ICES INSIGHT

Issue No. 50 September 2013

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

Collaboration and knowledge exchange

Our front cover image depicts the Silfra rift in Iceland. Located in Þingvellir National Park, the underwater rift is internationally renowned, not only for its beauty, but as a visible reminder of where the Eurasian and North American tectonic plates meet.

ICES member countries themselves stretch from Canada and the US in the west to the Russian Federation in the east, encompassing the wide expanse of the North Atlantic and its adjacent seas. It is therefore appropriate that Iceland plays host to the ICES Annual Science Conference (ASC) in September 2013 where almost 700 researchers, experts, students and stakeholders are meeting to exchange and debate the latest marine scientific knowledge over the course of a week.

The ASC plays an integral role in communicating ICES science, but it also honours excellence in marine science through various awards conferred on early career scientists, presenters and esteemed leading researchers in the ICES community. Recognizing exceptional work is an important aspect of furthering excellence in marine science.

"The ASC provides an opportunity for many official and unofficial business meetings with ICES customers, policy makers, managers and communicators, benefiting from the great audience that the ASC attracts," says ICES Science Committee chair Manuel Barange. "The conference is also an opportunity for the new generation of scientists (many of whom receive travel assistance from ICES) to get involved in what is the largest network of regional marine scientists in the world."

This latest issue of *ICES Insight* includes some of the latest discoveries and issues of interest in the marine science forum. Contributors are based in a range of countries from Canada to Norway to Japan and bring with them a wealth of knowledge and expertise from their individual fields. We hope you enjoy *ICES Insight* and twould love to hear more from our readers. Any feedback or suggestions for future articles are welcome at info@ices.dk.

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Silfra rift, Iceland. © Charles Hood

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On the origin of escaped farmed salmon

Øystein Skaala and Kevin A. Glover examine how old questions and new problems are addressed by genetics

Human impacts on wild salmonid populations have been the subject of a significant amount of attention in the course of the past few decades, and impact factors have been well documented. In 1983, an intergovernmental organization, the North Atlantic Salmon Conservation Organization (NASCO; www.nasco.int) was established with the objectives of conserving, restoring, enhancing, and rationally managing the Atlantic salmon through international cooperation. In the course of the subsequent thirty years, a series of international symposia have addressed and documented these effects (Anon, 1991; Hutchinson, 1997, 2006).

In Norway, which has management responsibility for a significant proportion of the remaining wild salmon populations, not to mention a multibillion-euro salmon farming industry, the Ministry of Fisheries and Coastal Affairs drew up a "Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry" (Taranger *et al.*, 2011). This stressed the following five potential impacts of salmon farming: 1) genetic impact on wild fish, 2) organic discharge, 3) transmission of diseases and salmon lice to wild populations, 4) allocation of aquatic habitat to fish farming, and 5) the problem of obtaining adequate feed resources from an already heavily exploited marine ecosystem.

While escaped farmed salmon give management authorities a headache, the problem has presented an opportunity for scientists to develop advanced genetic and statistical methods that are now being employed to learn more about the Atlantic salmon and assess its genetic impact on wild populations: How does natural selection shape and adapt local populations? Are salmon populations adapted to their local environment? How and to what extent does gene flow from domesticated salmon affect survival and production in wild populations? And finally, can we identify the origins of the escapees?

There is little doubt that wild salmon have been an important resource for many communities for centuries, and that the species has been the source of many conflicts in the course of the years. Written sources tell us that as early as the 14th century there were conflicts regarding how salmon should be managed, for example in Suldalslågen, where farmers, the monks of Halsnøy Monastery, and landowners with fishing rights in the lower reaches of the river broke into open warfare. As far back as 400 years ago the priest Peder Claussøn Friis (1545–1614) observed that salmon populations from different rivers could have different characteristics, and that spawning salmon migrated to their home river to spawn.

"…and what is most to be wondered at, every salmon seeks the stream and the very place in which it was born, which is demonstrated thus. First, each river and stream has its own particular type and difference from the salmon of other rivers. Lyngdal, Undal, Mandal, Torridal, and Topdal salmon have each their own characteristics, by which we can to some extent recognize which stream they belong to (even) if they should mistake their way and are taken in another stream."

The priest was right!

Almost 400 years later, salmon scientists carried out a DNA-based project to which Peder Claussøn Friis would probably have given a nod of approval. The reasons for our anxiety regarding the genetic impact of escaped farmed salmon are to be found to some etxtent in a comprehensive literature that has largely confirmed the priest's observations, and which, with the help of advanced molecular genetics and statistical analyses has quantified the genetic differences between wild salmon populations. We now know, for example, that the genetic distinctions between salmon stocks on the eastern and western seaboards of the Atlantic are approaching the level of species differences. We also know that within its European distribution range, there are major differences between the salmon of the Baltic and the Atlantic, and between salmon from Russia and northern Norway and more southerly stocks. In collaboration with other research centres, the Institute of Marine Research has charted the genetic relationships of 284 salmon stocks via the SALSEA project.

Ladies from Voss with their catch one fine day in 1912. Photo: The Voss hatchery foundation. The Vosso salmon has survived in the Norwegian Gene Bank for Atlantic salmon.

We can also identify robust differences within individual regional stocks, for example within a single county, and in some cases even within individual large rivers. The background for these differences lies in the life history of the salmon, in which fish that are ready to spawn have an extremely well-developed ability to find their way back to the native river in which they themselves had hatched, in order to reproduce. The consensus of a large number of tagging experiments has been that, of the wild salmon that survive the feeding migration to the open sea and return to a river, 95 per cent or more reach their natal river. Scientists have long asked themselves just why salmon have evolved such an orientation ability. According to the theory of evolution, such behaviour ought to have advantages for the individual, and in nature, the prize should be a larger number of surviving offspring. In theory, evolution via natural selection should lead to a stock becoming well adapted to its environment. There exists a great deal of scientific literature that suggests that this works in practice; for example, many stocks of Atlantic salmon and other salmonid species are well-adapted to local conditions.

Although these are simple and fundamental questions in both evolutionary biology and salmon management, testing them in ways that can give us hard data is both time and resource intensive. How rapidly does a local adaptation develop? What is the geographical distribution of a locally adapted stock? Some very recent studies carried out by a Danish-Canadian group (Fraser *et al.,* 2011) have dealt with these questions. Their results show that in more than half of the cases studied, the salmon stocks have adapted to their environment, and on average, the survival rate of the local population is 1.2 times as great as that of non-local populations. The geographical distribution ranges from a few kilometres to more than 1000 km. The local adaptation unit need not be a single river, but may be a larger or smaller area, although increasing geographical distance tends to lead to stronger adaptation.

Are wild and farmed salmon genetically different?

There currently exists an extensive scientific literature that documents genetic differences between wild and farmed salmon. This is scarcely surprising, given that farmed salmon have been selected for specific production characteristics such as rapid growth and delayed sexual maturation for eight to ten generations. In tank trials, farmed salmon grow at least twice as rapidly as wild salmon, and a number of other differences between these groups have been documented; these include aggressive behaviours and responses to predators. So what do we know about the impact of escaped salmon on wild stocks? Over the course of the approximately 25 years during which we have identified escaped salmon in the spawning grounds of wild salmon, we have seen that their incidence is very variable, both from year to year, between different parts of the country, and between individual rivers. What we do not know so much about is the extent to which the offspring of escapees survive and modify the inherited characteristics of wild salmon populations.

Performance of wild and farmed salmon under natural conditions

Two earlier studies, one in Burrishoole in Ireland (McGinnity *et al.,* 2003) and one in Imsa in Norway (Fleming *et al.,* 2000), have concluded that the offspring of farmed salmon have a much lower survival rate in nature than those of wild salmon. Different crosses of wild and escaped salmon have different survival rates, ranging from poor to practically as good as wild salmon among offspring whose mother is wild. The Burrishoole study found that the offspring of farmed salmon had a very low survival rate through the marine stage compared with wild salmon, but such differences were not found in Imsa.

In order to obtain a more accurate understanding of the fate of the offspring of farmed salmon in nature, we carried out an experimental field trial at the Institute of Marine Research's field station in Guddalselva (Skaala *et al.,* 2012). Studies of this sort in a natural environment are demanding and time-consuming, which means that they are seldom carried out. At the same time, they are an important complement to model studies and laboratory experiments, precisely because the animals are observed in their natural element. A prerequisite for performing such studies is the existence of facilities (Figure 1) that offer good control conditions and representative collection of experimental animals, which means that there exist extremely few places where such field studies can be carried out. In our study, we compared genetic differences in survival, age, time, and size at smoltification and choice of diet in families of farmed and wild salmon and crosses of these two groups. Since escaped salmon tend to have poor spawning success compared to wild salmon, we started our study by setting out a known number of eyed eggs, so that differences in spawning success due to environmental differences would not create "noise" in the results. We set out a total of 205,266 eyed eggs from 69 individual salmon families above the smolt trap in the River Guddal, some of which were pure farmed salmon families, while others were pure wild families.

Figure 1
When salmon smolts pass the trap in River Guddal on their way to the Norwegian Sea, they have to "deliver" a little DNA sample for parentage testing and comparison of survival rates in farm and wild salmon families.

The survival rates of the eyed eggs to the yolk-sac stage were extremely good in all three of the year classes. What was most surprising was the wide variation in survival among the farmed salmon families, some of which had very high survival rates. Moreover, some of the crosses with farmed mothers had more or less the same survival rate as the wild salmon. Since the observed rates of survival differed so widely between families, we developed a statistical model to describe the variation on the basis of the available parameters. The model showed that egg size had a major influence on survival until the smolt stage. This was perhaps not particularly unexpected, but that we were able to specifically demonstrate this effect, and moreover at family level, was rather more than we had expected when we started. In this particular study, the parents of the farmed families were much larger (12–14 kg as compared to 4 kg) than those of the wild salmon. This environmental effect camouflaged the real genetic differences between the groups, and at first glance, therefore, there appeared to be only minor differences between the offspring of wild salmon and escapees. In order to be certain that the model was not misleading us, we also compared half-sibling families; i.e. we divided the eggs from a number of farmed hen fish into two groups and fertilized one group with milt from a farmed male and the other with milt from a wild male. In 15 of the 17 comparisons that we performed, the half-sibling families that were offspring of wild fathers had higher survival rates than the half-siblings both of whose parents were farmed fish (Figure 2). Egg size is influenced by both genetic and environmental factors; large fish produce the largest eggs. At the same time, it has been shown that domestication reduces the size of the eggs they produce. Since egg size is highly variable in both cultivated and wild fish, this experiment shows that it would be extremely difficult to predict the outcome of an influx of escaped salmon in any given case in a river.

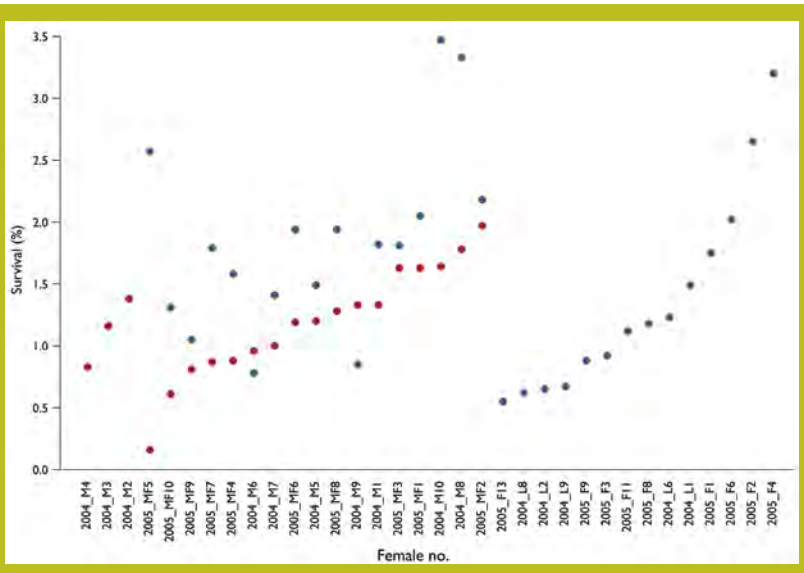

Figure 2
Pairwise comparison of survival from eyed egg to smolt stage in salmon half-sib families in a natural river habitat. All mothers are farmed females. Red: sired by farmed male; blue: sired by wild male.

Competition for resources reduces the production of wild salmon

In rivers, the availability of food is limited, and survival depends on fish density. In the River Guddal study, we were also interested in looking at whether the density of young fish in the river had an influence on the relative competitiveness of cultivated, hybrid, and wild salmon. We did this by increasing the quantity of eyed eggs in each year class. In practice, this meant that the density of the fry increased for each year class, while at the same time, each new year class also had a year class of elder salmon fry to deal with, as well as the river's stock of trout. Small salmon fry are on the menu of both large salmon fry and trout, so popping their heads out of the gravel when the yolksac has been consumed is a risky business for the former. We found that compared to that of half-siblings with a wild father, the survival rate of cultivated salmon fell as fish density increased, from 0.86 in the 2004 year class to 0.62 in the 2005 year class. This is an indication both of a difference in competitiveness, and that the higher the density of wild salmon in a river, the lower the survival rate of the offspring of escaped salmon.

Wide variations in size between the families at the same age were also observed in the study, and in the material as a whole the smolt with farmed parents were around one gramme heavier than the hybrids, which in turn were about one gramme heavier than the wild smolt. We also observed that the offspring of farmed salmon were in a hurry to leave the river in spring. In any given year, the offspring of farmed salmon arrived at the smolt trap on average several days before the hybrids and the wild fish. The most usual prey of salmon fry in rivers are mayflies, caddisflies and stoneflies, in addition to chironomids and gnats. There was nothing to suggest that farmed and wild salmon have different dietary preferences, and their choice of diet overlapped completely. In most rivers the availability of food is limited, which means that the offspring of cultivated salmon are competing with wild fish for the same food, which leads to a reduction in the production of wild salmon smolts.

