of data to the World Data Center system. In recent decades, the Council's role as a regional hydrographic data centre has expanded as its participation in marine environmental research has grown, and it now includes marine chemistry and other fields as well as oceanography.

Smed remains modest about his role in the quality-control, exchange, promulgation, and archiving of hydrographic data collected by ICES Member Countries. He deflects questions about his personal importance, but the history speaks for him.



▲ *Jens Smed.*

Since his retirement[2], he has worked steadily, turning out a stream of historical papers, which continues unabated to this day. Upon his retirement, members of the Hydrography Committee wished Smed "a long and happy retirement". Based on his output of papers and commentary since then, it seems that this wish has been fulfilled. We haven't heard the last from Jens Smed.

[2] *Former General Secretary Emory Anderson remembers, "Even after retirement, he was given office space in the Secretariat at the Palægade site. He remained there until about 1990, when the growing Secretariat staff made it necessary to re-assign his office for other purposes. It was hard for me to tell him he had to leave, but I assured him that he was always welcome to use the library, etc."*

### *Literature cited*


*ICES. 1984. Introduction. In Hydrobiological Variability in the North Sea and Adjacent Seas, pp. 5–6. Rapports et Procès-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer, 185. 296 pp.*

*Rozwadowski, H. M. 2002. The Sea Knows No Boundaries: A Century of Science Under ICES. University of Washington Press, Seattle, WA. 410 pp.*

*Smed, J. 1948. Note on the Council's Hydrographical Card-Index. Journal du Conseil International pour l'Exploration de la Mer, 15(2): 232.*

*Went, A. E. J. 1972. Seventy Years Agrowing: A History of the International Council for the Exploration of the Sea 1902–1972, p. 199. Rapports et Procès-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer, 165. 252 pp.*

▲ *During the moulting season in May through June, grey seals gather in colonies of up to more than a thousand individuals on the islets of the outer archipelago. Photo by Mervi Kunnasranta.*

# Dealing with Success: Seals vs. Fisheries in the Baltic

*Mervi Kunnasranta and Petri Suuronen provide details on the rise and fall of grey seal populations in the Baltic, but that's not good news for everyone.*

The grey seals glance up, made curious by the noise and movement of our single-engine Cessna as it circles their moulting grounds. Below us, in the sparkling water, hundreds of seals rest on rocks and sand, unaware that they have just become part of the spring seal census. The numbers are encouraging, if you're a seal. Other members of the ecosystem are not so optimistic.

The grey seal (*Halichoerus grypus*) is the largest and most abundant of the three seal species inhabiting the Baltic Sea. Grey seals occur throughout the Baltic, but most of the population lives on the sea's northern edge, between latitudes 58°N and 61°N. In spring, the largest concentrations of grey seals are found in the southwestern archipelago of Finland and in the Swedish archipelago.

## Growing seal populations

The grey seal population has doubled since 2000, when approximately 10 000 grey seals were counted during annual spring censuses conducted by Finland, Sweden, Estonia, and Russia. In 2008, more than 22 000 Baltic grey seals were counted. Typically, grey seals are highly mobile, with a wide seasonal migration range, resulting in census counts that are always smaller than the actual size of the population. The proportion of the population represented by the census is unknown but, in good conditions, can be close to 80%. As the census is repeated at the same time each year, the results give a good idea of grey seal population trends.

The size of the Baltic grey seal population has fluctuated during the last century. It has been estimated that, one hundred years ago, the grey seal population comprised 100 000 individuals. By the late 1970s, the population had fallen to less than 4000 as a result of intensive hunting and the effects of high loads of contaminants, mainly polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT). There is evidence that high concentrations of organochlorine compounds can weaken seals' health, especially their reproductive health.

During recent decades, the situation has improved; the contaminant load has fallen, and the reproductive health of female grey seals is currently normal. The annual rate of increase was 7 to 10% during the 2000s.

In addition, the population of the Baltic ringed seal (*Phoca hispida botnica*) is increasing in the Bothnian Bay, but not as quickly as that of the grey seal. In future, climate change will probably affect the breeding conditions for both species. The effects for ringed seals can be significant because their breeding is strongly influenced by ice and snow cover, whereas grey seals can probably adjust fairly well to ice-free winters.

### Lunch is served

Seal-induced damage, including loss of catch and damage to nets, has increased in the coastal trapnet and gillnet fisheries as the number of seals has increased. Grey seals cause the most damage, although ringed seals also cause damage in the northernmost part of the Baltic. In the most affected areas, the damage is so great that it seriously threatens the existence of small-scale coastal fisheries. Many fishers consider seals to be a serious threat to their livelihood.

Various attempts have been made to mitigate seal-induced damage. Seal-safe trapnet modifications reduce some damage. Acoustic harassment devices provide temporary relief, but seals learn to tolerate the 200-decibel tone, which they soon recognize as an invitation to lunch. Unfortunately, no single gear modification or scaring device provides complete protection.

As seal damage increased in the coastal fishery, grey seal hunting was resumed at the end of the 1990s in Finland and some time later in Sweden. The hunting season for grey seals in Finland runs from 16 April to 31 December. The quota for the hunting year 2009/2010 is 1050 grey seals in mainland Finland. An additional 450 individuals were added to the quota around the Åland Islands in 2009. So far, permission to hunt the ringed seal has not been granted. Hunting grey seals by traditional methods is difficult, especially during the open-water season. Along the Finnish coast (including the Ålands), only half of the yearly quota is taken.

## Grey seals can probably adjust fairly well to ice-free winters.

### A matter of diet

The nutritional requirements of seals vary by season. They eat less during the spring moult and increase their intake towards the end of summer and in autumn. Adult grey seals eat an average of 4.5–7.5 kilogrammes of fish daily. In the Baltic, they feed on more than twenty different fish species, although only a few species contribute substantially to the diet.

The diet also varies by sea areas. Baltic herring (*Clupea harengus membras*) dominate the diet of grey seals in both numbers and biomass, and in all age classes. Common whitefish (*Coregonus lavaretus*) and sprat (*Sprattus sprattus*) are also important prey species. In the central Baltic, cod (*Gadus morhua*) may also be important prey. In many studies, salmonids Atlantic salmon (*Salmo salar*) and sea trout (*Salmo trutta*) have been found in less than 10% of the grey seals examined, mainly in older grey seals.

▼ *An example of the contents of an adult grey seal's intestinal tract. Note the Carlin tags. Photo by Mia Valtonen.*

▲ *Photos by Mervi Kunnasranta.*

Although the overall amount of salmonids in the seals' diet seems insignificant, it is unclear what the affects of growing seal populations might be on salmonid populations. Efforts to assess seal–salmonid interactions in the Baltic Sea have been restricted by limited data on seal predation at crucial periods in critical areas. Most research on seal diet has been conducted at times and in areas where seal and salmon do not occur simultaneously. Most diet analyses have been conducted on hunted grey seals, mainly caught in the spring ice, before the salmon run, which begins in the Gulf of Bothnia in late May and peaks in late June.

### The research on diet continues

To assess the influence of grey seals on salmonid populations in the Baltic, the Finnish Game and Fisheries Research Institute (FGFRI) launched a study in summer 2008 that aims to provide reliable and representative information about the diet composition of grey seals during periods of high salmonid vulnerability; in other words, when salmonids leave the sea and return to rivers. The study is being carried out in the Bothnian Bay in summer, when salmon are aggregated and most vulnerable to predation. Both traditional digestive-tract and isotope analyses are being used to examine diet composition.

In 2008, nineteen grey seals and twelve ringed seals were collected between late May and early July. The three most common prey species for grey seals were vendace (*Coregonus albula*), Baltic herring, and common whitefish. The stomachs of six grey seals also contained remnants of salmonids, most of them smolts. Three grey seals had Carlin tags in their stomachs; these tags are used to mark the stocked salmonids (ca. 2% of stocked salmon are tagged). Three-spined stickleback (*Gasterosteus aculeatus*) dominated in the ringed seal's diet, but no salmonids were found. The study found that the proportion of salmonids in the grey seal's diet was higher than in previous studies, which is probably connected to the study area and time. The study continues in 2009.

The FGFRI has also tried to develop methods to mitigate the damage caused by seals. To noticeably reduce catch losses and gear damage, selective removal of grey seals near fishing gear is sometimes necessary. The FGFRI has developed a grey seal live-capture technique that can be used in conjunction with a pontoon trap. The system should allow undisturbed fishing while permitting the live capture of seals. Individuals that have specialized in finding their food in fishing gear can then be removed and terminated quickly and ethically. Thereby, their valuable resources (meat, train oil, skin, bones) can be maintained in good quality. In the northern Baltic coastal areas, a long tradition of seal hunting exists. In addition, ringed seals incidentally caught in the trapnets can be released alive.

*Mervi Kunnasranta is a biologist with expertise in ringed and grey seal ecology. She is currently working as a research scientist at the Finnish Game and Fisheries Research Institute.*

*Petri Suuronen was Research Director at the Finnish Game and Fisheries Research Institute between 1996 and 2009 and currently works in the FAO Fisheries and Aquaculture Department. His research interests include the development of environmentally friendly fishing methods and management measures that reduce the affects of fishing operations on ecosystems.*

# Good environmental status: from dream to reality at last?

*Gert Verreet gives details about the EC's Marine Strategy Framework Directive – but achieving its goals won't be a walk on the beach.*

The question of how to make an "ecosystem-based approach" operational has been on the ICES table for at least a decade, and ICES, along with other organizations, has urged policy-makers to move in this direction. Gradually, they are taking up the challenge.

The EC's Sixth Environmental Action Programme 2002–2012 promised the establishment of a Marine Strategy, and the EC subsequently elaborated its proposal, taking into consideration the input from many stakeholders. In brief, the Marine Strategy Framework Directive (MSFD), which has been in force since summer 2008, has been put forward as Europe's plan to achieve "good environmental status" under an ecosystem-based approach.

### Getting down to business

The MSFD has become one of the environmental pillars of the overall integrated maritime policy that is being elaborated by the EC. Although agreement has been reached, the legislation is substantial and the work now necessary to bring it alive will require the best – and most practical – scientific minds to balance ambition with feasibility. A steep learning curve looms. Recent scientific insights will need to be harvested for applications to marine environmental policy.

It is now generally recognized that the health of the marine environment requires a systemic approach, and it is refreshing to leave behind the piecemeal approaches of the past. Table 1 describes how the ecosystem approach outlined by ICES (2005) has been incorporated into the management steps formulated by the MSFD (EC, 2008).

### New ambitions, new friction

The ambition to adopt a new, ecosystem-based approach creates several new kinds of friction that need to be resolved, including:

**a) the friction between the more traditional "reactive" approach and the forward-looking "proactive" approach;**

**b) the friction between a holistic approach and an approach based solely on observable symptoms.**

#### Reactive vs. proactive

Moving from a reactive to a proactive approach requires a new mindset. Marine environmental policy will shift from a position of cure and – to some extent – prevention to a position guided by the drive to achieve future objectives and promote "good status". This requires the formulation of explicit management objectives (Table 1, Steps 4 and 5).

| ICES (2005) | MSFD 2008/56/EC (EC, 2008) |
|---|---|
| **Step 1**<br>Scoping the current situation<br>(1) Evaluate the ecosystem status<br>(2) Evaluate relevant ecosystem policies<br>(3) Compile inventory of human activities<br>(4) Evaluate relevant economic and social policies | Article 8. Assessment: initial assessment of marine waters, notably including an "economic and social analysis of the use of those waters and of the cost of degradation". |
| **Step 2**<br>Contrasting with the Vision<br><br>**Step 3**<br>Identifying important ecosystem properties and threats | Article 9. Determination of good environmental status "by reference to the initial assessment". |
| **Step 4**<br>Setting ecological objectives | Article 9. Determination of good environmental status, i.e.: "a set of characteristics for good environmental status". |
| **Step 5**<br>Deriving operational objectives with indicators and reference points | Article 10. Establishment of environmental targets: "establish … environmental targets and associated indicators". |
| **Step 6**<br>Ongoing management | Article 13. Programmes of measures: "identify the measures which need to be taken in order to achieve or maintain good environmental status". |
| **Step 7**<br>Periodic updates | Article 17. Updating: "ensure that… marine strategies are kept up to date [every 6 years]" |
| Measuring progress towards implementation | Article 11. Monitoring programmes: "establish and implement coordinated monitoring programmes for the ongoing assessment of the environmental status". |

▲ *Table 1. ICES ecosystem approach and MSFD management steps.*

These objectives should represent key features that express (or are indicative of) the main properties of the ecosystems. It is vital that the correct management objectives are chosen. To do this requires knowledge of what constitutes a healthy system. However, in the past, we have mostly documented signs of deterioration and dysfunction, rather than identifying the properties of a normal, healthy system. What is "good" is not just the negation of what is "bad", although there is often little else available as a starting point.

The overall legislative framework is now in place, including a general definition of the conditions that constitute good environmental status and a number of qualitative dimensions (descriptors). Further guidance on criteria and methods is being elaborated by scientists in a project coordinated by the EC's Joint Research Centre (JRC) and ICES. The science-based proposals will be discussed by EU Member States and stakeholders under the Common Implementation Strategy for the MSFD, which has been agreed by the Marine Directors of the Member States.

## Holistic approach vs. observable symptoms

This leads to the next challenge: avoiding oversimplification. There are several aspects to this.

One of the well-known built-in risks of management by objectives is that, by focusing on selected objectives, the view of reality becomes distorted, so that, eventually, only the specific terms of the objectives matter, not the reality that they are meant to represent. This risk may be compounded by the legal setting, which exacerbates the tendency to focus on the second-order reality of words rather than on the first-order reality of facts. A dynamic and close link between the assessment process (MSFD Article 8, which is intended to be broad and comprehensive) and the formulation of the objectives (MSFD Articles 9 and 10, which are geared more to management), plus the monitoring programme, should allow a continuous reality check throughout the process of MSFD implementation.

Another risk is the selectivity of indicators. Countries will wish to cover as much of significant reality with as few indicators as possible. Especially in the case of threats, if there are too many, there is a danger of the more significant issues being overlooked. The environmental threat posed by pollution, which encompasses a vast number of hazardous substances, is a particular example. (For hazardous substances, an approach that begins by identifying their existing and potential effects and risks, complementing what the Water Framework Directive is already achieving in coastal waters, seems to be the way forward.)

To embrace an ecosystem-based approach under a legal management regime will require strong management of the resulting friction. In addition, in order to make the marine ecosystem "clean, healthy, and productive", managers will need to focus on correcting the main dysfunctions, rather than solving some of the more superficial symptoms which may attract attention, but may not have much systemic meaning (for example, highly visible projects with a limited impact, even on local ecosystem functioning). Now that policy-makers have moved in this direction, marine ecologists and system analysts should help them in making wise decisions!

### ***How*** **many dimensions?**

Physicists now theorize that reality may have eleven dimensions, which, apart from the four describing space–time, are "curled up" (as a sort of point vibration, we're asked to imagine) inside everyday space–time. It would seem that, for the majority of mankind, whose lives are not affected by string theory, there may be seven dimensions of reality that don't matter. The MSFD posits eleven "qualitative descriptors" of good environmental status[1]. The point is that, unfortunately, in most seas, these are not all curled up – so we will have to deal with the *n*-dimensional reality of marine environmental status! The MSFD lists eleven "qualitative descriptors" of good environmental status (see page opposite).

Most of these descriptors express an aspect of environmental status that is fundamental to the overall make-up of a clean, healthy, and productive marine ecosystem. For some descriptors (e.g. 3, 5, 8, and 9), normative frameworks exist that can be used to some extent under the MSFD. For others (notably 1, 2, 4, 6, 10, and 11), either some "objective-setting" experience exists or it has been long acknowledged that a more normative framework is badly needed to address them properly, and the MSFD will now drive it forwards.

### Developing the right tools

To make any of these descriptors/dimensions operational in Member States' expressions of good environmental status, a common European methodological toolkit (headed by an instrument adopted through the Committee procedure of the MSFD) is being developed. The first version should be available in 2010 and will allow Member States to implement MSFD Article 9(1) on a sufficiently common basis. Given the magnitude of the challenge, we would expect the most progress to be made for the more "mature" descriptors; for the others, the approaches may need further elaboration. As the policy needs become more precise, a dynamic dialogue between the policy-makers and the scientists should be established. This will require a strengthened science–policy interface. Some developments under the EU's marine and maritime research strategy will allow us to address this need (EC, 2008).

Agreement on the set of boundaries that constitute good environmental status under the various descriptors will be a big step towards an ecosystem-based approach and a targeted management action that will have an effect on reality, at least as we know it. Ideally, these should be clearly related to the conceptual model of the marine ecosystem under consideration, including its natural variability and adaptations to large-scale phenomena, such as climate change. A progressively better understanding of the large, open systems that are oceans and seas should accompany this, so that the properties chosen as vectors of "objectives" are well understood and the objectives themselves the most pertinent for achieving clean, healthy, and productive seas.

[1] *The "descriptor–dimension" analogy breaks down easily when one realizes that these are not independent system properties, but aspects that manifest strong links. The scientists working on them have readily understood this!*

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*Gert Verreet worked as a marine policy officer in the European Commission's Directorate-General for the Environment (DG Environment) from September 2005 until August 2009. He submitted this article in a personal capacity.*

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### *Literature cited*

*EC. 2008. Marine Strategy Framework Directive 2008/56/EC. Available online at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0534:FIN:EN:PDF*

*ICES. 2005. Guidance on the application of the ecosystem approach to management of human activities in the European marine environment. ICES Cooperative Research Report No. 273. 22 pp.*

## Qualitative descriptors for determining good environmental status (MSFD, Annex I)

(1) Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic, and climatic conditions.

(2) Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems.

(3) Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock.

(4) All elements of the marine foodwebs, to the extent that they are known, occur at normal abundance and diversity, and at levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.

(5) Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms, and oxygen deficiency in bottom waters.

(6) Sea-floor integrity is at a level which ensures that the structure and functions of ecosystems are safeguarded and that benthic ecosystems, in particular, are not adversely affected.

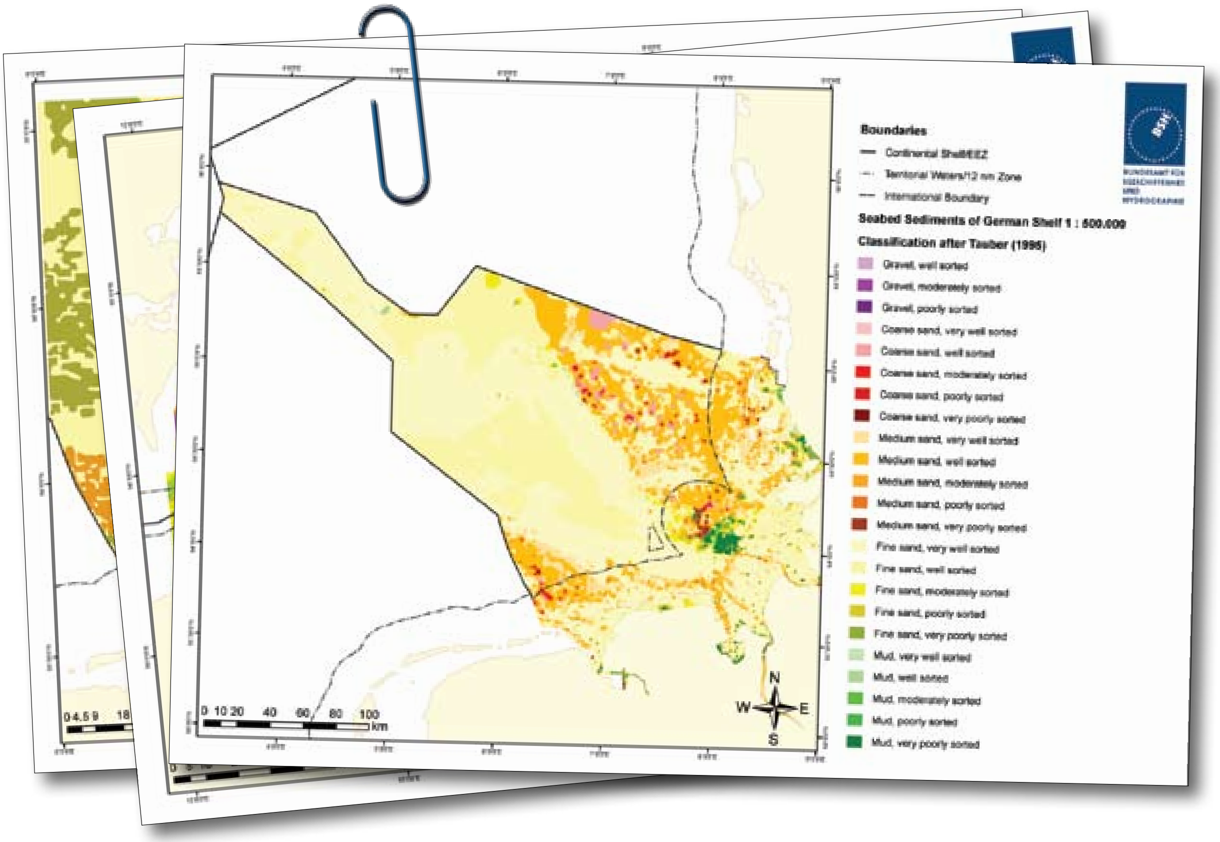
(7) Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems.

