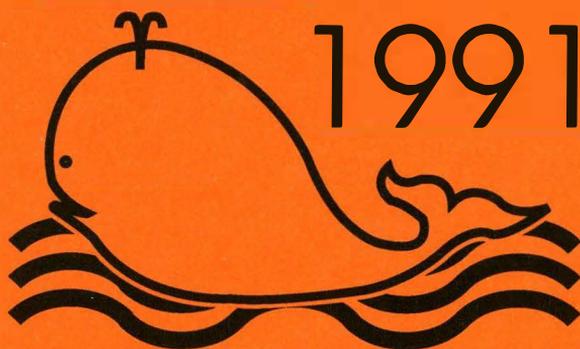


WHALES

BIOLOGY – THREATS – CONSERVATION



SYMPOSIUM

Brussels, 5-7 June 1991

PROCEEDINGS EDITED BY

J. J. SYMOENS

Permanent Executive Secretary of the
Royal Academy of Overseas Sciences
Professor at the Vrije Universiteit Brussel

ROYAL ACADEMY
OF OVERSEAS SCIENCES

J.-Y. COUSTEAU CHAIR
VRIJE UNIVERSITEIT BRUSSEL

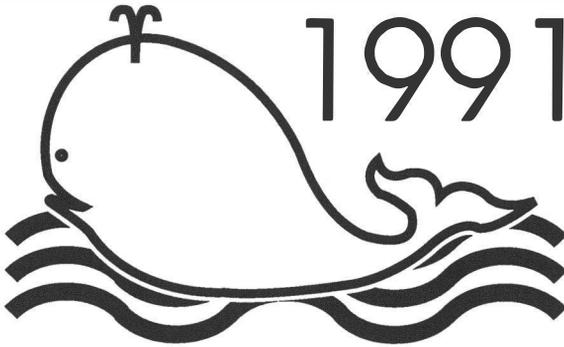


BRUSSELS
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LA BALEINE INDISPENSABLE

La baleine est le plus étonnant animal que la Terre ait porté. Elle fait naître les superlatifs. Elle est un vivant superlatif... Elle dépasse plusieurs fois par la masse les dinosaures géants du Secondaire. On devrait réunir vingt-cinq éléphants, ou deux mille êtres humains, pour équilibrer le poids d'une seule baleine bleue. La langue de cette dernière pèse autant qu'un pachyderme. La baleine bleue est longue comme quatre autobus. Son squelette pèse 22 tonnes, son lard 25, sa viande 50. Lorsqu'elle souffle à l'horizon des vagues, on jurerait qu'elle ajoute un nuage à l'atmosphère.

Mais cette montagne de graisse et de muscles développe une nage aussi fluide que l'élément dans lequel elle baigne. C'est une créature sociable, intelligente et pacifique, qui cajole et éduque ses enfants, défend ses semblables, discours dans une langue énigmatique et chante à tue-tête dans le fracas des tempêtes.

Or, qu'avons-nous fait de ces animaux jusqu'à ce jour? De l'huile pour nos lampes, des tiges pour nos corsets, de la viande pour nos animaux domestiques, du rouge à lèvres pour nos maquillages, de la graisse pour lubrifier les rouages de nos engins de guerre... Pendant que des hommes envoient des sondes spatiales à la recherche de la vie sur les autres planètes, certains représentants de notre espèce s'ingénient à faire disparaître les plus admirables animaux de la Terre! Y compris de nos jours. En dépit du moratoire sur la chasse commerciale aux grands cétacés, signé en 1986 par les membres de la Commission Baleinière Internationale.

De plus en plus de citoyens comprennent aujourd'hui que le profit est injustifiable dès lors qu'il met en cause l'existence même d'une espèce. Nous vivons une ère d'inversion radicale des valeurs: ce qui était réservé au petit nombre (les biens de consommation industriels) se banalise; et ce qui était abondant et gratuit (l'air et l'eau purs, la forêt, la mer, le spectacle de la nature en fête) devient rare. Dans ce contexte, un petit rorqual prend plus de prix qu'une flottille entière de navires baleiniers.

L'espoir existe, mais il est temps... Pour certaines espèces ou populations locales de cétacés, la réduction des effectifs est si grave que, même en l'absence de toute chasse, le redressement démographique est compromis. Ces groupes d'animaux semblent frappés de ce que le Professeur C. Roux appelle une «mélancolie génésique»...

Au reste, comme toutes les créatures de la mer, les baleines souffrent du saccage et de la pollution.

Elles endurent les marées noires et les déversements de poisons d'origine domestique, industrielle ou agricole.

Elles pâtiſſent des destructions mécaniques, du mur de béton, des abus du tourisme... Le trafic maritime les gêne. Les hélices de bateaux les blessent. Les baleines ont ce handicap particulier sur les autres espèces qu'elles sont énormes, et qu'on les suppose (consciemment ou non) indestructibles.

Elles peuplent une immensité liquide où l'on a toujours l'impression qu'elles doivent finir par échapper aux harpons. Trompeuse illusion... Les hommes sont partout; et partout ils colonisent et détruisent les espaces naturels.

Pratiquement toutes les espèces de grands cétacés sont encore menacées. C'est maintenant que nous devons les autoriser à survivre. Pour notre plaisir. Pour nos enfants. Au nom des droits des générations futures... Sinon comme on parle au passé de l'aurochs, de la rhytine de Steller, du pigeon migrateur américain, du dodo de l'île Maurice, du grand pingouin, de trente-six espèces de mammifères et de quatre-vingt-quatorze espèces d'oiseaux éteintes depuis l'an 1600 par la faute de l'homme, de même il faudra conjuguer au mode écoulé l'histoire de la baleine franche au bonnet de bernacles, de la monstrueuse baleine bleue, des rorquals effilés et rapides, de la baleine à bosse aux admirables plaintes, de la baleine grise des déserts de Californie et du cachalot musculeux qui a pu, voilà longtemps, passer pour redoutable...

Commandant J.-Y. COUSTEAU
de l'Académie Française

Symposium
« *Whales: Biology – Threats – Conservation* »
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ADDRESS OF THE PERMANENT EXECUTIVE SECRETARY
OF THE ROYAL ACADEMY OF OVERSEAS SCIENCES

BY

J. J. SYMOENS *

It is my privilege in my capacity as Permanent Executive Secretary of the Royal Academy of Overseas Sciences and member of the Board of the Jacques-Yves Cousteau Chair, to welcome you in the name of both organizing Institutions.

It has become a tradition that, on the occasion of the World Day of the Environment, the Academy organizes a Seminar on some subject related to the environment of overseas regions. In June 1986, we organized, in co-operation with the Information Centre and Liaison Bureau of the United Nations, a Seminar on the Problems of Environment in the Third World. In June 1990, our partner was the Technical Centre for Agricultural and Rural Co-Operation, in the organization of a Seminar on Agricultural Intensification and Environment in Tropical Areas.

This year, we are meeting to talk about whales, or rather about cetaceans, that is the whales, dolphins and porpoises.

Perhaps one might wonder why our Royal Academy of Overseas Sciences deals with cetaceans. A first reason is that the statutory aim of the Academy is to contribute to the progress of scientific knowledge of overseas regions; and many cetaceans are indeed common in the seas adjacent to the Neotropical, the Ethiopian, the Oriental and the Australasian zoogeographical regions; several species even occur

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in their rivers, such as the Amazon boutu and tucuxi, the Ganges susu and the Yangtze baiji. We also know that most of the whaling campaigns occurred in Southern seas, a.o. around South Georgia and the Southern Orkney Islands.

Another reason for our interest in cetaceans is that we think that both enhancement of development and care for the environment must occur within the framework of a global strategy for conservation of the natural resources and of the biological diversity of our planet.

This is also a concern of the Jacques-Yves Cousteau Chair which was created in 1990 at the Free University of Brussels (V.U.B.), with the aims of promoting studies on the long-term habitability of our planet, on the methods and criteria of decision-making to ensure the future generations' enjoyment of life in a world whose integrity will be protected, of organizing seminars in these areas and of creating a forum for active intellectual interchange among students, scholars and the public.

When we think about integrity of life in the world, it is evident that we must consider and give serious attention to some of the most extraordinary living beings of our planet: the cetaceans.

Cetaceans are really fascinating animals. In spite of the many books written on the subject, we still know too little about their biology. Each research project reveals exciting characteristics concerning their adaptation, behaviour, language and intelligence.

Yet, these large sea mammals were the victim of exploitation which reduced the populations of many species to dramatically low levels, perhaps even to the brink of extinction. A moratorium which has just been renewed prohibits the commercial hunting, but some countries continue to harpoon whales for scientific purposes.

Furthermore, thousands of kilometres of high sea drift nets sweep huge areas of the oceans, entangling any living animal that swims into them, including the smaller cetaceans. Similarly, the purse seine nets used in tuna fishing operations trap the associated dolphins which are then crushed and suffocated. The toll on small cetaceans is growing by the day.

In addition, sea mammals are sensitive to the ever increasing threat of marine pollution. Heavy metals and organochlorines have been detected at high levels in cetaceans. Although it is not proved that they directly cause these animals' death, their presence could affect their immune system, which then would make them more vulnerable for viral, bacterial or other parasitic diseases.

I think it is time for all individuals, all governments, all nations to realize that cetaceans, in all their diversity, are part of the world ecosystem, are part of our common heritage, and deserve their place on our planet.

Drawing the attention of our scientific community, as well as of the public, to these fascinating but often endangered animals, we hope the present meeting will contribute to this understanding.

Commandant Jacques-Yves Cousteau who has already contributed so much to the progress of oceanographical research and to the campaigns in favour of whale protection expressed his regrets not to be able to attend this Symposium, but we gratefully appreciate his elegant message «La baleine indispensable» addressed to our assembly.

We thank Dr. D. Cahen, Director of the Royal Institute of Natural Sciences, for his kind authorization to hold this Symposium in the Institute. Our gratitude is expressed also to Dr. A. Quintart, head of the Educational Department of the Institute, for his precious help in all local arrangements ensuring the good occurrence of our activities.

Financial support from the Belgian National Fund of Scientific Research and the WWF-Belgium is also thankfully acknowledged.

Finally, I am pleased to thank the Secretariate staff of the Royal Academy of Overseas Sciences as well as of the Department of Human Ecology of the Free University of Brussels for their efficient participation in the organization of the Symposium.

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WHALING: PAST, PRESENT AND FUTURE

BY

Cassandra PHILLIPS *

SUMMARY. — Small-scale subsistence whaling is thought to have been started in Europe at least 2,000 year ago. Commercial whaling started in the 11th century, when the Basques began killing large numbers of right whales in the Bay of Biscay; by the 16th century right whales had become severely depleted and the Basques then moved on to exploit right and humpback whales off North America. They were followed by the Dutch, English, and later by the Americans who, by the mid 19th century, were killing 8 to 10,000 whales a year. In the meantime, the Japanese developed a thriving commercial whaling industry. During the 20th century, technical advances allowed the whaling industry to develop in the Southern seas, to a point of overexploitation, causing a dramatic population collapse. In 1931, the first Convention for the Regulation of Whaling was signed by 22 nations, but lacked enforcement measures, some of the largest whaling nations refraining from joining it. A further Convention was signed in 1937, and World War Two gave the whales a short respite, but, when it ended, the old whaling ships were refitted and the hunt resumed. The 1946 Convention, negotiated by the main whaling countries of the time, created the International Whaling Commission (IWC), but did nothing effective to prevent the depletion of nearly all whale species. In 1974, the IWC adopted the New Management Procedure (NMP) aimed at limiting exploitation to sustainable levels by deciding catch limits according to the estimated status of each whale stock. However, an escape clause allowed catches to continue at previous levels from whale stocks about which little was known, in the absence of specific evidence that the stock was declining. The 1980 World Conservation Strategy, prepared by IUCN, called for a more precautionary policy, including a moratorium on all commercial whaling, until several conditions could be fulfilled. Such a moratorium was to come into effect in 1986 and four of the nine IWC member states engaged in commercial whaling stopped by the 1986 deadline. The position of the World Wide Fund for Nature is that the whaling moratorium should stay in place for many years and that any new whale management procedure should guarantee that the risk of extinction of any major population is zero, the risk of serious depletion of any major population is held below a low pre-specified risk level, that already depleted populations are completely protected to allow recovery, and that, in case of uncertainty about the state of populations, the benefit of the doubt is given

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to the whales. An effective system of observation, monitoring, international inspection and regulation of scientific whaling is necessary, whilst a further condition for an eventual lifting of the moratorium is that whaling should be conducted in a more humane manner, imposing less suffering on the whales.

* * *

The latest annual meeting of the International Whaling Commission—IWC—has just ended in Iceland. I expect that several of you have come hot-foot from Reykjavik, as I have. Considerable progress was made there in agreeing the essential guidelines for a revised management procedure for whaling, which is broadly in line with the WWF thinking on this subject. I do not think that I will need to change what I had planned to say before that meeting, to take account of the results there.