Populations differ in their resilience

Since it is difficult to predict the extent of interbreeding on the basis of observations of the proportion of escaped salmon in a river, we also compared the stability over time of the DNA profiles of wild populations with a large proportion of escaped salmon (Skaala *et al.*, 2006; Glover *et al.*, 2012). These studies also gave us new and to some extent unexpected insight. It is not surprising that we found that the DNA profile of some stocks with a relatively large proportion of escapees in their spawning grounds had changed. In the samples taken following the return migration of escaped salmon, we found genetic variations that were not present in older samples taken before there were significant numbers of escaped salmon in the rivers. We also observed that the genetic difference between populations had shrunk in the course of time; i.e. stocks have become more similar, as scientists predicted they would some twenty years ago, before we had DNA-based tools capable of quantifying the changes. Although stocks are influenced by a number of natural and anthropogenic factors, escaped farmed fish are the most likely explanation of these genetic changes. Our study identified clear changes in six out of 21 populations (29%) along the coast of Norway (Glover *et al.*, 2012). Perhaps the biggest surprise was that we did not find any changes in several populations that had contained a large proportion of escapees for many years. One example of this phenomenon is the River Etne in the Hardangerfjord, which has held a large number of escaped farmed salmon for at least 20 years. This suggests that we still have a number of wild salmon stocks that have been little affected or completely unaffected by escaped farmed salmon.

Removal of escaped farmed salmon from spawning areas

The Institute of Marine Research has documented that escapees are in the process of altering the genetic make-up and structure of wild salmon populations (Skaala *et al.*, 2006; Glover *et al.*, 2012). It is difficult to imagine that even large-scale efforts by the aquaculture industry to prevent escapes would have a realistic prospect of significantly reducing the extent of escapes as long as current production technology remains in use. In the short term, it will therefore be necessary to implement measures that make it easier to identify escaped salmon in nature, so that it is possible to differentiate between escaped and wild salmon and remove the escapees from spawning stocks. One simple and cost-effective method that has been suggested, and that would not harm farmed salmon, would be to remove the adipose fin (Figure 3). This would mean that escapees could be identified at the river's edge without time-consuming and expensive studies of patterns of growth or morphology or DNA testing. At the same time, it is essential to possess technology that would prevent escaped fish from migrating into the spawning grounds of wild salmon. It must be possible to sort out escapees while leaving wild fish with access to their spawning grounds in the river.

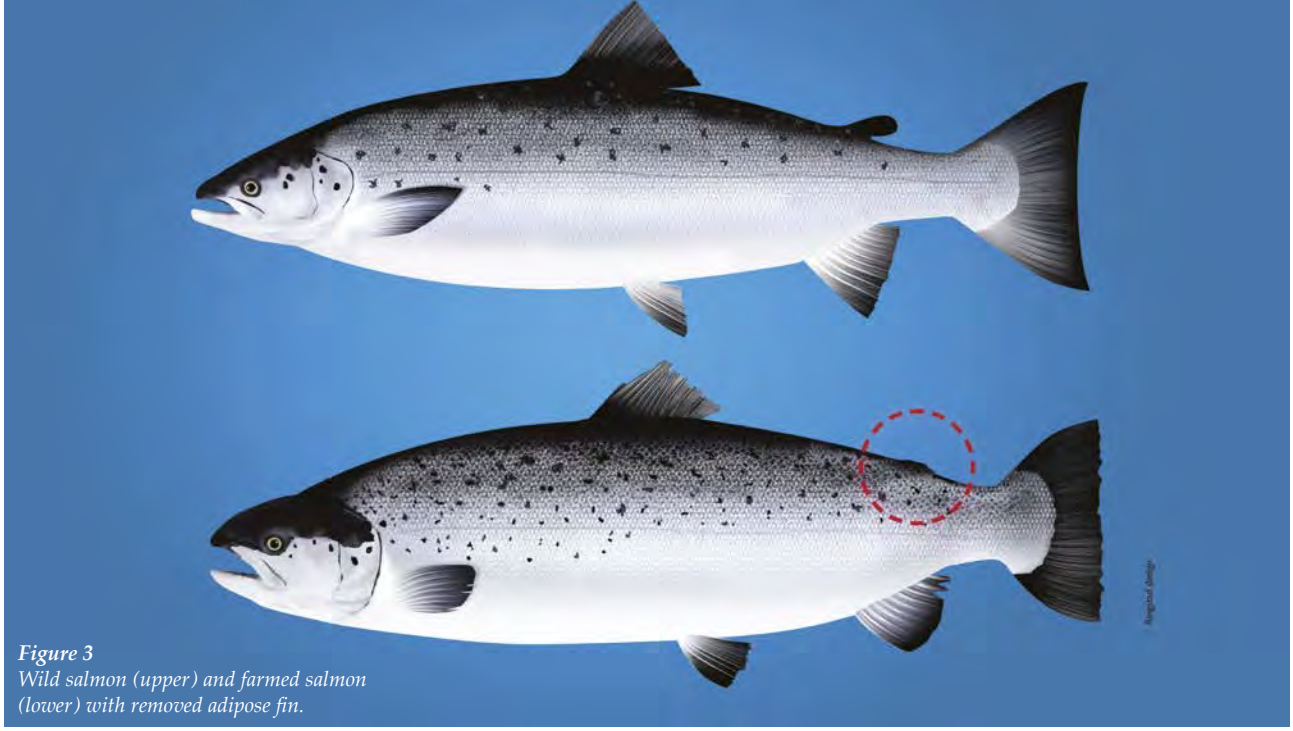

Figure 3
Wild salmon (upper) and farmed salmon (lower) with removed adipose fin.

Several methods of removing escaped farmed salmon from the spawning areas of wild populations have been tested through a series of small projects, ranging from angling, gillnetting and harpooning in the rivers, to fykenets in the estuaries, and trawling in the fjord. In a series of studies that involved setting out farmed salmon, Skilbrei (2010) and Skilbrei *et al.* (2010) showed that as soon as farmed salmon escape they spread out over a large area, and after as little as a week may migrate as much as 40 km from the farm from which they had escaped. A significant proportion of these escapees also dive to depths that make it difficult to catch them with traditional fishing gear.

Portable trap facilities (Figure 4), such as resistance board weirs (RBWs), which have been in use in North America for about two decades (Tobin, 1994), would appear to be rather useful in removing farmed salmon escapees from rivers. At the same time, such systems would provide good opportunities to improve the monitoring of wild anadromous populations by introducing a consistent sampling method, reducing sampling bias in datasets and allowing for development of time-series, all of which are extremely valuable management tools. RBWs are a relatively new modification to very old technology, and are typically operated in close proximity to known spawning areas. This American fish-capture technology is currently being tested in Europe for the first time on Atlantic salmon in the Norwegian salmon river Etneelva, with the aim of preventing escaped salmon from migrating into the spawning ground of wild salmon.

Figure 4
The North American resistance board weir portable salmon trap system now tested in River Etneelva, Norway, to eliminate farmed salmon from the spawning grounds of wild salmon.

Tracing the origin of escapees through their DNA

We do not know just how many farmed salmon escape. Some regions have more escapes than others; in many rivers there are very few escapees, while in others, in some years there may be as many escaped salmon as there are wild fish. Small numbers of escapees are difficult to detect, and probably mostly go unreported. The tracing studies carried out by the Institute for Marine Research for the national fisheries management authorities also show that some escapes are not reported, although fish farmers are obliged to report escapes when they realize that they have occurred.

There are two reasons why we wish to identify escaped farmed salmon, and these make different demands on the methodology used to identify escaped fish. As far as recapturing escaped farmed salmon is concerned, it is sufficient to decide whether a fish is wild or an escapee. In such cases, the aim is to remove the escapee before it spawns, possibly affecting the genetic make-up of the wild population. However, if we wish to identify the origin of the escaped fish (i.e, the farm of origin), a more stringent methodology is required. The point of identifying the origin of an escapee is that it also allows us to identify the cause of the escape, implement measures to prevent its recurrence in order to reduce the extent of escapes, and learn from what has happened. At the same time, the authorities can decide whether there are circumstances associated with an escape that need to be further investigated, in case a fish farmer should be made responsible for an escape and its potential environmental and economic consequences.

DNA has been used in forensic medicine since the 1980s, when Professor Peter Gill and his colleagues of the Forensic Science Service in the UK realized that DNA could be used to identify criminals. All of us have our unique DNA "fingerprint", and when developments in molecular genetics made it possible to identify differences in DNA, we gained a new and very powerful tool that led to a revolution in forensic medicine. DNA is found in every cell of the body, and the quantity in a hair root or even on a fork or a cigarette stub can be sufficient to identify a person. For our purposes, a piece of a fish-scale may be sufficient. DNA exists in virtually all biological material, is extremely stable, is not affected by what you eat or drink or by your physical environment, and it does not change in the course of the life of the individual. The DNA that we inherit from our mother and father stays with us all our life, and for long after. The use of DNA in forensic medicine is based on extremely strict procedures with very high standards of quality assurance.

When Norwegian politicians suggested tagging all farmed fish (White Paper no. 12 (2001–2002): "Clean and rich seas", and Parliamentary Proposition no.134 (2002–2003): "On designating national salmon rivers and salmon fjords"), the aim was to develop a method of identifying the sources of unreported escapes. A national Tagging Commission was appointed that included representatives of the authorities, research and the aquaculture industry. The Commission surveyed all known methods of tagging, including external tags, electronic, physical and chemical tags, and DNA, and identified six criteria that a tag would have to fulfil:

1. Tags must not affect the health or welfare of the fish.
2. Tags must not affect either the market for fish, or public health.
3. Physical tags must be so small that fish can be tagged before they are transferred to enclosures in the sea.
4. The results of analyses must be easily available.
5. Tags must be suitable for use on large numbers of fish.
6. The total cost per tagged fish must be low.

Each of the methods has its advantages and disadvantages, and these are often related to level of accuracy, animal welfare, logistics, market or economics. Among the aquaculture representatives on the commission, for example, there was some anxiety that methods that involved the addition of chemicals or physical tags could have a negative influence on the market. The Institute of Marine Research has subsequently developed the DNA Stand-by method (Figure 5), which utilizes the DNA of the fish to identify the sources of escaped salmon. The method has now been thoroughly tested in 15 concrete cases, and has been documented and quality assured via publications in international scientific journals (Glover *et al.*, 2008; Glover, 2010). We therefore know the accuracy, limitations, and cost of this method, while other methods are still at an early stage of development (Table 1). The method is not based on parent-offspring relationships, but on comparing the DNA profile of individual escaped salmon with that of fish from farms within a certain distance of the appearance of escapees. The method was developed with the aim of identifying the source of concentrated unreported escapes, and is not suitable for small, diffuse losses of fish. The procedures for the Stand-by method are based on a rapid response on the part of the authorities. When members of the public register abnormal catches of escapees and contact the fisheries

management authorities, these must immediately find out whether losses of fish from nearby farms have been reported. If no-one has reported such loses, samples must be taken both of escaped fish and of fish from farms in the vicinity that contain fish of similar size.

In practice, it turns out that when the fisheries management authorities react quickly enough with the collection and processing of samples, and when we examine biological characteristics such as the size of the escapees, there are not so many farms that lie in the area within which the escape is likely to have occurred. One example of this is a tracking in the County of Troms, where there were nine potential sources of an unreported escape episode. Tests showed that 37 of the 48 recaptured escapees matched the profile of one particular farm (Figure 6), while the other eight farms were found "not guilty" since the DNA profiles of the escapees did not match those of these farms. For the first farm, on the other hand, only 12 of the 48 escapees did not match up.

The DNA Stand-by method requires neither tagging of the fish nor the development, operation, and maintenance of a database of either farmed or wild salmon, as the other methods would have done. The method only begins to cost something when the authorities register a case that they wish to follow up. For a typical case, such as that in Troms, involving analyses of fewer than 1000 fish, the costs will be made up of the scientist's and technician's salaries, laboratory expenses, and the cost of collecting samples of escaped fish and reference samples from fish farms in the vicinity; a total of less than NOK 300,000. The DNA Stand-by method is thus both simple and cost-effective.

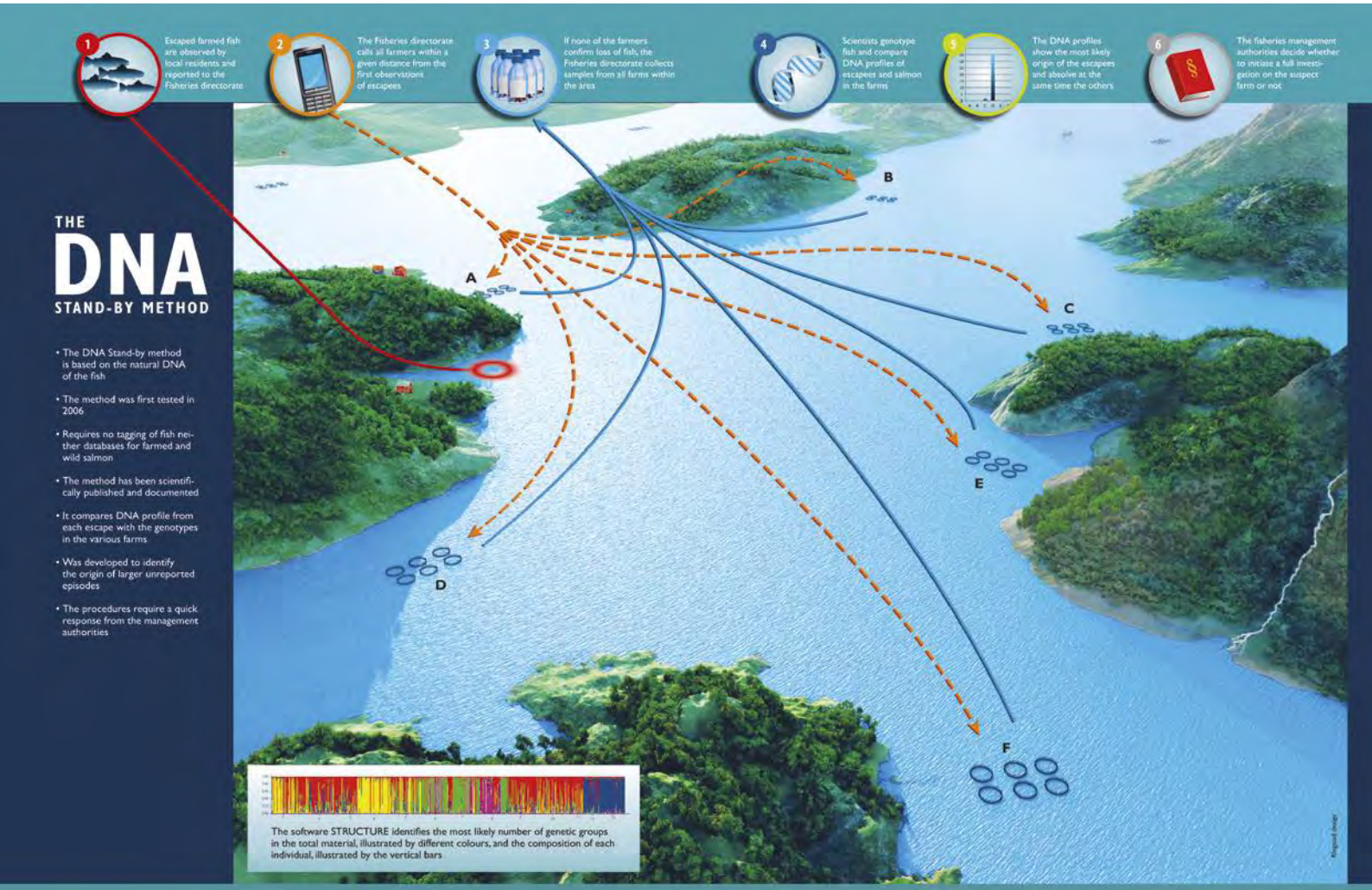

Figure 5
The DNA Stand-by method implemented by Norwegian fisheries management authorities to identify salmon farm of origin and escapees.