(8) Concentrations of contaminants are at levels not giving rise to pollution effects.

(9) Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards.

(10) Properties and quantities of marine litter do not cause harm to the coastal and marine environment.

(11) Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.




# Information on the Shelf

*Manfred Zeiler and Maria Lambers-Huesmann report on the increasing need for geological information on the seabed, especially in shelf seas, and how the Shelf Geology Explorer is making that information available.*

If you are going to build your house, or your offshore wind turbine or your offshore oilfield, on sand, it's helpful to know what's under the sand. This requires reliable geological and geotechnical parameters of the seabed to ensure the constructional integrity and environmental friendliness of your installation – or your house. If you are designing and routeing submarine pipelines and cables, knowledge of surficial geology and sediment dynamics is crucial, for both technical and environmental reasons.

Clearly, there are many ways of providing many kinds of information about marine geology. For example, multimethod approaches to marine environmental protection, using modern hydroacoustic equipment and ground-truthing data (grab samples and underwater video images), provide full-coverage geological information. This is a prerequisite for localizing potential benthic habitats, such as reefs, sandbanks, feeding and nursery grounds for marine life, and protected species.

The ecosystem-based approach requires essential parameters, such as morphology and composition of the seabed. Because biological data for many marine species are still scarce, geological maps, in combination with bathymetric and oceanographic data, may help to identify areas of marine environmental interest.

Marine spatial planning also requires reliable intelligence on seabed geology in order to manage human activities in offshore waters in an environmentally friendly and sustainable fashion.

### Answering the call for information

In 2006, the German Federal Maritime and Hydrographic Agency (BSH) established a geo-database called Shelf Geology Explorer that uses the technology of a geographical information system (GIS) to make available its comprehensive geological data on the seabed in the North Sea and the Baltic. The data comprises analogue and digital information on hydroacoustic lines, coring, and cone penetration testing (CPT) sites, as well as printed geological maps, sediment core descriptions, and more.

The Shelf Geology Explorer's structure is based on a number of modules:

- **The Survey module covers information about the surveys, cruises, methods and equipment, and locations of corings and CPTs, and the like, and gives an overview of the existing datasets.**

◀ *Distribution of seabed sediments at a scale of 1:500 000 in the North Sea. This GIS layer gives an overview of the surficial sediment composition on the German shelf. The classification is based on median grain size and sorting according to Tauber (1995). The seabed sediment distribution is quite heterogeneous in the eastern and southwestern parts of the German shelf, and reflects areas of former Pleistocene landscapes, which were reworked during the postglacial marine transgression of the North Sea.*

- **The Intermediate module stores the first results of seismic interpretations and ground-truthing data as point data for geostatistical analysis (e.g. interpolation by kriging).**
- **The Products module comprises layers on the distribution of seabed and subsurface sediments, sediment thickness, palaeogeographical features (e.g. Pleistocene meltwater valleys), and the like.**

The sediment layers are organized into categories based on scales ranging from 1:500 000 down to 1:100 000. The data model is able to handle different sediment classifications to meet the requirement of the different customers and users.

### User friendly

The Shelf Geology Explorer was developed in line with the German Spatial Data Infrastructure initiative, which itself is the national implementation of the EC Directive 2007/2/EC, Infrastructure for Spatial Information in Europe (INSPIRE). This includes comprehensive meta-information on the single datasets with respect to data source, data formats, data processing, coordinate systems, revision methods, and status of confidence. The data model also includes information on operational issues such as database and data-model history and GIS editors.

The project was finalized at the beginning of 2008. The next step, currently in progress, is the implementation of the Shelf Geology Explorer as an operational GIS. This is embedded in the ISO 9001 certified management system of BSH to ensure high-quality data and user-friendly accessibility.

Speaking about sediments, *ICES Cooperative Research Report No. 297* entitled "Effects of extraction of marine sediments on the marine environment 1998–2004", is now available online at the ICES website: **http://www.ices.dk/pubs/crr/crr297/CRR%20297.pdf.**

With respect to the public availability of this geo-information, the Shelf Geology Explorer is being incorporated into the Spatial Data Infrastructure (SDI) at BSH, which is available as a GIS web service at http://www.bsh.de/de/Meeresdaten/Geodaten/index.jsp .

Close cooperation of federal and state agencies and research institutions will substantially enhance geological information on the German shelf in the coming years. For example, the BSH is cooperating with the Federal Institute for Geosciences and the State Authority of Mining, Energy and Geology of Lower Saxony on a five-year project to map the German shelf in the North Sea. The project, called GeoPotential German North Sea, will provide new and updated geo-information on subsurface geology down to 1000 m below the seabed. This includes digital seabed sediment maps as well as geo-information on geotechnical properties of the upper seabed, reserves of marine aggregates, aspects of past and present sea-level rise, potential reserves for oil and gas, and possible $CO_2$ storing capacities.

## It's helpful to know what's under the sand.

On behalf of BSH, the Baltic Sea Research Institute has been mapping the seabed sediments on the German Shelf in the Baltic on the scale of 1:100 000 since 1994. The sheets "Darss", "Falster-Møn", "Arkona", "Adlergrund", and "Pomerian Bight" have been completed. This mapping programme, including a final harmonization of the GIS layers, will be completed in 2011.

### *Literature cited*

*Figge, K. 1981. Sedimentverteilung in der Deutschen Bucht. Map No. 2900. Deutsches Hydrographisches Institut.*

*Folk, R. L. 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. Journal of Geology, 62(4): 344–359.*

*Tauber, F. 1995. Characterization of grain-size distributions for sediment mapping of the Baltic Sea bottom. The Baltic 4th Marine Geological Conference. SGU/Stockholm Center for Marine Research, Uppsala.*

# First Things First

*In case of emergency, do we save the seal or the beetle?* ***Sakari Kuikka, Inari Helle**, and **Taina Ihaksi*** *report on new software that identifies priorities for preserving biodiversity when an oil spill threatens.*

In the chaotic aftermath of an oil spill, preservation of biodiversity may not be the first thing that springs to mind. Yet, without established priorities, the immediate and difficult decisions that containment operators are forced to take can be disastrous to the affected area's biodiversity. If it is impossible to save everything from the path of encroaching oil, how do rescuers focus their efforts to save species, populations, habitats, or areas most important to biodiversity? Scientific facts as well as practical issues must be considered.

Software developed as part of the OILECO project, and now available to regional rescue services on the north coast of the Gulf of Finland, integrates our knowledge of biodiversity, the values of society, and current technical know-how to minimize the loss of biodiversity.

**The Gulf of Finland is extremely vulnerable to oil spills.**

### Cause for alarm

The Gulf of Finland, the easternmost part of the Baltic Sea, has many features making it extremely vulnerable to oil spills: It is shallow, experiences limited water exchange, and has ice cover in winter. In addition, the coastline features a vast archipelago, especially on the Finnish side of the Gulf. The shoreline is exceptional in having no regular tide, but both winter ice and an unstable water level make it an extremely challenging place in which to live, especially compared with lakes or oceans.

The area is an important migratory path for Arctic birds, and the shoreline shelters many rare and threatened species. In addition, foodwebs in the Gulf are typically less complex than in oceans and freshwater because fewer species are adapted to the Gulf's brackish water and low temperatures. Therefore, the disappearance of a single species from the ecosystem can have far-reaching consequences.

The threat is magnified by the limited distribution and dispersion capabilities of many of the species. The situation becomes even more alarming given the probability that populations there have made local genetic adaptations. It is impossible to "repeat the game", and the loss of biodiversity is potentially permanent.

For example, distinct populations of the vendace (*Coregonus albula*), a typical freshwater fish living in northern European lakes, are found in eastern parts of the Gulf. Disappearance of the genetic adaptations possibly made by these populations to the Gulf's unique environment, and their alleles, would be a permanent loss. Although the northern part of the Gulf of Bothnia has a flourishing, well-managed commercial vendace fishery, it is unlikely that these populations from a different environment could replace the small stocks in the Gulf.

The Gulf has witnessed a rapid increase in oil transport in the past fifteen years, which, it is estimated, will exceed 190 million tonnes by 2010. The radical increase is mainly the result of the export of Russian oil from the port of Primorsk, site of the Baltic's largest oil terminal. It was developed as a terminus of the Baltic Pipeline System at a cost of $2 billion and began operation in December 2001. Approximately 25% of exported Russian oil passes through the Gulf. Clearly, the possibility of an oil spill is a threat to the Gulf's distinctive ecosystems.

Fortunately, large-scale oil spills have been rare in the Baltic, especially in the Gulf. The largest accident in recent years occurred in 2001, when the oil tanker "Baltic Carrier" collided with the bulk carrier "Tern", spilling 2700 tonnes of heavy fuel oil on the coast of Denmark. In March 2006, the cargo vessel "Runner 4" sank on the Estonian side of the Gulf after colliding with another ship in its convoy. In February 2007, the Greek tanker "Propontis", carrying crude oil, ran aground in the eastern Gulf. Fortunately, the double hull prevented any oil leakage.

**To protect or not to protect, that is the question**

The purpose of the OILECO project was to plot the ecological values of the Finnish and Estonian parts of the Gulf of Finland, evaluate their significance, and produce supportive information in order to facilitate operational decision-making and thereby protect the most valuable populations and habitats in case of an oil spill. It was determined that a spatial mapping software program would be the most effective tool.

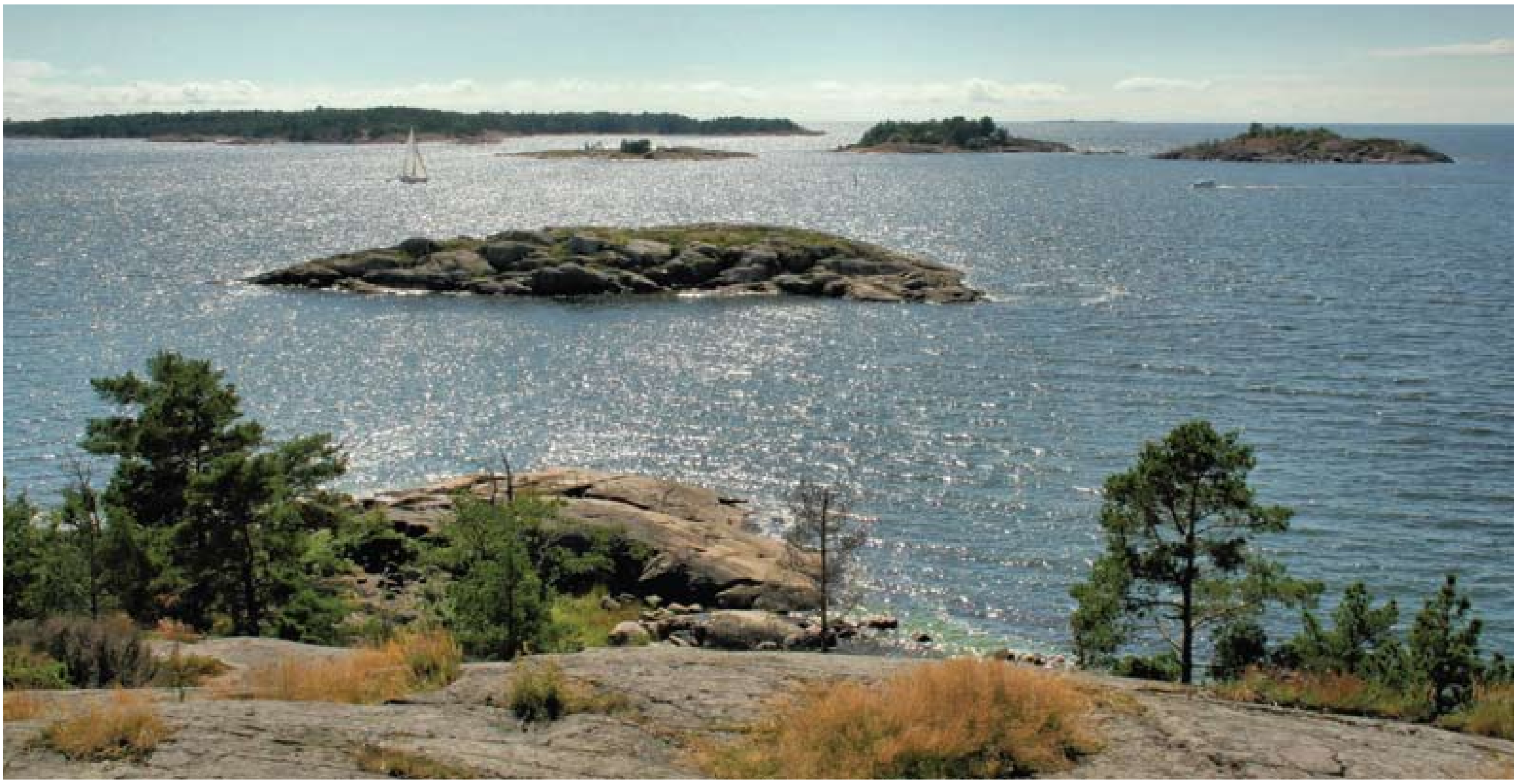
The program that was developed bases its prioritization on an index system, which gives a relative value for a given population based on estimates of its recoverability and conservation value. In addition, an overview was made of the technology available to combat an oil spill. Finally, the probability of an oil spill was determined to help in calculating the amount of investment the Finnish population was prepared to spend on avoiding damage to the ecosystem.

**In the chaotic aftermath of an oil spill, preservation of biodiversity may not be the first thing that springs to mind.**

As in every assessment, the first step is to select which species should be included in the analysis and which should be left out. As the objective is to combine the protection of biodiversity with efficient oil boom set-up and clean-up, the following questions were asked:

- **Does the species have a conservation value?**
- **Will a large-scale oil spill have long-term effects on the populations of the species?**
- **Does the species have a predictable distribution, i.e. do we know where the individuals are located so that site-specific, oil-combating measures can be used effectively?**

▼ *The Gulf of Finland has a vast archipelago and an indented coastline that is a challenge to both navigation and the combat of oil spills. Photo by Inari Helle.*



▲ *The prickly saltwort (*Salsola kali kali*) is classified as endangered in Finland. It inhabits sandy beaches, which are vulnerable to oil spills. Photo by Terhi Ryttäri.*

▲ *Long-tailed ducks (*Clangula hyemalis*) are vulnerable to oil spills, especially in their wintering grounds in the Baltic Sea. Photo by Julian Bell.*

▲ *Oiling is fatal for birds, whose thermoregulation depends on the insulation capacity of their plumage. Photo by Julian Bell.*

The first question (conservation value) can be interpreted in various ways. It is tempting to think that the most common species are the most important, inasmuch as they may possess, for example, a key species function in the ecosystem and the potential number of kills is great. However, we built our interpretation from the biodiversity point of view and suggest that, in order to maintain biodiversity, one should safeguard those species that have a limited distribution and a limited dispersion capacity, or in other words, those species that are less likely to recolonize the area.

**The approach is also suitable for other environmental problems where biodiversity is threatened.**

The work, therefore, is based on established principles, such as the legal status of a species as threatened, as mentioned, for example, in the EC's Birds Directive or Habitats Directive, or in the 2000 Red List of Finnish Species, which uses the International Union for Conservation of Nature (IUCN) categories in a national scale and catalogues plants and animals that face a heightened risk of national extinction, classifying them as Critically Endangered (CR), Endangered (EN), Vulnerable (VU), or Near Threatened (NT). Such species were regarded as being already prioritized by society. None of the species on the Finnish list also appear on the global IUCN list. (Further information can be found in The 2000 Red List of Finnish Species, published by the Ministry of the Environment.)

The second question (recoverability) eliminates species that also have viable inland populations, while the third (related to the efficiency of oil-combating measures) eliminates species whose locations are impossible to define in a meaningful way and which therefore cannot be protected with floating oil booms. The white-tailed sea eagle (*Haliaeetus albicilla*) is an extreme example.

After this selection, three indices related to conservation value, recoverability, and the efficiency of oil-combating actions were estimated for all populations of selected species living on the northern side of the Gulf of Finland.

## Calculating indices and programming software

As it is impossible to estimate the survival probabilities of more than a hundred species using available resources, we applied simple indices.

### Conservation value

The conservation value of the population was evaluated to give an index that describes the relative importance of a given population for the survival of the whole species on a national scale (based on the Finnish Red List class of the species), the relationship of one Red List class to another (for example, the number of populations of a VU species with the same value as a single population of a CR species), and the significance of the species status as a directive species. The index values were estimated by a panel of experts in conservation biology.

### Recoverability

The recoverability of a particular population was evaluated as an index describing the relative ability of the population to recover from an oil spill through reproduction and/or recolonization, given that a certain proportion of the population will be lost as a result of mortality induced by exposure to oil. Evaluations of the damage caused by exposure to oil, and of subsequent mortality, were also made, based either on behaviour (for highly mobile animals, such as birds and seals) or on the location of the population in relation to sea level, given the prevailing weather conditions (for sessile organisms). The final value for recoverability was based on expert judgments and existing scientific literature.

### Efficiency of oil-combating measures

As the time and resources available to combat oil spills are limited, it is important to focus on populations that can be most helped by oil-combating activities. The efficiency of safeguarding species with oil booms at close range (approximately 400 metres from the habitat) is described by the booming efficiency index. This varies widely depending on species; for example, safeguarding birds is much more challenging than safeguarding sessile littoral species.