I will start by giving an outline of the story of whaling up to the formation of the IWC under the International Convention for the Regulation of Whaling, just after the Second World War in 1946.

As my colleague Simon Lyster says in his book, *International Wildlife Law*: «The history of man's depletion of one species of great whale after another is perhaps the most infamous example of human mismanagement of the earth's natural resources».

Small-scale subsistence whaling is thought to have been started in Europe by the Norsemen at least 2,000 years ago. Commercial whaling, however, did not start until the 11th century, when the Basques began killing large numbers of right whales in the Bay of Biscay. They traded in all the products of these whales, meat, oil, and baleen. The rate of killing was small but steady, and must have been greater than the rate at which the whales were able to replenish the population. By the 16th century right whales had become severely depleted. The Basques then moved on to exploit right and humpback whales off the new colonies of North America. The pattern of commercial whaling was thus established, the pattern that has been repeated again and again — locate a population of whales to exploit, kill them until there are too few to hunt further, then move on to exploit another population elsewhere in the world.

The Basques were followed by the Dutch and English, who exploited the bowheads off the Arctic ice and round Spitsbergen, making very handsome profits killing up to 2,000 whales a year. By the late 18th century those whales were nearly all gone, and the focus of whaling moved to North America. Coastal whaling for humpback,

right, grey and bowhead whales, and pelagic whaling for sperm whales grew rapidly, and by the mid 19th Century the Americans were killing 8 to 10,000 whales a year, mostly for their oil.

In all, around half a million great whales were killed by the Americans in the 19th century. They brought all the species they hunted close to extinction, with the exception of the sperm whales which were more numerous to begin with.

In the meantime, the Japanese also had a thriving commercial whaling industry, from the 17th to the end of the 19th centuries.

They developed a skilful but slow method of killing, involving entangling the whales in nets. They made use of all parts of the whales' bodies, unlike the Europeans and Americans who only caught the whales for their oil and whale-bone.

So by the beginning of our century almost all of the nine species of great whales were close to extinction, or at least severely depleted in numbers, over almost all the oceans of the world, and it seemed as though the whaling industry was finished.

There remained, however, the Southern Ocean, around Antarctica. These seas are the summer feeding grounds of the biggest and commercially most valuable whales — blue, fin and sei. Because these animals swim fast, dive deep, and sink after death, they were not available to the early whaling industry which pursued its quarry in open boats and killed them with hand harpoons. But in 1868, the Norwegian Svend Foyn perfected his harpoon gun, mounted on a ship with steam power. At about the same time, the technique of keeping carcasses afloat by pumping air into them was developed.

These technical advances allowed the whaling industry to revive, and to move south for a bonanza. Factories were built on South Georgia, Deception Island in the South Shetlands, and Signy Island in the South Orkneys near the tip of the Antarctic Peninsula. Converted steamer ships were moored in a number of places, sending out fast catcher ships in search of prey. Then, from the 1925-26 season, factory ships with immense range, with stern slips, opened the whole of the high seas to pelagic whaling.

What happened in Antarctic waters in the first half of the 20th century is a classic example of the «tragedy of the commons», with human misuse of a resource that belongs to nobody and is exploited competitively and irresponsibly. First the Southern Ocean humpbacks, then the blue whales (the largest species of all), then fin and then sei whales (the next two largest species) were over-exploited and

driven towards population collapse. Today, despite the efforts at agreed regulation, only the much smaller minke whales remain in numbers comparable with those encountered by the first ships to enter the Antarctic seas.

Long before this appalling position was reached, the industry did try to regulate itself. In 1931, the first Convention for the Regulation of Whaling, signed by 22 nations, protected right whales as well as immature whales, calves, and females with calves. However, the treaty lacked enforcement measures, and some of the largest whaling nations including Japan, Germany, Chile and Argentina did not join it.

A further Convention was signed in 1937, but whale catches began declining even while the number of shore stations, catcher boats and factory ships continued to increase. World War Two gave the whales a short respite, but when it ended the old whaling ships were refitted and the hunt resumed. It was at this point that the present International Convention for the Regulation of Whaling came into force, and established the International Whaling Commission, whose 43rd annual meeting has just finished.

The 1946 Convention was negotiated by the main whaling countries of the time, and its basic constitution reflects their interests. Nevertheless, the Convention does emphasise conservation in its statement of objectives, which read: «to provide for the proper conservation of whale stocks and thus make possible the orderly development of the whaling industry», and states that whale stocks should be «safeguarded for future generations». However, it does not contain the provisions that would ensure that these objectives could be fulfilled. The International Whaling Commission was left with a free hand to act as it desired regardless of the objectives of the Convention. In its first twenty years the Commission concentrated on trying to regulate whaling in the Antarctic, where it failed dismally to make any significant impact on the unremitting depletion of blue and humpback, fin and sei whale stocks. Only in 1965, after they had become so rare that to refrain from catching them no longer required an economic sacrifice on the part of the whalers, were blue and humpback whales finally protected.

From the late 1960s onwards, public concern for the plight of the whales began to make itself felt, leading to the adoption of a Recommendation at the 1972 UN Conference on the Human Environment in Stockholm for a ten-year moratorium on commercial

whaling. This Recommendation was adopted by 53 votes in favour, none against, with three abstentions. One of the abstentions was from Japan, the most important whaling country, which recorded its technical reason for abstaining but declared that «it was favourable to a moratorium on commercial whaling».

Although this Recommendation was endorsed by the UN General Assembly, and was re-affirmed several times by the UNEP Governing Council, the IWC rejected it. Instead, in response to the increasing pressure of public opinion, the Commission in 1974 adopted the so-called «New Management Procedure» (or NMP), aimed at limiting exploitation to sustainable levels and at ensuring that populations already depleted to unproductive levels be fully protected so as to maximise their chances of recovery.

The NMP was meant to provide a set of rules for deciding catch limits according to the estimated status of each whale stock. The intention was to avoid the horsetrading approach to catch limits which had prevailed during the 1950s and 1960s at the expense both of the whale stocks and the long-term future of the industry. The responsibility was placed on the Scientific Committee to divide up the world's oceans into separate stock areas for each species, and to estimate the so-called maximum sustainable yield (MSY) level for each stock. For stocks estimated to be above their MSY level, the Committee was required to estimate the MSY itself which formed the basis for the catch limit.

The implementation of the NMP in 1976 led quickly to the protection of both fin and sei whale stocks in the Antarctic and in the North Pacific (but not in the North Atlantic). But once protection had been granted to the most heavily and obviously depleted stocks and species, the implementation of the NMP ran into difficulties. The problem was that the Scientific Committee lacked precise enough estimates of the abundance of any whale stocks. The only data available for this purpose were the indices of catches per unit of whaling effort (such as catcher days' work) from whaling operations, and limited quantities of data from tagging of whales. Catch per unit of effort data provided at best a very inaccurate indication of trends in whale stocks, and it is now known that such data can be thoroughly misleading by distorting or even masking completely the true extent of declines in stocks.

For example, new estimates of the surviving numbers of baleen whales were made by the IWC Scientific Committee in 1989, based on

annual sightings surveys since 1979. Of an initial population of around a quarter of a million blue whales on the Antarctic summer feeding grounds, only about 500 are now estimated to remain, even though they have been protected from whaling for 25 years. Of an original population of over half a million fin whales, only about 2,000 are estimated to remain, or less than 0.5%. Sei whale numbers are more uncertain because much of their range has not been covered by the surveys, but they have probably been reduced to a similar extent.

Because these whales are so scarce, these estimates of the surviving numbers of blue and fin whales are inevitably based on very few actual sightings and the margin of error in the estimates could be up to a factor of five in either direction. Nevertheless, there are clearly far fewer blue and fin whales than was indicated by previous estimates. Thus, the final assessments of the Antarctic fin whale stocks based on such data which led to their protection in 1976 indicated that about 100,000 of the original 500,000 population remained (that is, 20%). The new data illustrate dramatically how misleading the old catch-based methods of assessing whale stocks could be.

One of the most serious disadvantages of the NMP was the escape clause that allowed catches to continue at previous levels on whale stocks about which little was known, in the absence of specific evidence that the stock was declining. There was therefore a strong disincentive on whaling operators to supply data which could be used to reassess the state of their stocks. In other words, the New Management Procedure was based on the opposite of the «precautionary principle», which has since been agreed as the best way to approach environmental questions in international law. The precautionary principle states that activities should be prohibited until they can be proved harmless, as opposed to the NMP which allowed whaling to continue on stocks for which there was little or no information.

At the same time as these deficiencies in the NMP were becoming apparent, the membership of the IWC gradually became more representative, rather than being almost exclusively composed of whaling or recently ex-whaling countries. Many of the new members actively supported the 1980 World Conservation Strategy, prepared by IUCN with the support of UNEP, WWF, FAO and Unesco. The World Conservation Strategy calls for a moratorium on

all commercial whaling to last until the following conditions can be fulfilled :

- The consequences for the ecosystems concerned of removing large portions of the whales' populations, and such populations' capacity for recovery, can be predicted;
- Permitted levels of exploitation are safe, and an effective mechanism exists for detecting and correcting mistakes in the management of any stock;

and

- Member nations of the IWC are no longer purchasing whale products from, or transferring whaling technology and equipment to, or otherwise supporting, non-member nations, or pirate whaling ships.

(WCS Section 18: The Global Commons)

These were the influences which eventually led to the IWC's 1982 decision for zero catch limits. This moratorium was to come into effect only in 1986, and to last indefinitely but to be reviewed by 1990 in the light of a comprehensive assessment of the effects of the decision on whale stocks. The moratorium is therefore a good example of the precautionary principle at last being applied to whaling.

Of the nine IWC member states that were engaged in commercial whaling in 1982, four stopped by the 1986 deadline. However, other countries maintained formal objections to the decision and continued whaling, and the moratorium did not actually come fully into effect until April 1988.

Even then some whaling under special permits for scientific research continued on a scale not much less than that of the preceding commercial whaling. Several governments, NGOs and scientists have pointed out that this «scientific whaling» was merely commercial whaling under another name, and that its main purpose was to keep in place and ready the ships, crews and infrastructure of the whaling industries until the moratorium was lifted. Certainly, one effect of the «scientific whaling» has been that the Scientific Committee was forced to spend much of its time reviewing the scientific programmes in each year since 1986, and so has had insufficient time to carry out the comprehensive assessment of the effects of the zero catch limits on all whale stocks. Claims that the scientific whaling programmes of Japan and Iceland will contribute information useful

for the comprehensive assessment and for the development of an alternative management procedure have been shown to be quite unfounded. In fact, none of the possible revised management procedures being developed requires the sorts of information that was sought by the scientific whaling programmes, such as improved estimates of natural mortality (see Comprehensive Assessment Workshop on Management Procedures, IWC SC/41/Rep1).

The work of the Scientific Committee during the moratorium period has established even more clearly than before that:

- Under the NMP, population declines could not be detected until long after they had occurred, so that warnings of depletion came too late;
- At the time of the 1972 Stockholm conference and the call then for a ten year moratorium, the Southern hemisphere populations, certainly of blue, humpback and fin whales, and probably also of sei and sperm whales, had already been reduced far below what was then thought even by pessimists;
- Scientists remain very uncertain about what could be a sustainable rate of exploitation (the MSY level) of baleen whales, but the currently presumed range of likely rates is much lower than the values presumed ten years ago. Furthermore, scientists have no idea what would be an appropriate sustainable exploitation regime for sperm whales;
- Although progress has been made in estimating the numbers of minke whales remaining in the Southern hemisphere, and work is now starting to estimate some species in the North Atlantic, the estimates are not nearly precise enough for effective monitoring of changes in stock over periods shorter than decades, and there are still no reliable estimates of other stocks that were being exploited until the moratorium came into effect;
- Since largely arbitrary species stock boundaries were established by the IWC in 1976, for year-to-year management purposes, virtually no progress has been made in improving the scientific basis for such boundaries, or indeed in answering the question «what is a stock?».

So much for the past and the present, what of the future?

It is my position, and that of the organisation I represent, WWF—the World Wide Fund for Nature—that the whaling moratorium should stay in place for many years to come. There are many

reasons for this, which I will only have time to run through fairly quickly.

Since the 1975 New Management Procedure failed to conserve the world's whale populations, it is clear that the first essential condition for lifting the moratorium is the adoption by the IWC of a revised management procedure.

Any new whale management procedure should have at least the following properties before it can be considered as a basis on which to authorise the resumption of commercial whaling:

- The risk of extinction of any major population is effectively zero (too low to measure);
- The risk of serious depletion of any major population is held below a low pre-specified risk level;
- Already depleted populations should be completely protected to allow recovery;
- All doubt and uncertainty about the state of each population must be taken into account in a way that gives the benefit of the doubt to the whales. In accordance with the precautionary principle, the less the amount and quality of the information on a population, the lower the level of catch that should be allowed. No catch should be allowed from stocks for which there is no information about population size.