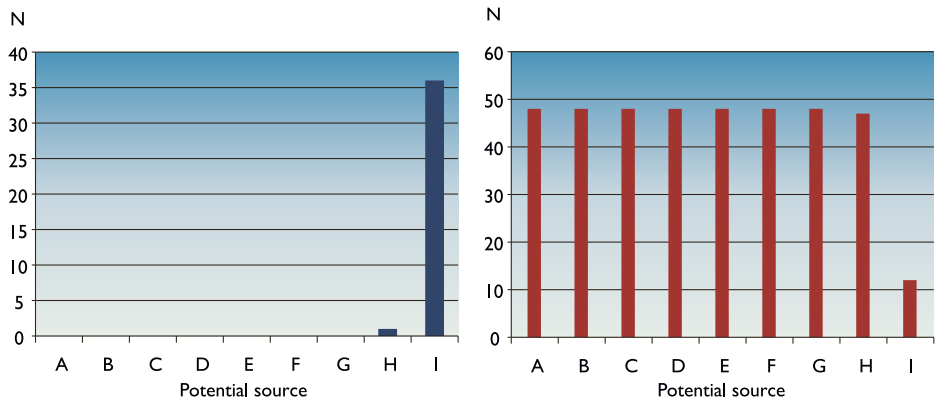

Figure 6
In this case there were nine potential sources, A-I, for the captured escapees. The diagram on the left shows how many of the 48 captured escapees fit the DNA profiles of the various potential sources, and identifies the most likely source. The diagram on the right shows how many of the escapees that did not fit the DNA profiles of the potential sources.

Towards a scientifically based monitoring programme for escapees?

There is no doubt that salmon farming has become an economically significant industry that depends on the availability of coastal areas and large amounts of marine resources. At the same time, however, the negative consequences of salmon farming on wild anadromous stocks include a massive release of salmon lice and large numbers of escaped farmed fish. This in turn affects recreational values and other nature-based industries that depend on adventures, many of which are also dependent on marine and anadromous fish stocks. To gain an overview of whether salmon farming is sustainable or comes into conflict with the Norwegian government's Strategy for an Environmentally Sustainable Aquaculture Industry, the authorities need accurate information about the extent of individual impact factors, in addition to science-based management advice. While nation-wide professional monitoring of salmon lice in wild fish, which is another important impact factor of salmon farming, has been established, the registration of escaped farmed fish is still fragmented into a number of small, uncoordinated activities that lack a secure financial basis. One consequence of this is that information tends to be registered from a number of different sources, collected via different methods at different times and with different standards of quality assurance. As a result, conclusions regarding numbers of escaped fish in Norwegian rivers tend to be widely divergent. We thus lack a national, coordinated, science-based, quality-assured programme under public-sector control that monitors escapes of farmed fish and removes escapees from the spawning grounds of wild salmon. This obviously makes it difficult for the authorities to monitor environmental effects of escapees and to manage wild salmon populations. Our experience of monitoring salmon lice demonstrates the value of official national coordination and quality-assurance of the impact factors of fish farming, with a predictable and necessary system of financing. Given the current scope of fish farming, it is unlikely that with existing production technology we will be able to completely prevent escapes, despite the serious efforts that are being made by the aquaculture industry. If escapes continue to occur at the same level as we have experienced until now, a growing number of wild salmon stocks will be affected and will become more similar to farmed salmon. This will bring about undesirable and irreversible loss of genetic resources. To avoid this, fish farms will have to be enclosed to a greater extent. It is also worth pointing out that sterile salmon, which are currently being trialled on a commercial scale, could significantly reduce the problem of negative genetic effects on wild stocks.

Tagging system	Advantages	Disadvantages
A: Physical tagging of all fish	Accurate identification is possible. Also identifies "drip" escapes. Continues to identify fish long after they have escaped (even after slaughter). Allows farmed salmon to be identified in nature and to be removed from wild stocks.	Fish welfare, handling, stress, injuries. Major investments in logistics and equipment. Questions regarding relative times of tagging and escape. Tag has to be removed before fish can be consumed. Requires major documentation and management efforts on the part of the authorities. Potential loss of tags. Large annual operating costs. Major investment of resources on fish that do not escape.
B: Removal of adipose fin	Easy identification of escaped fish in rivers.	Useless for tracing escaped fish back to farm. Potential welfare problem when large-scale tagging involved.
C: Chemical tagging via feed or vaccine	Fish farmers pay for tagging process.	Tagging via feed requires widespread control of the production and sale of many individually tagged types of feed. Tagging via vaccines requires similar widespread control of the production and sale of many individually tagged types of vaccine. Potential consumer reactions to adding chemicals to fish.
D: DNA with databases	No physical or chemical tagging involved. Fish are not handled. Can be traced back to hatchery or ongrowing farm. Costs can be claimed back from polluter rather than industry as a whole.	Requires establishment and operation of major databases. Requires reorganization of aquaculture industry logistics. Major investments in logistics and equipment. Requires major documentation and management efforts on the part of the authorities. Major annual costs.
E: DNA Stand-by method	No investments in equipment required. No fish handling or adaptation of aquaculture industry logistics required. No need to set up and operate databases of farmed fish. Costs begin to run only in event of an escape event. Extremely cost-effective. Costs can be claimed back from polluter rather than industry as a whole.	Not suitable for small "drip" escapes. Requires rapid response following escape. Requires the authorities to maintain a contingency team. Not every case will result in diagnostic identification of the individual farm involved.

Table 1:
Advantages and disadvantages of the best-known tagging systems for identifying escaped farmed salmon.

Facts about escaped and wild salmon

Escapes of farmed salmon have led to genetic changes in at least six of 21 (29%) Norwegian salmon populations studied. These changes have taken place in the course of a relatively short time (15–30 years), i.e. within about three to six generations.

The genetic changes accumulate over time, and continued escapes will therefore lead to greater changes in wild salmon in the course of time.

Since the spawning success of farmed salmon is gender-specific and will also vary in time and space, at the same time as there are wide variations in survival rates of the offspring of farmed salmon in nature, it is unlikely that there is an absolute limit to the proportion of farmed salmon a wild salmon population can absorb.

There is no scientific evidence that crossing escaped farmed salmon with wild salmon populations has any positive effects on the latter.

An important aim of further efforts will be to develop good indicators of the effects of escaped farmed salmon on wild populations.

The fact that a large number of genetic combinations can produce salmon with identical phenotypes means that although we can select our way back to a salmon that resembles the "old" phenotype, we cannot re-create the genetic material of a population such as it was before the farmed salmon bred into the wild stock. Evolution is not reversible.

A number of measures have the potential to reduce the effects of farmed salmon on wild stocks; these include enclosed farms, introducing sterile farmed salmon, removing the adipose fin of farmed salmon, traps in rivers, gene banks, and planting out eggs of wild salmon.

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Greenland's first living deep-water coral reef

A joint team from Denmark and Canada look at the discovery of the first live eye-coral found in Greenland

Photo: Fisheries and Oceans Canada

Until 2012, living colonial stone corals had not been recorded in Greenland. However, in that year two Canadian expeditions found living specimens of *Lophelia pertusa*, the eye-coral, and showed the presence of reef-like structures at about 800 m depth off southwest Greenland. The considerable extension of the known geographic range of these corals raises questions of fishery regulations and of the creation of MPAs in Greenland territorial waters.

"They live in the darkness of deep waters and feed by catching minute animals with their tentacles."

Cold-water coral reefs

Cold-water corals, both solitary and colonial, are found in most regions of the world's oceans. In contrast to the more well-known tropical relatives, they live in the darkness of deep waters and feed by catching minute animals with their tentacles. The best known species, although not the one with the widest geographical distribution, is *Lophelia pertusa*, the eye coral, which is the dominant colonial form in the Atlantic.

Biology of *Lophelia*

Dredging, trawling, photography, video-recording and multibeam bathymetry have demonstrated an extreme variation in *Lophelia* colony-size, the largest single formation known being the Sula Reef at 300 m depth off mid-Norway. It is 13 km long, about 400 m wide and up to 35 m high in places. The largest known *Lophelia* reef complex is further to the north, in depths between 300 and 400 m, west of Røst Island in the Lofoten archipelago. It covers an area approximately 40 km long by 3 km wide. Most localities reported are hard substrate of slopes, ridges, banks, seamounts and thresholds of fjords, in other words places where local current is intensified, and food conditions therefore improved. *Lophelia* reproduces both a sexually and sexually, but while the budding is well described, there is poor knowledge of the formation of sexual elements and larvae. The reefs are supposed to grow mainly through budding, and the growth rate is estimated to be on average about 1 cm per year. The growth must compensate for an appreciable degradation of the dead, lower parts of the reef, mainly caused by weakening of the calcium carbonate skeleton through the activity of boring organisms in combination with water movements.

The reef community

The living corals seem to have few predators. The reef itself, however, offers numerous different spatial possibilities for species to find suitable habitats and is the basis for a fauna of high diversity. While only the superficial 10–20 cm of the reef is occupied by living corals, the major part constitutes a framework of dead coral branches combined with living and dead skeletal structures from other kinds of animals, especially sponges, stylasterids, polychaetes and bryozoans. In the framework, all degrees of both current-exposed surfaces and more or less protected sediment-filled crevices and pockets can be found. A full taxonomic analysis of the reef fauna is a comprehensive and demanding task, listing in each case several hundred species that represent nearly all phyla. The overall picture resulting from such work is that the associated fauna is different in composition between regions (e.g. Norway, the Faroes, Bay of Biscay) with only few species in common, and that the majority of the species in each case is from the local area.

Lophelia in Greenland

From time to time, there have been claims of *Lophelia* occurring in Greenland waters, but all samples checked turned out to represent either dead fragments of other corals, or old worn skeletons from stylasterids. However, during an international multidisciplinary cruise onboard the Canadian "CCGS Henry Larsen" in September–October 2012, staff from the Bedford Institute of Oceanography, Dartmouth, secured *in situ* photographs of parts of a reef between 670 and 1050 m depth off southwest Greenland. The area is a current-swept steep part of the continental slope. The locality of the reef seems to be a rocky outcrop, where hexactinellids, demosponges, and octocorals also find a habitat. The temperature was 4.86 °C, the water mass being of Atlantic origin. The site was located when a 25 cm large fragment of a living *Lophelia* colony was entangled in CTD wire while working in the area during the Fisheries and Oceans Canada cruise for the Atlantic Zone Off-Shelf Monitoring Program (AZOMP) the previous June. The associated fauna is represented by sponges, hydroids, polychaetes, crustaceans, bryozoans, and echinoderms. The area is characterized by sustained inflow of relatively warm and saline waters from the Irminger Sea by the Current Water, representing the northwestern branch of the North Atlantic Current, carrying modified water of subtropical origin.

Lophelia in adjacent regions

The eye-coral has been found all over the Atlantic Ocean along continental margins, on banks and on seamounts, with most recorded instances in the northern Atlantic, as that is where numerous investigations and intensive search for reefs have taken place. In the Northeast Atlantic, it is distributed from northern Norway to West Africa, and from the Faroe Islands to Iceland and the Reykjanes Ridge. In the Northwest Atlantic it is found from the Scotian Shelf to Florida.

The new Greenlandic coral reef: importance and perspectives

The record of live *Lophelia pertusa* in Greenland waters is biogeographically important, indicating connection between the eastern and western distribution areas. For future investigations, questions are raised about the distribution of the species off Greenland and eastern Canada, immigration from where to where and at what time (the age of the reef), including a possible Pacific connection in the past.

It has been proved that trawling is highly damaging to *Lophelia* reefs. Both because of great national value as an addition to the Greenlandic nature diversity and because of its scientific importance, the authors feel the reef and its nearby area should be placed under some kind of regulatory measure as soon as possible.

There is an obvious international interest as the ICES Working Group on Deep-Sea Ecology (WGDEC) through recent years made an effort to map the reefs in the NAFO and ICES areas of the North Atlantic. The mapping is part of the WGs working plan: to identify and characterize benthic vulnerable marine ecosystems (VMEs) and ecologically significant areas in the region.

The live Lophelia sample. It measures about 25 cm across. Photo: DFO (Bedford Institute of Oceanography)

Southern Greenland. The position of the site on the continental slope, where the Lophelia sample was secured. Figure by: Mr. Camille Lirette (Bedford Institute of Oceanography)

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Marine biotechnology in a changing world

Laura Giuliano and Kiminori Ushida outline the challenges and benefits

Marine life – Gold rush

Marine biological diversity underpins a significant proportion of the world's economy. Technological advances in recent decades have led to the rise of '*marine bioprospecting activities*', the search for a new generation of products[1], processes, and technologies from marine biological sources with potential commercial applications so that adding more and more value to marine living forms - are now indicated as 'marine genetic resources'.

nutritional security, molecular medicine, environmentally-safe technologies for pollution abatement, biodiversity conservation, and (bio)industrial development, marine biotechnology can contribute significantly to global wealth.

In many developing countries, marine biotechnology is being targeted as a potential source of economic development and social progress for a number of reasons. Entry into the field is easy and costs are

> As mining companies look forward to exploit copper and gold from the seabed, marine ecologists prepare to explore unique ecosystems for finding new biomolecules and processes with industrial applications.

Marine biotechnology is the means by which marine genetic resources and their elements can be developed into new marketable products. It is seen as one of the greatest intellectual enterprises of humankind, providing impetus for understanding marine life processes and utilizing them to the advantage of humanity. By enhancing the productivity and cost-effectiveness of aquaculture and agriculture,

less; many countries have a base from which marine biotechnology can develop and grow; and they have rich marine resources that can be used through biotechnology (Zilinskas and Lundin, 1993).