**The mapping program represents the coastline in a grid of 200 × 200 metre cells.**

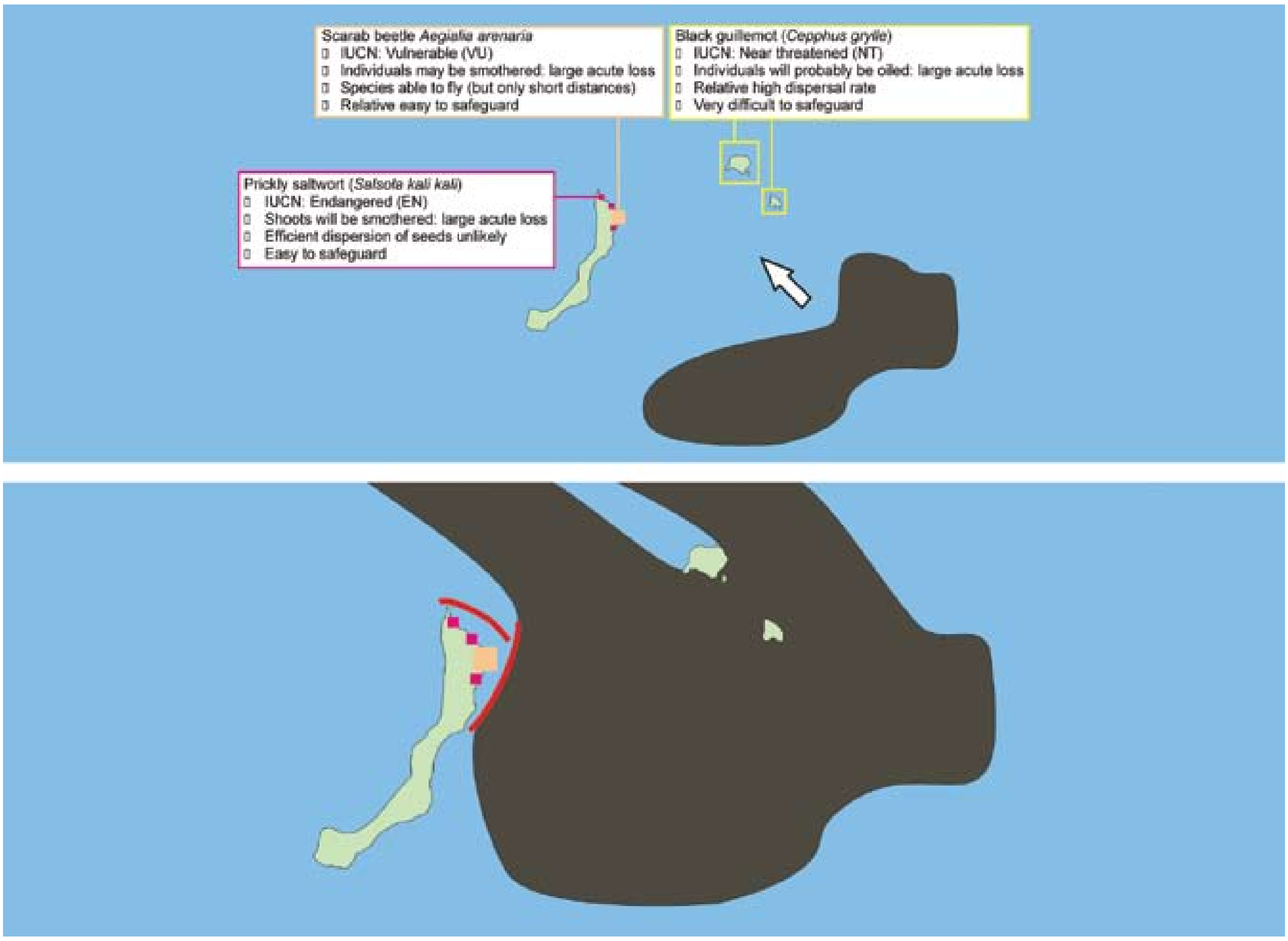
### Final index value

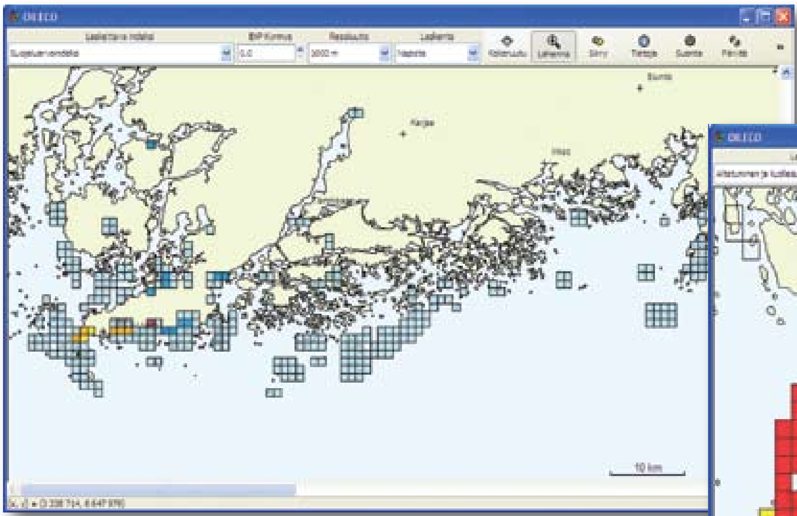
The final index value is calculated from a combination of these three subindices. The mapping program represents the coastline in a grid of 200 × 200 metre cells, where the value of a single cell is determined as the sum of the final index values of the populations present in the cell. With the map application, rescue personnel can easily choose areas at which combating efforts should be targeted, if the biodiversity of the area is given top priority.

### When oil comes ashore

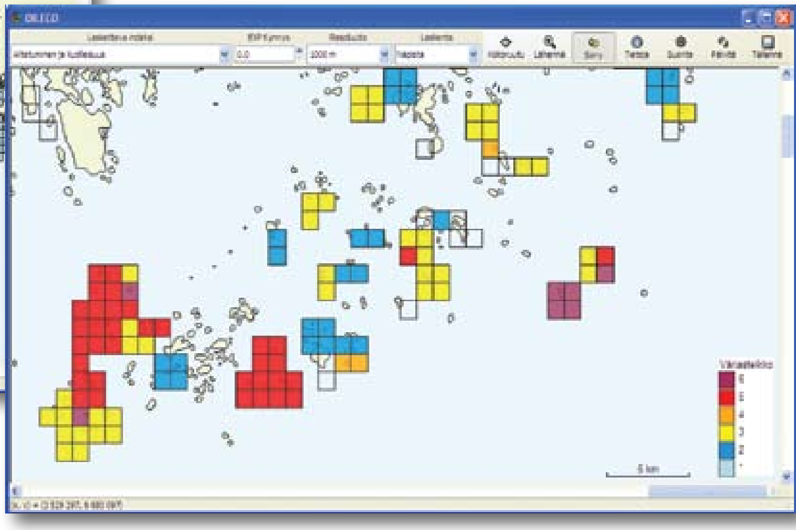
As an example of how the program's logic might be used in a real situation, let us assume the following scenario. An oil spill has taken place in the Gulf in summer, and the oil slick is drifting towards a cluster of small islands (Figure 1). Island A is inhabited by two endangered species: prickly saltwort (*Salsola kali kali*, a terrestrial vascular plant; IUCN status EN) and a scarab beetle (*Aegialia arenaria*; IUCN status VU). Islets B and C are occupied by populations of the black guillemot (*Cepphus grylle*; IUCN status NT). It is clear that acute mortality would be substantial in all species. However, when we compare the recovery potentials of the species, the black guillemot, a more mobile organism, has better dispersion capacity than the other two species, whose recolonization is further hindered by the long distances between populations. In addition, the conservation value is clearly higher for EN and VU species than for NT species, even if the relative importance of the populations for the survival of the species on a national scale is equal. Finally, oil-combating actions are more effective in safeguarding prickly saltwort (sessile) and scarab beetles (which

▼ ***Figure 1.*** *Top: a drifting oil slick is seen approaching an island and some islets inhabited by three threatened species. Bottom: the situation after the oil has spread, conservation decisions have been taken, and oil booms have been put in place.*






▲ *This screenshot from the OILECO mapping software shows the westernmost part of the Gulf of Finland. Purple grid cells indicate areas with the highest conservation value index.*




▲ *In this screenshot from the OILECO mapping software, purple grid cells indicate areas that are inhabited by species most affected by exposure to oil and that suffer the greatest mortality as the result of an oil spill.*

move only short distances) than black guillemots, which may take fright at conservation activities and leave their nests, thus exposing themselves to floating oil.

Therefore, it is clear that, in order to protect the biodiversity efficiently, rescue personnel should target Island A rather than Islets B and C. This may appear self-evident in the light of the reasoning presented above. However, in real oil-spill situations, the focus is usually on highly visible and charismatic species, such as birds and seals, which receive most attention in the popular media. Although this rather anthropocentric view is understandable, it is not the best option from the viewpoint of biodiversity.

### Other applications: biodiversity and fishing

The preceding scenario illustrates how populations and species might be prioritized in situations where difficult decisions have to be made. The approach is also suitable for other environmental problems where biodiversity is threatened. One undoubtedly relevant case is fishing, and the challenging task of planning marine protected areas, i.e. areas that are used to protect harvested fish populations from overexploitation that may lead to a decline in biodiversity. If such a method is used, it is very important that the selection of closed areas is done in a coherent way using the values of the society and that the areas are selected to minimize the risk to biodiversity. Our approach offers a way of achieving this.

▶ *These photos are from the 2005 HELCOM BALEX DELTA exercise, which has been conducted annually since 1989 to test the Baltic Sea countries' readiness to respond to a major oil accident at sea. The exercise is a test of HELCOM's response system, its command and communication system, as well as the cooperation between response units of the Baltic Sea countries. The operation is the largest maritime emergency and counter-pollution drill of its kind in the Baltic Sea area and one of the largest worldwide. Photos by Nikolay Vlasov, HELCOM.*

## A short interview with author Inari Helle

### What does OILECO stand for?

*I think the name was meant simply as an easy-to-remember combination of the words* oil *and* eco*, referring to oil spills and the vulnerable ecosystem in the Gulf of Finland. The project's full name, "Integrating ecological values in the decision-making process on oil spill combating in the Gulf of Finland", was a bit too long for everyday use.*

### What other applications might this program have?

*This is mapping software that offers a systematic way of thinking about biodiversity. It is a tool that can provide greater clarity about local biodiversity, especially when it is possible to focus on discrete areas, for example, in fisheries.*

*With eutrophication, for example, it's difficult to draw boundaries around the affected areas. Our program is good at establishing priorities on a local scale.*

*Each country has its own list of endangered species. The importance of each species and each occurrence is determined in relation to the other species and occurrences in the area, not in isolation. How do the species interact? Rankings are based on expert local knowledge of the species. Experts from the Finnish Environmental Institute established their values in relation to other species in Finland. These can be global questions, but you need the opinion of the local experts.*

*OILECO was a three-year Finnish–Estonian project to study oil-spill management, but at the moment, our program is only available in Finland, because Finland and Estonia have different kinds of databases regarding endangered species. If the program is to be used by another country, data on the local endangered species must match the program's parameters and be entered for that country.*

### What happens when an oil spill occurs?

*A report is made and the Finnish Environmental Institute initiates efforts to combat the oil spill. When the oil is on the open sea or the accident is very large, the Finnish Environmental Institute will lead the combating operations. However, when oil reaches the shore, it becomes the responsibility of the regional rescue services. Personnel can decide whether or not to use the program; it is voluntary. They have received some training, but because the software was only developed in 2007, they have had no practical experience with it. There have been no serious spills, so it hasn't been tried out yet!*

*First, they try to secure the ship to keep the oil from spreading. That is the best option: keep the oil in the vessel. If they can't stop the leakage, they use booms to try to keep the oil from spreading, but booms are very vulnerable to wind, currents, and waves. Finally, if it reaches the shore, the regional rescue services deal with it there, but this is the most expensive way to deal with an oil spill.*

### Do tankers cause most oil spills?

*Two-thirds of all oil is transported by tanker, and tanker accidents, such as collisions, groundings, hull failures, and fires, have accounted for most of the world's largest and most publicized oil spills. However, most spills from tankers happen during routine operations, such as loading and discharging.*

*Still, spills caused by tanker accidents are far less frequent than other kinds of spills, such as pipeline breaks and deliberate illegal oil discharges from ships. The latter is a common problem in the Baltic, although the number of illegal oil discharges has been decreasing gradually every year.*

# UNCOVERing What We Already Know:

## The Mechanisms of Fish Stock Recovery

*Cornelius Hammer and Andreas Dänhardt explain that the UNCOVER project is designed to utilize existing information, not chase after new data. The project will help assemble a picture from the many existing pieces of the EU marine puzzle.*

There are no crystal balls in the recovery and management of fish stocks. Instead of gazing into a crystal ball, the UNCOVER project is searching through existing knowledge and information. Its goal is to pull together the diverse results and products from the past decade and tie all of the loose ends into a set of recommendations for management for the European Commission.

### The problem

Fishery policy should accomplish four things: conserve fish stocks, protect the marine environment, ensure the economic viability of the fleets, and provide high-quality food to consumers.

Today, far too many fish are being taken from the sea by fishing, and several important fish stocks are depleted, on the verge of depletion, or in the process of recovery. The Food and Agricultural Organization of the United Nations estimates that 28% of all stocks are overfished, collapsed, or recovering; 51% are fully exploited; and only 21% could yield larger catches.

Beyond the damage done to fish stocks themselves, the situation has significant knock-on socio-economic effects on fishers' income, on the balance of the marine ecosystem, and on the supply of fish to market.

Worldwide marine ecosystem services are estimated to be worth €21 trillion annually. In European waters, this includes fish landings exceeding 10 million tonnes per year at a value of approximately €10 billion (taken as average gross fish-market revenues for the period 1999–2002). Overfishing and mismanagement, along with inappropriate rebuilding strategies, threaten these services and reduce potential revenue.

**Beyond the damage done to fish stocks themselves, the situation has significant knock-on socio-economic effects.**

Past attempts to manage fisheries by means of total allowable catches and technical regulations have failed in many cases; this calls for new management strategies that define new recovery plans. It is obvious that the impact of anthropogenic factors on stock recovery, and their underlying mechanisms, must be mitigated.

Demand for the sustainable use of European marine ecosystems and their resources has been clearly acknowledged in many legal frameworks, for example, OSPAR, HELCOM, the EU Water Framework Directive, and the green paper on the European Common Fisheries Policy Regulation (CFP). The CFP is explicit in its requirement to adopt recovery plans for fisheries that are exploiting stocks outside safe biological limits. Furthermore, the EU is committed to the targets set by the Johannesburg World Summit on Sustainable Development's Plan of Implementation, including the restoration of depleted fish stocks by the year 2015. When this plan was agreed in 2002, a time-frame of thirteen years was set to restore EU stocks. Now, only six years remain.

## The approach

Some stocks recover according to predictions, others do not, and some recover more slowly than predicted. One of the aims of the research project Understanding the Mechanisms of Stock Recovery (UNCOVER) is to investigate why this happens by consolidating and analysing all available information from previous and current EU projects and to develop strategies for rebuilding. Since it began in 2006, UNCOVER has engaged more than one hundred scientists from twenty-six institutes in fifteen countries in developing recommendations for the recovery of European fish stocks. Its funding of more than €3.5 million makes it one of the largest fishery projects in the Sixth EU Framework Programme.

The amount of money and collective research expertise involved illustrates the complexity of this endeavour, as does the diversity of approaches.

UNCOVER's purpose has never been to carry out *de novo* research and produce new basic data. The programme was designed to make use of available knowledge from previous and ongoing projects as well as scientific papers and, from it, to model recovery scenarios and synthesize clear-cut recommendations for action to save overfished stocks in European waters.

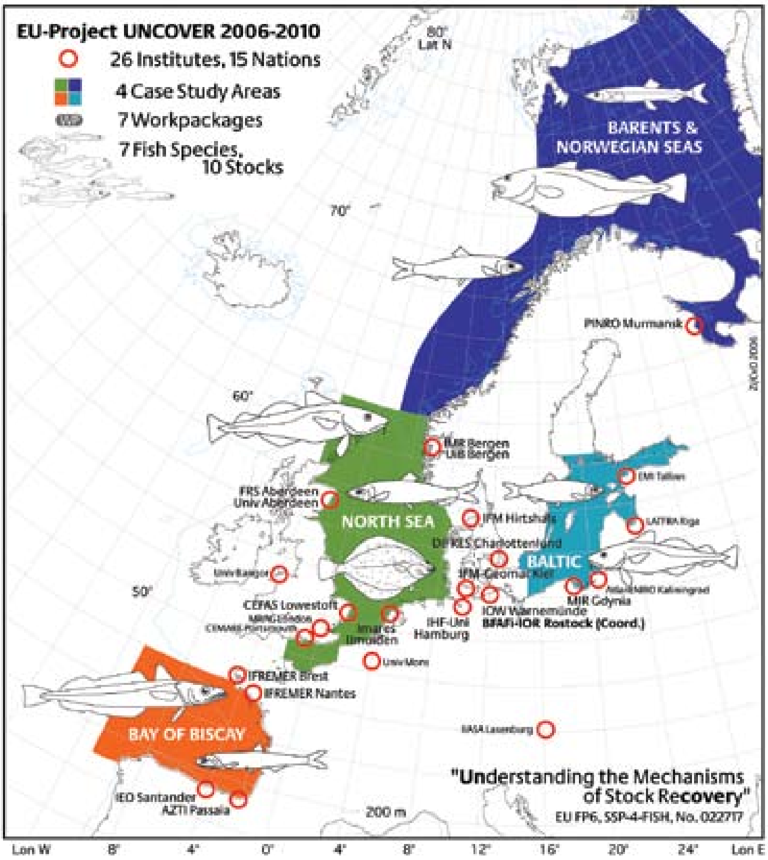
**Past attempts to control fisheries through total allowable landings and technical regulations have failed in many cases.**

The fish stocks investigated in the four UNCOVER case studies are: Arctic cod, Norwegian spring-spawning herring, and capelin in the Barents Sea; cod, herring, and plaice in the North Sea; eastern cod and sprat in the Baltic Sea; and hake and anchovy in the Bay of Biscay.

The stock structure and reproductive success of fish, their physical environment, and their trophic relationships have long been key interrelated drivers of fish population dynamics and, as a consequence, of stock recovery. This biological reality is mirrored in the conceptual set-up of UNCOVER.

In each of the four regional seas, operational models based on established time-series and process models were run to summarize the impact of stock collapse on the migration and distribution of the target species and on their potential to successfully reproduce and, finally, to recover. Together with aspects of reproduction and spatial distribution, historical variations in recruitment have also been related to abiotic and biotic conditions during periods of high and low stock productivity.

▼ *A subsample of the UNCOVER participants at a workshop in Barcelona.*




▲ *The UNCOVER case-study areas, model species, and project partners.*

In a next step, the state of the ecosystems was characterized in relation to recruitment success by identifying the factors driving the recruitment variability of target stocks. In addition to stock-inherent traits and environmental variability, predator–prey interaction is another force that can hamper or, for that matter, foster stock recovery. In combination with fishing and environmental forcing, switches in magnitude and direction of trophic control on population dynamics and stock recovery were investigated. All three processes together can change entire foodweb structures and thereby affect potential stock recovery.

When this plan was agreed in 2002, a time-frame of thirteen years was set to restore EU stocks. Now, only six years remain.

This biological information will be used to develop process models that identify candidate strategies for management control, which can be compared, tested, and evaluated. This exercise will reveal whether or not recovery strategies are robust to changes in various assumptions about biological and ecological processes or particular fishing practices and management measures.

A management plan is only as good as its implementation, which, in the end, depends on fisher compliance. How do management regulations influence the short-term (in other words, effort allocation and discarding) and long-term (in other words, investment and decommissioning) decisions of fishers or, more generally, fishers' behaviour and fishing mortality? How do management measures affect the day-to-day quality of life of the people and the communities in which they live, work, relate to each other, organize to meet their needs, and generally cope as members of a fishing society? These questions are being answered by another essential building block of UNCOVER: dealing with social, economic, and governance influences on recovery-plan effectiveness.

The amount of money and collective research expertise involved illustrates the complexity of this endeavour, as does the diversity of approaches.

A project as large as UNCOVER offers the advantage of embracing all relevant topics and allows for a holistic approach to the problems outlined above. Models are developed interactively and are applied to both real ecosystems and real social systems. This has not only afforded an enhanced mechanistic understanding of stock recovery and recommendations for the recovery of EU fish stocks. It has also provided a set of modelling tools to integrate and apply available knowledge in general.

**Selected results**

Six months before the project's completion, many interesting results had already been produced in all of the four case-study areas.

One of the many highlights is the explanation of changes in the spatial distribution of fish populations. Variability in the spatial distribution of fish populations can have many causes, one of which is stock size, which is directly influenced by fishing. The area inhabited by a stock of a given fish species will be greater at a large stock size than at a small stock size. This became apparent in North Sea cod, in which stock size showed a strong positive correlation with the area occupied.

Demography is another factor structuring fish populations. Large-scale changes in herring overwintering grounds have long been reported, for example in the Barents Sea, where the abundance ratio of four-year-old to five-year-old and older herring also conveys a message about migration and overwintering. Analyses carried out in UNCOVER revealed that these spatial shifts of overwintering areas occur when strong recruit cohorts develop into the parental stock. The ratio of four-year-old to five-year-old and older herring now allows for modelling the likelihood of distributional change of the stock, based solely on the ratio of recruits to their older conspecifics.

Spatial distribution, however, has yet another facet. Migrations of tagged cod in the North Sea provide strong evidence that cod exhibit two different types of spatial behaviour: residency (a limited diffusion during the migratory season) and homing (defined as directed and significant movement away from the point of release, followed by a return to the locality of tagging in time for the spawning season).