It is essential that data used for estimating the status and trends of whale populations and hence the setting of catch limits be accurate and reliable. One of the reasons for the failure of the NMP was the poor quality of data which were often open to more than one interpretation: consensus in the Scientific Committee was rarely achieved.

An effective system of observation and inspection is necessary to ensure confidence that catch limits and other regulations are being enforced. The IWC should have the power to appoint international observers to supervise catching operations, landings, and also whale surveys where the results are to be used in setting catch limits. Observers should be allowed to conduct random checks at short notice.

So far, the IWC has given little or no attention to resolving the problems related to the implementation and enforcement of decisions, and to the lack of full and prompt provision of data from commercial

whaling operations. These problems have impeded the effectiveness of the IWC for many years.

The revised management procedure fulfilling the properties listed, including the data requirements, and with an effective international system of observation and inspection, must all be incorporated into the Schedule of the International Convention for the Regulation of Whaling before the moratorium is lifted. This condition contrasts with the attempts by the remaining whaling countries—Japan, Norway and Iceland—to persuade the IWC that it is desirable to set «provisional interim» catch limits for certain stocks and whaling operations even before a revised management procedure is agreed — attempts which the IWC has so far successfully resisted.

The exemption of «scientific whaling»—i.e. whaling conducted for apparently scientific purposes—from international regulation has proved to be a serious loophole in the ICRW. Even when agreement is reached on a satisfactory revised management procedure, the effectiveness of the new procedure will remain in doubt so long as any country can at any time ignore its provisions simply by declaring its whaling to be «scientific». A further condition for the lifting of the moratorium is, therefore, an agreement that scientific whaling should not involve sample sizes of a commercial magnitude.

Whaling has not only been criticised because species after species has been severely depleted and some even brought close to extinction, but also because it has involved a high degree of cruelty. A further very important condition for any eventual lifting of the moratorium is that any whaling should be conducted in a humane manner. The level of suffering imposed by killing whales with harpoons with explosive grenades is far more than would be permitted under most countries' national legislation on the killing of animals. Yet no move has been made by the whaling countries to rectify this. Iceland and Japan in fact still have objections lodged on the use of the even more inhumane non-explosive cold harpoon.

If all these improvements were in force, the IWC would have gone some way towards meeting the conditions in the World Conservation Strategy for lifting the whaling moratorium, but there would still be gaps.

In particular, no progress has been made on the WCS condition, that «the consequences for the ecosystems concerned of removing large portions of the whales' populations... can be predicted». No such predictions are yet available and the IWC has never even

considered trying to examine this question. Certainly, the Antarctic marine ecosystem is still grossly distorted and subject to wild oscillations—for example in fur seal populations—probably as a result of the killing of such a large proportion of the whale populations in the Southern Ocean.

There is a final, most important, point to mention. All whales, and most dolphins, are migratory species, in whose conservation everyone has a legitimate interest, whether or not they are involved in killing them for commercial profit. Further, an increasing number of people all over the world think that commercial whaling is both unethical, and unnecessary, in modern society, even if it could be guaranteed to be both sustainable and humane. As more and more is learnt about the remarkable qualities of live cetaceans, so the feeling grows that the whale populations that have survived the disorderly whaling industry should be allowed to recover without further harassment. There are many benign uses of whales, such as the multi-million dollar whale-watching industry, that can benefit mankind while the moratorium remains in place.

I will end by quoting Sir Peter Scott, the artist and naturalist who was one of the founders of the WWF, who attended the IWC meetings for many years:

In the light of present knowledge of these intelligent mammals, no civilised person can contemplate the whaling industry without revulsion and shame at the insensitivity of our own species.

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THE INTERNATIONAL WHALING COMMISSION: GIVEN ITS PAST, DOES IT HAVE A FUTURE?

BY

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SUMMARY. — The paper traces the background to the signing of the International Convention for the Regulation of Whaling in 1946 and the forming of the International Whaling Commission. Several features of the Convention are examined and it is shown how these have shaped the Commission's history. The twofold aims of the Commission are the «conservation of whale stocks» and the «orderly development of the whaling industry». The history of whale management from 1946 is reviewed in the light of the attempts and failures that have arisen as a result of the difficulties in finding a balance between those two aims. In particular, at the present time, many of the Antarctic whale stocks remain heavily depleted and there is a world-wide ban on commercial whaling. On the face of it at least, it appears that the International Whaling Commission has failed to achieve either of its aims. However, from another perspective, the International Whaling Commission has achieved much, particularly in recent years, and particularly at a scientific level. The paper concentrates on two related aspects of this: the «Comprehensive Assessment» of whale stocks and the development of a «revised management procedure». The former initiative has reviewed the suite of research techniques necessary to improve our understanding of the population biology of whales, including molecular genetics, photo-identification and survey methodology and analysis to determine population sizes. The latter has led to the development of management procedures that do not require more knowledge about whale populations than we are likely to obtain. The author concludes by examining the main issues affecting the International Whaling Commission today.

Introduction

With the many conservation campaigns mounted over the last 20 years based on the premise that whales are almost extinct, it may seem difficult to believe that an inter-governmental body to regulate

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whaling has been in existence for the past 45 years. In fact, several attempts at international regulation had been made as early as the 1930s, largely inspired by economic considerations. The 1930/31 Antarctic catch of over 40,000 baleen whales led to a huge surplus of baleen oil and a catastrophic drop in the price per barrel. It was clearly in the industry's own interest to stabilise the catch and market, and a series of agreements were drawn up, with various levels of success, in 1931, 1937 and 1938 (TØNNESEN & JOHNSEN 1982).

In 1934, seventy years after the Norwegian Svend Foyn had heralded the start of modern whaling by inventing the explosive harpoon system, Norway was still the dominant force in world whaling, taking 49% of the Antarctic catches (which accounted for over 80% of world catches), not only in terms of Norwegian expeditions but also by supplying expertise to the other nations involved. The second power was Great Britain with about 48% of the Antarctic catches (and a high proportion of Norwegian crewmen). However, by 1939 the percentage of catches by country was as follows: Norway 30.0; United Kingdom 29.2; Japan 19.6; Germany 13.2; others 7.8.

Whaling operations effectively ceased during the Second World War and after it, Norway and Great Britain believed that the Antarctic situation would revert to that of the early 1930s, i.e. with Japan and Germany excluded. However, the war had caused a world shortage in the supply of fats and several nations had their eyes on profits from pelagic whaling. It was in this light that discussions were held in London in 1945 and in Washington in 1946 on the international regulation of whaling.

ESTABLISHMENT OF THE INTERNATIONAL WHALING COMMISSION

At the 1946 Conference, the International Convention for the Regulation of Whaling was signed. Membership was open to all nations, whaling and non-whaling alike. The Convention was seen as a major step forward and a precedent for international regulation of natural resources.

The Convention, which established the International Whaling Commission, is a detailed legal document (INTERNATIONAL WHALING COMMISSION 1950b). Here, I will limit the discussion to just a few key factors which have particularly influenced the Commission's history.

1. THE PREAMBLE

This sets out the rationale and aims of the Convention and, after noting the history of over-exploitation of whale resources, culminates in a statement that the Convention was established «to provide for the proper conservation of whale stocks and thus make possible the orderly development of the whaling industry». This was a laudable aim, but finding the balance between «conservation» and the «interests of... the whaling industry» was not going to be easy.

2. THE INTERNATIONAL WHALING COMMISSION

The Commission comprises one Commissioner from each government who has «one vote and may be accompanied by one or more experts and advisers». The Commission can appoint its own Secretary and staff, but, until 1976, the Secretariat was provided on a part-time basis by the UK Ministry of Agriculture, Fisheries and Food.

3. THE SCHEDULE

As whaling regulations would likely have to be changed from time to time, it was agreed to include, as part of the Convention, a «Schedule» which would include the regulatory measures (catch limits, seasons, size limits, inspection, etc.) and which could be amended when necessary by a three-quarters majority of members voting (excluding abstentions). This allows a rapid (by inter-governmental standards) response in regulations to changing circumstances.

4. THE OBJECTION PROCEDURE

Notwithstanding the above, any government can «object» to any decision with which it does not agree (and thereby does not have to comply with it), provided it is done within 90 days of notification of the decision. Should this happen, further time is allowed for other governments to object. This mechanism has been strongly criticised as rendering the Commission «toothless», but without it the Convention would probably have never been signed. In addition, without such a right, a government would still have been able to withdraw from the Convention and thus not be bound by any of the regulations.

5. LIMITS TO TYPE OF REGULATIONS

At a time when «free trade» was an important issue, especially for the USA, it was agreed that the Commission could neither restrict operations by numbers or nationality nor allocate quotas by operation. Although it may be questioned whether the Commission could have agreed to national quotas or numbers of vessels, certainly if such limitations had been reached this would have reduced the pressure on effective regulation caused by increasing numbers of vessels chasing quotas (see below).

6. THE BLUE WHALE UNIT (BWU)

For the purpose of setting a quota for the Antarctic, it was considered that one blue whale (*Balaenoptera musculus*) was equal to 2 fin (*B. physalus*), 2.5 humpback (*Megaptera novaeangliae*) or 6 sei (*B. borealis*) whales (based on their relative oil yields). In 1945, a catch limit of 16,000 BWU, 46% of the 1930/31 catch, was set (suggested by three scientists as being a «reassuring» value in between their estimate of 15-20,000!). The flaw in such a system is apparent—it allows catching of depleted species below levels at which catching that species alone would be economically unviable.

7. ENFORCEMENT

Enforcement of the regulations was to be carried out by nationally appointed inspectors and penalties for infringements to be determined by national governments. Concern was expressed about the effectiveness of this, particularly after the serious infringements of almost every regulation shown to have occurred by a vessel, *The Olympic Challenger*, which was flying the Panamanian flag in the early 1950s (NORSK HVALFANGSTTID 1955; 1956a; 1956b). Discussions on an International Observer Scheme began as early as 1955, but it was not until 1973 that such observers were appointed.

8. SCIENTIFIC ADVICE

The Convention requires that amendments to the Schedule «shall be based on scientific findings». To this end the Commission established a Scientific Committee comprising scientists nominated by member governments and invited experts when appropriate. The

difficulty of reconciling scientific advice with the «interests of... the whaling industry» was to prove a major factor in the history of the Commission, particularly up to the 1970s. The Scientific Committee reports to the Technical Committee of the Commission. The Technical Committee, which comprises Commissioners or their nominees, takes Scientific Committee recommendations into account when making its recommendations—which require only a simple majority—to the full Commission.

The early years: 1946-1958

The first meeting of the Commission was held in London in 1949, and dealt with the many administrative matters arising out of the establishment of a new Commission. In addition to continuing the Antarctic quota of 16,000 BWU, certain of the regulations were amended or clarified (INTERNATIONAL WHALING COMMISSION 1950a).

How did the Commission prevent catch limits being exceeded? At the first level there was a limit to the catching season. In addition, vessels had to report their catch at the end of each week (and later, day) to the Bureau of International Whaling Statistics in Norway who, acting on behalf of the Commission, estimated when the total quota would be reached and if necessary closed the season early.

This resulted in an «Olympic» system, where it became a race to catch as many whales as possible before the total quota was reached—leading to waste during processing and the use of increasing numbers of catcher boats (in 1946/47, 129 catcher boats—in 1951/52, 263). This neither made economic sense nor encouraged conservation.

In 1952/53, the quota was not reached and it was apparent that it was too high. The Commission agreed to proposals by the Scientific Committee for a reduction of 500 units to 15,500 in 1953/54 and later to a reduction to 14,500 for the 1956/57 and 1957/58 seasons (INTERNATIONAL WHALING COMMISSION 1956). The attempt to continue this for a further season led to the first major crisis in the IWC.

A time of crisis: 1959-1972

As early as 1955 the Scientific Committee had believed that 11,000 BWUs represented a sustainable quota; but, in deference to

problems faced by the industry, had proposed a gradual lowering to this level (INTERNATIONAL WHALING COMMISSION 1955). However, the Netherlands believed that there was insufficient evidence to show that stocks were declining and proposed an increase in the quotas to 16,500 BWUs for the 1958/59 season. Although the other nations voted for 14,500, the Netherlands objected, followed by the others who did not want to compete on unequal terms — and the quota was eventually set at 15,000 (INTERNATIONAL WHALING COMMISSION 1959). This was the start of a very difficult period for the Commission, trying to match the evidence of science against the needs of the industry.

Although the Commission could not set national quotas, this was the only sensible solution and Commission « blessing » was given to attempts by the five pelagic nations: Norway, the Netherlands, Japan, the UK and the USSR to arrive at a « private agreement ». Although all but the Netherlands agreed that a reduction was desirable, they could not agree on how the quotas should be allocated among them. Norway and the Netherlands withdrew from the Convention and the survival of the Commission seemed in doubt. For the following two seasons the quota was suspended to allow the pelagic nations to negotiate, while transmitting the Commission's view that catches should not exceed those of 1959/60 (15,500 BWUs). It was also agreed to set up a Committee of three independent scientists or « Three Wise Men » (CHAPMAN *et al.* 1964), to examine the Antarctic whale stocks and recommend catch limits by 1964. The major stumbling block to discussions appeared to be the percentage required by the Netherlands. A quota agreement between the nations was finally agreed upon (helped by the fact that 3 out of the 5 countries failed to reach their internally allocated limits during the period of suspension of the total quota) which gave Japan 41%; Norway 28%; the USSR 20%; the Netherlands 6% and the UK 5%, but allowed the selling of vessels (and their quotas) between countries.