[1] *Marine natural products (MNPs) are novel chemical compounds that are produced by marine organisms as defence mechanisms toward predators, competitors, and fouling organisms (Pawlik, 1993; Hay, 1996; Paul and Ritson-Williams, 2008).*

Mind to Market

The market capitalization of bio technology companies has been estimated to be around $400 billion for the United States and $25 billion for Europe (Burrill & Company, 2007).

Biotechnology has been market driven by the global biopharmaceutical industry[2], which is currently worth over $145 billion (BioPlan Associates). Many of the largest international (Big Pharma) companies are now investing nearly half or even most of their R&D in biopharmaceuticals (vs. drugs), with much of this targeted for development of monoclonal antibodies and cancer therapeutics. The market has benefited from the need for pharmaceutical manufacturers to boost output, but it has a high risk factor: only three out of ten drugs that pass to the clinical phase ultimately receive market clearance. Cost containment and biosimilar entry in developed markets continue to see slow growth, and if the small number of approvals and their economic impact persist, the industry is headed for big trouble (Rader, 2012).

Over the coming five-year period, factors such as development of emerging markets and a rich late-stage pipeline are expected to fuel growth. Marketed bioactive compounds will become more diverse in terms of their underlying technologies and fields of application. Marine biotechnology represents a pivotal sector to provide future profits in such a new, diversified scenario. A fundamental aspect is related to aquaculture: new methodologies will help in selective breeding of species, increasing sustainability of production and in enhancing animal welfare, including changes in food supply, preventive therapeutic measures, and use of zero-waste recirculation systems. Moreover, aquaculture products will be improved to gain optimal nutritional properties for human health. Another strategic area of marine biotechnology is related to the development of renewable energy products and processes, mainly using marine algae. Marine biotechnology could be further involved in addressing key environmental issues, such as in biosensing technologies to allow *in situ* marine monitoring, in bioremediation, and in developing cost-effective and non-toxic antifouling technologies. Finally, marine-derived molecules could be of high utility as industrial products or could be used in industrial processes as new enzymes, biopolymers, and biomaterials (Buonocore, 2013).

[2] Biopharmaceuticals are used in the prevention and treatment of disease, and there are over 300 approved biopharmaceuticals on the market, with many in clinical development.

Innovating innovation

Marine biotechnology, with its broad range of techniques and processes, is a genuine interdisciplinary technology. It receives impulses from science (i.e. marine biology, marine ecology, biochemistry, and molecular biology), information technology, engineering, and the optical industry and incorporates them in its development work. Innovations of this kind call for many different competences along the value chain.

As a biobased industry, the marine biotech industry builds mostly on biorefineries (including biowaste refineries), processing biomass into a spectrum of marketable products and energy. Therefore, marine biotech is exposed to 'bottlenecks' that are typical of the sector, such as the costs associated with pilot studies, demonstration, and commercial production facilities.

Key issues include the possible lack of competitive supply of sustainable feedstock (biomass feedstock may be scattered, variable, and seasonal) and the very low concentrations at which biological compounds are produced by the source marine organisms. A classical example is provided by bryostatins, a group of active compounds first isolated in the 1960s from the bryozoan *Bugula neritina* and now developed as drug candidates to treat Alzheimer's disease. The low concentration in bryozoans (to extract one gramme of bryostatin, roughly one tonne of raw bryozoans is needed) makes extraction unviable for large-scale production. Molecular-based studies on structure and activity relationship may help in the future, and allow the total synthesis of analogues which exhibit similar biological profile and, in some cases, greater potency. The first plant-expressed FDA-approved biopharmaceutical to achieve worldwide marketing by far embodies the most bioprocessing innovation. It is manufactured by suspension cell culture of transformed carrot cells in single-use bioreactors.

Needless to say, businesses based on marine biotechnology should integrate sustainability into their strategy and innovation systematic approaches. Together with the tools that monitor resource efficiency, new tools for monitoring and assessing sustainability of complex 'ecological-social' systems will be necessary (Giampietro *et al.*, 2009).

New innovative value chains are needed to cover the costs associated with marine biotechnology research and demonstration efforts. A possible solution could be multi-scale marketing modules at the interface of different traditional productive sectors (i.e. chemicals, food and feed, detergents, paper and pulp, textiles, fuels or plastics).

Substantial efforts in prenormative research are also required in reference to standards, labelling, and certification systems so as to achieve broad customer acceptance.

Responsible research

Marine biotechnology can contribute significantly to environment-friendly development and result in benefits on a global scale. However, if carried out in in the same manner as previous resource exploitation ventures, it can have harmful effects on biodiversity conservation and hinder sustainable development.

> Based on the realization that marine bioprospecting provides a ready example that through the "rapid acceleration of science and technology, man has acquired the power to transform his environment in countless ways on an unprecedented scale"[3] there is a clear need for an adequate legal regime regulating access to, and use of marine biological resources to benefit mankind today, while protecting them for future generations.

[3] Declaration of the United Nations Conference on the Human Environment (Stockholm Declaration), 1972.

The pinnacle of this hydrothermal vent chimney is inhabited by a thriving community of tubeworms (Ridgeia piscesae).

Photo: NEPTUNE/Ocean Networks Canada

The Last Frontier – Deep-sea Bioprospecting

Technological developments now allow for fishing and for the exploitation of hydrocarbons andminerals at depths below 2000 m. There are therefore large and accelerating challenges facing the deep sea.

Deep-sea environments harbour high diversity hot spots that are very attractive for bioprospecting. These include various hydrothermal vents, or fissure that cluster along plate tectonic boundaries, out of which flows water that has been heated by underlying magma.

Since the first vents were observed in 1977, new animal species have been found in such ecosystems, at a rate of about one per month, with no sign of discovery rates dropping. What makes these ecosystems remarkable is that the entire foodweb depends on microbes that get their energy by oxidizing hydrogen sulphide emitted from the vents. Some of the microbes live as symbionts inside larger organisms.

This chemosynthesis is fundamentally different from the photosynthesis that sustains most life on Earth. The fear is that lacking sufficient knowledge, environmental assessments may not be rigorous enough to preserve the diversity of such ecosystems. Vent fields differ radically in the species present and possibly the extent to which they embody unique genetic diversity. According to vent scientists, "Each of them needs an appropriate assessment". Given that vent ecology is still poorly understood, some researchers argue that it is too early to begin commercial exploitation (Ramirez-Llodra *et al*., 2011; Van Dover, 2011).

Work to support an international regime to regulate access to marine genetic resources, including the share of benefits that derive from their use, is underway[4]. Some are pushing for a highly regulatory approach, arguing that strict rules need to be imposed as otherwise developing countries will not get their fair share of this "green gold" from royalty payments. Other views emphasize the urgency of ensuring that marine bioprospecting remains attractive for the private sector, and call for 'market-based' systems relying on property rights. As a part of current efforts enabling the development of regional and supranational approaches, the Mediterranean Science Commission (CIESM) has proposed a code of conduct for marine resource sampling (CIESM charter), which has been recently refined through public consultations and via an online forum.

> *"Without the guarantee of exclusivity, industry would not invest in research activities and beneficial discoveries would not be made", as stated in 2005 by economists Timothy Wolfe and Benjamin Zycher (Pacific Research Institute, San Francisco), "150–200 drugs would be lost over the next 20 years by excessive bureaucracy" (Wolfe and Zycher, 2005).*

While it may be desirable to fully prevent intellectual property rights over biological resources, financial imperatives mean that this option is not foreseeable. However, it is possible and realistic to attach conditions to the grant of intellectual property rights to ensure benefit sharing.

Bureaucracy, legal uncertainties, and weak regulatory frameworks make companies reluctant to invest in marine bioprospecting, especially in developing countries. Policy measures should facilitate access for responsible bioprospecting and increase the likelihood of commercially useful discoveries, while safeguarding the rights of appropriate authorities to claim a share in potential benefits to encourage investments and the supply of biotech products.

Global challenges – global strategies

Japan and the USA have been the major investors in the marine biotechnology sector for a long time, but various European countries, and especially those that have traditional strengths in conventional biotechnology (e.g. Germany, France, UK, and Spain) are now gaining ground. In the future, all maritime regions (including both emerging and developed markets) appear well positioned to have a stake in the marine biotechnology sector and reap the benefits. It is not only because marine biotechnology encompasses lower-tech activities and "conventional" aquaculture but also because even the most technologically advanced nations will have to reach out to other countries to fulfil the increasing demands for innovative use of marine bioresources.

In recent years, marine bioprospecting-based industries have been globally relocated, keeping pace with shifting markets and opportunities. Such new modes of development must rely on contractual arrangements beyond traditional instruments. Transnational research and demonstration projects carried out jointly by several partners, should be consistent, but will also experience public–private partnerships within geographically diverse legal contexts.

The various parties involved in a marine bioprospecting relationship often have competing agendas and conflicting interests. States, often caught between the interests of their traditional communities, regional governments, and development objectives, and the external interests of transnational enterprises and other parties pushing the enforcement of multilateral agreements, may be hesitant to take a definite stand and resolve policy disputes.

A lack of political will within governments which impedes coherent implementation of access and benefit sharing (ABS) regulations in relation to marine genetic resources (both within and beyond national jurisdiction) is seen as a key problem by many researchers and industry.

Until the Convention on Biological Diversity (CBD), which came into force in 1993, access to marine genetic resources was unrestricted, based on an understanding that those resources were a "common heritage of mankind". Now, armed with sovereign rights over marine natural resources within their territorial zones (and, when applicable, their zones of economic interests), nation states play the most crucial role in regulating access to marine genetic resources and benefit sharing. Nevertheless, species distribution is not limited by political boundaries and "*few species have convenient geographical niches to fit the ABS agreements*" (Bell, 1997).

[4] In recent years the question of the status of genetic resources of marine areas both within and beyond national jurisdiction has been the focus of diplomatic discussions (directly and indirectly) in no less than five different international institutions and processes. These include meetings associated with the Convention on Biological Diversity (CBD), the International Seabed Authority, the United Nations Informal Consultative Process on the Law of the Sea, the annual debates of the United Nations General Assembly on Oceans and the Law of the Sea, and more recently, in the deliberations of the *Ad Hoc* Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction.

Marine genetic resources are distributed in patterns that represent evolutionary, not political history. Therefore, it is almost impossible to determine the countries of origin for most of them.

Marine species distribution patterns may follow defined 'ecoregions' of distinct size (e.g. zones of similar geology, physiography, hydrology, etc.). Multilateral System (MLS) agreements among countries within each defined 'ecoregion' might be a suitable solution for governance. Consistently with previous agreements of this kind, MLS would allow the concerned parties (countries) to include their 'shared' marine genetic material under their control, allowing access to this material upon the signing of an internationally-negotiated Standard Material Transfer Agreement. A well-designed regulatory framework would combine various instruments that would be managed by individual bioprospecting agreements. Flexibility is also a key issue as the framework should be able to accommodate different stakeholders, their varying objectives, and the different types of marine bioresource being accessed.

Overlapping jurisdiction of various government agencies poses a further problem. This has been a common complaint of marine bioprospectors who often have to apply for different permits as required by multiple institutions that lack a coordinating mechanism. As such, and significantly for countries that do not have identified authorities in the sector, industries will have to choose a country that not only has high marine biodiversity, but also has an efficient marine genetic resources governing legislation in place.

Clear, strong, and equitable policy is needed in both developed (innovative incentive and funding structures) and developing countries (biosafety regulations, intellectual property right arrangements).

A global effort to create incentives for collaboration between industrial and developing countries can pave the way to win–win scenarios. For example, geopolitical specificities typical of most developing countries can help to sidestep some marine biotech-associated constraints, such as space-demanding installations (i.e. demonstration and commercial-scale production facilities) and cost-effective manufacturing. New science, partnerships, and forms of collaboration, together with improved innovation systems will be needed to rise to these challenges.

Cooperation plans must integrate the real biotechnological needs of developing countries so that marine biotechnology becomes a tool for human development everywhere. The priority consideration when utilizing and developing all available and future technologies must be that "technologies in general do not transfer from developed to developing countries. Rather they need to be built up *in situ* using local knowledge and innovative ability after which, if successful, they are being adopted" (Douthwaite and Ortiz, 2001).

Coordinated efforts between different countries will help to pool and coordinate public and private investments, obtain critical mass, and facilitate market access.

Quoting a researcher at a French cosmetics company: "Companies need security and for things to be clear. We want to know what we can do, where we go to ask for authorization, what partners are allowed to work with us, who can collect and send plants to the company. We are happy to apply for authorization and share benefits, but it can be very difficult to know how to do this" (Laird and Wynberg, 2005).

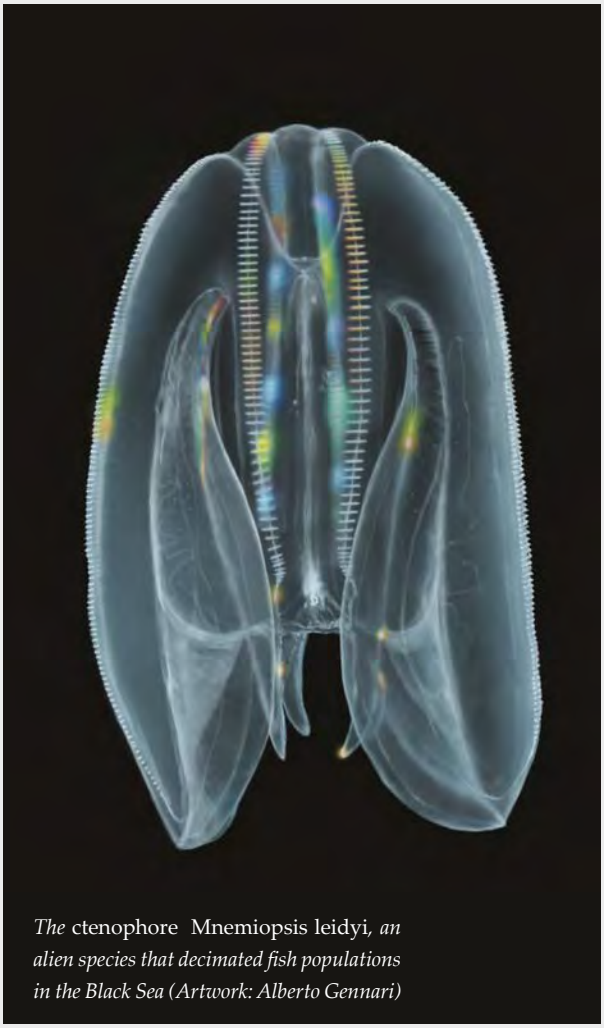
A case study: jellyfish

In recent years, massive blooms of jellyfish populations have impacted some of the world's most important fisheries and tourist destinations, causing huge economic losses in the process. This phenomenon aligns with specific conditions (such as concentration of jellies' predators and competitors, food availability, currents, temperature, salinity, and oxygen content of the water) that favour jellies' survival and proliferation. By jamming boat engines, breaking nets with their weight, and poisoning commercial fish, jellyfish swarms have damaged fish farms, seabed mining operations, desalination plants, coastal power plants, and fishery vessels. It is not just the future of the maritime industry that is at stake, but also the continued health of the world's largest ecosystem.