The spatial distribution of one species has consequences for other species in the ecosystem. It determines the degree of overlap, for example between predator and prey. In terms of considering predator–prey overlap in space and time as a requirement for predatory interactions, there has been a great leap towards more realistic multispecies models.

As an example, older textbooks on fish behaviour state that fish aggregate in shoals to reduce predation risk. Where predators themselves aggregate on such shoals, the protection usually provided by the shoal for individual fish seeking shelter can just as easily turn into a disaster.

**A management plan is only as good as its implementation, which in the end depends on fisher compliance.**

UNCOVER and another EU project, BECAUSE, demonstrated the relevance of this mechanism on the scale of marine ecosystems.

An aggregation of more than 50 million juvenile cod was wiped out in five days by predatory whiting, which aggregated on these juveniles in an area of approximately eighteen square kilometres. The total number of cod consumed in thirty-two "hot-spots" of similar magnitude, as observed in this study, is equivalent to the average size of an incoming North Sea cod year class and is a striking example of the system-wide structuring force of small-scale, high-intensity predation events. Emanating from this study, changes in spatial predator–prey overlap were considered in diet-selection models, yielding substantially improved results.

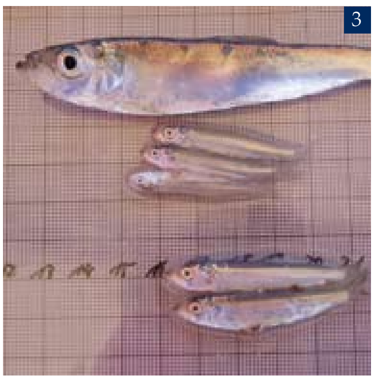
In addition to biological models, another central aspect of UNCOVER has been the socio-economic and political dimension of stock recovery. The analysis of existing management plans worldwide demonstrated that rapid and often large reductions in catches at the start of the recovery process played a key role in the ability of populations to recover, as well as in the life-history strategies of species and the demographic composition of the stock.

Recovery is more effective when the recovery plan is part of a legal mandate that is automatically triggered when predefined limit reference points are reached. Recovery is also more likely when reductions in fishing effort are created through fewer days at sea, decommissioning, or harvest control rule (HCR) schemes, and when there are positive recruitment events during the recovery period, either stimulated by or coincident with the effort reductions. Recovery is ineffective when the ability to create large reductions in fishing mortality is removed by the HCR and overfishing is allowed to continue during the recovery period.

An example of an unsuccessful rebuilding measure was demonstrated in the eastern Baltic Sea by means of hydrodynamic modelling, which was used to hindcast larval drift of Baltic cod. It became apparent that an established marine protected area (MPA) was not the origin of successful offspring. The adults that produce surviving larvae were therefore not being effectively protected from fishing. In fact, the current MPA may be not only ineffective but even counterproductive as a result of re-allocation of fishing effort to areas of potential survivor origin just outside the MPA.

*1. Pelagic schooling fish from the Bay of Biscay: the anchovy. Photo by AZTI-Tecnalia.*
*2. Plaice is one of the species under observation by the UNCOVER project. Photo by Daniel Stepputtis.*
*3. These young herring are part of UNCOVER's wide-ranging interest. Photo by Andreas Dänhardt.*
*4. An example of a tagged hake. Photo by AZTI-Tecnalia.*






### The tools

Of course, the modelling tools developed by UNCOVER are not a crystal ball. They cannot forecast the future precisely. What they can do is provide quantitative scenarios that have a good chance of becoming reality. Hydrodynamic models can forecast potential nursery grounds and hindcast the origin of survivors. This information can then be used to design MPAs and to evaluate their performance. Individual-based models are available to identify the origin of individual larvae observed in surveys, to partition the abundances according to spawning area, and to calculate the survival by spawning area. Spatial models can describe the variability of migration patterns under varying stock sizes (for example, collapsing and recovering) and climatic conditions. Operational models capture the variability of a stock's reproductive potential, genetics, distributions, and migration patterns under varying stock sizes and environmental conditions.

The integrative nature of UNCOVER will ideally translate into improved model quality and realism, for example, by coupling different models once the links and mechanisms of their respective subjects are sufficiently understood. Uncertainty can be reduced by running several independent models for the same purpose and, thus generating robust predictions, continuously tested by real data.

The project's closing date is rapidly approaching. The insights gained and the recommendations developed will be presented at an international symposium held in Rostock–Warnemünde between 3 and 6 November 2009. Presentations and subsequent discussions will contribute to tackling probably the hardest, but nevertheless the most important, task: the synthesis of all project results and their eventual translation into clear-cut management advice. This advice may then be implemented by the EU in order to improve the situation that initially made a project like UNCOVER necessary.

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*The UNCOVER project is coordinated by Cornelius Hammer and managed by Harry Strehlow, Christian von Dorrien, and Andreas Dänhardt, all from the Institute of Baltic Sea Fisheries in Rostock, Germany. For more information visit www.uncover.eu.*

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*Andreas Dänhardt is a project scientist in the UNCOVER project, working at the Institute of Baltic Sea Fisheries in Rostock, Germany.*

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*Cornelius Hammer is project coordinator of the UNCOVER project and Director of the Institute of Baltic Sea Fisheries in Rostock, Germany.*

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Among other species, sprat larvae are receiving the attention of the UNCOVER project. Photo by Daniel Stepputtis.

### A short interview with Cornelius Hammer

**Where did the idea of the UNCOVER project originate?**

*It had its genesis in ICES work as well as European Commission work. If I remember correctly, it came up over beers and conversation between the Commission and some of us from the ICES assessment working groups. Some of those who are involved in the assessment work started talking about this. I think Fritz Köster proposed the idea during an EFARO meeting, and it struck a nerve with Commission members.*

*That was six years ago, and at that time, the Commission was being criticized for its inefficient management of the stocks and handling of recovery and management plans for fish stocks. It has improved since then, but at that time, there was substantial criticism, also within the Commission itself. As a consequence, they were seeking new ways and alternatives.*

*UNCOVER is unique in that the Commission doesn't want only advice in the typical scientific way, which means models with a lot of uncertainty. In this case, they also want clear-cut management advice. That puts a lot of pressure on us.*

*From ICES, on the other hand, the Commission wants clear biological advice within the precautionary approach.*

*This is a significant difference; sometimes ICES advice appears to be politically naive to outsiders, for instance if the precautionary approach obliges us to give advice for a zero catch, even when a management plan would allow substantial catches. The precautionary approach requires us to give advice for recovery in the shortest possible time, which is one year. Full recovery in the shortest possible time often means zero catch. However, as an alternative to the precautionary approach, a management plan would deliver a stock-specific plan stating how fast to reach this, allowing a fishery to be maintained at the same time, although on a relatively low level. UNCOVER helps to develop such plans. While doing so,* *we have to remain absolutely neutral or risk being accused by one side or the other of being politically biased. In assessment work generally, we have adopted a complex language and format for the advice, which makes the whole thing extremely complicated and difficult to comprehend, with hundreds of footnotes and exemptions and considerations and different options. If ICES didn't adhere to this, it would be ground up between the millstones of political and commercial interests.*

*In the UNCOVER project, we are asked to come up with a strategy on how to rebuild certain fish stocks in an economically and ecologically tangible way, and to submit this in an unusually comprehensive way.*

### The Johannesburg Plan gave us thirteen years to restore EU stocks. There are only six years left. Do you think it's possible to meet the goals in that time?

*Not really. For some stocks it might be possible but only for some. For a couple of stocks, we see good recovery at present. However, the plan disregards the fact that, while some stocks are decreasing, others are increasing. It is a totally natural process in which we interfere by overfishing. But still this process of dominance and predation on stocks continues. There are natural ups and downs and there are artificial ups and downs, but both processes exist simultaneously and sometimes cumulatively. Distinguishing between the two is difficult.*

*Take the example of anchovy on the west coast of South America. For thousands of years, the anchovy spawned there and, while spawning, lost their scales. Scientists have excavated scales from the sediments, quantified the number of scales, and quantified the ups and downs of the stock under perfectly natural conditions without humans having interfered there substantially or at all. The results reveal tremendous ups and downs. So, now to expect the entire ecology to remain on a stable, high level is simply disregarding the biological facts of the ecosystem. Ecosystems are stable only if looked at from a very, very elevated standpoint, from where the picture is so blurred that you don't see the dynamics within the system anymore.*

*In the Baltic, the ecosystem is relatively simple (I mean simple in the way that it is simple enough that we understand a little of it). In most other areas, it's far less simple, but this is how life is. It's a dynamic process and you cannot fix this into a framework.*

### Which stocks have recovered according to predictions and which ones haven't and why?

*Herring in the North Sea recovered more or less according to the predictions but only because recruitment was more or less normal. Recruitment is key to recovery.*

*Herring in the North Sea and the North Atlantic recovered fine, but for the Norwegian spring-spawning herring, we had to wait more than twenty years until the stock started to behave according to the expectations, and that was a stock that was almost wiped out by fishing and recruitment failure at the same time. The Canadian cod stocks off Newfoundland are not behaving according to expectations that they would recover in a certain time. Now we see signs of slow recovery, but have found that other factors play an important role in the ecosystem, which we hadn't taken into account because we simply don't know about them.*

*At the moment, there is an interesting process to observe: Does the cod stock in the North Sea recover if protected sufficiently or will climate change have a word to say, too? We can see that the stock has been moving farther North, which raises the question: What recovery scenarios do we have to develop in times of climate change? The recovery of yesterday will probably not be the same as the recovery of tomorrow, although this is something UNCOVER cannot deal with.*

### It seems that most of the people leading this project are at the Institute of Baltic Sea Fisheries. Is that a coincidence or is the project officially based at your institute?

*This is how the project developed. Some six or seven years ago, we had a meeting of the European Fisheries and Aquaculture Research Organization (EFARO) in Brussels, where we discussed projects, and this project came up. (This is a meeting of the directors of fisheries and aquaculture research institutes.) Someone came up with the idea that our institute should coordinate the project, which means in plain terms that I should bring a team together and write a proposal with them. I had been at the Institute for Baltic Sea Fisheries for one or two years, and I was in the process of reorganization. We thought that, if the Institute took over the project's coordination, it would bring the Institute more into the mainstream. Also, I needed money to hire new staff here, to mix the old crew with new blood, so to speak; so, the big project was exactly what I needed.*

# New Tagging Technologies:

*Because fish are not required to carry passports, it is often difficult to gather data about their movements between marine management areas.* **Shelley Armsworthy** *and* **Kurtis Trzcinski** *are part of a programme that is developing new tagging technologies for Atlantic halibut.*


True to the title of Helen M. Rozwadowski's history of ICES, *The Sea Knows No Boundaries*, the Atlantic halibut could be the poster child for species for which uncertainties about stock distribution and stock mixing remain. The Halibut Assessment Team at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia, is integrating new and old tagging technologies and applying them to Atlantic halibut. The results will help us better understand this enigmatic species and could find application in other tagging scenarios.

**What we know and what we don't**

The Atlantic halibut is the largest of the groundfish species, which includes haddock and cod, reaching lengths of more than two and a half metres and a weight of more than 300 kilogrammes. It is one of the most economically important, yet biologically misunderstood, fish species in the Atlantic Ocean off Canada. Historically considered a nuisance fish, it is now a major food source.

The species ranges widely over the continental shelf and shelf slopes of the Northwest Atlantic, but the distribution of individual populations is unknown. Two management areas for Atlantic halibut, each containing what is believed to be a different stock, are recognized in Canadian waters, one within the Gulf of St Lawrence and one occupying inshore and offshore waters of the Scotian Shelf and southern Grand Banks. Even so, the biological basis for this separation remains debatable.

Conventional tagging studies indicate that Atlantic halibut move extensively throughout the Northwest Atlantic, often well outside Canada's 200-mile exclusive economic zone. It is possible that halibut located outside Canadian management areas, in US waters, the Flemish Cap, and waters north of Newfoundland, might be part of the same stock.

Maine's Department of Marine Resources recently reported similar large movements and, interestingly, found that 28% of the tags applied in nearshore Maine waters were recaptured in Canadian waters. However, no halibut tagged in Canadian waters has ever been caught in US waters. These results have raised concerns among US fishers and regulatory agencies, leading to the suggestion that Atlantic halibut should be treated as a transboundary stock, with Canada and the US sharing management responsibilities. Given the uncertainties about stock distribution and stock mixing, research was urgently needed.

**Expansion of tagging methods**

Between 2006 and 2008, a conventional tag–recapture study of halibut on the Scotian Shelf and southern Grand Banks was launched jointly by Fisheries and Oceans Canada (DFO) Science and the Atlantic Halibut Council (AHC), which includes members from the halibut fishing industry. Tagging was conducted as part of the annual halibut longline survey, developed collaboratively in 1998 by industry and DFO Science to monitor the Atlantic halibut stock throughout the Scotian Shelf and southern Grand Banks.

# (Not) Just for the Halibut

Unlike previous opportunistic halibut tagging studies, the new tag–recapture study was designed not only to detect movement patterns but also to estimate the level of exploitation by commercial fishing. Movement patterns give some indication of migration routes and can be used to confirm or redefine a stock management area. Exploitation rate is used to gauge whether or not the stock is being harvested at an appropriate level and is estimated by releasing a known number of tagged fish and determining the proportion recaptured.

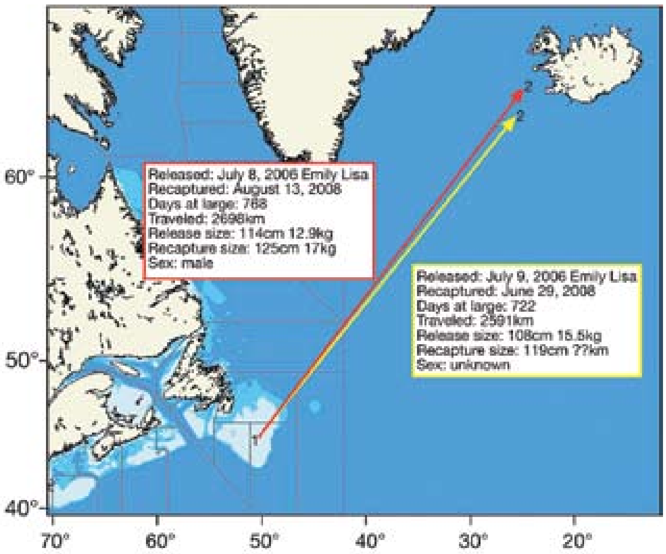
During the three-year study, we on the Halibut Assessment Team tagged 2076 halibut, ranging in length from 50 to 207 centimetres, with two pink spaghetti tags (also called T-bar anchor tags), applied fifteen centimetres apart at the widest point near the dorsal fin on the dark side, or topside, of the body. Using two tags on each fish allowed us to determine how often tags fall out and are lost, assuming it is unlikely that both tags would be lost at the same time. Before the pink-tagged halibut were released, we recorded the release location, release date, and size of the halibut.

**Given the uncertainties about stock distribution and stock mixing, research was urgently needed.**

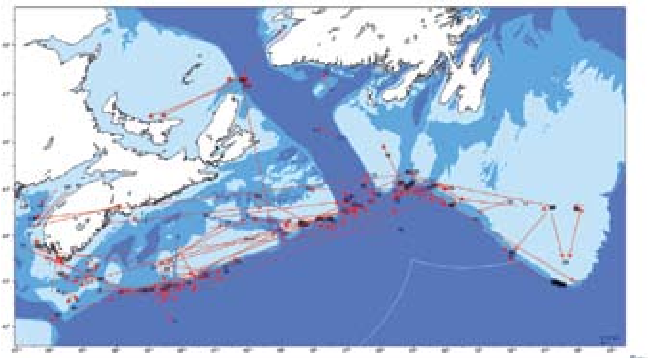
When tagged halibut are caught, the tags are returned to the Halibut Assessment Team. Because each tag is uniquely identified, we are able to determine when and where the halibut was tagged, how far it travelled, how long it was at large, and how much it grew while carrying the tag. Our ability to track halibut movements using these spaghetti tags depends on how much information is provided by the person who catches the fish. Critical information includes location and date caught, fish length and sex, and the fisher's name and contact number. For each halibut pair of tags returned with the vital catch information, the fisher is rewarded with $100 by the Atlantic Halibut Council, plus the opportunity to participate in a quarterly lottery offering a prize of $1000.

By July 2008, 135 of 2076 tagged halibut had been recaptured. The greatest numbers were caught during times of intensive halibut fishing, such as surveys and the spring fishery. The tagged fish had journeyed between 1 and 2698 kilometres from their release sites.

Notably, two halibut travelled approximately 2600 kilometres from the Grand Banks to Icelandic waters in about two years. Although their exact route cannot be determined using conventional tagging, commercial fishing data indicate that most halibut prefer the edge of the continental shelf.




▲ *Movement of two spaghetti-tagged Atlantic halibut from the Grand Banks off Newfoundland to nearshore Icelandic waters. Graph by Shelley Armsworthy.*



▲ *As of July 2008, 135 of 2076 spaghetti-tagged halibut were recaptured 1 to 2698 kilometres from their release sites. Graph by Shelley Armsworthy.*

▲ *Shelley Armsworthy displays an Atlantic halibut with a satellite pop-up transmission tag. To the right is George Rennehan, former president of the Atlantic Halibut Council. Photo courtesy of Shelley Armsworthy.*

There was no relationship between days at large and distance travelled, although the dominant movements were eastward and westward, with easterly movements covering greater distances than westerly movements. The estimated level of Atlantic halibut exploitation by the commercial fishery was 10.7% in 2006 and 14.9% in 2007, a level that is probably close to optimal.

**Given the uncertainties about stock distribution and stock mixing, research was urgently needed.**

### New tagging technologies

Tracking halibut movement using new tagging technologies offers different types of information that can complement information gained from conventional tagging. A satellite pop-up archival transmission (PAT) tag is an electronic device that can be attached to mobile aquatic species to record depth, temperature, and approximate location for up to twelve months. At a user-specified date and time, the tag activates a corrosion pin on the tag's tether, thus releasing it from the halibut. The tag then rises to the surface, where it transmits a data summary to satellites that are part of the Argos satellite system. In June 2007, for the first time in Atlantic Canadian waters, a PAT tag was successfully deployed on a large Atlantic halibut (a sixty-eight-kilogramme female).

The large female was caught, tagged, and released on the tail of the Grand Banks. Externally attached to the halibut for slightly more than six months (June–December 2007), the tag was carried for approximately 350 kilometres. The PAT tag results indicate that this halibut preferred a narrow temperature range, between 3° and 5° Celsius, had a depth range of between 400 and 1500 metres, and made rapid ascents and descents in the range of 500 metres. They also suggest that this halibut spent extended periods in the water column, possibly feeding.

**For each pair of halibut tags returned with the vital catch information, the fisher is rewarded with $100.**

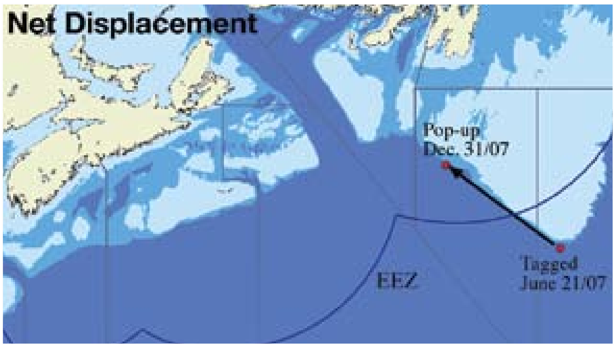
Results from this single deployment demonstrate the value of conducting future PAT tagging. In October 2008, the International Governance Strategy Science Program funded a proposal by the Atlantic Halibut Assessment Team to provide up to twelve PAT tags to be attached to Atlantic halibut in the Scotian Shelf and Southern Grand Banks. These tags were attached between December 2008 and March 2009. As of this writing, two tags popped up on May 31 and one on July 31, all three having successfully transmitted their information. The remaining nine will pop up during February and March 2010.

### The old and the new

Old and new tagging technologies provide different information about the distribution, movement, and behaviour of Atlantic halibut. Conventional tagging studies using spaghetti tags can be cost-effectively deployed in large numbers, which allows an estimation of exploitation rate, an important indicator for optimum management of the halibut fishery.