The total quota agreed for 1962/63 was 15,000 BWUs — but the realised catch, 11,300 BWUs, emphasised the critical status of the stocks. A call from the Scientific Committee for quotas by species was rejected but the total quota was reduced to 10,000 BWUs and humpback whales given protection throughout the Southern Hemisphere. The Three Wise Men were asked to continue their work (and indeed became four) and their report (CHAPMAN *et al.* 1965) was the

basis of the reductions in quotas from a «voluntary» 8,000 (no quota was agreed) in 1964/65, to 2,300 in 1971/72 due to a commitment to set catches below the sustainable yield. The protection of the blue whale in 1965, albeit long overdue, ultimately led to the withdrawal from Antarctic operations by Norway, the Netherlands and the UK.

So far the discussion has centred on the IWC and Antarctic whaling, and certainly this was the major focus of attention until the mid-1960s—no quota limitations were in force for any other area. However, the proportion of non-Antarctic catching grew as Antarctic catching declined, particularly in the North Pacific, where catches by number had almost equalled those in the Antarctic by 1965.

The Commission appeared to have learned some lessons from the Antarctic «experience» and in addition to a special scientific sub-committee, a series of special Meetings of Commissioners from the North Pacific whaling nations (Canada, Japan, USSR, USA) was convened, beginning in 1966. These suggested, and the Commission agreed to, complete protection for blue and humpback whales and led to the first example of quotas being set by species, when catch limits were set for fin, and sei and Bryde's (*Balaenoptera edeni*) whales (INTERNATIONAL WHALING COMMISSION 1970). Catch limits for sperm whales (*Physeter macrocephalus*) were set the following season for both the North Pacific and Southern Hemisphere.

A period of change: 1972-1978

One of the key meetings affecting the Commission in the 1970s was in fact a non-IWC meeting. In 1972, the UN Conference on the Human Environment passed a resolution which called for an increase in whale research, a ten-year «moratorium» on commercial whaling and a strengthening of the IWC. The results of this conference appeared just before the 1972 IWC Annual Meeting. At the following four meetings, proposals for ten-year moratoria were tabled but failed to reach the required three-quarters majority, largely because the IWC Scientific Committee did not find scientific evidence to support the idea. It had fought long and hard for management on a stock-by-stock basis (Antarctic catches were first set by species in 1972) and believed this to be the most sensible approach—if required each stock could be independently protected.

The UN resolution was taken seriously by the IWC. By 1976, a permanent Secretariat had been established in Cambridge, an International Decade of Cetacean Research had been declared and a programme designed, and a management procedure had been developed by the Scientific Committee and agreed by the Commission (in 1975). This procedure (e.g. see ALLEN 1980) was aimed at bringing all stocks of whales to an optimum level at which the largest number of whales can be taken consistently (the maximum sustainable yield or MSY) without depleting the stock. The procedure required all stocks to be classified into one of the three categories below (assuming the MSY level to occur at 60% of the population size before exploitation).

1) *Initial Management Stocks*: those over 72% of the original stock size; catch limits are always set below MSY and to ensure that the stock is not reduced below 60%, the MSY level;

2) *Sustainable Management Stocks*: those between 54-72% of the original stock size; catch limits are again set below MSY, the degree below depending on how far below the MSY level the stock is;

3) *Protection Stocks*: those below 54% of the original stock size; no catches are allowed on such stocks.

This procedure was regarded as a major step forward in the management of whaling, designed to bring stocks to an optimum level and giving protection to stocks well before they became endangered. It also appeared to take the issue of catch limits largely out of the hands of the politicians; the Scientific Committee would calculate them according to the procedure contained in the legally binding Schedule, and one could expect the Commission to «rubber-stamp» the numbers proposed. It would conserve whale stocks and allow long-term planning by the industry—the elusive blend of science and industry appeared to have been found! (but see DONOVAN 1985). In addition to this, the long-awaited international observer scheme was in operation (from 1973) thereby answering criticism that whaling countries would not observe the new catch limits.

Shortly after this the main threat to whales appeared to be whaling carried on outside the IWC: in 1977 by Chile, Peru, Portugal, Spain and the Republic of Korea, as well as by a «pirate» Somali-registered vessel. The Commission, by a mixture of diplomatic

approaches to countries to join, legal action against nationals participating in «pirate» whaling and perhaps most effectively a ban on the importation of whale products from non-member nations, succeeded in closing the pirate operations and persuading all the non-member nations, apart from Portugal, to join the Commission in 1979.

As is so often the case, however, this rather rosy picture did not last long. It involved two fundamental assumptions: (i) near-perfect knowledge of the dynamics of all whale populations by the scientists; (ii) political agreement that whaling, even sustainable, was desirable. Both of these were beginning to be questioned.

Developments up to the «moratorium»: 1979-1986

A major feature of the Commission in recent years has been the increase in membership. In 1963 there were 18 member nations, of which only 4 were non-whaling countries; in 1978 there were 17 of which 8 were non-whaling but by 1982 the membership had increased to 39. Of the 13 whaling nations, three had only aboriginal/subsistence operations (Denmark, the USA and St. Vincent and The Grenadines).

The 1979 meeting was a turning point in the Commission's history. Doubts were expressed by some members of the Scientific Committee concerning not only the theoretical concepts behind the «new» management procedure but the ability of scientists even to estimate numbers of whales. In some quarters, both within and outside the Commission, the morality of whaling was being questioned, irrespective of the status of the stocks. Moratorium proposals were again tabled and although a proposal to end land station whaling did not obtain the required three-quarters majority, a proposal to end pelagic whaling for all species except minke whales was adopted and a Sanctuary was declared for the Indian Ocean outside the Antarctic (INTERNATIONAL WHALING COMMISSION 1980). Whereas the onus in the past had been for positive evidence of a decline before a reduction in catch limits was agreed, the tendency now was towards positive evidence being required if a catch limit was to be set.

Not only commercial whaling was coming under pressure. In June 1977, the Commission had decided to remove the exemption for Alaskan Eskimos to take animals from the heavily depleted stock of bowhead whales, in the light of a strong recommendation by the

Scientific Committee. Before this had any practical effect, a «small» catch was agreed at a special meeting in December 1977. The question of establishing a catch limit for this and other aboriginal fisheries on stocks well below the protection level for commercial whaling has continued to be one of the most difficult faced by the Commission. A management procedure for aboriginal/subsistence whaling (currently carried out by Alaskan Eskimos, Greenlanders and natives of Chukotka in the USSR and St. Vincent and The Grenadines) was agreed by the Commission in 1982 in an attempt to solve this problem. However, the procedure was adopted without the advice of the Scientific Committee and, perhaps even more than the management procedure for commercial whaling, requires information which the Scientific Committee is not always able to provide (DONOVAN 1991).

It was at the 1982 meeting that a Schedule amendment was adopted that implemented a pause in commercial whaling (or to use popular terminology, a «moratorium») from 1986 (INTERNATIONAL WHALING COMMISSION 1983).

The initial proposal simply stated that «catch limits for the killing of whales for commercial purposes shall be zero» but before the vote was taken an amendment was made that was an attempt to indicate to the whaling countries that the Commission was not closing its door on the possibility of whaling resuming. The actual wording was «This provision will be kept under review, based upon the best scientific advice, and by 1990 at the latest, the Commission will undertake a comprehensive assessment of the effects of this decision on whale stocks and consider modification of this provision and the establishment of other catch limits».

Adoption of the proposal had hinged on the decision of one whaling nation, which had spoken against the proposal during Technical Committee, to support the proposal in the plenary session.

Four whaling nations, Japan, Norway, Peru and the USSR, lodged objections to this decision—although Peru and Japan have subsequently withdrawn theirs and neither Norway nor the USSR currently carry out commercial whaling despite their objections.

The moratorium and beyond

The obvious question to ask as the IWC's moratorium came into effect was had the Commission been a success? At one level the

answer must be no—indeed it could be argued that it has been a disaster. For example, if we look at the Antarctic, the most important area to the IWC initially:

(i) Blue and fin whales have been reduced to at best 5% and 20% of their original numbers, and possibly much less, respectively — hardly a good example of «conservation of whale resources»;

(ii) The 1983/84 catch was 6,655 minke whales, a species not considered worth catching in 1947/48 when the catch was 25 times greater (assuming 10 minke whales per BWU)—hardly «the orderly development of the whaling industry».

So, what, if anything, has the IWC achieved? First of all, while it is easy with current levels of knowledge to criticise the IWC's performance, it has to be said that modern whaling has not resulted in the extinction of any species of whale — the history of the Commission up to the 1970s may well have been too little too late, but its actions were better than nothing. Since the 1970s the trend has been very much towards conservative catch limits based on scientific advice, to a degree probably unparalleled in any fisheries commission. It has been argued by some Commissioners that this trend reached unreasonable limits with the introduction of the «moratorium». It is indicative of the inherent problems within the Commission's aims that the same decision of the Commission is hailed on the one hand as its greatest success and on the other its most abject failure.

In this final section of the paper, I examine some of the major issues affecting the IWC today and look at some of the areas, particularly scientific, where it can be said to have had some success.

THE COMPREHENSIVE ASSESSMENT

As noted above, when the Commission adopted the moratorium proposal it had also agreed to a «comprehensive assessment» of the effects of this decision on whale stocks. Similar terminology had been adopted for the aboriginal whaling scheme the following year (INTERNATIONAL WHALING COMMISSION 1984). However, there was no discussion at all as to the meaning of «comprehensive assessment» even though it became part of the Commission's Schedule to the Convention.

After vainly trying to get the Commission to explain what it meant by «comprehensive assessment», the Scientific Committee

decided that if progress was to be made it would have to define what it thought was a comprehensive assessment and establish how one might be accomplished (INTERNATIONAL WHALING COMMISSION 1986).

At a special meeting in 1986, it was agreed that from a Scientific Committee viewpoint the Comprehensive Assessment* can be considered as an in-depth evaluation of the status of all whale stocks in the light of management objectives and procedures and that this would include the examination of current stock size, recent population trends, carrying capacity and productivity (INTERNATIONAL WHALING COMMISSION 1987b). To achieve this, three major areas of work are required:

- 1) To review and revise our current knowledge concerning methodology, stock identity and data availability;
- 2) To plan and conduct the collection of new data;
- 3) To examine alternative management regimes.

These three areas are heavily inter-related and particularly important is the relationship between management regimes and data and methodology requirements. I have already noted some of the difficulties the Scientific Committee had in implementing the management procedure adopted in 1976. As an integral part of the Comprehensive Assessment the IWC has therefore funded a series of simulation studies of alternative feedback management procedures which have more realistic data requirements (COOKE 1989; DE LA MARE 1989; MAGNÚSSON & STEFÁNSSON 1989; PUNT & BUTTERWORTH 1989; SAKURAMOTO & TANAKA 1989). At its most recent meeting, the Scientific Committee recommended one of these procedures to the Commission for the case of known biological stocks; further work is being carried out so that this procedure can be applied to actual situations where precise stock boundaries are not known.

This brings us to another major area of concern—that of stock identity. To assess the abundance and dynamics of a stock we must know what comprises that stock. At present, we do not have a good idea of the stock identity of many of what we term «management

* Instant «tradition» has resulted in the Comprehensive Assessment, as defined by the Scientific Committee, to be given capital initials. It is broader in scope than the comprehensive assessments referred to in the Schedule but should, if and when completed, provide the information to carry out the review required by the Schedule.

stocks» (see review by DONOVAN 1991). There are two approaches to this problem. One is to simulate the effects of possible boundary errors and design a management procedure that can take such errors into account, as noted above. The other is to go out into the field and collect the relevant data. Of course, a combination of both methods is required. The Commission has funded and encouraged a considerable amount of work on the use and potential of molecular techniques to examine stock identity questions (see the excellent review by HOELZEL & DOVER 1989) and this culminated in a Workshop on the subject in 1989 (HOELZEL 1991).

Another major methodological area addressed was that of estimating trends in abundance. Classical fisheries theory has emphasised the use of CPUE (catch per unit effort) data and they have historically been a major element in the assessments of many whale stocks. However, surprisingly little attention had been paid to the key assumptions behind this, i.e. that CPUE is firstly a true index of abundance in the area where whaling has occurred and secondly that this can be extrapolated to the total stock area. A 1987 IWC workshop (INTERNATIONAL WHALING COMMISSION 1988a) found that apart from giving a gross picture where there is a major crash in a population, the inherent variability in CPUE data means that, at present, most CPUE data are unlikely to be useful in assessing trends in population size—a conclusion which has ramifications in several other fisheries situations.