The ecological impact of jellies

One classical example of the impact that jelly blooms can have on the marine environment is the ecological and economic disaster caused by the arrival (via ship) of *Mnemiopsis leidyi* from North America to the Black Sea (1982). Because of the absence of its natural predators, in less than a decade *Mnemiopsis leidyi* had reached a biomass of one billion tonnes, outcompeting the local fish. *Mnemiopsis* simply ate the plankton that fed the fish, so anchovy fish stocks plummeted by 85% and blooms of toxic algae prevailed.

The happy ending to this story came some ten years later, by the accidental introduction (once more via ship) of another carnivorous jelly, *Beroë ovate,* which selectively preys upon *Mnemiopsis.* The local fish stocks have since recovered strongly (CIESM, 2001).



The ctenophore Mnemiopsis leidyi, *an alien species that decimated fish populations in the Black Sea (Artwork: Alberto Gennari)*

A number of ongoing projects are collecting critical information on jellyfish bloom emergence, development, and distribution to assist in predicting and/or managing them optimally. Furthermore, new 'jelly-tracking websites' encourages the public to report jellyfish sightings, thus helping fill the research gaps (i.e. *JellyWATCH*, by NSF in the United States; *CIESM-JELLYWATCH*, by CIESM for the Mediterranean region ; '*STOP JELLY*', by MAFF in Japan; etc.).

Despite those essential efforts, long-term data and time-series from around the world are still too limited to conclude that jellyfish numbers are on the rise. What is clear is that jelly biomass has reached a very important size, estimated by certain researchers at nearly 40 per cent of the total biomass (total weight of living matter) of the open ocean.

What should we do with jellyfish? How should we manage this species in a manner that is rational from both a socio-economic and an ecological perspective?

Jellyfish are usually discarded on the grounds of pest control while they could be a potentially valuable new resource. Jellies can provide collagen for the cosmetics and pharmaceutical industries. Some jellies produce fluorescent proteins that are used in medicine (*Hydromedusa* spp.), proteins with antioxidant activity that can act as possible supplements in the food and pharmaceutical industries (*Rhopilema esculentum*). Other jellies are considered edible (i.e. the giant jelly *Nemopilema nomurai*, which is part of Chinese cuisine) or may play crucial roles in their natural environment (i.e. in sustaining healthy populations of sea turtles). Due to their very peculiar physiological features, jellyfishes have also inspired technology to a significant extent. For example, nematocysts (i.e. the microscopic harpoon-like structures that cover jellies tentacles in huge numbers and when activated by touch, pierce the victim's skin and inject venom) have inspired microchips as well as submicron injectors for transdermal drugs delivery. The dynamics and mechanics of jelly locomotion based on jet-propulsion is stimulating researchers towards more efficiently engineered systems of propulsion and energy technologies that could harness wind and wave power. Jellies have also inspired stem cell-based therapies. Noteworthy is the case of *Turritopsis dohrnii*, a tiny Mediterranean jellyfish (only 1 mm across), which does not undergo ageing. After it becomes sexually mature and mates, *Turritopsis* can revert back to being a juvenile through a process called 'transdifferentiation', whereby the cells transform from one type to another and so return to a youthful state. As a result, *Turritopsis dohrnii* has been defined by scientists as a 'biologically immortal' animal. In the last years, the economic potential of jellies has been tackled more and more vigorously and realistically (see CIESM, 2011), accompanied by targeted economic models developed for proposing constructive options.

Unfortunately, studying jellyfish is notoriously difficult. Some small species are so delicate that they explode when touched, making netting them for population surveys more or less futile. Jellies also have complicated and poorly understood life cycles, and some are quite dangerous to humans. Because of our inability to predict the location and apparition of jelly swarms, large-scale production of jelly products is a risky venture that is associated with exorbitant costs. Due to the extremely low fraction of usable material in jellyfish (e.g. *Aurelia aurita* contains only 1–2% organic material and 1–2% salts or minerals), the costs of downstream processing are too high compared to the potential gains. Costs are also associated with the collection (imagine the total weight of hundreds of plastic bags filled with water!), the maintenance (the jellyfish body degrades very quickly due to the activity of their very efficient proteases, which persist even at −50°C), and the storage of jellies (when stored at ambient temperature they often produce a harmful smell). Since any increase in the product yields of jellies requires huge investments, the jelly-based industry can only focus on extremely high value products. In spite of this, the various jelly compounds that have so far captured industrial attention (i.e. type II and V collagens for cosmetic use, qniumucin, aequorin, the green fluorescence protein) have not offered cost-effective production possibilities. The conversion of jelly biomass to valuable products (e.g. fertilizers) is also not achievable because of its high salt content.

If we analyse the three main strategies actually followed for optimizing the economic value of marine life, namely (i) the search for bioproducts to be extracted, purified, and produced at industrial scale, (tii) the search for 'good ideas' reproducible by synthetic methods, and (iii) the direct use of the whole biomass for feed, jellies have been used successfully only as edible species. The promotion of jellies as food containing some healthful compounds (i.e. antioxidant molecules) could be of great benefit for marketing.

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Marine Spatial Planning

Hans Lassen details the important ICES role in effective planning and collaboration

Marine spatial planning (MSP) is not synonymous with marine protected areas. MSP is about how humans use the marine environment this being as a sewer, for tourism, for aquaculture, for fishing, for sand and gravel extraction, for energy production, or for transport. MSP has become a hot topic because marine space has become a scarce commodity particularly in the coastal zone and for scarce commodities we regulate user access to the resource, in this case marine space. The marine environment shows numerous examples of regulated access. We have coastal aquaculture for fish, shellfish, oysters, clams and mussels, we have wind energy farms, we have oil and gas production from platforms, we extract sand and gravel from the seabed, cables have been drawn across the seas and oceans, and there are shipping lanes. Artificial reefs limit access for certain users, e.g. trawling. All these activities need reserved space with restricted access to avoid conflicts with other use of the space. There are also widespread activities that influence our use of the marine space, e.g. waste management on ships and clean beaches for tourism. Not all human impacts from our use of marine ecosystems are confined to specific areas.

MSP is a public process aimed at analysing and allocating the spatial and temporal distribution of human activities. This analysis helps obtain insight in how one may achieve ecological, economic, and social objectives. The process focuses on operationalizing ecosystem-based management by finding space for biodiversity conservation and sustainable economic development in marine environments. MSP is not a substitute for single-sector planning and management; it is not only conservation planning or ocean zoning. All plans emphasize that this is a continuous process and not a one-off activity.

Planning is only one element of the marine spatial management process. Additional elements include: enforcement, monitoring, evaluation, research, and public participation. And above all, implementation requires financing.

The regulatory legal framework in the ICES area is based on national legislation, although in many cases, it is implementing international agreements. However, with the exception of fisheries (regulated under the Common Fisheries Policy) there is no international legal framework that binds the states to a joint and coherent regulation. However, the EU Marine Strategy Framework Directive (MSFD) is a step in this direction. There are regional conventions and organizations that provide forums for coordination and cooperation (in the Northeast Atlantic OSPAR, HELCOM, NEAFC, and UNEP and IMO at the global level). In the Northeast Atlantic NEAFC, HELCOM, and OSPAR work together on their respective programmes and, as a member of these three organizations, the European Commission provides some coordination among the EU states. Norway is also a member of NEAFC and OSPAR and has established integrated management plans for the Barents Sea–Lofoten area and for the Norwegian Sea, and has designated protected areas. The Norwegian plans address all important economic sectors including oil and gas development, fisheries, marine transport, and marine conservation, but the plans are only advisory in nature. These are two of the few plans worldwide that integrate fisheries management measures with other marine sectors. The international institutional arrangements look rather incongruent and to remedy the system the organizations have established cooperation groups. The reason for this muddle is historical development from sector-based planning to more integrated approaches, a development that is recognized by the organizations adapting to the new situation. This approach is rational if one takes into account the efforts otherwise needed to reform the existing conventions and international organizations. Efforts are better spent on reaching consensus among countries on substantive issues, combined with the hope that time will remedy the problems. The EU MSFD takes this approach and highlights the regional organizations as essential in the implementation of the directive.

Planning is the prerequisite for regulation and we need regulations to control the fight for space. Furthermore, we need a rational basis for such planning. ICES is an advisory body on human impact on the marine environment and therefore has its natural role in MSP. For this reason the ICES Science Committee (SCICOM) developed a strategy in 2010 and the Study Group on Spatial Analysis for the Baltic Sea was set up. The ICES Annual Science Conference in Bergen in 2012 included a theme session on marine spatial planning and there is also a session looking at the multidisciplinary approach of MSP at the 2013 conference.

Planning was originally intended to resolve conflict among marine users. However, today conservation of biodiversity and abiotic features play a major role in the application of MSP. It is also often seen as synonymous with the establishment of marine protected areas (MPA), to the point, that such areas are seen by many as the ultimate tool for protection and conservation of biodiversity at sea. The EU, OSPAR, and HELCOM all have programmes for achieving or maintain good environmental status through establishing protected areas. There are numerous national regulations that in many cases are implementations of international conventions and international agreements. We have RAMSAR areas for bird protection, OSPAR is establishing an ecologically coherent network of well-managed marine protected areas, and HELCOM works along similar lines with the Baltic Sea Protected Areas. The regional organizations of the EU, OSPAR, and HELCOM work with environmental effects of shipping while the UN organization, the International Maritime Organization (IMO), looks at general rules regulating shipping. Then there are national policies such as harbour construction, affecting shipping lanes and thereby spatial planning.

From an ICES perspective, there is much focus on four nature conservation programmes in the Northeast Atlantic: the EU Natura 2000, the OSPAR system of ecological coherent network, HELCOM's Baltic Sea Protected Areas, and outside the Economic Extended Zone (EEZ), the NEAFC programme on protection of vulnerable marine ecosystems. The formal criteria defined for each programme differ slightly but all four programmes aim at ensuring favourable status of marine biodiversity and restoring such favourable status where needed. The regulatory approach is to create MPAs. Such areas are not marine reserves banning all human activities, but are based on an assessment of which human activities do not compromise the conservation objectives.

However, this leads to a complicated process on reaching consensus with stakeholders concerning which human activities to allow in the assigned areas. And it can lead to the establishment of complicated and detailed regulations. MPA as a regulatory tool is not procrustean. It is an effective tool where the conservation objective is confined to a specific area. This means that protection of spawning or nursery grounds, areas for sand and gravel extraction,

seamounts with cold-water corals or reefs are good candidates, while protection of migratory species is less suited for this approach.

The present process has its weaknesses, including a lack of clear definition among key players. This is illustrated by the current process for defining fisheries measures in the Natura 2000 Dogger Bank site. NGOs and the fishing sector are represented in the process, while the wind energy industry – a potentially important player – is not integral to the process.

The legal framework can be quite confusing. EU fisheries are regulated through the Common Fisheries Policy based on binding decisions at the EU level, while environmental concerns are addressed through national regulations although the EU Marine Strategy Framework, Habitat, and Bird directives lay down the fundamental rules. Because of the national approach to environmental concerns, neighbouring and similar areas could be subject to different environmental regulations and, at least potentially, states may apply different national policies in designating protected areas. This may result in users not experiencing coherent and logical marine management and lead to regulations losing their legitimacy. Fortunately, some states have anticipated this issue and in the case of the Dogger Bank for example, the International Dogger Bank Steering Group was established to agree on a consistent set of fisheries regulatory measures that are expected to achieve the conservation objectives.

MSP is a central topic for management of human activities in the sea and ICES has a long history in science coordination of work relevant to coastal-zone management. For offshore areas ICES has advised on specifics for marine protected areas, mostly in relation to fisheries impact. However, ICES advisory role has hitherto focused on general issues, e.g. advice on sampling schemes, sampling methods, and programmes.

ICES, through its advisory committee (ACOM), has provided traditional advice on the design of MPAs. However, MSP includes a public process and the ICES Secretariat has supported several of the MSP processes in recent years (EMPAS, FIMPAS, and the Dogger Bank) by providing background information and helping mediate the process. This role has been criticized by some, claiming that the involvement of the secretariat may put ACOM's integrity at risk. With the expansion of stakeholder involvement in all parts of the management process, from data analysis to implementation, ICES should develop an effective model that allows ICES to assist the processes and at the same time provide independent advice, ensuring that its procedures maintain the required divisions to uphold the integrity of the important ICES advisory process. The roles should be clear: the secretariat provides a technical service while ACOM determines whether the proposed measures will deliver on the client objectives. ICES has made efforts recently to more clearly communicate the division between the two functions as service provider and provider of unbiased advice.

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Marine litter – Trashing the waves

Thomas Maes explains how a lack of litter awareness is clogging up our oceans

What is marine litter?

Some of us might wonder exactly what marine litter is and where it comes from. We all know the term "litter" and have seen it in some form in our daily lives; an empty plastic bag drifting in the wind, cigarette butts on the pavements, empty drink bottles in the park or even remote and idyllic places blighted by the presence of litter. What we see as litter on land is not different from what is found in the sea and thus the term "marine litter" has been introduced to describe discarded, disposed of, or abandoned man-made objects present in the marine and coastal environment worldwide. Originating from both ocean-based (fishing vessels, cargo ships, stationary platforms, fish farming installations, pleasure crafts and other vessels) and land-based sources (littering, dumping, poor waste management practices, untreated sewage and storm water discharges, riverine inputs, industrial facilities, tourism, extreme natural events), marine litter can now be found around the globe. The major sources of marine pollution are land based, and some studies have indicated that up to 80% of marine litter originates on land. Marine litter, mainly plastic, can pose a serious environmental threat to marine organisms as well as a series of economic and social problems. The majority of marine litter consists of plastic materials, between 60 and 80% overall, and 90% of the marine litter is floating[1].

How did it get so bad?