One downside of conventional tags is that they can only be returned if fishing is being carried out in the area. Further, although conventional tagging can show if a halibut moves from its tagging site, it provides no information about its migration route. Pop-up satellite tags can provide this information, but the number that can be used is limited by their much higher cost.

In contrast, halibut tagged with PAT tags do not need to be recaptured, and so this method can be used to reconstruct migration pathways, as well as determine net movement, without any bias resulting from local concentration of fishing effort. Depth and temperature profiles recorded by PAT tags can reveal spawning times and locations, and provide estimates of survival after capture and release. Spawning rises have been observed in other flatfish species, including the Pacific halibut, and these rises would be recorded by PAT tags should Atlantic halibut exhibit the same behaviour. In addition, the PAT tags provide information on vertical and horizontal habitat utilization.




▲ *Movement by a PAT-tagged halibut between 21 June 2007 and 31 December 2007. Graph by Shelley Armsworthy.*

In addition to integrating conventional and PAT tagging, we also plan to deploy acoustic tags on Atlantic halibut, which will be monitored by the Ocean Tracking Network. Integrating results from multiple data sources can improve our understanding of Atlantic halibut biology and ecology, and should improve our ability to optimize fishery catches without jeopardizing conservation.

**Conventional tags can only be returned if fishing is being done in the area.**

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*Shelley Armsworthy is a biologist with the Population Ecology Division of Fisheries and Oceans Canada. Although her formal background is the physiological ecology of marine invertebrates, Shelley currently studies marine fish. Her current activities include assisting in the annual stock assessment of Atlantic halibut and conducting basic research on Atlantic halibut, including tracking movement and behaviour and on ageing halibut using otolith technology.*

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*Kurtis Trzcinski is a research scientist in the Population Ecology Division of Fisheries and Oceans Canada. His current responsibilities include the assessment of Atlantic halibut, and haddock. He has developed models that estimate the impact of grey seal foraging on the recovery of cod, and his current research focuses on explaining recruitment variability and survival of cod and haddock.*

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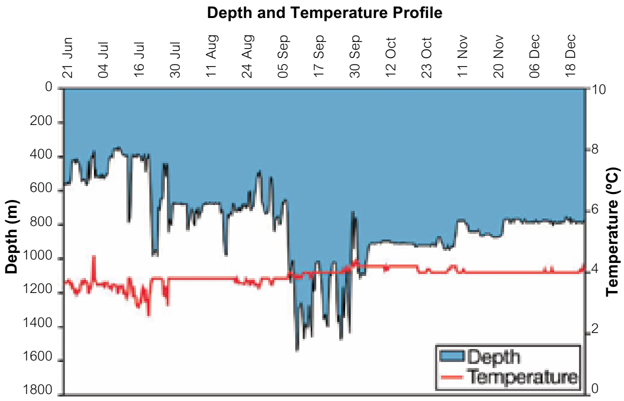



▲ *Temperature and depth profiles from a PAT-tagged halibut: halibut have a narrow temperature preference (3–5° Celsius) and make rapid ascents and descents (~500 metres), but the purpose of the vertical utilization of the water column is unknown. Graph by Shelley Armsworthy.*

▶ *An Atlantic halibut with two pink spaghetti tags on the dorsal fin. Photo by Shelley Armsworthy.*

# The Dawn of Darwinian Fishery Management

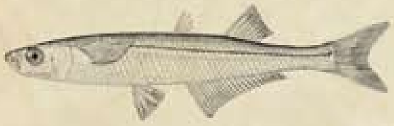
**American plaice**
***Hippoglossoides platessoides***
PMRN shift towards younger ages and smaller sizes (Labrador, Newfoundland, Canada: Barot *et al.*, 2005; source: ICES).

**Argentine**
***Argentina silus***
Maturation at smaller size (Scotian Shelf: Beacham 1983d; source: ICES).

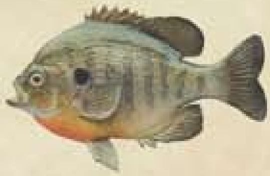
**Atlantic cod**
***Gadus morhua***
Maturation at younger age and smaller size (Barents Sea: Heino *et al.,* 2002b; Scotian Shelf: Beacham 1983b; Southern Gulf of St Lawrence: Beacham 1983a; North Sea, Sea to the west of Scotland: Yoneda and Wright 2004; Baltic Sea: Cardinale and Modin 1999), shift of PMRN maturation schedule towards younger ages and smaller sizes (Barents Sea: Heino *et al.,* 2002b; Georges Bank, Gulf of Maine: Barot *et al.,* 2004; Northern cod, Southern Grand Bank, St. Pierre Bank: Olsen *et al.,* 2004, 2005; Baulier *et al.,* 2006; Grand Bank, St Pierre Bank: Barot *et al.,* 2005; Baltic Sea: Vainikka *et al.,* 2009), maturation at lower condition (Northern cod, St Pierre Bank, Southern Grand Bank: Baulier *et al.,* 2006; Baltic cod: Vainikka et al. 2009), reduced annual growth (Southern Gulf of St Lawrence: Swain *et al.,* 2007), increased reproductive effort (North Sea, Sea to the west of Scotland: Yoneda and Wright, 2004).

**Atlantic herring**
***Clupea harengus***
Shift of PMRN maturation schedule towards younger ages and smaller sizes (Engelhard and Heino, 2004; source: Norwegian Institute of Marine Research).

**Atlantic salmon**
***Salmo salar***
Reduced annual growth (Godbout River, Quebec, Canada: Bielak and Power 1986), later smolting, lower sea age (Rivers in Spain: Consuegra *et al.,* 2005; source: Fotolia).



**Atlantic silverside**
***Menidia menidia***
Reduced growth rate; decrease in fecundity, egg volume, larval size at hatching, larval growth rate, larval survival, consumption, growth efficiency, food conversion efficiency, willingness to forage under threat of predation, and number of vertebrae (experimental tank populations: Conover and Munch, 2002; Walsh *et al.,* 2006; source: Fisheries and Oceans Canada).

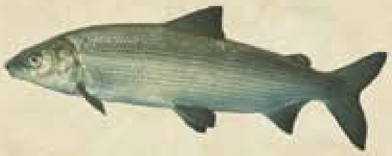


**Bluegill**
***Lepomis macrochirus***
Maturation at younger age and lower condition (lakes in Minnesota: Drake *et al.,* 1997; source: Istockphoto).

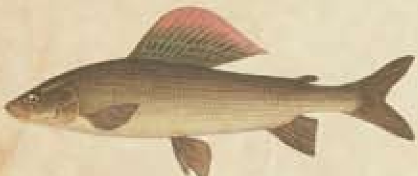
**Brook trout**
***Salvelinus fontinalis***
Maturation at younger age, smaller size, and lower condition (lakes in Canada: Magnan *et al.,* 2005; source: US Fish and Wildlife Service).

**Coho salmon**
***Oncorhynchus kisutch***
Maturation at smaller size, reduced annual growth (British Columbia, Canada: Ricker, 1981, 1995; source: NOAA).

**Common carp**
***Cyprinus carpio carpio***
Maturation at younger age, leaner body, higher viability, higher escapement (aquaculture lineages, China: Wohlfarth *et al.,* 1975; source: NOAA).



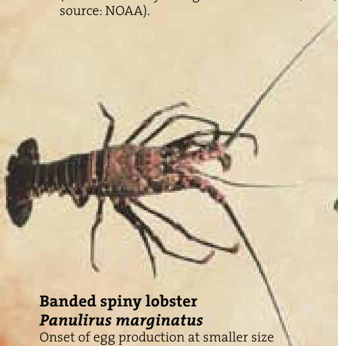
**Common whitefish**
***Coregonus lavaretus***
Reduced annual growth (Lake Constance, Germany/Switzerland/Austria: Thomas and Eckmann, 2007), increased reproductive effort (Lake Constance, Germany/Switzerland/Austria: Thomas *et al.,* 2009; source: Swedish Board of Fisheries).



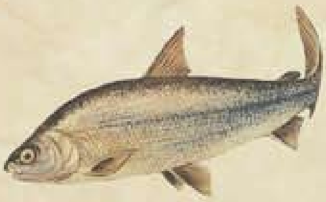
**Grayling**
***Thymallus thymallus***
Maturation at younger age and smaller size (lakes in Norway: Haugen and Vøllestad, 2001; source: NOAA).

**Guppy**
***Poecilia reticulata***
Maturation at younger age and smaller size, larger number of offspring, smaller offspring size, higher reproductive effort (comparison of field populations: Reznick *et al.,* 1990; Reznick and Ghalambor, 2005; source: www.akwarium.net).

**Haddock**
***Melanogrammus aeglefinus***
Maturation at younger age (southern Grand Bank: Templeman *et al.,* 1978; St Pierre Bank: Templeman and Bishop, 1979; Scotian Shelf: Beacham, 1983c), increased reproductive effort (North Sea: Wright, 2005; source: Norwegian Institute of Marine Research).



**Banded spiny lobster**
***Panulirus marginatus***
Onset of egg production at smaller size (Hawaii: Polovina, 1989; source: NOAA).



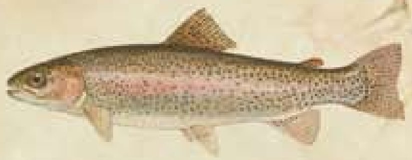
**Lake whitefish**
***Coregonus clupeaformis***
Maturation at lower condition, reduced annual growth, decreased condition (Lesser Slave Lake, Alberta, Canada: Handford *et al.,* 1977; source: NOAA).

**Largemouth bass**
***Micropterus salmoides***
Reduced parental care, reduced resting metabolic rate, poorer swimming performance (experimental field populations: Cooke *et al.,* 2007; source: NOAA).

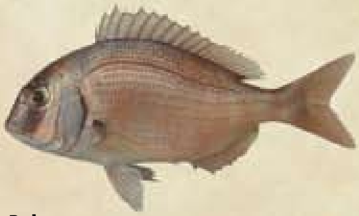
**Mozambique tilapia**
***Tilapia mossambica***
Reduced growth rate (experimental tank populations: Silliman, 1975; source: Wikimedia).

**Pink salmon**
***Oncorhynchus gorbuscha***
Maturation at smaller size, reduced annual growth (British Columbia, Canada: Ricker, 1981, 1995; source: US Fish and Wildlife Service).

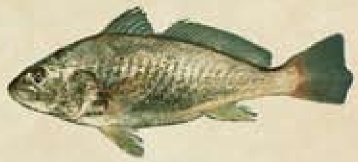
**Plaice**
***Pleuronectes platessa***
Maturation at younger age and smaller size (North Sea: Rijnsdorp, 1989, 1993a, 1993b), shift of PMRN maturation schedule towards younger ages and smaller sizes (North Sea: Grift *et al.*, 2003, 2007; Mollet *et al.*, 2007), increased reproductive effort (North Sea: Rijnsdorp, 1991; Rijnsdorp *et al.*, 2005; source: Norwegian Institute of Marine Research).



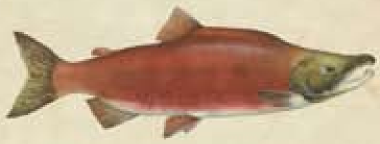
**Rainbow trout**
***Oncorhynchus mykiss***
Selection for reduced growth rate and less active/bold behaviour (experimental field populations: Biro and Post, 2008; source: US Fish and Wildlife Service).



**Red porgy**
***Pagrus pagrus***
Maturation at younger age and smaller size (South Atlantic Bight: Harris and McGovern, 1997; source: US Fish and Wildlife Service).



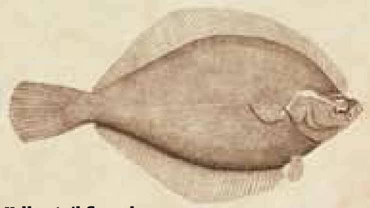
**Small yellow croaker**
***Pseudosciaena polyactis***
Maturation at younger age and smaller size (Yellow Sea: Dieckmann *et al.*, 2005).



**Sockeye salmon**
***Oncorhynchus nerka***
Earlier run time (Bristol Bay, US: Quinn *et al.*, 2007; source: US Fish and Wildlife Service).

**Sole**
***Solea solea***
Shift of PMRN maturation schedule towards younger ages and smaller sizes (Mollet *et al.*, 2007; source: Norwegian Institute of Marine Research).

**Witch flounder**
***Glyptocephalus cynoglossus***
Maturation at younger age and smaller size (southern Gulf of St Lawrence, Scotian Shelf: Beacham, 1983f; source: ICES).



**Yellowtail flounder**
***Limanda ferruginea***
Maturation at younger age and smaller size (southern Gulf of St Lawrence, Scotian Shelf: Beacham, 1983e; source: NOAA).

▲ *Observed trends suggestive of fishery-induced evolution. Based on Jørgensen* et al.*, (2007) with modifications.*

*Ulf Dieckmann, Mikko Heino, and Adriaan Rijnsdorp suggest that we are incurring a "Darwinian debt" that will have to be repaid by future fishers and consumers.*

## Looking back

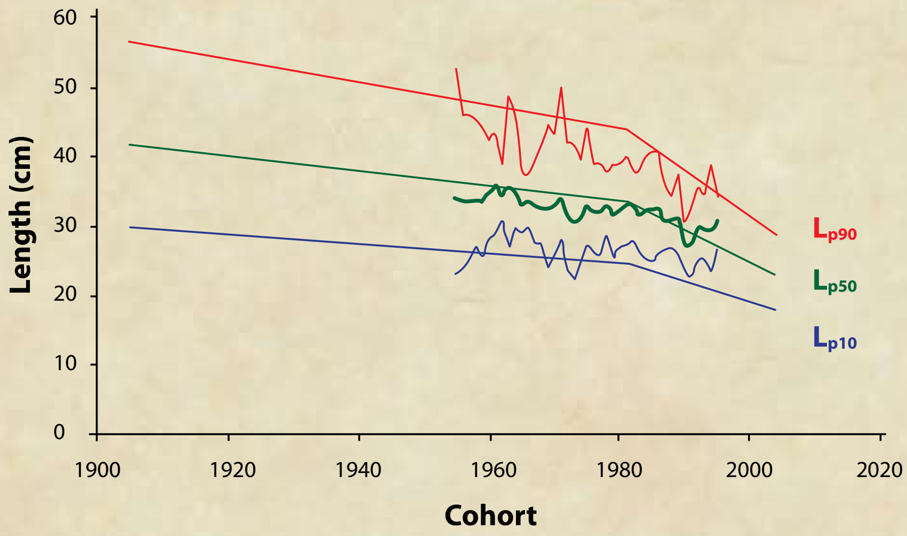
Let us compare a livestock farmer and a fisher. The farmer selects and breeds individuals that exhibit the most desirable characteristics. This is good practice, because it increases the prevalence of these characteristics in the next generation of the stock. In contrast, the fisher catches large, fast-growing fish, so their desirable characteristics are less likely to be passed on to the next generation of the stock.

Fish that grow quickly tend to be caught sooner and therefore may produce fewer offspring. Fish that delay maturation tend to be caught before they have the chance to reproduce, so the fish that are left to breed are those that mature at a younger age. Fish that limit their current investment in reproduction in order to increase future reproductive success will often be harvested before such savings have a chance to pay dividends. The mortality imposed by fishing can therefore act as a selective force that favours slower growth, earlier maturation, and higher reproductive investment.

Clearly, the selections made by the farmer and the fisher work in opposite directions. The farmer selects desired characteristics that improve his stock, whereas the fisher selects characteristics that may inadvertently reduce a stock's productivity and resilience. Therefore, fishery scientists need to incorporate both ecological processes and evolutionary processes in their research programmes in order to ensure the best scientific basis for fishery management.

The notion that fishing can affect the genetic composition of exploited populations has been recognized for a century. Perhaps the earliest account can be credited to Cloudsley Rutter (Rutter, 1904), a US salmon biologist, who warned more than a hundred years ago:

> [A] stock-raiser would never think of selling his fine cattle and keeping only the runts to breed from. ... The salmon will certainly deteriorate in size if the medium and larger sizes are taken for the markets and only the smaller with a few of the medium allowed to breed.




▲ ***Figure 1.*** *Changes in the probabilistic maturation reaction norm (PMRN) of female North Sea plaice at the age of 4 years. The figure shows how the body lengths at which female plaice of this age mature have dropped precipitously throughout the 20th century (blue curves, 10% probability; green curves, 50% probability; red curves, 90% probability.) Based on Grift* et al. *(2003; grey curves) and van Walraven* et al. *(2009; black curves).*

Yet, it was not until the 1980s that decreasing trends in the age- and size-at-maturation of northeast Arctic cod and North Sea plaice renewed interest in this topic. In the UK, Richard Law explored the implications of fishery-induced evolution for fishery yields, demonstrating that maturation evolution in response to fishing could reduce productivity (Law and Grey, 1989). In the Netherlands, Adriaan Rijnsdorp (Rijnsdorp, 1993a) analysed changes in maturation, reproductive investment, and growth in North Sea plaice in an attempt to quantify how much of the observed change in these life-history characteristics were caused by the environment and how much could be attributed to evolution.

**Stocks that become better adapted to fishing usually do so at the expense of becoming less well adapted to their "natural" environment.**

In ICES, the topic was discussed at a meeting of the Long-term Management Working Group in 1993, chaired by Kevin Stokes. From 1995 onwards, various working groups were given the task of reviewing the literature in this field. Intensified research, conducted since around 2000, led to theme sessions at the ICES Annual Science Conferences in 2002 and 2006 and the establishment of the ICES Study Group on Fisheries-Induced Adaptive Change (SGFIAC) in 2006. These activities, in turn, attracted more researchers to the field. Reviewing the evidence for fishery-induced evolution and discussing its implications for fishery management, the first SGFIAC report was summarized as a Policy Forum article in Science (Jørgensen *et al.*, 2007).

## The evidence

The available evidence for fishery-induced evolution stems from three different sources.

- **time-series analysis of long-term field data on maturation, reproductive investment, and growth**
- **experiments in controlled laboratory environments**
- **model-based studies**

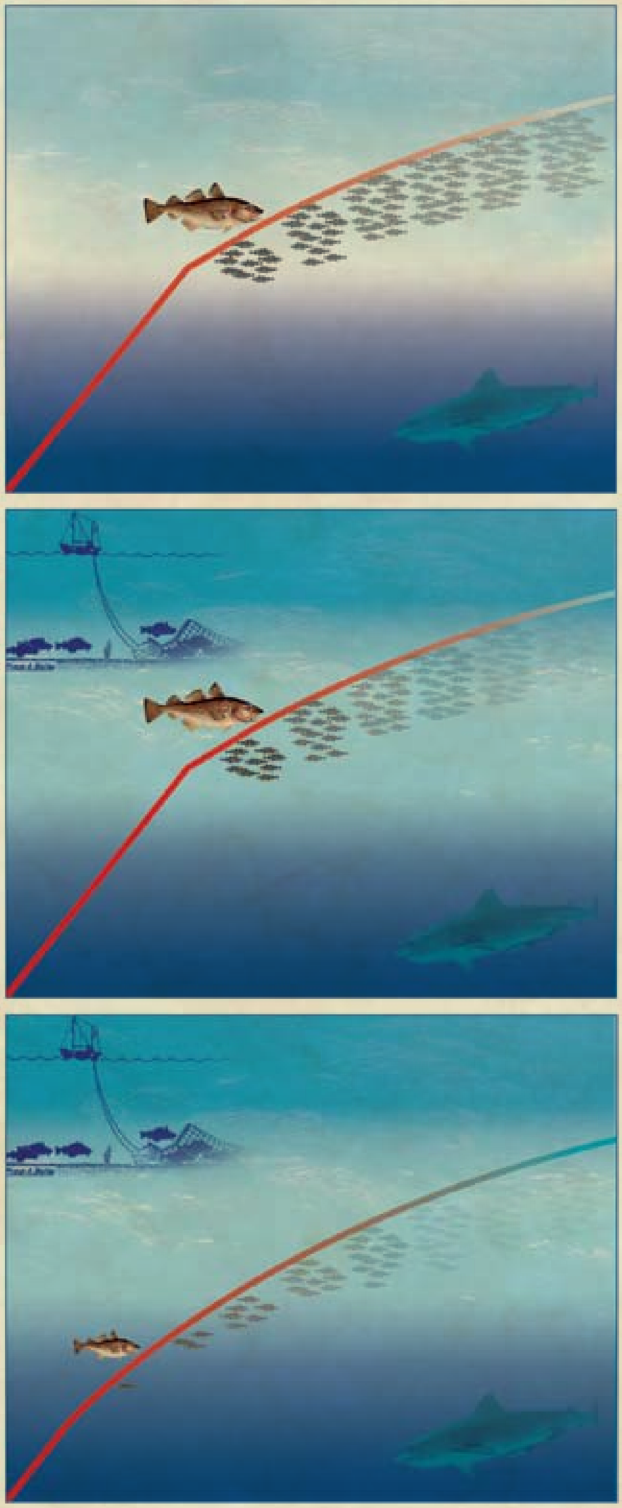
The illustration on the first two pages of this article provides an overview of empirical findings suggestive of fishery-induced evolution across species and stocks (based on Jørgensen *et al.*, 2007, with modifications).