Of course, estimating the actual population size is an important aspect of management. As part of its initial examination of methodology, the Scientific Committee examined the question of the estimation of current numbers (in particular, survey techniques) and the use of mark-recapture data. The major review of techniques (HIBY & HAMMOND 1989) covered both practical and theoretical aspects of shipboard, aerial and land-based surveys. Large numbers of whales had been marked using Discovery marks (steel tags fired into a whale and recovered from the carcass) but no rigorous analyses of these data had been carried out. After a theoretical review (POLLOCK 1987), an analysis of the best mark-recapture data available (that for the minke whales in the Southern hemisphere), was undertaken (BUCKLAND & DUFF 1989).

Not all mark-recapture analyses require animals to be killed. An important factor in what might be termed pre- and post-moratorium whale science is that many of the «classical» methods of estimating

abundance and biological parameters such as age at sexual maturity, mortality rates, etc. depended on information collected from dead whales. Irrespective of the value of the resultant estimates for management, the availability of samples is now clearly limited. Over the last 10 years several exciting non-lethal techniques have been developed which enable information required for management to be obtained for at least some species and populations. The Commission recognised that these techniques must play a part in the Comprehensive Assessment programme and sponsored the symposium and workshop in 1988, which concentrated on the use of such techniques with regard to individual identification of whales (primarily by photo-identification) to obtain information needed for management (HAMMOND *et al.* 1990).

The intention is that the Comprehensive Assessment should include all whale stocks. However, this is a major task and priorities had to be set. Population estimates thus far accepted are given in Table 1.

SCIENTIFIC PERMIT CATCHES

A major area of discussion since the moratorium has been the issuance of permits by national authorities for the killing of whales for scientific purposes. The issuance of such permits is not new. The right to issue them is enshrined in Article VIII of the Convention (that furthermore requires that the animals be utilised once the scientific data have been collected) and prior to 1982, over 100 permits had been issued by a number of governments including Canada (e.g. MITCHELL 1973), USA (e.g. RICE & WOLMAN 1971), USSR (e.g. KUZMIN *et al.* 1979), South Africa (BEST *et al.* 1984) and Japan (OHSUMI 1980). Since the «moratorium», three countries, Japan, Norway and Iceland, have issued scientific permits as part of their research programmes (Table 2). The discussion has centred around accusations that such permits have been issued merely as a way around the moratorium decision (e.g. HOLT 1986; 1988) on the one hand, and claims that the catches are essential to obtain the necessary information for rational management and other important research needs on the other (e.g. NAGASAKI 1989; 1990). All proposed permits have to be submitted for review by the Scientific Committee and in recent years a large number of guidelines concerning the issuance of scientific permits have been developed to assist in such reviews

Table 1

Population estimates for some species of great whales. This table summarises our best estimates (and approximate 95% confidence intervals) and is based on the Comprehensive Assessments thus far completed. For details see the reports of the IWC Scientific Committee (International Whaling Commission 1988 — In Press).

Species/area	Estimate	95% CI
Minke whales		
Southern Hemisphere	761,000	514,000-1,138,000
North Atlantic (excl. Canada/USA)	99,600	not-available
Western North Pacific	25,200	12,800-38,600
Fin whales		
North Atlantic (excl. Canada/USA)	35,500	19,300-54,000
Gray whales		
Eastern North Pacific	21,000	19,800-22,500
Bowhead whales		
Eastern Arctic	7,500	6,400-9,200
Humpback whales		
Western North Atlantic	5,500	2,900-8,100

Table 2

Catches of whales taken under Scientific Permit from 1986 to 1990

	1986	1987	1988	1989	1990
Iceland					
Fin	76	80	68	68	
Sei	40	20	10		
Norway					
Minke			29	17	5
Japan (Antarctic)					
Minke		273	241	330	327

(INTERNATIONAL WHALING COMMISSION 1989a). It is not appropriate to go into the details of the debate over each permit here. There are a considerable number of complex scientific and indeed

legal issues involved. The interested reader is referred to the relevant reports of the Scientific Committee (INTERNATIONAL WHALING COMMISSION 1986; 1987a; 1988b; 1989b; 1990; 1991) which also refer to the numerous scientific papers arising out of the permit catches.

SMALL CETACEANS

In my view, no species of large whale is endangered by whaling today and will not be by any resumption of whaling under a new management procedure. Threats to those species, such as the North Atlantic right whale, that remain severely reduced, do not include hunting (e.g. KRAUS 1990). The most seriously threatened cetaceans (by direct hunting and incidental captures in fisheries) are some species and populations of the smaller cetaceans (BROWNELL *et al.* 1989). At present there is no international body responsible for their conservation and management. There is considerable disagreement within the Commission as to whether the present Convention is sufficient to allow the IWC to assume such a role (DONOVAN 1987). Fortunately, there now appears to be general agreement that the Scientific Committee can examine such matters and it has recently completed two major reviews of direct and incidental takes of small cetaceans (INTERNATIONAL WHALING COMMISSION In Press a, b), resulting in a number of recommendations for action—it is to be hoped that governments individually and collectively respond. It remains a matter of urgency that an international agreement or series of regional agreements be reached to ensure the conservation of small cetaceans.

NON-SCIENTIFIC ISSUES

If, as envisaged, an effective alternative management procedure is in place within the next 2-3 years, then this may bring to the fore in the Commission's agenda certain non-scientific (I term them «politico-ethical») considerations. In this section I will put forward rather simplified summaries of the issues and the likely range of opinions within the IWC over these matters.

Of prime consideration from both a scientific and an ethical viewpoint is the possibility of extinction of any population due to whaling. No population of whales is currently under threat from

whaling and it is clear that any acceptable management procedure will ensure that this cannot happen. However, this presumes an acceptance that whales are a natural resource to be harvested. While this is certainly the stated position of many members of the IWC, it is also not universally accepted. There is a body of opinion that holds that whales are such a «special» group of animals that they should not be killed under any circumstances (e.g. BARSTOW 1990). This has been to some extent linked to the «intelligence» of whales. Scientific problems about measuring intelligence in animals as diverse as the many small cetacean species and the large baleen whales aside (e.g. CALDWELL & CALDWELL 1973; KLINOWSKA 1989), moral questions linking utilisation and intelligence are clearly complex.

In this regard, the question of humane killing has once more arisen within the Commission, with some nations stating that even if a safe management procedure is adopted, catch limits should not be set unless a «satisfactorily humane» killing method is available. This subject has been addressed several times during the history of the IWC (see DONOVAN 1986; MITCHELL *et al.* 1986) and the Commission has been active in promoting work on more humane killing techniques for whaling—in the mid-1980s, Japan and Norway developed an explosive grenade harpoon for minke whales which is vastly superior in terms of reduced killing time over the non-explosive harpoons used previously. This expertise is being shared with the aboriginal fisheries in Alaska and Greenland. The Commission is hosting a Workshop to examine recent progress in 1992. However, obtaining agreement on what comprises a «satisfactorily humane» technique will not be simple. To give some idea of the type of problems to be faced, it is interesting to look at the question of time-scale. Does one for example, simply examine the time taken from the impact of the harpoon to the death or unconsciousness of the animal? Or, as some have suggested, should the stress of the chase also be taken into account? If this larger time-scale is envisaged however, others have argued that the total «quality of life» of the animal should be considered—is it more humane for an animal to live freely in the seas for many years before being killed than for an animal to be brought up in a «factory farm» environment, bred solely for slaughter?

At present, most of the attention concerning the morality of whaling and the humaneness of the kill has centred on commercial whaling. However, particularly in the latter case, they are also

relevant to aboriginal subsistence whaling, where arguments of tradition and culture can clash with the adoption of modern technology. The IWC has, since its inception, recognised the discrete nature of this kind of whaling, and allowed aboriginal catches from stocks that have been reduced to levels at which commercial whaling would be prohibited. Since the moratorium decision, there has been considerable discussion as to whether a further category of whaling, «small-type whaling» should be recognised, which lies somewhere between full commercial whaling and aboriginal subsistence whaling (e.g. see BOREAL INSTITUTE FOR NORTHERN STUDIES 1988). An example of this would be the coastal minke whaling carried out by certain villages in Japan which shares characteristics of both types of whaling. As yet the IWC has not agreed to any change in the recognised categories.

Conclusion

Many of these «politico-ethical» issues are linked to questions of culture and freedom and are complex and almost inevitably will not be resolved unanimously. This is not the place to enter into a philosophical debate over the rights of nations or groups of nations to impose their moral values on others, but merely to point out the necessity of such a debate and the need for a degree of compromise if the IWC is not going to fragment. The value of an IWC that does not include nations that are currently whaling is questionable. There is clearly a divergence of opinion within the IWC on such matters to an extent unparalleled in any similar organisation. It is, for example, difficult to think of any fisheries organisation where some of the members believe it is immoral to catch fish under any circumstances.

Perhaps then, as a final thought, the question to ask of the IWC should not be «has it been a success?» but, given the circumstances, «could any other intergovernmental body have done better?»

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USE OF MOLECULAR TECHNIQUES IN THE STUDY OF CETACEA PHYLOGENY AND DISCRIMINATION OF THEIR POPULATIONS

BY

M. C. MILINKOVITCH *

SUMMARY. — Recent morphological data on *Archaeoceti* fossils suggest that cetaceans originate from archaic ungulates and have made a gradual transition from land to sea in early Eocene (GINGERICH *et al.* 1983, 1990). In addition, differences of geographical distributions and even of morphological features between various groups of the same Odontoceti species could signify that they form distinct genetically isolated populations. A more complete understanding of evolution can be obtained if both interspecific diversity (phylogeny) and intraspecific diversity (microevolution) are combined and studied accordingly. The use of biological macromolecules in these two aspects of evolutionary studies have recently assumed an increasingly important role. This paper presents: (1) Data from DNA-DNA hybridization experiments that show a closer evolutionary relationship between cetaceans and [artiodactyls + perissodactyls] than between cetaceans and other tested mammals (primates, rodents, lagomorphs, carnivores) and thus, support the morphological based hypothesis of GINGERICH *et al.* (1983, 1990); (2) Indications as to the usefulness of the DNA-fingerprinting technique in the determination of Odontoceti populations.

1. Introduction

When used in its very broad sense, systematics includes the comparative study of biotic diversity at any level. The work of major pioneers such as Darwin and Haeckel developed the ideas of phyletic relationships as being a basis of classification rather than having the Linnaeus hierarchical nomenclature (LINNAEUS 1758) as an indepen-

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dent subject of evolutionary theory as generally accepted by the «Scientific Community» of the time.

Morphological and behavioral variations were the first clues studied by systematists but the use of biological macromolecules in evolutionary studies has recently assumed an increasingly important role.

A great many techniques have become routine laboratory practice with sensitivity increasing rapidly:

- Proteins are largely used in molecular systematics and main techniques used are: protein electrophoresis, specific histochemical staining and comparisons of amino-acid sequences;
- Variation in chromosome structure and number also provides very useful genetic markers;
- But major advances in the manipulation of DNA and RNA have led to the study of nucleic acid variation with techniques such as: restriction endonuclease analysis, DNA-DNA hybridization and comparison of the DNA or RNA primary sequences.

Molecular taxonomy is a recent and complex field providing great help in clarifying phyletic relatedness between species (e.g. O'BRIEN *et al.* 1985, BRITTEN 1986, MIYAMOTO & GOODMAN 1986, CACCONE & POWELL 1987, 1989, 1990, HILLIS & MORITZ 1990). However, I would like to emphasize that the conflict between molecular and morphological systematics is an empty discussion, each approach having distinct advantages and disadvantages and therefore to utilize data from both approaches provides a more complete picture for interpretation (HILLIS 1987, BLEDSOE & RAIKOW 1990, HILLIS & MORITZ 1990).

Traditionally, interspecific diversity (phylogeny) is studied by systematists and intraspecific diversity (microevolution) by population geneticists. However, a more complete understanding of evolution is obtained if both aspects are combined and studied accordingly.

The first part of this paper will focus on interspecific diversity by presenting my work on Cetacean phylogeny and the second part will be reserved to the succinct description of some experiments of population genetics in which I mainly use the DNA-fingerprinting technique.

2. Origin of the Cetaceans

The Order Cetacea is among the most specialized of all mammals. It includes at least 76 living species of whales, dolphins and

porpoises (LEATHERWOOD *et al.* 1983, EVANS 1987) in which anatomy, physiology and behavior are modified for a completely aquatic way of life.

It is well known that early scientists wrongly classified these animals as fish simply based upon their external appearance. However, there is even now a great deal of difficulty in finding an appropriate place within the classification of mammals because of the high degree of specialisation that these aquatic animals have acquired and the lack of data on their origin.

Nevertheless, anatomical, physiological and paleontological evidence (VAN VALEN 1978; BARNES & MITCHELL 1978; BARNES *et al.* 1985) suggest a close phyletic relatedness between cetaceans and ungulates.