Plastics began being produced on an increasingly industrial scale midway through the 20th century. Since 1950, there has been an average annual global increase of 9% in the production and consumption of plastics. From 1.5 million tonnes in 1950, total global production reached 245 million tonnes in 2008, and this number will continue to grow, reaching over 365 million tonnes in 2015 and 540 million tonnes in 2020 (using a conservative annual rate of increase of 6.5%)[2]. The ever-growing demand for plastic and single-use items, in combination with ineffective waste management and slow degradability, has led to an enormous surplus of mainly synthetic polymers, commonly known as plastics. Plastic waste of all sizes and shapes eventually ended up in the marine environment and became a transboundary pollution problem with a powerful driver – the ocean. Scientists began reporting the spread of plastic litter in the oceans in the early 1970s. Across Europe, the distribution and abundance of marine litter on the seabed has been investigated in conjunction with existing International Council for the Exploration of the Sea (ICES) stock assessment surveys since the beginning of the 1990s. In the United States, the National Oceanic and Atmospheric Administration (NOAA) estimates that three times more rubbish is dumped into the world's oceans annually than the weight of fish caught during the same period[3].

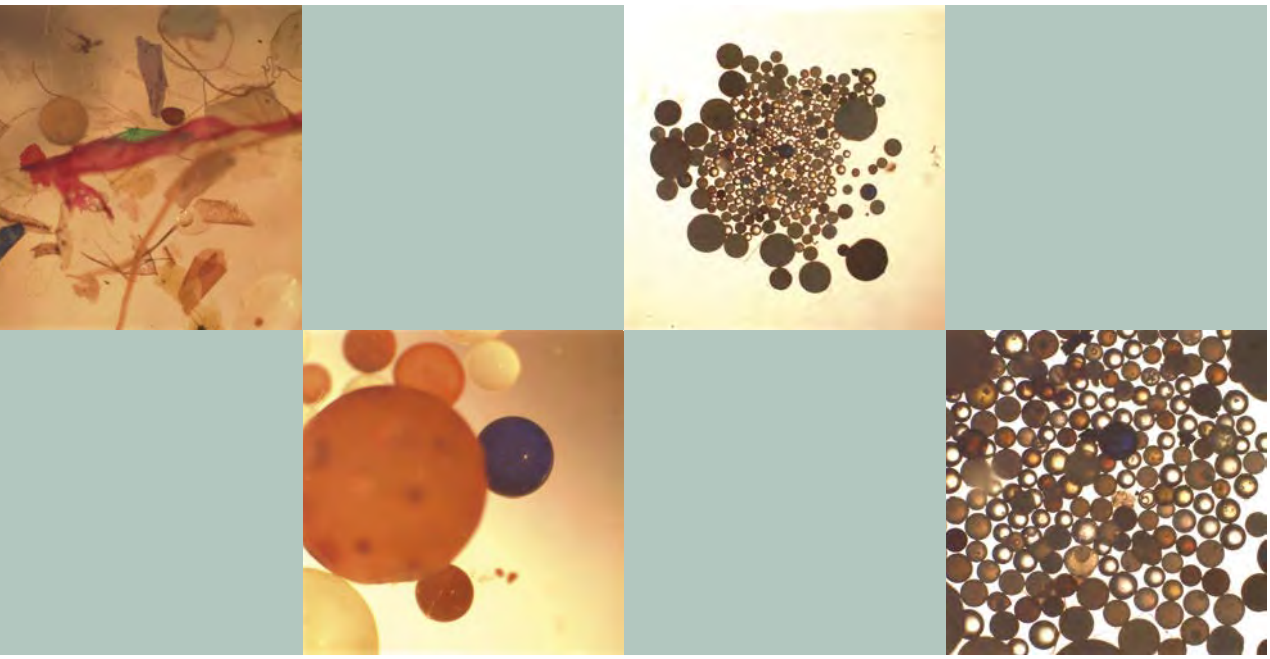
> **"Marine litter has the potential to kill or harm marine life through entanglement or ingestion"**

Does it have an impact on the marine environment?

Marine litter has the potential to kill or harm marine life through entanglement or ingestion and thus could put an even higher strain on systems already under stress from overfishing and other anthropogenic influences. "Ghost fishing" by discarded or lost fishing nets is just one of several examples of that. The Convention on Biological Diversity (CBD) Secretariat and the Scientific and Technical Advisory Panel (STAP) recently reviewed and synthesized the available literature in order to describe the impact of marine litter on biodiversity and concluded that around 663 different animal species, mainly birds and fish, have been impacted by marine litter. The report also revealed that all known species of sea turtles, about half of all species of marine mammals, and one-fifth of all species of seabirds, have been affected by entanglement or ingestion of marine litter[4].

Plastics also create habitats for micro-organisms and other species, allowing would-be invasive species to hitch rides to new areas of the ocean. Other threats to wildlife include the smothering of the seabed, or environmental habitat disturbances created by marine litter. It is clear that impacts may vary depending on the type and size of the marine litter items and the organisms that encounter them. Marine litter also causes damage to people, property, and livelihood and thus incurs high economic costs. People are affected when litter fouls boat propellers or nets, clogs water intakes, blocks pumping systems, or causes risks to human health. In addition, the presence of litter along shorelines can lead to a loss in aesthetic value and result in serious economic problems for regions that are dependent on tourism.

Divers remove netting from a reef.
Photo: Dwayne Meadows, NOAA



Microplastics under the microscope. Photo: © Crown copyright, permission granted by Thomas Maes, Cefas.

Macro and micro?

The lightness and durability of plastic makes it such a useful and versatile material for manufacturers, but also makes it a long-term problem for the environment. Plastics accumulate because they don't readily biodegrade, unlike many other organic substances. Although they don't degrade they do fragment in the environment; this is caused by a combination of mechanical forces like waves and/or photochemical processes triggered by sunlight. This means that plastic breaks down into smaller and smaller fragments, better known as microplastics. The origin of these fragments can be determined as stemming from fishing nets or lines, plastic bags, films and bottles, remains of oxo-biodegradable plastic, industrial raw materials like plastic pellets, or from other direct sources of microplastics such as facial cleansers or toothpastes. Another source of microplastics has recently been identified, namely the shedding of synthetic fibres from textiles through washing. Those fibres pass through treatment screens at wastewater plants and eventually arrive in the marine environment. Microplastics normally float on the surface because they are less dense than seawater, but the buoyancy and density of such plastics may change during their time at sea, due to weathering and biofouling, which means they are eventually found at the sea surface as well as in both the water column and the sediments. Because of their size, they are available to a broad range of organisms and have been shown to be ingested by several species, ranging from lugworms, mussels, and crustaceans to fish, and even birds. The ingestion of microplastics by species at the base of the foodweb causes concern as little is known about its effects and transfer across trophic levels.

Contaminated pills?

To make matters worse, plastics can leach toxic additives, used in the manufacture of plastic materials (e.g. Tetrabromobisphenol-A or TBBP-A), into the marine environment and can also absorb and accumulate other persistent organic pollutants (POPs), such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and organochlorine pesticides. Plastic litter can absorb and concentrate POPs, yielding up to a million times higher concentrations than in the surrounding seawater which, when consumed by marine animals, could endanger both the creatures that ingest them and organisms higher up in the food chain. This means that the possible effects of microplastics on marine organisms after ingestion are probably twofold: the physical blockage or damage of feeding apparatus or digestive tract, and the leaching of plastic additives and POPs into organisms after digestion, with the potential for toxic effects and bioaccumulation. Although some evidence may still be lacking, it is clear that marine litter could have a significant impact on individuals as well as potentially on populations and ecosystems. Alongside other significant anthropogenic stresses this could affect the important marine services on which our planet relies.

Solutions and measures?

The most effective way to manage the marine litter pollution issue is by limiting inputs, by changing the behaviours that allow marine litter to enter the environment initially by collection, retention, and disposal of waste in proper reception facilities. Targeted educational programmes for the general public and other stakeholders could encourage a change in littering behaviour. We must reduce the production of litter, but in many countries some plastic will always escape the preferred disposal routes and find its way into the ocean, from which it cannot realistically be collected. Obviously, we can reverse the current trends through reduction or better use of plastic packaging, the development of better designed plastics, improved labelling, and the promotion of local products and markets. Globally, a lot of sewage and associated litter is discharged without treatment of any kind, particularly during periods of high rainfall. Improving the function, storage, and efficiency of combined sewage overflows should effectively limit this input.

Land-based management

A lot of countries face significant barriers to the effective control of marine litter. In many cases, financial, cultural, and awareness barriers may impede development of political will to address the problem. This problem is not one that is merely typical of developing countries or industrialized areas, although regional differences and pressures may leave different imprints. In the European Union alone, three billion tonnes of waste is thrown away annually. This amounts to about six tonnes of solid waste for every man, woman, and child each year. Most of what we throw away is either burnt in incinerators or dumped into landfill sites (67%). The Organisation for Economic Co-operation and Development (OECD) estimates that by 2020, we might be generating 45% more waste than we did in 1995[5]. Unfortunately, stockpiling waste is not a viable solution and simply destroying it is unsatisfactory due to the resulting emissions and highly concentrated, polluting residues produced.

Prevention: Refuse, reduce, reuse, recycle

The EU is aiming for a significant cut in the amount of rubbish generated, through new waste prevention initiatives, better use of resources, and encouraging a shift to more sustainable consumption patterns. Where possible, waste that cannot be recycled or reused should be safely incinerated, with landfill used only as a last resort. Both of these methods require close monitoring because of their potential for causing severe environmental damage. EU laws governing waste disposal require more recycling of paper and plastic each year while generally prohibiting dumping in landfills; incineration, meanwhile, is now heavily taxed in most European countries[6]. These regulations also prohibit exporting waste to poorer parts of the world, unless the receiving country accepts that type of waste for processing by a certified recycler. The European guidelines ban the export of certain hazardous materials and so-called "problematic" waste, defined as waste that is not amenable to recycling and which would be harmful to the environment at its destination.

The waste trade, legal and illegal, is partly propelled by the fact that large fast-growing economies need raw materials. Recycled materials are cheaper than virgin ones; they reduce greenhouse gas emissions and the dependence on imports. So the primary objective should be to couple waste with money. Seeing waste as a resource may prove a powerful factor in litter reduction in the coming decades.

The effects of marine litter as found on Cefas cruises. Photo: © Crown copyright, permission granted by Thomas Maes, Cefas.

A life cycle assessment by the UK Environment Agency has shown that plastic carrier bags are the most environmentally sustainable option for carrying goods and protecting them from contamination. Replacing all plastic by organic products would put more stress on food production due to the spatial competition with production of edible crops, jeopardizing food security. Transport costs and oil consumption would also rise and there would be direct impacts on CO_2 production. Thus, instead of completely banning a product with clear pros and cons, we should target the negative points and reduce, reuse, and recycle single-use disposable products and packagings that often end up as waste.

Employment: Revalue, repurpose, rethink, and rebuild

A recent report on waste from the European Commission has indicated that waste management and recycling could make a big contribution to economic growth and job creation. The study provided an in-depth analysis of the effects of better implementation and enforcement of legislation and showed that benefits would be significant. The economic crisis in Europe is setting new priorities for our societies, and job creation and sustainable resource management should be at the core of it. The EU's waste management and recycling sector is very dynamic but still offers economic opportunities with vast potential for expansion[7].

Meeting the global challenge

The plastic litter problem has become a global problem requiring global solutions. Solutions should be based on sound science, including preparation of a global assessment. This would collate the available scientific information and make recommendations of use to the wide variety of policy, industry, and societal organizations with responsibility in this area, including waste management at the local level. Policymakers will need to take an integrated view of the whole process and develop a range of options for guidelines and directives, including packaging and treatment of integrated waste management from collection to final disposal.

There is a clear need for improved legislation and broader litter strategies with involvement of key stakeholders, local governments, and members of the public. In the end, the only sure solution is to prevent plastics from entering our waterways and reaching the sea. In order to reduce the sources of pollution, improved knowledge is critical. Scientific support and clarifying the key processes involved such as degradation, dynamics, and impacts, while also looking at the economics as well as social and employment aspects, will be crucial in developing the required global standards and wider perspectives on marine litter. Building a broad consensus around such integrated perspectives is the most promising approach to meeting the now global challenge of marine litter.

"Seeing waste as a resource may prove a powerful factor in litter reduction"

ICES scientific work involves delivering advice on the management of more than 200 finfish and shellfish stocks and conveying scientific information on how anthropogenic activity impacts the marine environment. Because of its nature, marine litter can be seen as a modern example of an anthropogenic pressure with an impact ranging across the wider marine environment and its users. Monitoring of marine litter can easily be integrated with existing ICES stock assessment surveys to determine potential influences on fish stocks and biodiversity. By taking advantage of research cruises already undertaken for other purposes, reliable data on marine litter can be obtained at affordable costs. ICES already provides advice to OSPAR, HELCOM, and the European Commission on the monitoring of marine litter in relation to the Marine Strategy Framework Directive (MSFD). The occurrence and effects of marine litter in the ICES area and complexity of this vast problem is still yet to be fully understood. It is hoped that the theme session at the ICES Annual Science Conference in Reykjavík focusing on marine litter will aid the understanding of this multifaceted issue.

Photo: Steve Springs/Marine Photobank

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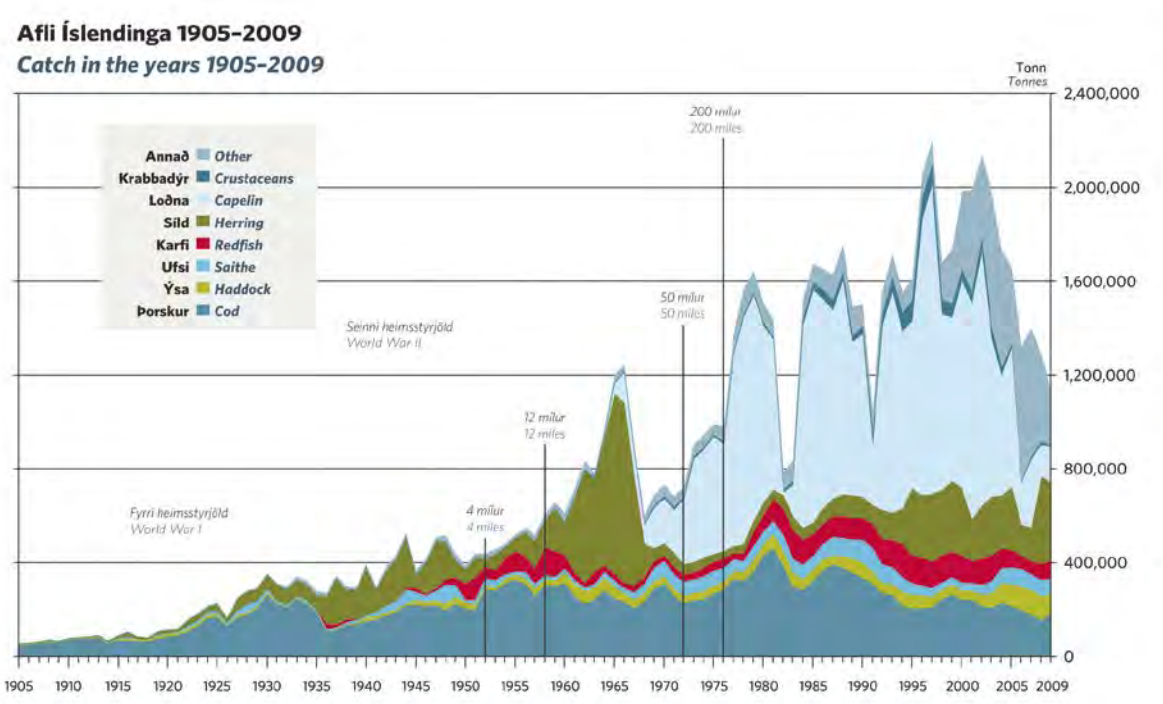
From John the Learned to harvest control rules for fish stocks

Jóhann Sigurjónsson looks at the development of fisheries and marine research in Icelandic waters

The importance of fisheries in the Icelandic economy

Icelanders depend greatly on the oceans for their livelihood and well-being. Fishing has been an important activity in Iceland since the earliest days of settlement and during the past century the development of fisheries has provided the basis for the country's progress and rapid economic growth. Fish products constituted as much as 95% of Iceland's merchandise exports in the 1940s. At the end of the 20th century, fish products still accounted for over 60% of the exports. However, with further diversification of the Icelandic economy, fish products now constitute around 40% of the export merchandise value.