A challenge in the analysis of time-series of field data is that observable life-history characteristics are influenced by environment and genetics. It is well known that similar genotypes can give rise to a broad variety of phenotypes, depending on the environment that individuals experience. Trends caused by such phenotypic plasticity have to be taken into account before residual trends can be interpreted as being indicative of genetic changes.

For the process of maturation, therefore, a method has been developed to account for the impacts of growth-related phenotypic plasticity and survival changes (Heino *et al.*, 2002a; Dieckmann and Heino, 2007). In this manner, maturation schedules (called probabilistic maturation reaction norms, or PMRNs) can be estimated that describe the probability of an individual reaching maturation at a given age and size, provided it has grown and survived to that age and size. A shift in the PMRN, summarized by changes in the length-at-age at which the maturation probability reaches 50% ($L_{p50}$), means that observed maturation trends cannot be explained by growth-related phenotypic plasticity and survival changes alone. If such a change is in line with predictions of life-history evolution (adaptation towards earlier maturation under exploitation), it supports the hypothesis of fishery-induced evolution. Figure 1 shows the trend in $L_{p50}$, for North Sea plaice females at the age of four years.

It should be noted that analyses of long-term field data cannot provide definite proof of evolutionary change, because it is always possible that the observed residual trends may have been caused by additional environmental factors that were not considered. Nevertheless, the broad consistency of observed PMRN trends across a variety of different fish species, stocks, and ecosystems, and the agreement of these trends with the predictions of general life-history theory and of more specific models, makes an evolutionary interpretation likely. Empirical support for fishery-induced evolution in other life-history characteristics, such as reproductive investment and growth, is more ambiguous, partly because the disentangling of phenotypic plasticity and genetics is more complicated.

Definite proof that fishing mortality leads to evolutionary changes comes from studies that manipulated mortality in experimental populations. In the US, David Reznick and colleagues (Reznick *et al.*, 1993) demonstrated that differences in mortality led to differences in genetic life-history traits in guppies. David Conover and colleagues (Conover and Munch, 2002) exposed experimental laboratory populations of Atlantic silversides, a small pelagic species, to different types of size-dependent mortality and demonstrated a variety of genetic responses, as well as associated effects on yields.



▶ ***Figure 2.*** *The timing of maturation has a considerable influence on the size of females spawning for the first time (illustrated by the large fish above the red growth curves) and their expected reproductive success. The latter is determined by two components, relative clutch size (illustrated by clutches becoming larger as females grow) and probability of surviving to produce a clutch (illustrated by the fading colour of clutches). Which maturation age is evolutionarily favoured depends on natural mortalities and fishery mortalities (illustrated by gradients at the bottom and top of each panel). Top: In the absence of fishing, large fish face little mortality. Under such conditions, delayed maturation and growth to a large size are advantageous. Fishing turns this situation around by targeting large fish. Centre: Fish that delay maturation end up trying to reproduce at ages when they are at high risk of having been fished. Bottom: Fish that reproduce early and invest their resources in reproduction instead of growth are favoured by fishery-induced selection.*

### Support from model-based studies

Further support for fishery-induced evolution stems from model-based studies. These range from simple age-structured models (e.g. Law and Grey, 1989), to age- and size-structured models that account for growth-related maturation plasticity (Ernande *et al.*, 2004), to eco-

genetic models that combine the ecological processes of growth, maturation, reproduction, and survival with the quantitative genetics of the underlying life-history traits (Dunlop *et al.*, 2009).

Although simpler models can help to corroborate expected directions of evolutionary responses to fishing, reliably estimating the pace of such adaptations requires models that are more advanced. To be credible, such models need to do sufficient justice to the ecological and evolutionary complexities of natural stock dynamics, and they should be based as closely as possible on empirical measurements. Models accounting for these requirements can then be used to forecast the direction, speed, and outcome of future fishery-induced evolution, thus revealing the evolutionary implications of current management regimes. Studies of this kind have demonstrated that the selection patterns of current fisheries can indeed lead to fishery-induced evolution over a decadal time-scale and that such changes do affect the productivity of stocks.

**Fishery managers must adjust fishing selectivity in order to minimize fishery-induced evolution for traits that are considered important without sacrificing too much yield.**

The utility of models for studying fishery-induced evolution goes further.

First, models can help us to understand past fishery-induced evolution. In particular, they can provide a means of testing whether or not the observed life-history trends attributed to such adaptation are compatible with the selection pressures imposed by the life cycle of a stock and the fishing regime.

Second, fishery managers can use the information provided by models to support decisions regarding the prioritization of regulations and research. Specifically, a stock's evolutionary vulnerability differs with its current life history, the life-history trends that it may already have undergone, the amount of genetic variation that it currently harbours, and the detailed characteristics of its current fishing regime. These contingencies limit the value of one-size-fits-all models of fishery-induced evolution and, instead, underscore the importance of developing stock-specific models.

Third, and perhaps most importantly, models of fishery-induced evolution can assist fishery scientists and managers in the investigation of the evolutionary implications of alternative management scenarios. As changes in yield and sustainability depend on a complex interplay of life-history trends induced by fishing, responsible forecasts will often have to be model-based. In this regard, advanced models can be likened to flight simulators, allowing safe tinkering with a modelled stock, which would be far too costly or dangerous to implement without prior model-aided assessments.

### The good news/bad news

Fishery-induced evolution is adaptation fishing, and the better adapted the fish, the more progeny it is likely to produce. This sounds positive, at least from the perspective of the fish, but it is not always the case.

An increased awareness and avoidance of fishing gear among fish can be regarded as an evolution-aided "escape" from fishing. The evolution of reduced adult body size can also be seen from this perspective because fish below the minimum legal landing size are typically less attractive fishing targets.

In contrast, fishery-induced evolution of traits such as maturation schedules can be interpreted as a means of coping with the inevitable: the primary effect of such changes is not a diminished exposure to fishing but the increased production of offspring under conditions of fishing.

In both cases, fish stocks that have adapted to fishing through evolution can be expected to be more resilient to fishing than those lacking such adaptations. This prediction is supported by recent model-based studies: fishery-induced adaptation allows populations to sustain greater fishing pressures than would be possible without such adaptation (see for example Heino, 1998; Enberg *et al.*, 2009).

The advantage of enhanced resilience, however, comes at a cost.

First, stocks that become better adapted to fishing usually do so at the expense of becoming less well adapted to their "natural" environment. In particular, populations may become less resilient to long-term variations in their environment. For example, a long lifespan is usually interpreted as an adaptation to unpredictable variations in recruitment success, but fisheries favour individuals that live fast and die young, as illustrated in Figure 2. Second, theoretical and empirical studies suggest that the effects of fishery-induced evolution on fishing yields are largely negative. Total biomass yield usually declines when fish redirect the investment of energy from body growth into reproduction. Consequently, a greater proportion of the catch will consist of small, and therefore less valuable, fish.

Third, fish that are forced to reproduce early in life often do so less successfully than their older conspecifics, making the same spawning stock size less valuable in terms of the stock's reproduction. For these reasons, fishery managers will often want to minimize fishery-induced evolution.

**Turning it around**

What options are there for slowing or reversing unwanted fishery-induced evolution? Possible solutions fall into two categories.

First, reducing fishing effort, while keeping its selectivity unchanged, will almost certainly help to slow the pace of fishery-induced evolution. If the reduction is large enough, and conditions are especially favourable, the unwanted evolution might even be reversed. A reduction in fishing effort is often compatible with more traditional management goals: many fish stocks are overexploited, so, in the long term, reduced exploitation is likely to generate higher yields with lower costs and emissions and reduced ecosystem effects.

Second, changing the selectivity of fishing mortality is more likely to stop or reverse fishery-induced evolution, because – in principle – it allows fishery managers to fine-tune selection pressures to achieve this. Models are currently being developed to help fishery scientists and managers accomplish this.

A conceptually straightforward approach would be to make the size selectivity of fishing mortality similar to that of natural mortality. However, this simple strategy usually has two disadvantages.

First, when the size selectivity of fishing mortality matches that of natural mortality, the extra mortality resulting from fishing will continue to cause fishery-induced evolution. (At this point, it is helpful to recall that fully size-independent mortality still induces selection pressures, because such uniform mortality still devalues reproduction late in life.)

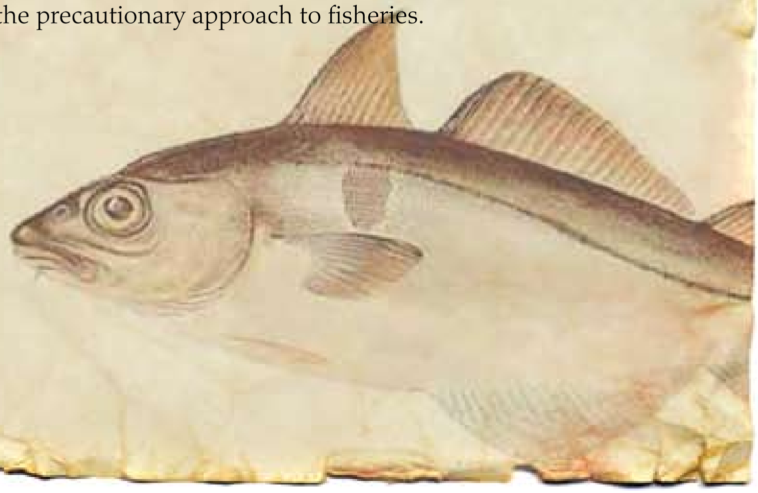
Second, as natural mortality is typically much greater for small fish than large fish, changing fishing selectivity to match such a pattern is liable to cause recruitment overfishing, which undermines yields.

Therefore, fishery managers need to adjust fishing selectivity in order to minimize fishery-induced evolution for traits that are considered important without sacrificing too much yield. How best to achieve this must be evaluated on a case-by-case basis, which will usually require the investigation of stock-specific models.

As long as some sacrifices are made, slowing down unwanted fishery-induced evolution is relatively straightforward. Reversing it is another matter. This is because reverse evolution would often have to rely on natural selection. Law and Grey (1989) have already suggested that natural selection for delayed maturation is relatively weaker than fishery-induced selection for earlier maturation.

This idea was corroborated by recent, more realistic models (Dunlop *et al.*, 2009; Enberg *et al.*, 2009), which demonstrate that the rate of evolutionary recovery is much lower than the rate of fishery-induced evolution. In other words, evolutionary "damage" usually occurs much faster than it can be repaired. Model results suggest that, for each year during which current exploitation patterns continue, several years of evolutionary recovery, under the best of conditions, may be required; this implies the build-up of a "Darwinian debt" that will have to be repaid by future fishers and consumers.

Given the social and political difficulties encountered when trying to implement major changes to current exploitation patterns, fishery-induced evolution could essentially be irreversible on time-scales that are of interest to fishery management (from years to a few decades). It seems self-evident that this observation should trigger the attention of managers subscribing to the precautionary approach to fisheries.



**Looking forward**

Despite the fact that evolutionary theory has been the cornerstone of biology since the publication of *On the Origin of Species* 150 years ago, the implications of Darwin's dangerous idea for fishery science have sparked a lively debate (Hilborn, 2006; Marshall and Browman, 2007; Kuparinen and Merilä, 2008). This debate does not so much question whether or not fishery-induced evolution occurs, but focuses on the strength of the empirical evidence and on the expected rate of fishery-induced evolution.

Although there may be some residual scepticism within the community of fishery scientists, and although the practical implications of fishery-induced evolution have yet to be examined more closely, the evidence supporting the likely and widespread occurrence of fishery-induced evolution has become sufficiently strong that fishery scientists and managers can no longer ignore the evolutionary dimension of fisheries.

This conclusion agrees with the precautionary approach to fisheries (FAO, 1995), which prescribes the exercise of

> …prudent foresight to avoid unacceptable or undesirable situations, taking into account that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to change in the environment and human values.

This approach also requires managers of over-utilized fisheries to

> …take immediate short-term action even on the basis of circumstantial evidence about the effectiveness of a particular measure.

In the long term, evidence for fishery-induced evolution is likely to be strengthened by modern genetic techniques based on the extraction and analysis of DNA sequences from historical otoliths or scales. Such approaches can document and quantify changes in gene frequencies over periods of several decades. In particular, changes in genes that are linked to life-history processes, such as growth, maturation, and reproduction, will be of interest. This does not mean, however, that we can expect to obtain definite proof of fishery-induced evolution by applying such techniques, because changes in gene frequencies may be caused either by fishery selection or by selection that is the result of other environmental factors, such as climate change.

Accordingly, the conclusive attribution of causal interpretations to correlative evidence is practically impossible for uncontrolled field observations, such as those obtained from fisheries. In addition, current knowledge of the full genetic underpinning of complex life-history processes, such as maturation, remains woefully incomplete. Therefore, for most species and stocks, it seems safe to assume that fishery scientists and managers must continue to rely on correlative phenotypic evidence for fishery-induced evolution for the next decade, if not longer. Mitigating actions cannot be postponed that long.

**Evolutionary "damage" usually occurs much faster than it can be repaired.**

Reflecting on the considerations above, we propose three courses of action.

First, the monitoring of salient life-history characteristics, such as growth rates, maturation schedules, and reproductive investments, should be integrated into routine stock assessments.

Second, stock-specific models need to be developed and calibrated that take into account the genetics as well as the ecological processes involved in the dynamics of the stock under exploitation.

Third, such calibrated stock-specific models should be used to explore and evaluate the implications of alternative patterns of fishery selection on the life history, productivity, and resilience of stocks.

This calls for close collaboration between life-history modellers and fishery scientists who assemble data and give management advice. We expect that case studies integrating the three components recommended here – life-history monitoring, model calibration, and strategy evaluation – will provide useful examples of how fishery management can develop its long overlooked evolutionary dimension.

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*For more information, visit SGFIAC's web page at the ICES website: www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=203.*

## Effects of fishery-induced evolution on reference points

Biological reference points quantify limits between desirable and undesirable states in fishery systems. Typically, reference points describe either the status of a stock (e.g. spawning–stock biomass, or SSB) or the pressure exerted on a stock (e.g. fishing mortality). To account for uncertainty, reference points are often set on a precautionary basis. Good reference points are insensitive to short-term variability of a fishery system, but may require adjustment when long-term changes in a fish stock or its fishery are taking place, for example, as a result of climate change.

ICES Study Group on Fisheries-Induced Adaptive Change (SGFIAC) is preparing an article entitled "Can fisheries-induced evolution shift reference points for fisheries management?" This explores two routes by which fishery-induced evolution may affect reference points, namely:

(i) by biasing the estimates of the indicators on which reference points are based (e.g. by biasing SSB estimates) and/or

(ii) by changing a stock's dynamics (e.g. by changing the SSB–recruitment relationship).

Changes along either route might result in a shift of a reference point. In one direction, a reference point might become more precautionary than intended, but the error will be on the side of safety. On the other hand, and more troubling, a reference point might be shifted in the direction of higher risk, thereby giving a false sense of security. Which of these outcomes is more likely depends on the reference point and on the details of the fish stock and its fishery.

## Evolutionary impact assessment

Fishery-induced evolution may change the utility of fish stocks, e.g. by altering utility components such as fishery yields, stock stability, recovery potential, trophic interactions, geographical distributions, genetic diversity, benefits to tourism, and the intrinsic values of species and ecosystems. Such changes modify the ecosystem services through which living aquatic resources provide value to society. Therefore, quantifying and characterizing the evolutionary effects of fishing is important for both economic and ecological reasons.

ICES Study Group on Fisheries-Induced Adaptive Change (SGFIAC) is preparing an article titled "Evolutionary impact assessment: accounting for evolutionary consequences of fishing in an ecosystem approach to fishery management". This describes evolutionary impact assessment (EvoIA; Jørgensen *et al.*, 2007) as a set of methods for assessing the evolutionary consequences of fishing and for evaluating the merits of alternative management options. This set of methods will:

(i) contribute to the ecosystem approach to fishery management by clarifying how evolution alters stock properties and ecological relationships;

(ii) support the precautionary approach to fishery management by addressing a previously overlooked source of uncertainty and risk;

(iii) help to realize the Johannesburg World Summit's commitment to the restoration of sustainable fisheries by helping fishery managers to cope with the evolutionary implications of fishing.