Paleontological data recently collected and analysed by Gingerich and coworkers have provided a major advance in the understanding of the evolutionary relationships between cetaceans and other mammals (GINGERICH *et al.* 1983, 1990). Indeed, in 1983, the discovery and subsequent description of *Pakicetus* cranial remains has provided morphological data on the oldest and most primitive cetacean known.

The description of dentition, basicranium and auditory bulla strongly suggests that *Pakicetus* is intermediate between well-known late Eocene whales and condylarth mesonychids. Condylarths consist of a vast array of archaic ungulates that were abundant in the early Paleocene and include the ancestors of artiodactyls, perissodactyls and perhaps sirenians and African ungulates (Fig. 1). All condylarths were typical herbivorous land mammals except for the carnivorous mesonychids which took the role of the order *Carnivora* which remained undeveloped until the Oligocene period (CARROLL 1988).

In addition, in 1990, in the desert of Zeuglodon Valley in North Central Egypt, Gingerich and other coworkers excavated several nearly complete skeletons of *Basilosaurus isis* where limb and foot bones were all found, for the first time, in direct association with articulated skeletons and undoubtedly represent this *Archaeoceti* species (*Archaeoceti* is a wholly extinct assemblage of early toothed whales). Metatarsals III and IV are the largest and longest metatarsals, making the foot paraxonic as in artiodactyls.

Therefore, it is clear that all these morphological data suggest that cetaceans originate from carnivorous land mammals (the meso-

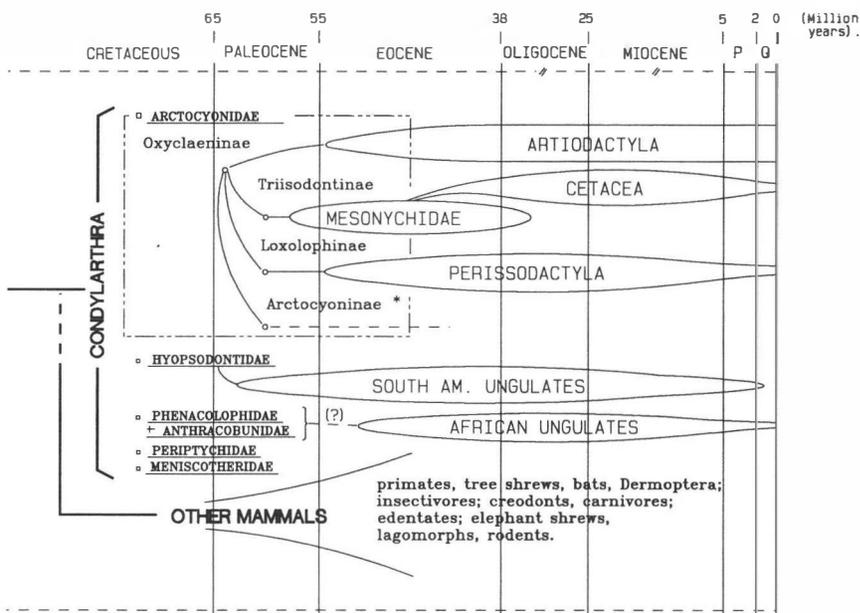


Fig. 1. — Phylogenetic relationship among Eutherian groups, based on anatomical and paleontological data (GINGERICH *et al.* 1983, 1990; CARROL, A. L. 1988).

* The Arctocyoninae are not thought to be directly ancestral to any other group.

nychids) and made a gradual transition from land to sea in early Eocene (Fig. 1).

Little molecular data is available to complete our knowledge of the origin of the cetaceans. However, multiple sequence comparisons in proteins (MIYAMOTO & GOODMAN, 1986) and a 4 species (dolphin, cow, human, mouse) comparison in mitochondrial DNA (SOUTHERN *et al.* 1988) seem to show a closer evolutionary relationship between cetaceans and [artiodactyls — perissodactyls] than between cetaceans and other mammals.

In my experiments, I have used DNA-DNA hybridization of unique sequences (MILINKOVITCH 1992) to test the morphological hypothesis of GINGERICH *et al.* (1983, 1990) and complement the sequence comparison analysis.

2.1. DNA-DNA HYBRIDIZATIONS

The 2 complementary stands of DNA can be separated by denaturation due to disruption of the hydrogen bonds between

nucleotide pairs. This can be accomplished in a number of ways such as the action of denaturing agents, by increasing or decreasing pH, increasing temperature, or by decreasing salt concentrations. However, the thermic denaturation (called «melting») is not linearly correlated to the temperature but occurs in a rather narrow temperature range. Under appropriate conditions of temperature and salt concentration, the 2 complementary sequences can specifically reassociate. This reassociation results from the collision of the 2 single strands and therefore, the rate of reassociation depends on their concentrations.

The log of the product between [initial DNA concentration] and [the time of incubation] is called C_0t and used to estimate the completion of the reaction.

Nevertheless, the eucaryotic genome is not only made of unique sequences but also includes moderately and highly repetitive sequences. The rate of reassociation, depending on the concentration of complementary sequences, correlates with the degree of repetition of these sequences (BRITTEN & KOHNE 1968). C_0t curves allow us to determine a C_0t value at which repetitive sequences have reassociated and can be separated from single-stranded single copy DNA (Scn-DNA), for instance by hydroxyapatite column chromatography.

2.2. PRINCIPLE OF THE METHOD

Let us consider 3 species A, B and C with the phyletic relationships displayed in Fig. 2. To reconstruct this phyletic tree by DNA-DNA hybridization, single copy sequences of A are isolated, radioactively labeled and combined with $\approx 1\ 000$ times the quantity of unlabeled total DNA of the species A (homoduplex reaction); B or C (heteroduplex reactions).

After denaturation, the mix is incubated in appropriate conditions of temperature and salt concentration to allow hybridization of the labeled sequences (tracer) with the complementary sequences of the unlabeled DNA (driver). In heteroduplexes, the double-stranded molecules that form between complementary strands from the 2 species will contain base mismatches because of their evolutionary divergence from a common ancestor. The temperature is increased by 2.5°C increments from 60°C to 95°C . Single stranded DNA is collected at each of the 15 temperature points giving a melting curve which is subsequently normalized. The T median (T_m) of each melting

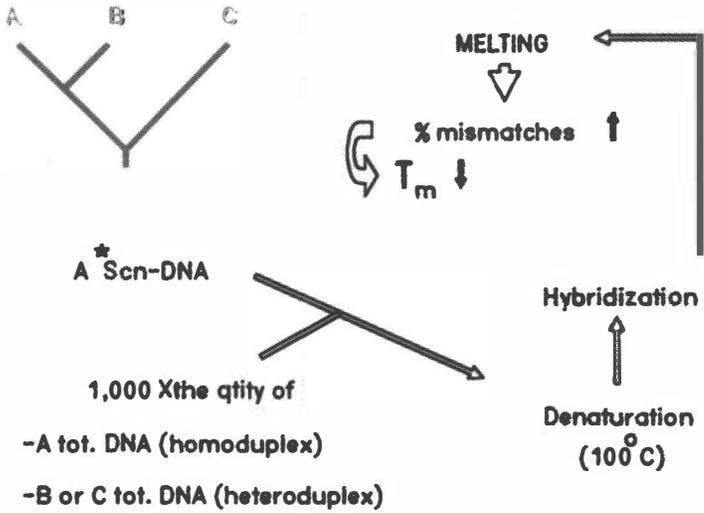


Fig. 2. — Principle of the DNA-DNA hybridization method to reconstruct phyletic trees.

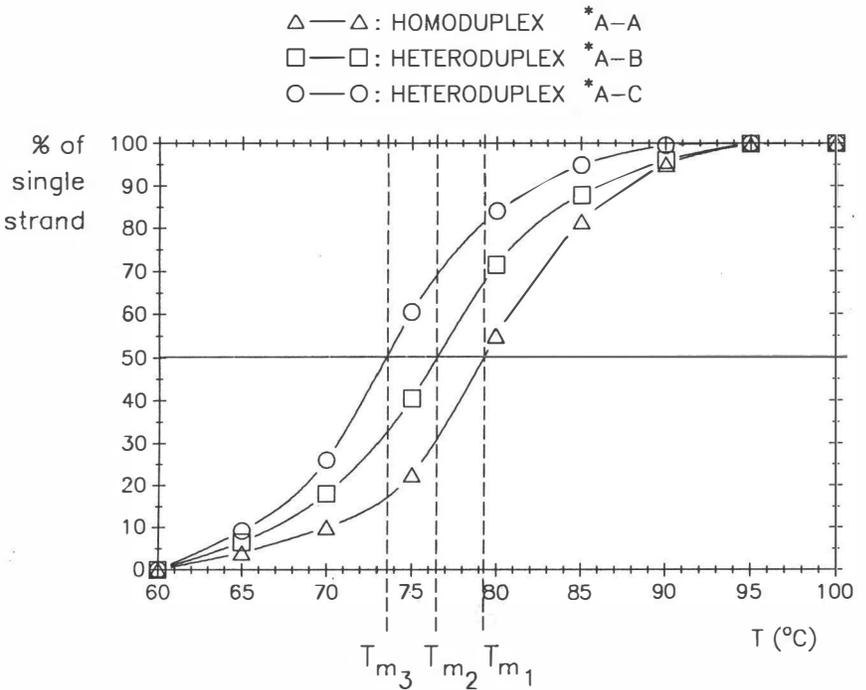


Fig. 3. — Hypothetical DNA-DNA hybridization curves allowing the reconstruction of the phyletic tree displayed in Fig. 2.

curve corresponds to the temperature at which 50% of the DNA that had undergone hybridization has melted.

The T_m will be dependent on the degree of «matching» between the DNA fragments and decreases with an increasing percentage of mismatches since it is easier to separate two DNA strands with fewer «H-bonded base pairs». Therefore, the decrease in T_m of a heteroduplex when compared to a standard homoduplex gives a measure of the degree of divergence between the two species in question (Fig. 3).

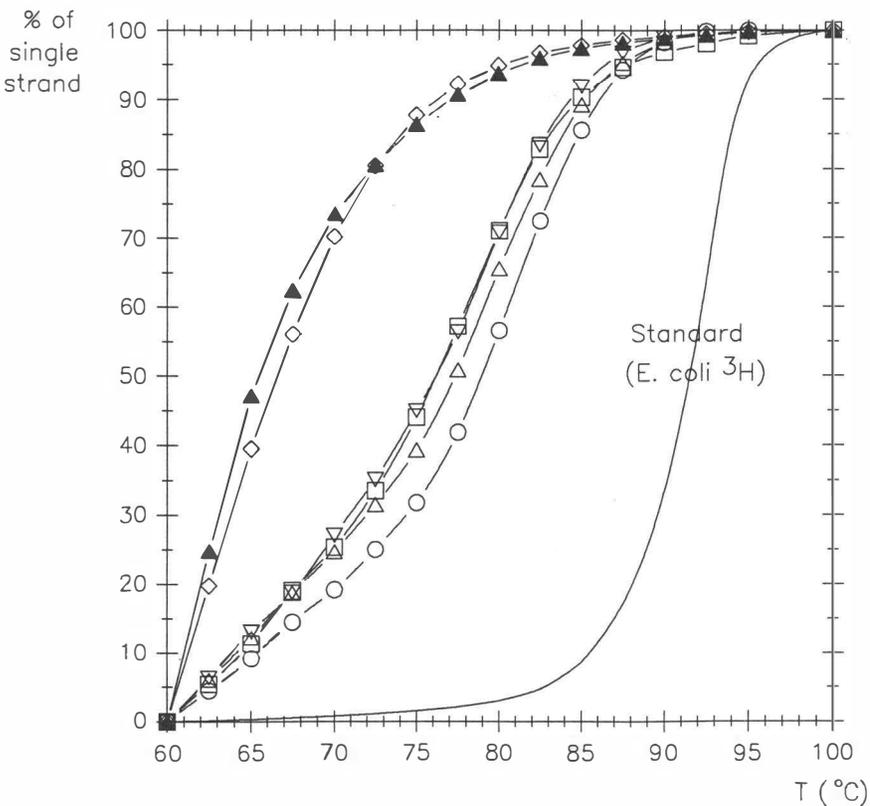


Fig. 4. — Thermal elution profiles of hybridized ^{32}P -*Lagenorhynchus obscurus* Scn-DNA with unlabeled total DNA from:
 ○—○: *L. obscurus* (Delphinidae), △—△: *T. truncatus* (Delphinidae);
 □—□: *P. phocoena* (Phocoenidae), ▽—▽: *P. spinipinnis* (Phocoenidae);
 ▲—▲: *H. sapiens* (Primates), ◇—◇: *B. taurus* (Artiodactyla).
 (Reproduced from MILINKOVITCH, 1992, with kind permission of Birkhäuser Verlag, Basel).

2.3. DNA-DNA HYBRIDIZATIONS TESTING THE HYPOTHESIS OF UNGULATE ANCESTRY OF CETACEA

Results displayed in Figs. 4 and 5 show that the protocol described here is well suited to the analysis of phylogenetic distances between cetacean species (see MILINKOVITCH 1991 for data).