The graph below shows the development of Icelandic fishing fleet catches since the early 1900s. In 1905, the total catch was 54 000 tonnes, mainly cod (*Gadus morhua*). The total annual catch steadily increased and was around 400 000 tonnes between 1930 and 1955, cod still being the most important species, although other species, such as herring (*Clupea harengus*), haddock (*Melanogrammus aeglefinus*) and redfish (*Sebastes* spp.) also played an important role. Since 1976, the total annual Icelandic catch has varied between 1 and 2 million tonnes, with an average of 1.6 million tonnes. The increase in catch level is mainly due to increased pelagic fisheries, including Atlantic mackerel (*Scomber scombrus*) in the last decade.



1905-44 afli við Ísland, 1945-2009 afli af öllum miðum *1905-44 catch around Iceland, 1945-2009 from all fishing grounds*
Heimild: Fiskifélag Íslands, Hagstofa Íslands *Source: Fisheries Association of Iceland, Statistics Iceland*

Effective fisheries management has long been seen as essential in gaining the full benefits from marine resources. Therefore, fisheries management has a long history in Iceland. In 1901, Iceland declared a fishing limit of three nautical miles, which remained in effect until this was extended to four miles in 1952, to 12 miles in 1958, to 50 miles in 1972, and finally to 200 nautical miles in 1976. Icelandic waters have been popular international fishing grounds for decades, leading to increased fishing intensity. The extension of the Exclusive Economic Zone (EEZ) to 200 miles was seen as an essential measure to protect the fish stocks from overexploitation.

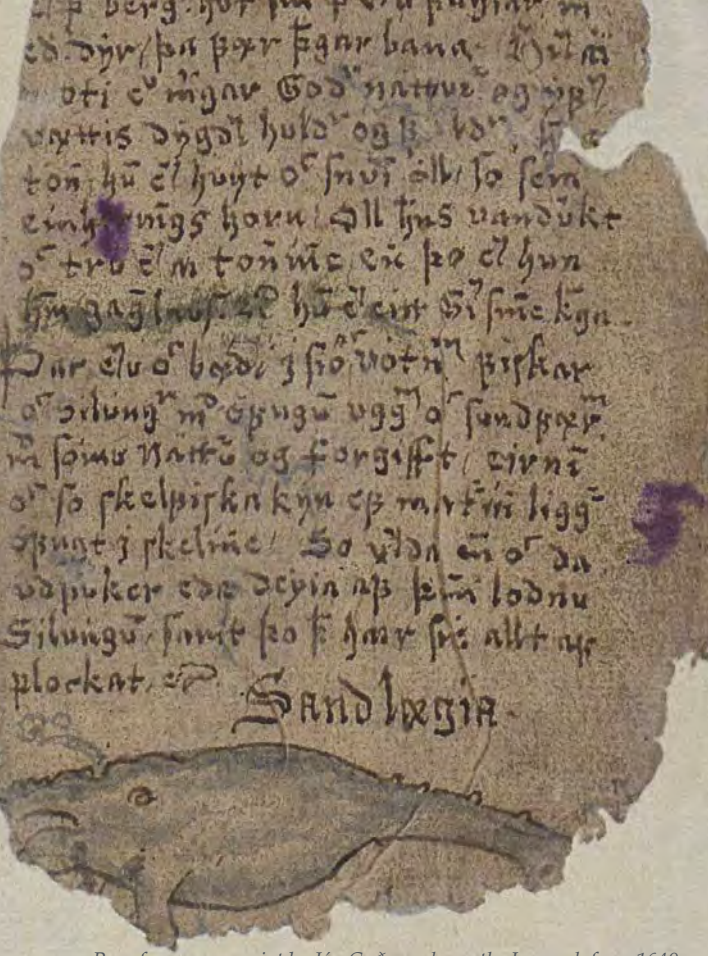
The Marine Research Institute (MRI) was established in Iceland in 1965 and is the principal organization conducting marine environment and fish stock monitoring, as well as research to provide the basis for scientific advice to authorities and the industry on the valuable resources around the island. Extensive monitoring of fish stocks and their productivity are prerequisites for sustainable management.

Historical Icelandic literature and John the Learned

The earliest written information on marine animals in Iceland is found in one of the Icelandic sagas (Snorra Edda) from the 12th century, where 56 fish, four invertebrates, and 26 names of whales are identified. In *Speculum regale* ("The King's Mirror"), written in the 13th century, "all species of seals and whales occurring in the waters around Iceland" are described along with some observations on biology, behaviour, and use of their resources. Although much of what is written on marine animals in this work and other ancient Icelandic literature is fantasy (like the map shown) and not based on fact, it is clear that the authors often made accurate descriptions, especially if they had personally observed such animals.

The most remarkable account on natural history from ancient times in Iceland was written by Jón Guðmundsson the Learned (1574–1658), a self-educated polyhistor who wrote a manuscript called "On the diverse natures of Iceland" around 1640. He was well known and often cited in Iceland. His work is a mixture of keen observations of whales and uncritical superstition. Jón the Learned was acquainted with the Basques who were whaling off the northwest coast of Iceland, and it seems from his skillful drawings that he himself saw the animals he describes. His drawing and description of sandlægja (the whale laying in the sand) the now extinct Atlantic gray whale (*Eschrichtius robustus*) is unique. It is among the very few written accounts with clear drawings of this species in the North Atlantic. Several centuries-old bone remains have been found on both sides of the North Atlantic.

Map of Iceland dating back to 1590 (Source: islandskort.is)



Page from manuscript by Jón Guðmundsson the Learned, from 1640, of sandlægja, the now extinct Atlantic gray whale (Source: handrit.is)

"Þór, as it was now named, thus became the first Icelandic owned research vessel."

As modern marine scientists we must remember that debate of our work does not have quite the same consequences as those experienced by our predecessors. Some of Jón the Learned's poetic works drew the ire of church leaders. He was taken to court, sentenced to exile and spent many years as a fugitive, part of the time on a deserted Icelandic island. Fortunately, he also had strong admirers and was allowed to live out his remaining years in restricted freedom in east Iceland.

The early years of marine and fisheries research in Iceland

The history of marine and fisheries research in Iceland stretches quite far back. Although the middle and early modern ages saw a number of well informed and some less informed naturalists, systematic marine research in Iceland did not take place until Danish oceanographic investigations began in the 1870s onboard the coast guard vessel "Fylla" and the military vessel "Ingolf", followed by the expeditions of the Norwegian research vessel "Michael Sars" in 1900. In 1895 and 1896, the Danish expedition onboard the Ingolf added much to our knowledge of oceanography and marine life around Iceland, which appeared in a series of scientific publications.

However, in the period 1903–1905, the "Thor" expeditions in the waters around Iceland, funded by the Danish government and lead by the famous Danish scientist and explorer Johannes Schmidt (1877–1933), laid the foundations for scientific knowledge of the main fish stocks and other marine life around Iceland, including the first tagging experiments. RV "Thor" was a 115 ft fishing trawler, built in England in 1899, and bought in 1902 by the Danish government for conducting marine research. In 1920, it was sold to the Westmann Islands Rescue Association (south Iceland) and later to the Icelandic state for rescue and coastguard purposes and for conducting fisheries research and oceanographic measurements. In 1929 it was stranded and lost in Húnafjörður, north Iceland.

RV "Thor" in Icelandic waters in 1903

Herring research (Photo: MRI)

The "Thor" expeditions were carefully planned and carried out in cooperation with the first Icelandic fisheries scientist, Bjarni Sæmundsson (1867–1940), who studied natural sciences and geography at the University of Copenhagen. Although Sæmundsson was a school teacher for 29 years, his mind was focused on research, particularly marine zoology and fisheries biology. In 1923, he was finally able to devote all of his time to his scientific research and writing, thus being the first fulltime fisheries researcher in Iceland.

After the "Thor" expeditions, Sæmundsson was able to convince Icelandic authorities to continue these efforts. The first Icelandic fisheries research investigations occurred between 1908 and 1909 under his leadership with various vessels addressing oceanography and animal life in general, and with emphasis on the life history and biology of the most important fish stocks in Iceland.

In 1931, the Icelandic Fisheries Association initiated fisheries research under the leadership of Dr Árni Friðriksson (1898–1966), a young zoology graduate from the University of Copenhagen, whose thesis focused on the occurrence of marine mammals in Icelandic waters. Along with his mentor Sæmundsson, Friðriksson is also regarded as one of the great pioneers of fisheries and marine research in Iceland. He was inspired by the enthusiastic work of Johannes Schmidt and was assistant to Åge Vedel Tåning (1890–1958), the leader of the "Dana" expeditions which focused on fisheries and zooplankton research. Friðriksson started working on cod research, including large-scale ageing studies. He was later attracted to the gradually developing herring fishery, where migrations and stock identity became major scientific issues for proper development and management of the large international fishery in the post-war years. Tagging experiments initiated by Friðriksson and his Norwegian colleagues helped demonstrate the extensive seasonal migration of the Atlanto-Scandian herring and its distribution in time and space.

It was not until 1937 that a designated research organization, the Fisheries Department of the Institute of Applied Research at the University of Iceland, was given the task of studying the marine environment around Iceland, the fish resources, and the future possibilities of utilizing these in a sustainable manner. The newly graduated Friðriksson was first offered the job of leading this work until he took over the position of ICES General Secretary during the period 1954–1964.

The Marine Research Institute

In 1965, the university's three departments of applied research were dissolved and separate sectoral research institutes devoted to applied research established, including the Marine Research Institute (MRI). The first director general of the MRI was Jón Jónsson (1919–2010), who had taken over the leadership of the Department of Fisheries after Friðriksson left in 1954. Jónsson, who was a cod specialist, headed the MRI until 1984, spanning more than three decades of great development of marine and fisheries research in Iceland. During this time, fisheries science played a major role in the dramatic development of the fishing industry in Iceland and extensions of the EEZs took place.

The MRI headquarters in Reykjavik with RV "Árni Friðriksson" (70m, built in 2000) (Photo: E. Ásgeirsson). The institute also owns another smaller (56m) ocean-going vessel RV "Bjarni Sæmundsson", built in 1970. Planning of a new vessel is underway.

Jakob Jakobsson (b. 1931), a leading herring expert, became Jónsson's successor in 1984. Jakobsson was known in Iceland for successful cooperation with the herring fleet in the 1950s and early 1960s and was actively involved in delevoping the science behind the ncessary conservation efforts. Before Jakobsson left his position at the MRI in 1998, he served as president of ICES during the period 1988–1991 and as professor in fisheries biology at the University of Iceland. Since 1998, the MRI has been headed by the author of this article.

The role of the MRI was defined by law in 1965 as the principal organization in Iceland to carry out various investigations into the marine environment and living resources of the sea for orderly development of the fishing industry. The institute is also responsible for providing annual advice to the government on catch levels and conservation measures for all exploited fish stocks and living resources of the sea.

Communicating science to young people and layman is of paramount importance (Photo: MRI)

Finally, the MRI has an important role in informing the government, the fishery sector, and the public about the sea, its living resources, and their sustainable use. The institute conducts regular formal and imformal consultations with fishermen and the fishing industry on matters related to fish stock assessment and fisheries science. This is of paramount importance for acquiring the necessary information on the status of the stocks and to provide a bridge between science and industry, which is prerequisite for sustainable management of the resources. The MRI conducts a series of joint research and monitoring projects in cooperation with the fishing industry that have proven successful in gathering valuable knowledge and in building confidence between scientists and fishermen.

MRI has around 160 employees, including experts in marine geology, oceanography, marine ecology, and in fisheries and aquaculture science. The institute owns two ocean-going research vessels and runs five branch laboratories located in fishing communities in different parts of Iceland. The branch laboratories provide important data on fisheries and carry out research in close contact with the local fishing communities.

MRI's activities are organized into three main divisions:

- *The Marine Environment Division* investigates environmental conditions (nutrients, temperature, salinity) in the sea, marine geology, and the ecology of algae, zooplankton, fish larvae, fish juveniles, and benthos.
- *The Marine Resources Division* investigates biology and productivity of exploited stocks of fish, crustaceans, molluscs, and marine mammals.
- *The Fisheries Advisory Division* scrutinizes stock assessments, prepares the formal advice on TACs, and develops sustainable fishing strategies for authorities.

Among the larger projects undertaken within the Marine Environment Division in recent years are investigations on surface currents using satellite monitored drifters, assessment of primary productivity, overwintering and spring-spawning of zooplankton, and studies on spawning of the most important exploited fish stocks. Extensive mapping of the topography of the seabed and habitat mapping has been given priority and following recommendations from the MRI have resulted in closure of vulnerable areas to fishing activities where cold-water corals occur.

Examples of some extensive projects within the Marine Resources Division are annual groundfish surveys since the mid-1980s covering the shelf area around Iceland (spring and fall surveys) and surveys for assessing inshore and deep-water shrimp (*Pandalus borealis*), Norway lobster (*Nephrops norvegicus*), and scallop (*Chlamys islandica*) stocks. The pelagic stocks of capelin (*Mallotus villosus*) and herring are also monitored and investigated annually in extensive research surveys using acoustic methods. Furthermore, an extensive programme concentrating on multispecies interactions of exploited stocks in Icelandic waters has also been carried out. In light of the large whale stocks present in Icelandic waters, particularly during the summer feeding season, considerable resources have been used on large whale investigations since the mid-1980s, including regular large-scale whale sighting surveys.