## *Literature cited*


*Barot, S., Heino, M., O'Brien, L., and Dieckmann, U. 2004. Long-term trend in the maturation reaction norm of two cod stocks. Ecological Applications, 14: 1257–1271.*

*Barot, S., Heino, M., Morgan, M. J., and Dieckmann, U. 2005. Maturation of the Newfoundland American plaice (*Hippoglossoides platessoides*): long-term trends in maturation reaction norms despite low fishing mortality? ICES Journal of Marine Science, 62: 56–64.*

*Baulier, L., Heino, M., Lilly, G. R., and Dieckmann, U. 2006. Body condition and evolution of maturation of Atlantic cod in Newfoundland. ICES Document CM 2006/H:19. 11 pp.*

*Beacham, T. D. 1983a. Growth and maturity of Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. Canadian Technical Report of Fisheries and Aquatic Sciences, 1142. 31 pp.*

*Beacham, T. D. 1983b. Variability in median size and age at sexual maturity of Atlantic cod,* Gadus morhua*, on the Scotian Shelf in the Northwest Atlantic Ocean. Fisheries Bulletin US, 81: 303–321.*

*Beacham, T. D. 1983c. Variability in size and age at sexual maturity of haddock (*Melanogrammus aeglefinus*) on the Scotian Shelf in the Northwest Atlantic. Canadian Technical Report of Fisheries and Aquatic Sciences, 1168. 33 pp.*

*Beacham, T. D. 1983d. Variability in size and age at sexual maturity of argentine,* Argentina silus*, on the Scotian Shelf in the Northwest Atlantic Ocean. Environmental Biology of Fishes, 8: 67–72.*

*Beacham, T. D. 1983e. Variability in size and age at sexual maturity of American plaice and yellowtail flounder in the Canadian Maritimes Region of the Northwest Atlantic Ocean. Canadian Technical Report of Fisheries and Aquatic Sciences, 1196. 75 pp.*

*Beacham, T. D. 1983f. Variability in size and age at sexual maturity of witch flounder,* Glyptocephalus cynoglossus*, in the Canadian Maritimes Region of the Northwest Atlantic Ocean. Canadian Field Naturalist, 97: 409–422.*

*Bielak, A. T., and Power, G. 1986. Changes in mean weight, sea-age composition, and catch-per-unit-effort of Atlantic salmon (*Salmo salar*) angled in the Godbout River, Quebec, 1859–1983. Canadian Journal of Fisheries and Aquatic Sciences, 43: 281–287.*

*Biro, P. A., and Post, J. R. 2008. Rapid depletion of genotypes with fast growth and bold personality traits from harvested fish populations. Proceedings of the National Academy of Sciences of the USA, 105: 2919–2922.*

*Cardinale, M., and Modin, J. 1999. Changes in size-at-maturity of Baltic cod (*Gadus morhua*) during a period of large variations in stock size and environmental conditions. Fisheries Research, 41: 285–295.*

*Conover, D. O., and Munch, S. B. 2002. Sustaining fisheries yields over evolutionary time scales. Science, 297: 94–96.*

*Consuegra, S., García de Leániz, C., Serdio, A., and Verspoor, E. 2005. Selective exploitation of early running fish may induce genetic and phenotypic changes in Atlantic salmon. Journal of Fish Biology, 67(Suppl. A): 129–145.*

*Cooke, S. J., Suski, C. D., Ostrand, K. G., Wahl, D. H., and Philipp, D. P. 2007. Physiological and behavioral consequences of long-term artificial selection for vulnerability to recreational angling in a teleost fish. Physiological and Biochemical Zoology, 80: 480–490.*

*Dieckmann, U., and Heino, M. 2007. Probabilistic maturation reaction norms: their history, strengths, and limitations. Marine Ecology Progress Series, 335: 253–269.*

*Dieckmann, U., Heino, M., and Jin, X. 2005. Shrinking fish: fisheries-induced evolution in the Yellow Sea. Options, Autumn 2005: 8.*

*Drake, M. T., Claussen, J. E., Philipp, D. P., and Pereira, D. L. 1997. A comparison of bluegill reproductive strategies and growth among lakes with different fishing intensities. North American Journal of Fisheries Management, 17: 496–507.*

*Dunlop, E. S., Heino, M., and Dieckmann, U. 2009. Eco-genetic modeling of contemporary life-history evolution. Ecological Applications, 19(7): 000–000.*

*Enberg, K., Dunlop, E. S., Jørgensen, C., Heino, M., and Dieckmann, U. 2009. Implications of fisheries-induced evolution for stock rebuilding and recovery. Evolutionary Applications, 2: 394–414.*

*Engelhard, G. H., and Heino, M. 2004. Maturity changes in Norwegian spring-spawning herring before, during, and after a major population collapse. Fisheries Research, 66: 299–310.*

*Ernande, B., Dieckmann, U., and Heino, M. 2004. Adaptive changes in harvested populations: plasticity and evolution of age and size at maturation. Proceedings of the Royal Society of London, Series B, 271: 415–423.*

*FAO. 1995. Precautionary approach to fisheries. Part 1: Guidelines on the precautionary approach to capture fisheries and species introductions. FAO Fisheries Technical Paper 350, Part 1. 54 pp.*

*Grift, R. E., Rijnsdorp, A. D., Barot, S., Heino, M., and Dieckmann, U. 2003. Fisheries-induced trends in reaction norms for maturation in North Sea plaice. Marine Ecology Progress Series, 257: 247–257.*

*Grift, R. E., Heino, M., Rijnsdorp, A. D., Kraak, S. B. M., and Dieckmann, U. 2007. Three-dimensional maturation reaction norms for North Sea plaice. Marine Ecology Progress Series, 334: 213–224.*

*Handford, P., Bell, G., and Reimchen, T. 1977. A gillnet fishery considered as an experiment in artificial selection. Journal of the Fisheries Research Board of Canada, 34: 954–961.*

*Harris, P. J., and McGovern, J. C. 1997. Changes in the life history of red porgy,* Pagrus pagrus*, from the southeastern United States, 1972–1994. Fishery Bulletin US, 95: 732–747.*

*Haugen, T. O., and Vøllestad, L. A. 2001. A century of life-history evolution in grayling. Genetica, 112–113: 475–491.*

*Heino, M. 1998. Management of evolving fish stocks. Canadian Journal of Fisheries and Aquatic Sciences, 55: 1971–1982.*

*Heino, M., Dieckmann, U., and Godø, O. R. 2002a. Measuring probabilistic reaction norms for age and size at maturation. Evolution, 56: 669–678.*

*Heino, M., Dieckmann, U., and Godø, O. R. 2002b. Reaction norm analysis of fisheries-induced adaptive change and the case of the northeast Arctic cod. ICES Document CM 2002/Y: 14. 14 pp.*

*Hilborn, R. 2006. Faith-based fisheries. Fisheries, 31: 554–555.*

*Jørgensen, C., Enberg, K., Dunlop, E. S., Arlinghaus, R., Boukal, D. S., Brander, K., Ernande, B.,* et al. *2007. Managing evolving fish stocks. Science, 318: 1247–1248.*

*Kuparinen, A., and Merilä, J. 2008. The role of fisheries-induced evolution. Science, 320: 47–48 (Letter).*

*Law, R., and Grey, D. R. 1989. Evolution of yields from populations with age-specific cropping. Evolutionary Ecology, 3: 343–359.*

*Magnan, P., Proulx, R., and Plante, M. 2005. Integrating the effects of fish exploitation and interspecific competition into current life history theories: an example with lacustrine brook trout (*Salvelinus fontinalis*) populations. Canadian Journal of Fisheries and Aquatic Sciences, 62: 747–757.*

*Marshall, C. T., and Browman, H. I. 2007. Theme section: disentangling the causes of maturation trends in exploited fish populations. Marine Ecology Progress Series, 335: 249–310.*

*Mollet, F. M., Kraak, S. B. M., Rijnsdorp, A. D. 2007. Fisheries-induced evolutionary changes in maturation reaction norms in North Sea sole* Solea solea. *Marine Ecology Progress Series, 351: 189–199.*

*Olsen, E. M., Heino, M., Lilly, G. R., Morgan, M. J., Brattey, J., Ernande, B., and Dieckmann, U. 2004. Maturation trends indicative of rapid evolution preceded the collapse of northern cod. Nature, 428: 932–935.*

*Olsen, E. M., Lilly, G. R., Heino, M., Morgan, M. J., Brattey, J., and Dieckmann, U. 2005. Assessing changes in age and size at maturation in collapsing populations of Atlantic cod (*Gadus morhua*). Canadian Journal of Fisheries and Aquatic Sciences, 62: 811–823.*

*Polovina, J. J. 1989. Density dependence in spiny lobster,* Panulirus marginatus, *in the northwestern Hawaiian Islands. Canadian Journal of Aquatic and Fisheries Science, 46: 660–665.*

*Quinn, T. P., Hodgson, S., Flynn, L., Hilborn, R., and Rogers, D. E. 2007. Directional selection by fisheries and the timing of sockeye salmon (*Oncorhynchus nerka*) migrations. Ecological Applications, 17: 731–739.*

*Reznick, D. A., Bryga, H., and Endler, J. A. 1990. Experimentally induced life-history evolution in a natural population. Nature, 346: 357–359.*

*Reznick, D. N., and Ghalambor, C. K. 2005. Can commercial fishing cause evolution? Answers from guppies (*Poecilia reticulata*). Canadian Journal of Fisheries and Aquatic Sciences, 62: 791–801.*

*Reznick, D. N., Bryga, H., and Endler, J. A. 1993. Experimentally induced life-history evolution in a natural population. Nature, 346: 357–359.*

*Ricker, W. E. 1981. Changes in the average size and average age of Pacific salmon. Canadian Journal of Fisheries and Aquatic Sciences, 38: 1636–1656.*

*Ricker, W. E. 1995. Trends in the average size of Pacific salmon in Canadian catches. Canadian Special Publication of Fisheries and Aquatic Sciences, 121: 593–602.*

*Rijnsdorp, A. D. 1989. Maturation of male and female North Sea plaice (*Pleuronectes platessa L.*). Journal du Conseil International pour l'Exploration de la Mer, 46: 35–51.*

*Rijnsdorp, A. D. 1991. Changes in fecundity of female North Sea plaice (*Pleuronectes platessa L.*) between three periods since 1900. ICES Journal of Marine Science, 48: 253–280.*

*Rijnsdorp, A. D. 1993a. Fisheries as a large-scale experiment on life-history evolution: disentangling phenotypic and genetic effects in changes in maturation and reproduction of North Sea plaice,* Pleuronectes platessa *L. Oecologia, 96: 391–401.*

*Rijnsdorp, A. D. 1993b. Selection differentials in male and female North Sea plaice and changes in maturation and fecundity.* In *The Exploitation of Evolving Resources, pp. 19–36. Ed. by T. K. Stokes, J. M. McGlade, and R. Law. Springer-Verlag, Berlin. 264 pp.*

*Rijnsdorp, A. D., Grift, R. E., and Kraak, S. B. M. 2005. Fisheries-induced adaptive change in reproductive investment in North Sea plaice (*Pleuronectes platessa*)? Canadian Journal of Fisheries and Aquatic Sciences, 62: 833–843.*

*Rutter, C. 1904. Natural history of the quinnat salmon. A report on investigations in the Sacramento River, 1886–1901. Bulletin of the United States Fish Commission, 22: 65–141.*

*Silliman, R. P. 1975. Selective and unselective exploitation of experimental populations of* Tilapia mossambica. *Fishery Bulletin US, 73: 495–507.*

*Swain, D. P., Sinclair, A. F., and Hanson, J. M. 2007. Evolutionary response to size-selective mortality in an exploited fish population. Proceedings of the Royal Society of London, Series B, 274: 1015–1022.*

*Templeman, W., and Bishop, C. A. 1979. Sexual maturity and spawning in haddock,* Melanogrammus aeglefinus, *of St. Pierre Bank. International Commission for the Northwest Atlantic Fisheries Research Bulletin, 14: 77–83.*

*Templeman, W., Hodder, V. M., and Wells, R. 1978. Sexual maturity and spawning in haddock,* Melanogrammus aeglefinus, *of the southern Grand Bank. International Commission for the Northwest Atlantic Fisheries Research Bulletin, 13: 53–65.*

*Thomas, G., and Eckmann, R. 2007. The influence of eutrophication and population biomass on common whitefish (*Coregonus lavaretus*) growth: the Lake Constance example revisited. Canadian Journal of Fisheries and Aquatic Sciences, 64: 402–410.*

*Thomas, G., Quoss, H., Hartmann, J., and Eckmann, R. 2009. Human-induced changes in the reproductive traits of Lake Constance common whitefish (*Coregonus lavaretus*). Journal of Evolutionary Biology, 22: 88–96.*

*Vainikka, A., Gårdmark, A., Bland, B., and Hjelm, J. 2009. Two- and three-dimensional maturation reaction norms for the eastern Baltic cod,* Gadus morhua. *ICES Journal of Marine Science, 66: 248–257.*

*van Walraven, L., Mollet, F. M., van Damme, C. J. G., and Rijnsdorp, A. D. 2009. Fisheries-induced evolution in growth, maturation and reproductive investment of the sexually dimorphic North Sea plaice (*Pleuronectes platessa L.*). Journal of Sea Research, doi:10.1016/j.seares.2009.07.003.*

*Walsh, M. R., Munch, S. B., Chiba, S., and Conover, D. O. 2006. Maladaptive changes in multiple traits caused by fishing: impediments to population recovery. Ecology Letters, 9: 142–148.*

*Wohlfarth, G., Moav, R., and Hulata, G. 1975. Genetic differences between the Chinese and European races of the common carp. II. Multi-character variation – a response to the diverse methods of fish cultivation in Europe and China. Heredity, 34: 341–350.*

*Wright, P. J. 2005. Temporal and spatial variation in reproductive investment of haddock in the North Sea. ICES Document CM 2005/Q:07. 24 pp.*

*Yoneda, M., and Wright, P. J. 2004. Temporal and spatial variation in reproductive investment of Atlantic cod* Gadus morhua *in the northern North Sea and Scottish west coast. Marine Ecology Progress Series, 276: 237–248.*

# No Mussel

*Peter Cranford, Barry Hargrave, and William Li consider how mussel culture interacts with the ecosystem and remind us that the bell tolls for whole ecosystems (with apologies to John Donne).*

Aquaculture is the fastest growing food-producing sector in the world and is the only means of filling the growing gap between consumer demand and seafood production from traditional capture fisheries. To fill this gap, aquaculture must continue to expand worldwide. Developments of the industry, however, must be promoted and managed in a way that minimizes negative environmental effects (FAO, 2008).

In Canada, marine aquaculture encompasses a multiplicity of species, including a variety of fish, shellfish, and plants. Shellfish culture in Atlantic Canada is a highly diverse industry, and mussel culture in particular has developed at an exceptional pace since the 1970s. This is largely the result of the ease with which wild juvenile mussels can be collected and the ability of suspended culture methods to achieve a high cultured biomass per unit area at relatively low cost.

**The interaction between mussel culture and the supporting ecosystem is extremely complex.**

Unlike finfish culture, which requires feed and chemical additives, mussel farming relies entirely on natural food sources. Environmental concerns arise primarily from the way in which cultured mussels interact with the ecosystem. Mussels belong to an exclusive class of animals known as "ecosystem engineers", which have the ability to create, modify, and maintain habitat. The widely reported changes in the Great Lakes ecosystem caused by the invasion of the zebra mussel are a notorious example of this "ecosystem engineering".

Mussels live in dense colonies and have an exceptional capacity to filter large volumes of water in order to extract their food: phytoplankton and other suspended particulate matter. Although their considerable role as biofilters can cause many ecosystem changes, dense populations also excrete large quantities of ammonia and deposit undigested organic matter on the seabed. Both activities can affect the structure and functioning of coastal ecosystems (Cranford *et al.*, 2006, 2007).

The interaction between mussel culture and the supporting ecosystem is extremely complex. Scientists from Fisheries and Oceans Canada (DFO) are collaborating on multidisciplinary research with other leading researchers in Canada, Denmark, France, Norway, the Netherlands, and Spain. It is hoped that their work will improve and integrate the knowledge of bay-scale interactions between ecosystems and cultured bivalves, and aid the development of effective strategies that will promote the sustainability of the aquaculture industry.

Prince Edward Island accounts for the majority of Canadian mussel production. An intensive environmental sampling programme was conducted in multiple Prince Edward Island embayments, but with a focus on Tracadie Bay. Mussel farms (leases), which are owned by individuals and companies, expanded over the years to their present state, where a large part of Tracadie Bay is used for mussel farming. This study investigated the ecological effects of mussel filter-feeding, faeces deposition, excretion, and harvesting, as well as interactions between aquaculture and coastal eutrophication from land-use.

# is an Island

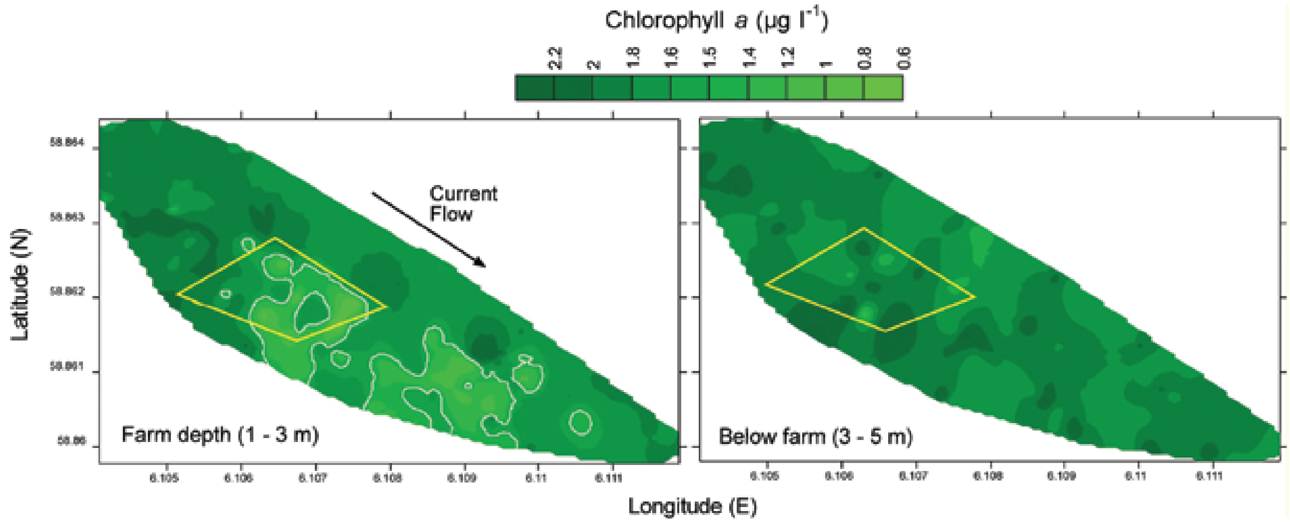
## Phytoplankton depletion

Filter-feeding by mussels naturally causes some local reduction of their phytoplankton food supply. If the mussels consume phytoplankton faster than it can be replaced by tidal flushing and growth, their food supply will be depleted. Lack of food will then limit their ability to reach their maximum productivity. This is referred to as exceeding "production carrying capacity" (see the box on page on 48).

If the spatial scale of phytoplankton depletion expands outwards from the farm(s) to include a significant area of the coastal inlet, this change in the basis of the marine foodweb raises concerns about the ecological costs to other components of the ecosystem. These costs can be used to define the "ecological carrying capacity" of the site. Detecting the zone of phytoplankton depletion in and around aquaculture sites is complicated by the large degree of natural variation in coastal waters.

A new approach, developed at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia, is to use a towed vehicle carrying electronic sensors. The Acrobat is a computer-controlled tow vehicle that undulates between set water depths while being pulled behind a small boat. The goal of each Acrobat survey is to collect three-dimensional (latitude, longitude, and depth) data on phytoplankton concentrations as quickly as possible before the distribution changes with tidal flushing. This rapid, high-resolution, three-dimensional mapping approach has proven reliable for quantifying food depletion at farm to bay-wide scales (Cranford *et al.*, 2006; Grant *et al.*, 2008).