Comparison of [cetaceans vs. cetaceans] melting curves confirm that Delphinidae and Phocoenidae—at least as represented by the few species used—are genetically distinct groups. Conversely, the method

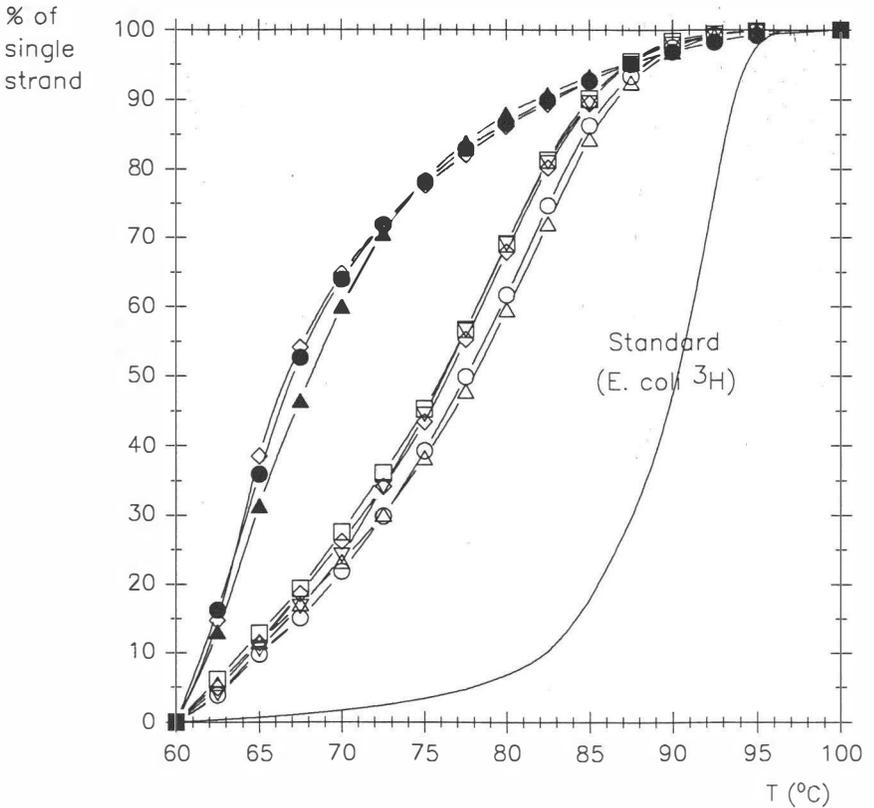


Fig. 5. — Thermal elution profiles of hybridized ^{35}S -*Phocoena spinipinnis* Scn-DNA with unlabeled total DNA from:

- △—△: *P. spinipinnis*, 2 superposed curves (Phocoenidae);
- : *P. phocoena* (Phocoenidae), □—□: *L. obscurus* (Delphinidae);
- ◇—◇ + ▽—▽: *T. truncatus* (Delphinidae); ●—●: *H. sapiens* (Primates);
- ▲—▲: *B. taurus* (Artiodactyla); ◇—◇: *C. familiaris* (Carnivora).

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is not successful when applied to species belonging to different orders because the curves do not comprise any inflection point (the first eluted fraction (=62.5°C) contains more radioactivity than subsequent fractions).

Nevertheless, sigmoid curves were obtained and the T_m was determined unequivocally in hybrids from distantly related species by using a modified protocol with thermal elution experiments starting at 45°C.

Using this protocol, ^{35}S -labeled Scn-DNA of *P. spinipinnis* were hybridized repeatedly with unlabeled sonicated total DNA of 3 cetaceans, 6 artiodactyls, 1 perissodactyl, 1 primate, 1 rodent, 1 lagomorph and 1 carnivore. For each group ([cetaceans vs. artio-

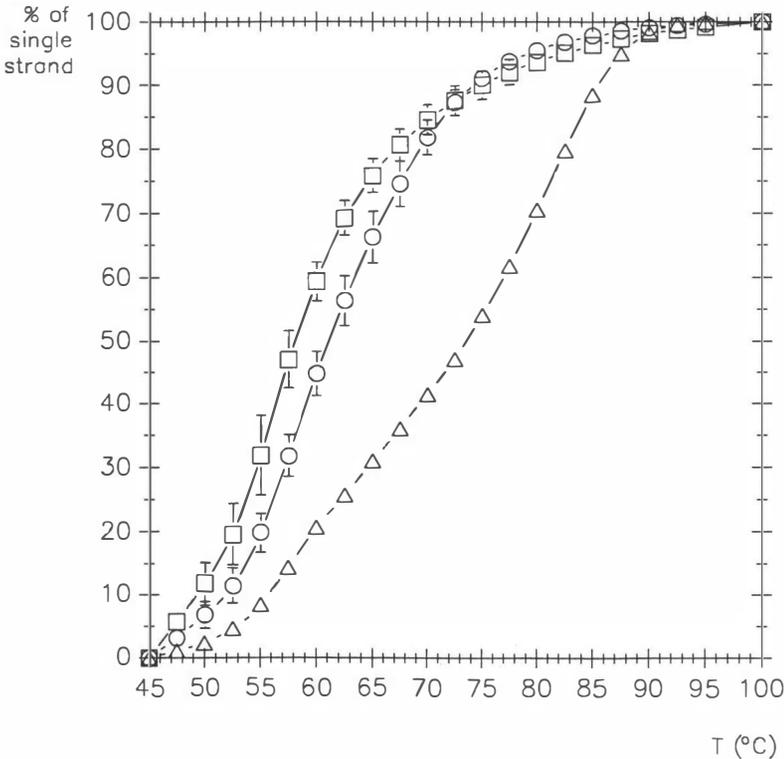


Fig. 6. — Thermal elution profiles (average-curve with standard deviation) of hybridized ^{35}S -*P. spinipinnis* Scn-DNA with unlabeled total DNA from:

- △—△: *P. spinipinnis* (Cetacea);
- : artiodactyls & perissodactyls (16 curves);
- : other mammals (7 curves).

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Table 1

t-tests calculated on the means of LR- T_m , SR- T_m and NPH for the comparison of two groups of hybrids: cetacean vs. artiodactyls + perissodactyls, and cetacean vs. other tested mammals

t-test	(artio. + perisso.)/other tested mammals
LR- T_m	$2p < 10^{-5}$
SR- T_m	$2p < 10^{-5}$
NPH	$2p < 3 \cdot 10^{-4}$

Abbreviations:

LR- T_m : T_m determined by linear regression between the two points bordering the 50% of the Hybrids,

SR- T_m : T_m determined by sigmoid regression of all the points of the curve,

NPH normalized percentage of labeled DNA which has hybridized.

perissodactyls] and [cetaceans vs. other mammals]), an average curve (Fig. 6) has been established and the data have been subjected to various *t*-tests (table 1) establishing that [cetaceans vs. artiodactyls + perissodactyls] hybrids were significantly more stable than [cetaceans vs. other tested mammals] hybrids.

Therefore, when combined with paleontological studies, the molecular data summarized here help to clarify the origin of Cetacea: comparison of the normalised percentage of hybridization (NPH), T_{mode} (point of inflection) and T_m of the melting curves for [cetaceans vs. artio. + perisso.] and [cetaceans vs. other mammals] shows clearly a closer evolutionary relationship between cetaceans and [artiodactyls + perissodactyls] than between cetaceans and other tested mammals and therefore, strongly supports the morphological hypothesis of Gingerich *et al.* (1983; 1990).

3. Use of DNA-fingerprinting to discriminate cetacean populations

In 1985, Alec J. Jeffreys and co-workers discovered and characterized the extraordinary features of particular and highly polymorphic regions in the human genome creating what are now known as «DNA-fingerprints» or «genetic bar codes» (JEFFREYS *et al.* 1985). The variable region consists of tandem repeats of a short sequence called a «minisatellite». The polymorphism results from allelic differences in the number of repeats arising by still unsolved genetic events.

The minisatellite length variation can be detected using any restriction endonuclease which does not cleave the repeat unit. The protocol to establish a DNA fingerprint is as follows:

The analysis is carried out using any sample of nucleated cells (i.e. blood or skin samples); DNA is extracted from the cells and then cleaved by restriction enzymes into thousands of fragments of variable sizes; the fragments are separated according to their size by gel electrophoresis; after denaturation and transfer to a nylon membrane, a radioactive probe, which is complementary to the minisatellite, is allowed to hybridize with the 2 DNA alleles immobilized on the filter.

However, a number of minisatellite loci share a common short «core» sequence in each repeat unit. In other words, these minisatellite sequences are sufficiently related by their sequence to hybridize simultaneously (at low stringency) with the DNA probe. After autoradiography, the result obtained corresponds to a series of bars at precise distances from each other, of characteristic intensity and which look like the bar codes of household product wrappings.

The number of possibilities are such that every individual person has his own code. Only monozygotic twins have a strictly identical bar code. Since fingerprint bands are transmitted in a mendelian fashion, the hypervariable sequences detected in this way provide a novel and very powerful method for identification of individuals and filiation tests (cf. Fig. 7).

Minisatellite loci are very numerous, dispersed in the entire genome and exist in almost all eucaryotic species investigated up to date. It is therefore possible to use this technique in cetaceans not only to analyse their breeding system but also to discriminate populations by the comparison of allele distributions, number of alleles and mutation rates in the different groups investigated.

The population structure of several south-American Odontoceti species is being currently analyzed by DNA-fingerprinting (MILINKOVITCH *et al.*, unpublished data). The samples used were obtained from animals caught in an expanding gillnet fishery in Peru (VAN WAE-REBEEK & REYES 1990) and in accidental catches in Chile (OPORTO 1985; GOODALL *et al.* 1988).

Moreover, y chromosome-specific DNA-probes were developed (data not shown) providing useful markers in population genetics (MILINKOVITCH *et al.*, in preparation).

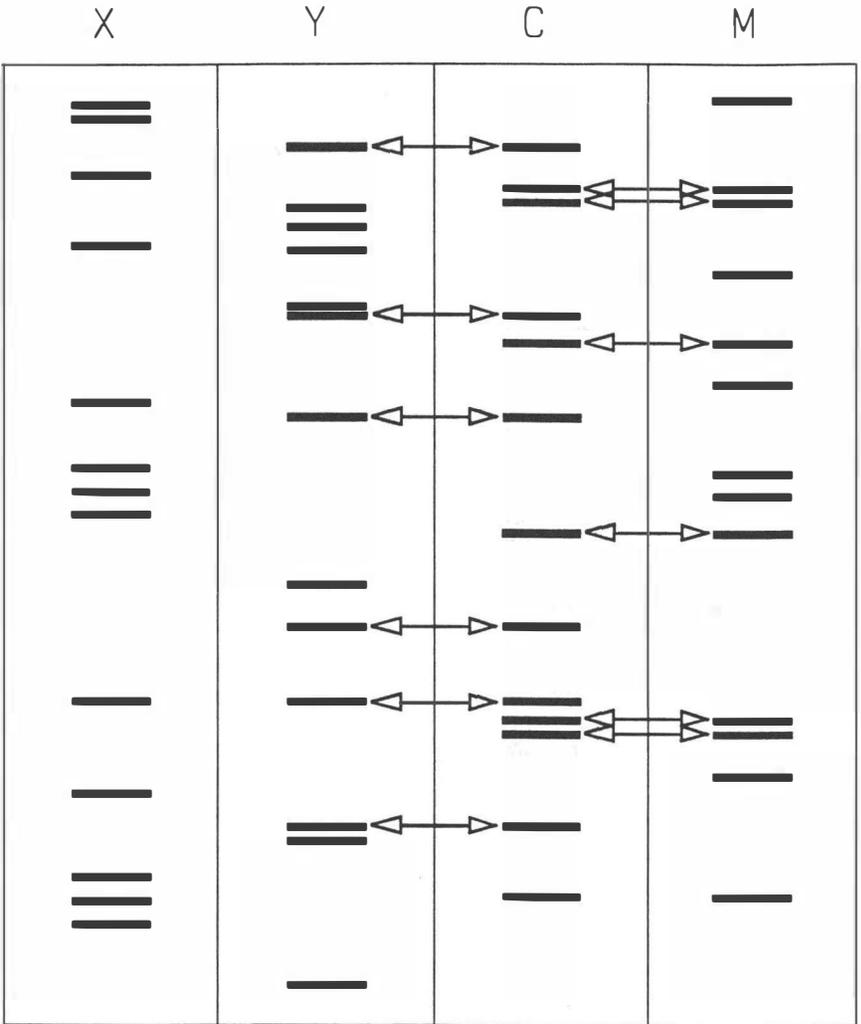


Fig. 7. — Who is the father? Y is the father, his code is found within the child's code (C = child, M = mother, X and Y = 2 possible fathers). Half of the DNA-fingerprinting bands are inherited from the mother and the other half from the father. Each child's band should therefore be found in at least one of the parental codes. This method allows the exclusion of false paternity but can also confirm the true ones.