Research activities

In the late 1970s and early 1980s many of the exploited fish stocks were depleted or in rather poor condition, particularly cod, haddock, and plaice (*Pleuronectes platessa*). Following a 1975 MRI report on the poor stocks, strict measures were imposed on the fisheries for most commercially important fish stocks caught in Icelandic waters. Subsequently, the main emphasis of the MRI research activities moved from exploratory research to investigations aimed at estimating stock sizes and productivity of commercially important stocks.

In the 1990s and particularly in recent years, the MRI has devoted significant resources into studying long-term harvest strategies, which have been the basis for developing harvest control rules for several of the most important fish stocks such as cod, haddock, saithe (*Pollachius virens*), and golden redfish (*Sebastes marinus*).

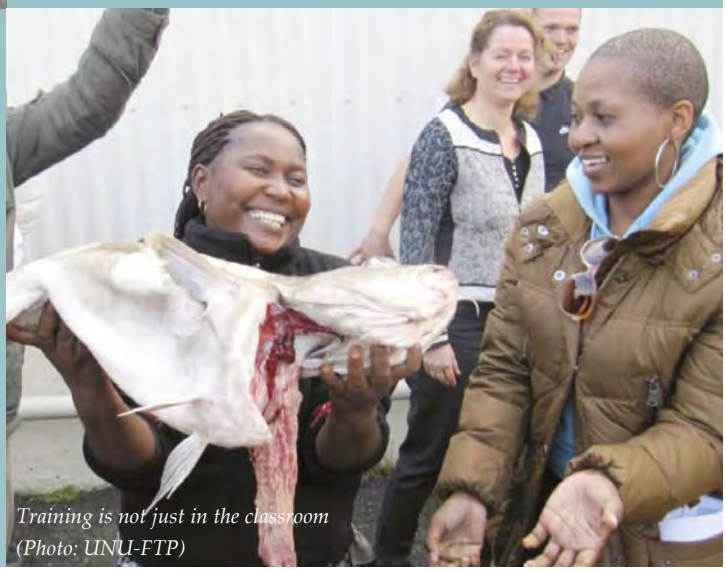
Much progress has been made in recent decades regarding sustainable use of the fish resources around Iceland. This could be due to a changing attitude towards scientific-based decision-making and marne management. There is not always agreement on the views and forecasts generated by the MRI, but welcomed debate takes place across Iceland. Scientists and policy-makers may not always agree but it is seen as a positive step that in 2013, MRI 's recommendations on Total Allowable Catch (TAC) were followed for each stock. The development and adoption of harvest control rules – developed by the scientists, under the leadership of authorities, and in cooperation with the fishing industry – is of fundamental importance. This enhances long-term views of resource utilization, gives authorities and the fishing industry a basis for long-term planning and stability, and secures the sustainability of the resource.

Tagging cod (Photo: MRI)

UNU-Fisheries Training Programme

In 1998, the Fisheries Training Programme (FTP) of the United Nations University (UNU) was established at the MRI according to an agreement made between the UNU in Tokyo and the Ministry for Foreign Affairs in Iceland. In cooperation with Icelandic institutes, universities and companies, the programme offers a six-month specialized post-graduate course in fisheries-related subjects (e.g. stock assessment and fisheries management) to professionals from developing countries. So far, 263 fellows from 47 countries have completed their studies in the UNU-FTP.

Post-graduate fellows on an excursion (Photo: UNU-FTP)



Training is not just in the classroom (Photo: UNU-FTP)

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Fish otoliths: National treasures that can enrich ICES science

Audrey J. Geffen and Beatriz Morales-Nin explain the importance of archiving these windows to marine history

Fish otoliths, which are seen as the "ear bones" of fish, are calcified structures that grow in layers throughout the fish's life. The periodic deposition of protein-rich and protein-poor layers of calcium carbonate produce growth zones at the daily, seasonal, and annual level. In many species, the growth structures are easily visible at low magnification. Seasonal features are zones of varying contrast, which usually mark times of different growth rates during the year. Yearly growth rings usually consist of a pair of opaque and translucent growth zones, and the width, number, position, and optical density of the periodic growth increments reflect the growth and metabolic history of the fish.

What can otoliths tell us?

The age estimation of fish is basic for population dynamic studies, which in turn is one of the foundation stones of analytical assessments and thus management for many valuable fisheries. Each year millions of otoliths are read and interpreted to determine age–length keys, mortality rates, age at sexual maturation (maturity ogives), etc., all basic parameters to assess the biomass that can be extracted from the sea.

Water temperature controls the fractionation of oxygen isotopes during the precipitation of calcium carbonate as the otolith grows. A temperature record that is thus deposited in each layer of calcium carbonate can be read by measuring the oxygen isotope ratios. In a similar manner, carbon isotope ratios are measured in the growth layers; these ratios probably reflect metabolic activity since the carbon is derived from respiration as well as from the surroundings. Other chemical elements are incorporated into the otolith as it grows, and the relative composition of the otolith can tell us something about the environment the fish has lived in. The chemical composition of the increments often reflects the local water mass, forming a permanent record of where a fish was born, and where it lived during its life. Analytical methods such as inductively coupled mass-spectrometry (ICPMS), used to measure otolith chemical composition, help determine the origin of the fish and its patterns of migration.

Otolith shape is another characteristic that differs between fish species, and between populations within each species. Modern image analysis techniques are used to quickly photograph, digitize, and analyse subtle shape differences – such as the pattern of scalloped margins or notches. For example, there are subtle, but identifiable differences in shape, as seen in the comparison of the "average" otolith shape from different hake populations around Europe.

Otolith size and shape variations are influenced by both genetic and environmental factors during development.

Average shape of otoliths from hake populations in European waters, analysed as part of the FishPopTrace project funded by the European Commission's 7th Framework Programme.

The result is a wide range of shapes and sizes (http://www.cmima.csic.es/aforo/). Due to the interspecific variation in shape, otoliths have been useful in taxonomy, identifying species and allowing the study of foodwebs from partially digested remains. Similarly, otoliths from archaeological and palaeontological finds have also been used in the reconstruction of palaeoenvironments and palaeofauna. Otolith morphometrics have also been used in species identification and to study geographical variations in populations and stocks of fish. Sometimes, otolith morphometrics can indicate the need for a closer look. For example, while ageing black scabbard fish from Madeira in the mid-1980s, a second minority otolith shape pattern was identified, and 25 years later the presence of two species in the area was finally confirmed genetically: *Aphanopus carbo* and *A. intermedius*.

The value of otolith archives

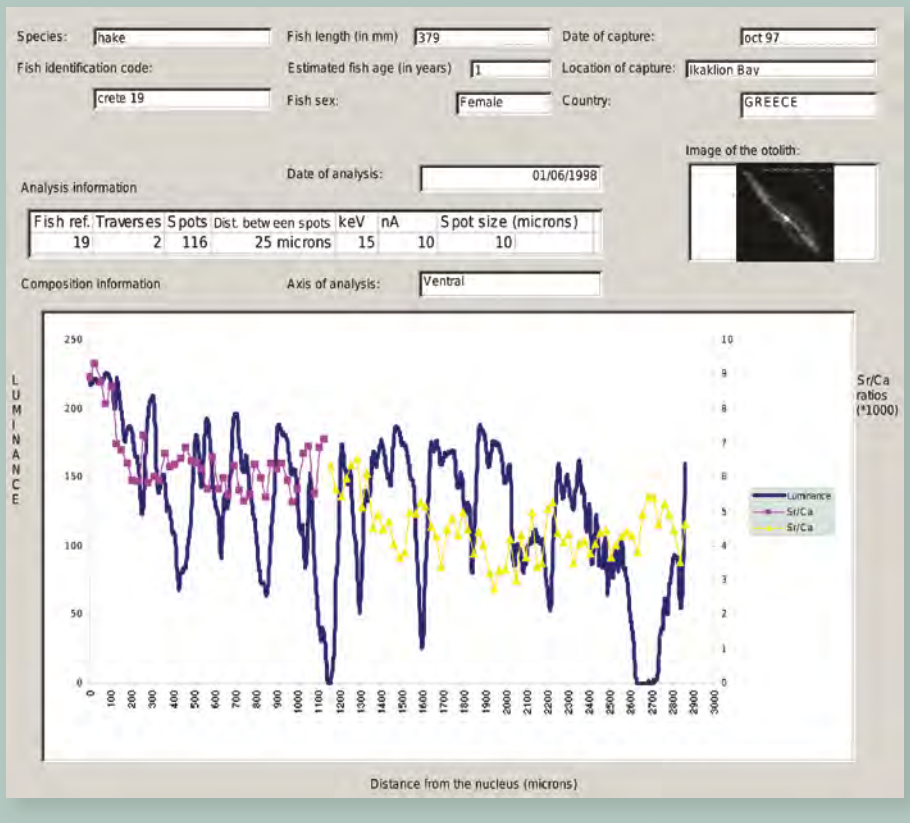
Since the early 1900s, fisheries scientists have carried out regular collections of commercial fish, to measure their abundance, growth, and condition. In addition to the day-to-day work of scientific investigations and fish stock assessment to support management, the data collection activities have given us a valuable legacy in the archives of otoliths.

In the late 1990s, the value of these otolith collections began to be realized and a number of papers were published which looked at long-term changes in fish populations and whether changes in growth or seasonality could be linked to climate change effects. Within a short time, the potential of the collections began to be revealed, from a flow of data supporting analyses of past population genetics/population structure, growth dynamics, and environmental conditions.

However, these collections have been assembled on an *ad hoc* basis at various institutes by individual researchers rather than by professional archivists, who would apply proper cataloguing and storage, with straightforward protocols for access to the collections. There is also extreme variation in size and quality of collection between institutions and between countries.

What to archive and how to sample

Fish otoliths can provide several types of data: the environmental record revealed by composition analysis, the genetic record revealed by microsatellite analysis of protein fragments, and the record of growth responses revealed by the analysis of the growth patterns.



Example database – chemical composition data and images of hake and cod otoliths analysed as part of the DGXIV Study Project 96-075 (1997–99): 'evaluation of otolith microchemistry as a means of validating age in commercial fish species'.

Analyses on the same otolith can help:

- reconstruct seasonal temperature cycles from stable isotope ($\delta^{18}O$) measurements along transects from the otolith edge to core, representing the fish's life. Aspects of individual metabolic condition may also be revealed from $\delta^{13}C$ measurements;
- reconstruct the size, age, and growth characteristics of individual fish and their populations based on seasonal otolith growth structures. The width of the growth zones reflect the growth rate of the individual, and the optical density of the growth zone reflect the seasonal cycle;
- estimate the seasonal time of capture for each individual based on the optical characteristics of the otolith margin (Marginal Increment Analysis) and stable isotope ($\delta^{18}O$) measurements;
- estimate the geographical source and stock identity of the individuals based on recovered DNA, the measured chemical composition of the otolith, and analysis of the otolith shape.

Fortunately fish have two sagittal otoliths and usually only one is prepared for age estimation. This leaves lots of material available for other analyses. In most cases, a staged protocol can be used to get the most out of each otolith. But because the number of samples is limited, and because they are irreplaceable, we must use the best procedures for getting the most information out of each sample. We can arrange the analytical steps into a series proceeding from the least destructive to the most destructive. Thus, the processing of each otolith sample could follow these steps:

1. Photographing, scanning, and digitizing the images of the outside otolith surface. This provides a permanent visual record of the intact otolith, allowing for an analysis of the features of the otolith shape which may be linked to populations or to age and growth.

2. Embedding and sectioning of the otolith, producing two or three sections (slices) of the otolith, each of which contains the core area. For older (fossil) otoliths, the other sections of the embedded otolith may be cut to give material for carbon dating and for X-ray crystallography (XRD). These analyses should be done to confirm assumptions about the age and mineral form of the sample.

3. Distribution of the core sections. Although we try to maximize the number of types of analyses done on each section, it can be challenging to restrict ourselves to using only one section for each otolith. It is reasonable to divide the analyses into:

    a. One section to be polished for visual examination and then micromilling for isotope analysis. The light microscopy provides digital images for records, images for age estimation, marginal increment analysis, and annual increment analysis. Isotope analysis will provide data on the small-scale variations in temperature experienced by these fish.

    b. One section to be cleaned and used for laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) to analyse the chemical composition of the otolith across the section.

4. All samples must be returned to the archives after analysis, along with copies of the digital images recorded during sample processing, and resulting data logs.

Otoliths embedded in resin in storage trays, ready for age estimation.

“Fish otoliths can provide several types of data records: environmental, genetic and growth responses.”

Do we have the basis for good otolith archives now?

In 1997, a European network was formulated, the European Fish Ageing Network (EFAN), followed by the Annual Workshop Towards Accreditation and Certification of Age Determination of Aquatic Resources (TACADAR). These networks gathered interest outside the original countries involved in the consortia, but were eventually dissolved with a lack of long-term funding. The task of coordination and progress has been left to *ad hoc* ICES working groups and workshops, e.g. WKAVSG, WKAMDEEP, and others, but many tasks have been repetitive and have tended toward reinvention rather than toward progress. However, there is renewed momentum for organizing these archives and improving access, supported by robust technology for searching, sharing, and interacting with data and images. Such archives do exist for other material such as tissue and biobanks, and there is no reason why other archives should not be linked to an otolith archive. It would then be possible to study, e.g. how toxic loading in planktonic fish food chain species is transferred through fish (with restricted growth rates) up into the human food chain, as seen in archival skeletal tissues.

The key is the organization, and there are many good examples – the organization of medical samples could be a good place to start. Sample tracking systems are available that can be initiated rather rapidly with low initial investment. For example, the use of bar codes on otolith envelopes is an easy way to initiate a tracking system and one that could be developed as resources become available.

International Otolith Symposium

IOS 2014 is the Fifth International Otolith Symposium (which is also an ICES Science Symposium; http://www.ices.dk/news-and-events/symposia/otolith/Pages/default.aspx) and will be held in Mallorca, Spain during 20–24 October 2014. The latest developments in otolith analytical techniques and novel applications will be presented. The focus of this symposium is the exploration of the use of calcified tissues as tools to support management and the formulation of a definition of indicators at environmental, community, population, and individual levels. Workshops on age validation and otolith shape analysis are also scheduled.

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