**The interaction between mussel culture and the supporting ecosystem is extremely complex.**

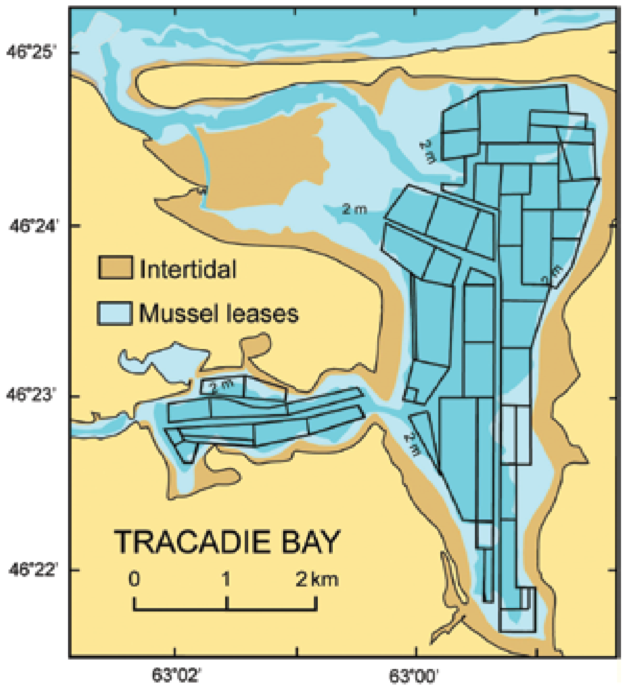



▲ *Maps of phytoplankton concentration (chlorophyll* a*) around a Norwegian mussel farm (outlined in yellow), showing food depletion within the depth zone of the farm (left), but not below the farm (right). Contours outlined in white represent the zone exhibiting more than 20% food depletion. The magnitude and extent of depletion within and outside the farm is related to the region's production and ecological carrying capacity, respectively.*

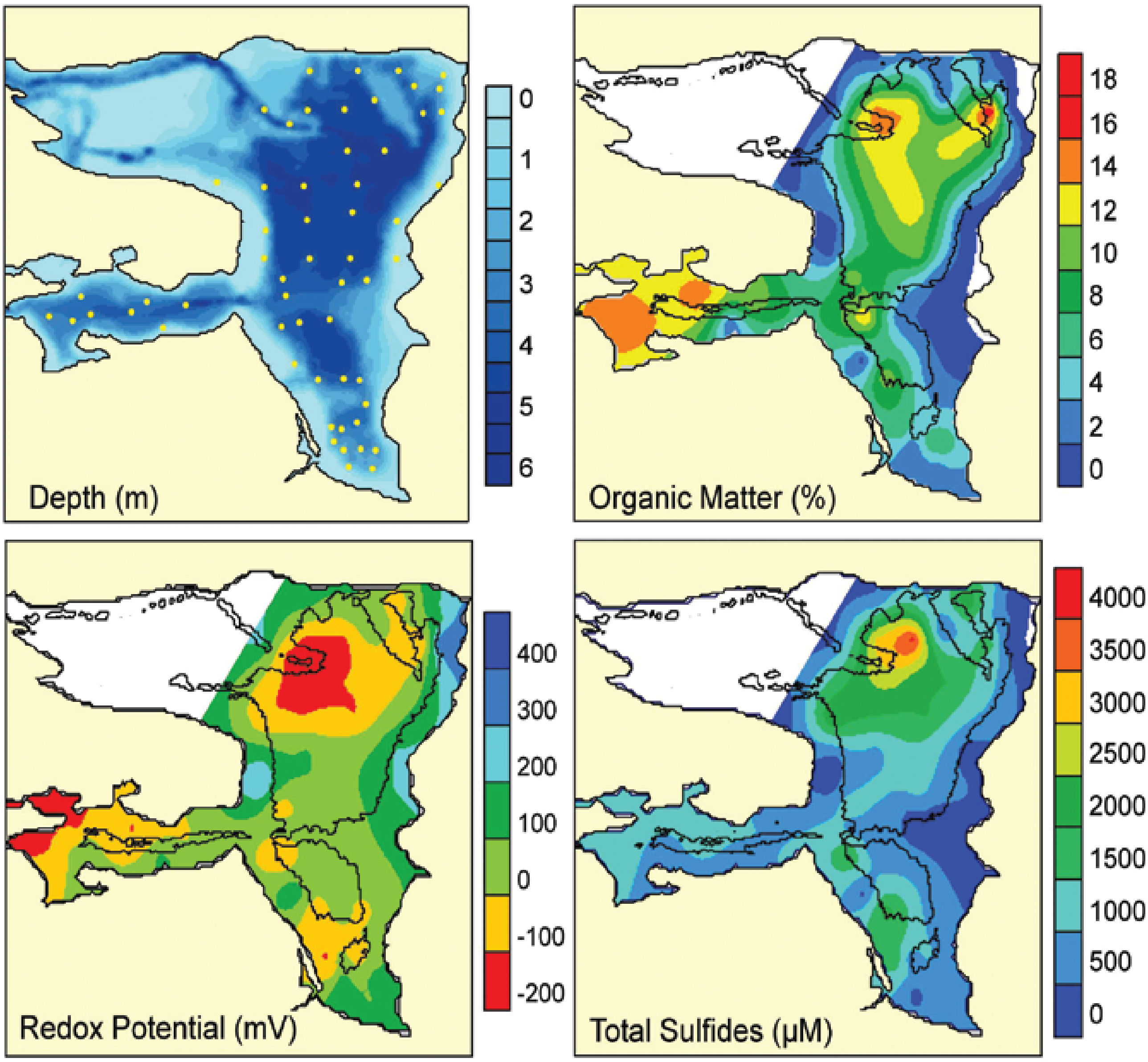
As discovered recently, intensive mussel culture not only affects phytoplankton concentration but can also alter the size of phytoplankton at the coastal ecosystem scale. In August 2008, a survey of several Prince Edward Island embayments found that, in bays with the highest risk of significant bay-wide particle depletion from mussel culture, the phytoplankton was dominated by small species that fall within a size class known as picophytoplankton (0.2–2.0 µm cell diameter). These organisms are able to dominate in these bays because they are too small to be captured by mussels, while their predators (ciliates and flagellates) and major competitors for light and nutrients are effectively ingested by the mussels.

**The aim of this regulatory science is to ensure sustainability and to maintain habitat, biodiversity, and ecosystem productivity.**

Although research indicates that the average picophytoplankton contribution in Prince Edward Island bays should be less than 30% of the total phytoplankton biomass, levels between 50% and 80% were observed in several bays. In fact, the picophytoplankton in Tracadie Bay were observed to reach densities that are ten times greater than have previously been recorded worldwide (Cranford *et al*., 2006). This indicates that the amount of food available for mussel growth is lower than is measured using standard water filtration and fluorometric techniques. From the perspective of coastal ecosystems, this result represents a destabilization of the basis of the marine foodweb. A change in phytoplankton size can be expected to alter competition and predator–prey interactions between many resident species.




▲ *Tracadie Bay, Prince Edward Island: the most extensively leased mussel aquaculture site in Canada.*




▲ *Tracadie Bay sites surveyed in July 2003 (top left) and results from geochemical analysis of seabed samples. Sediment organic enrichment, indicated by elevated hypoxic and sulphidic conditions (yellow to red areas), occurred near the river mouth on the left of the bay from land-use inputs, and in the deeper central region of the bay from the transport and deposition of detritus and mussel deposits. Adapted from Hargrave* et al. *(2008).*

### Spatial and temporal scales of benthic habitat effects

A study was conducted of the effects of increased organic-matter deposition on the benthic habitat beneath mussel farms in Prince Edward Island, using geochemical indicators of organic enrichment. Increasing seabed organic enrichment is closely linked to reductions in the diversity of the benthic community. An extensive survey of Tracadie Bay demonstrated significantly greater organic enrichment beneath mussel farms than at sites located outside farm boundaries, and also provided the first recorded observations of bay-scale benthic effects of shellfish culture (Hargrave *et al*., 2008).

A separate study of eleven coastal embayments in Prince Edward Island indicated that a 40% increase in mussel production over a four-year period resulted in a doubling of organic sediment enrichment effects beneath mussel farms (Cranford *et al*., 2009). This study revealed that measures of total sulphide and redox potential are

## Aquaculture carrying capacity

A fundamental difference between the management of wild fisheries and of aquaculture is that, without affecting the stock or the ecosystem, the former aims to maximize stock removal while the latter strives to maximize stock addition within a given area. A goal of aquaculture management is to have tools available that can predict or measure the capacity of an area to support the cultured species. This carrying capacity concept is rapidly evolving from an anthropocentric focus on maximizing aquaculture production into an ecosystem-based management approach that focuses on ecological sustainability.

These two concepts are defined as follows:

- **Production carrying capacity: the maximum sustainable yield of culture that can be produced within a region.**
- **Ecological carrying capacity: the level of culture that can be supported without leading to significant changes in ecological processes, species, populations, or communities in the growing environment.**

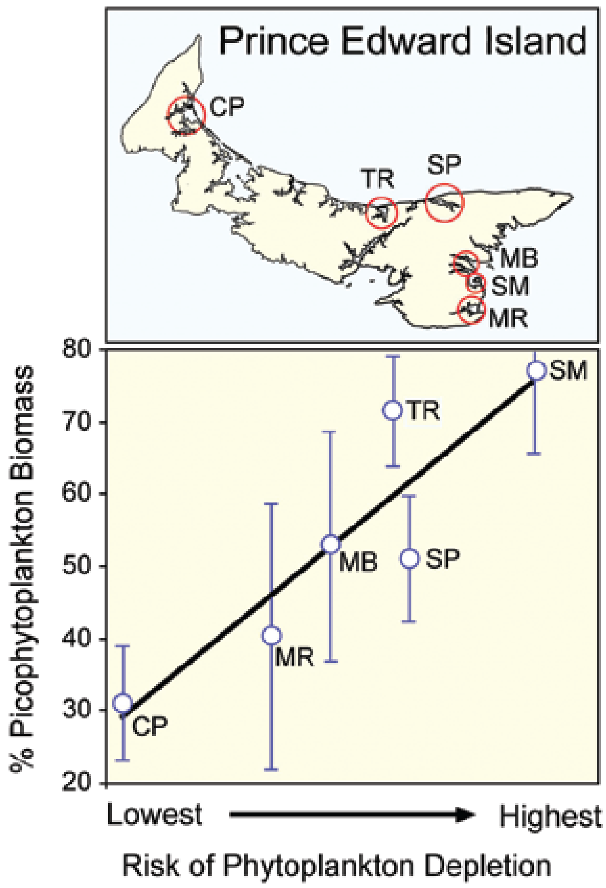
effective, low-cost indicators of benthic habitat status for differentiating aquaculture sites according to general oxic-to-anoxic seabed categories. The use of benthic status indicators and site status classifications are important for habitat and aquaculture management initiatives, and can be included in the ecosystem-based management toolbox.

### Looking forward

It is clearly imperative that the expansion of sustainable aquaculture should be accomplished in a way that minimizes negative social and environmental impacts (FAO, 2008). Regulatory scientific research based on an ecosystem approach will facilitate:

- **the development of impact risk assessment methodologies,**
- **the identification of monitoring tools and aquaculture management decision thresholds,**
- **the design of farm sampling/monitoring programmes, and**
- **The aim of this regulatory science is to ensure sustainability and to maintain habitat, biodiversity, and eosystem productivity.**

The magnitude of the interaction between the ecosystem and mussel culture is always site-specific, and site vulnerability depends on factors controlling food consumption and waste production (for example, intensity of mussel production and food concentration) and dispersion. The rate of dispersion determines the capacity of the local environment to manage excessive food depletion and benthic impacts.




▲ *Mean contribution of picophytoplankton in six Prince Edward Island embayments containing different levels of mussel culture (18–22 August 2008). The percentage contribution relative to total phytoplankton biomass is plotted against a phytoplankton depletion risk index that compares bay flushing characteristics with the biofiltering capabilities of the resident mussel farms.*

▲ *A population of blue mussels* (Mytilus edulis) *actively filtering food particles from the surrounding water. Underwater photo by Øivind Strand.*

Dispersion is controlled by hydrographic and physical factors including current, windspeed, tidal range, and water depth. The shallow, semi-enclosed tidal lagoons and estuaries in Prince Edward Island have a relatively high susceptibility to the effects of aquaculture because of their low-energy

hydrodynamic features, the shallow water, the relatively large areas leased for mussel culture, and the relatively high stocking density of mussels throughout much of the water column.

It is difficult to extrapolate results from one site to another, or to make generalizations about the environmental effects of shellfish aquaculture without employing sound ecosystem-based science. DFO scientists are currently working with international colleagues to continue to improve and test methods for predicting and measuring the interactions between shellfish cultures and ecosystems at a wide range of sites. These studies focus on providing practical tools for assessing the ecological carrying capacity for shellfish culture.

▼ *Mussel lines being lifted, showing the ropes and the mussels hanging from the longlines*

*The authors are research scientists at the Ecosystem Research Division of Fisheries and Oceans Canada at the Bedford Institute of Oceanography.*

*Peter Cranford conducts research on the ecological role of wild and cultured bivalve populations towards the development of science-based approaches and methodologies for assessing, monitoring, and managing environmental interactions with aquaculture.*

*William Li investigates the abundance and distribution of microbial plankton in natural and disturbed ecosystems.*

*Barry Hargrave is a benthic ecologist (retired) who continues to work towards the sustainable development of shellfish and finfish mariculture.*

### *Literature cited*

*Cranford, P. J., Hargrave, B. T., and Doucette, L. I. 2009. Benthic organic enrichment from suspended mussel* (Mytilus edulis) *culture in Prince Edward Island, Canada. Aquaculture, 292: 189–196.*

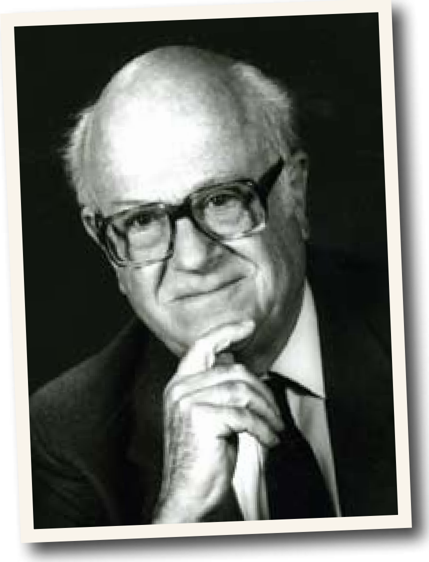
*Cranford, P. J., Anderson, R., Archambault, P., Balch, T., Bates, S. S., Bugden, G., Callier, M. D.,* et al. *2006. Indicators and thresholds for use in assessing shellfish aquaculture impacts on fish habitat. Canadian Science Advisory Secretariat Science Advisory Report 2006/034. Fisheries and Oceans Canada Science, Ottawa, ON. 125 pp.*

*Cranford, P. J., Strain, P. M., Dowd, M., Grant, J., Hargrave, B. T., and Archambault, M-C. 2007. Influence of mussel aquaculture on nitrogen dynamics in a nutrient enriched coastal embayment. Marine Ecology Progress Series, 347: 61–78.*

*FAO. 2008. FAO Aquaculture Newsletter No. 39. FAO, Rome. 39 pp. Available online at http://www.fao.org/fishery/publications/fan.*

*Grant, J., Bacher, C., Cranford, P. J., Guyondet, T., and Carreau, M. 2008. A spatially explicit ecosystem model of seston depletion in dense mussel culture. Journal of Marine Systems, 73: 155–168.*

*Hargrave, B. T., Doucette, L. I., Cranford, P. J., Law, B. A., and Milligan, T. G. 2008. Influence of mussel aquaculture on benthic organic enrichment in a nutrient-rich coastal embayment. Marine Ecology Progress Series, 365: 137–149.*



# Warren S. Wooster 1920–2008

*Gotthilf Hempel remembers.*

Warren S. Wooster, ICES President between 1982 and 1985, died peacefully at the age of 88, on 29 October 2008 in Seattle, Washington. What a loss to the global marine science community! For fifty years, he was a key personality in creating and fostering this community by bringing together marine scientists from different countries and from different disciplines. He bridged the gap between physical, biological, and chemical oceanography and fisheries biology. He inspired generations of students and colleagues all over the world, and he advised politicians and administrators on the establishment of national and international networks in marine science and marine policy.

A meticulous researcher and ingenious scientist, Professor Wooster was also a "bio-geo-politician" with extraordinary wit and will, as well as a gifted teacher, devoted to his students.

He was also an artist. His wonderful photographs of people and landscapes reflect his warm-hearted personality, full of humour and dedication. To many of us around the world, he was a great friend and fatherly adviser. In 1970, he joined me on board the RV "Meteor" for an expedition to the Canary upwelling region. It was his last expedition, and to benefit from his superb oceanographic knowledge and his wonderful companionship was a great experience for me.

Wooster was born in Massachusetts, but his scientific home was the west coast of the US. He started out as an inorganic chemist and served in the US Navy during the Second World War. He attended the California Institute of Technology as a graduate student and was awarded his PhD in chemical oceanography at the Scripps Institution of Oceanography in La Jolla in 1953. In those days, La Jolla was the hub of the world's oceanography. Hans U. Sverdrup and other heroes in physical oceanography were there, as were Roger Revelle, Milnar Schaefer, and Wib Chapman, who developed a new approach to fishery science and management.

As a young chemical oceanographer, Warren was part of the initial phase of the California Cooperative Oceanic Fisheries Investigations (CalCOFI). Almost fifty years later, in an interview in 2000, he reflected on those early days:

> So that got me interested in the matter of how did the ocean affect fish populations. That's when I began to slip over from being a chemist to wondering how it all worked, which meant I had to understand physics… That led me into what I suppose I'm now, a fishery oceanographer.*

In fact, Wooster became one of the best and most sceptical of fishery oceanographers, and his books on the subject are still worth reading.

In the 1950s, Wooster "began to get the wanderlust". He participated in some lengthy expeditions and went to Peru in 1957/1958, just in time to experience a major *El Niño* for a study of the Humboldt upwelling system. His papers on Peruvian upwelling are still cited.

Wooster's stay in Peru opened his eyes to the lack of marine research and marine institutions in developing countries. In the 1960s, as the first Secretary of the young Intergovernmental Oceanographic Commission (IOC) in UNESCO, and later as Secretary and subsequently President of the Scientific Committee on Oceanic Research (SCOR), he advocated not only the cooperation of the oceanographic centres in Europe and North America but also the expansion of oceanography from the privileged institutes in the north to the developing countries in the south.

On the initiative of SCOR, and later under the auspices of SCOR, the International Indian Ocean Expedition (IIOE) of 1962–1964 became the first truly international (albeit not well-coordinated) exercise in oceanography, covering an entire ocean and simultaneously offering assistance to the newly established marine research centres in the Indian Ocean region. India in particular made good use of the results, although IIOE did not directly help to feed the starving masses of southern Asia, as originally planned by the organizers.

** Quotations are taken from an unpublished interview by Keith Benson and Ronald Doel, Seattle.*

The US had been a member of ICES for a few years before the First World War. With the expansion of European fisheries into "American" waters beginning in the 1960s, and with the increasing links between oceanographers in North America and Europe, the US re-entered ICES in 1973. Warren Wooster soon became a US delegate. He recalls:

> I thought, ICES is an interesting in-between because it's intergovernmental but it doesn't have this formidable bureaucracy that IOC has… in ICES, they had a very clever institutional design, namely that scientists had a role in the governance. The scientists put together their ideas on what should be done, and then the delegates endorse it and get their governments to pay for it.

Wooster soon became prominent in the ICES Council and its Bureau. Patiently, tactfully, persuasively, and with great diplomatic skill, he persuaded us to think in broader geographical, scientific, and political terms. That was at the time of the Third UN Conference on the Law of the Sea, with its tremendous consequences for fisheries, as well as for the freedom of marine research.

## A meticulous researcher and ingenious scientist, with wit and will.

Working relationships with the EU had to be negotiated. As a member of the ICES Bureau, first as Vice President then, from 1982 to 1985, as President, and afterwards as Chair of the Consultative Committee, he succeeded in reshaping ICES to meet modern needs. He continued to make use of the ICES organizational set-up as an intergovernmental advisory body and as a scientific forum, open to scientists from all over the world. He recognized the strength of the many scientific working groups and the educational service they rendered to scores of newcomers and post-doctoral students.

However, with the growing importance of global scientific organizations such as SCOR and its affiliates, and with the multitude of regional and global, specialized or general oceanographic fora in place, ICES lost much of its uniqueness and, hence, much of its attraction to oceanographers and pure marine biologists. In the Northeast Atlantic, fishery regulation became largely a matter for the EU. Wooster spearheaded the reaction of ICES to these developments by a stepwise reshaping of the annual Statutory Meetings into scientific conferences that incorporated the deliberations of the standing committees and the working groups.

He was never totally frustrated by the conservative attitude of many of the Delegates. He believed in ICES talent for rejuvenation. His Centenary Lecture at the Annual Science Conference 1999 in Stockholm was proof of the high regard in which he held the role of ICES in ocean exploration. At the ICES History Symposium in 2000, he viewed "from the West" the "grand challenges for ICES" in the changing world of ocean management and governance.

By this time, he was deeply involved with PICES (North Pacific Marine Science Organization). This involvement had begun soon after 1976, when, after several years as Dean of the Rosenstiel School of Marine and Atmospheric Science at the University of Miami in Florida, he moved to the University of Washington in Seattle. There he was asked to develop an ICES for the North Pacific. This was a Herculean task in view of the different political powers bordering the North Pacific. It was fulfilled largely through "typical Wooster charm, tact, and diligence", as testified by John Knauss, Administrator of the National Oceanic and Atmospheric Administration from 1989 to 1993. PICES was eventually established in 1992, and Wooster became its first Chairman.

He remained the *spiritus rector* of PICES for more than two decades, although he spent most of his time teaching and writing major papers and books at the University of Washington's School of Marine Affairs. There he created a strong group of marine-policy students who, we hope, will follow his lead.

Three generations of marine scientists and close friends from all shores of the World Ocean join his wife Polly and their three children in mourning Warren S. Wooster.

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*Gotthilf Hempel, born 1929, became a fishery biologist in the 1950s, working mainly on herring larvae. After accepting a professorship at Kiel University in 1967, he was founding director of four marine institutes in Germany, and concentrated on capacity building in marine science in Third World countries. An active member of ICES for more than fifty years, he was its President between 1979 and 1982.*

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# Annual Science Conference

# ICES 2009

## 21–25 September

**Estrel Convention Center, Berlin, Germany**

**Open Lecture**
*The climate of the 20th and 21st century*
**by Mojib Latif, Germany**

**Invited Plenary Lectures**
*What can science tell us that fishermen don't already know?*
**by Elizabeth North, USA**

*Future fishery management in Europe – what are our options?*
**by Poul Degnbol, DG MARE, European Commission**

Theme Session topics and information on submission of abstracts and registration are found on the Conference website:

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ICES International Council for the Exploration of the Sea
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