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All the DNA-fingerprinting work was performed in association with Julio Reyes and Koen Van Waerebeek from CEPEC (Centro Peruano de

Estudios Cetologicas) in Peru and with Jorge A. Oporto from CIMMA (centro de investigación y manejo de mamíferos marinos) in Chile. Not only the samples used to extract DNA are collected on the animals they study but we would like also to compare their anatomical, morphological and behavioral data with the molecular data in order to obtain a picture as complete as possible of the genetic relationships between several South-American populations of Odontocetes. Moreover, a part of the cetaceans samples used in my phylogenetic studies have also been kindly provided by Julio Reyes and Koen Van Waerebeek. J. Smolders, Dr. Demeurichy (Antwerpen Zoo), L. Tolpe (Brugge dolphinarium), Dr. Van Gompel and C. Joiris (*P. phocoena* samples) provided me with some tissue samples used in the same study. I would like to thank also Prof. J. Bouillon, Dr. M. Georges and Dr. M. Ludgate, as well as the Leopold III Foundation.

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CETACEAN RESEARCH IN THE STRAIT OF GIBRALTAR

BY

D. HASHMI * & B. ADLOFF **

SUMMARY. — With a width of only 14 km at the Tarifa narrows, the Strait of Gibraltar is the only connection between the Mediterranean Sea and the Atlantic Ocean. Standardized recording during 388 crossings of the eastern part of the Strait (covering 11,350 km of trackline and 425.5 observation hours), carried out in autumn 1987, spring 1989 and, with support of the Greenpeace Mediterranean Sea Project, in autumn 1990, resulted in a sample of about 38,600 cumulatively counted cetaceans of 11 positively identified species. *Delphinus delphis*, *Stenella coeruleoalba*, *Tursiops truncatus* and *Globicephala melas* were regularly recored and altogether made up 99%. During the autumn surveys in 1987/1990, the proportion of animals moving west was 90%/69% in *D. delphis*, 69%/73% in *S. coeruleoalba*, 92%/69% in *T. truncatus* and 98%/85% in *G. melas*. The data, therefore, strongly suggest regular autumn migration out of the Mediterranean which may involve particularly large numbers of *D. delphis* and *S. coeruleoalba*. The semi-enclosed mediterranean basin has a limited water exchange with the Atlantic and its marine ecosystems are thus very vulnerable to pollution. At present it is unclear whether this or further possible threats like large scale fishing techniques have an impact on mediterranean cetacean stocks. If more details about cetacean migrations through the Strait can be revealed in the future, counts in the Strait may prove to be a good basis for a populations monitoring.

* * *

With a width of only 14 km at the Tarifa narrows, the Strait of Gibraltar is the only natural opening of the Mediterranean Sea, and a bottleneck for migrating cetaceans. In this paper, we briefly review the presence of cetaceans in the Strait. As all species known from the Mediterranean must at some time have passed Gibraltar, we also list

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Table 1
Species recorded in the Strait of Gibraltar and the Mediterranean Sea, and assumed status in the Strait

Species	Gibraltar	Mediterranean Sea	Assumed status in the Strait
<i>Phocoena phocoena</i>	CABRERA 1914 own observations	R. DUGUY, pers. comm.	-
<i>Steno bredanensis</i>	own observations	e.g. WATKINS <i>et al.</i> 1987	+
<i>Lagenorhynchus albirostris</i>	own observations	HENNIPMANN <i>et al.</i> 1961	+
<i>Lagenorhynchus acutus</i>	own observations	*	+
<i>Grampus griseus</i>	M. LAWRENCE, pers. comm.	*	+
<i>Tursiops truncatus</i>	own observations		++
<i>Stenella frontalis</i>	own observations	DI NATALE 1983 **	-
<i>Stenella coeruleoalba</i>	own observations	NOTARBARTOLO-DI-SCIARA 1987	+
<i>Delphinus delphis</i>	own observations	*	++
<i>Pseudorca crassidens</i>	own observations	*	++
<i>Orcinus orca</i>	own observations	*	+
<i>Globicephala melas</i>	own observations	*	++
<i>Mesoplodon bidens</i>		CASINOS & VERICARD 1976	+
<i>Mesoplodon densirostris</i>		CASINOS & FILLELA 1981	-
<i>Ziphius cavirostris</i>		*	+
<i>Hyperoodon ampullatus</i>		MCBREARTY <i>et al.</i> 1986	-
<i>Physeter macrocephalus</i>	own observations		+
<i>Kogia simus</i>		BACETTI <i>et al.</i> 1991	-
<i>Eubalaena glacialis</i>		TOSCHI 1965	-
<i>Balaenoptera acutorostrata</i>		*	-
<i>Balaenoptera borealis</i>	ALONCLE 1964	*	-
<i>Balaenoptera musculus</i>	ALONCLE 1964		-
<i>Balenoptera physalus</i>	own observations	*	-
<i>Megaptera novaeangliae</i>	M. LAWRENCE, pers. comm.	*	+

* See e.g. CASINOS & VERICARD (1976) or DUGUY *et al.* 1983.

** Correct identification doubtful.

+++ Common; ++ Regularly in small numbers; + Rare; - Absent or extremely rare.

species which have not been recorded in the Strait, but elsewhere in the Mediterranean.

Although the Strait has a geographic key position for recording cetacean migration it was only recently that systematic observations were initiated: D. Hashmi conducted three transect series in September/October/November 1987, April 1989 and August/September 1990, which comprise 383 crossings of the Strait, 426 hours of observation along 11,380 km of trackline and more than 38,000 cumulatively counted cetaceans. In September 1989, B. Adloff carried out 98 hours landbased observations from the southern tip of Gibraltar which yielded 176 cetacean recordings.

The mean cetacean density during the transect-series was 3.4 individuals per km. Of the 11 positively identified species (see table 1), *Delphinus delphis* and *Stenella coeruleoalba* were most common and together made up 95.5% of all encountered cetaceans, followed by *Tursiops truncatus* (2.5%) and *Globicephala melas* (1.2%).

Comparing the two autumn transect series, carried out in 1987/1990, the percentages of migrants steadily swimming west were 90%/69% in *D. delphis*, 69%/72% in *S. coeruleoalba*, 92%/79% in *T. truncatus* and 98%/75% in *G. melas*.

Within the northeast Atlantic, the Strait of Gibraltar is an area with a markedly high cetacean density and also comparatively large variety of species. The mainly westward oriented movements of the four most common species in autumn, which were observed in two different years, strongly suggest that populations of these species undertake regular migratory movements through the Strait. The high cetacean density in the Strait is probably mainly caused by migrating cetaceans which concentrate in the Strait.

The semi-enclosed mediterranean basin has a limited water exchange with the Atlantic and its marine ecosystems are thus very vulnerable to pollution. At present it is unclear whether this or further possible threats like large scale fishing techniques have an impact on mediterranean cetacean stocks. If more details about cetacean migration through the Strait of Gibraltar can be revealed in the future, counts in the Strait may prove to be a good basis for a population monitoring.

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SOME NOTES ON THE FIN WHALE
(*BALAENOPTERA PHYSALUS*)
IN THE WESTERN MEDITERRANEAN SEA

BY

L. MARINI, C. CONSIGLIO, A. SANNA & A. M. ANGRADI *

SUMMARY. — The knowledge about fin whale *Balaenoptera physalus* (L. 1758) in the Mediterranean Sea is still scarce and largely due to sightings coming from unskilled people. Strandings are rather rare and, anyway, they cannot offer but few quantitative data about the dynamic of the populations. Though many questions about the ecology of this species in the Mediterranean Sea are still open, some hypotheses are suggested here with regard to the presence throughout the year, the school size, the exchanges with Atlantic populations through the Gibraltar strait and the geographical distribution inside the basin: the work is based on bibliographic data and on the results of a long-term research in the Central Tyrrhenian Sea.

Present state of the research

The data concerning the ecology and the chorology of the fin whale (*Balaenoptera physalus*) in the Mediterranean Sea that are available at the present come from sea-sightings and strandings of dead animals.

SIGHTINGS

The results of sighting campaigns very often do not mention the methods employed, or the data reported were obtained from sightings done by non-specialized staff and in cruises not done for that specific purpose. Sometimes only the conclusions are reported, while data obtained are not illustrated: the informations given by this type of

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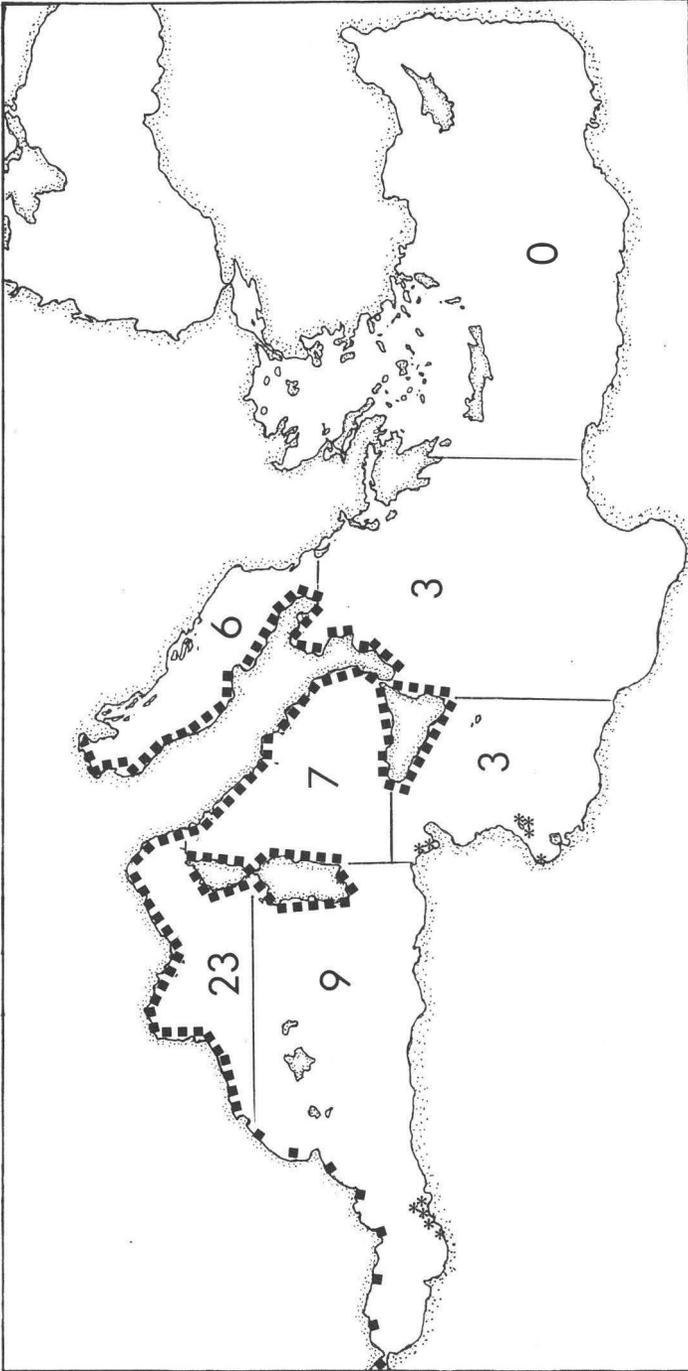


Fig. 1. — Present state of the research.

■ ■ ■ Network of strandings watchers.

* Isolated strandings of *Balaenoptera physalus*.

For each area the number of sighting cruises is reported.

results are not always trustworthy and, moreover, not precisely defined as far as the methods are concerned, thus they cannot be utilized for comparison with the results of other researches.

STRANDINGS

The frequency of strandings recorded is conditioned by several factors, such as the weather and sea conditions, the direction of the seacurrents, the dimensions and the competence of the networks of sighters. The data obtained on such occasions can be used for detecting the presence of this species in some areas and also for studying morphological parameters.

The high frequency of sightings and strandings recorded in some areas may be due to the high intensity of the commercial routes and also to the frequency of research done in those areas, to the detriment of the other less frequented ones. The Mediterranean network of stranding watchers, isolated strandings occasionally recorded along the North-African coast and the number of studies for each area are summarized in Fig. 1.

Moreover, it is possible that the number of *B. physalus* up until now has been over-estimated, due to the morphological similarity of this species with *B. edeni* and *B. borealis*, which can be recognized only by experts and at a very short distance. The importance of these two latter species in the Mediterranean fauna is unknown and their presence is only known from rare strandings.

Some data from the campaign in the Central Tyrrhenian Sea

During the sightings campaign on Cetaceans which is in progress by the Authors since September 1989 in the Central Tyrrhenian Sea, data were recorded with a standardized method, in order to get some informations on the presence of Cetaceans in that area in the course of the year and on their distribution (CONSIGLIO *et al.* 1990; MARINI *et al.* 1991).

In fig. 2 the sightings recorded are illustrated with the relative average per trip. The apparent variations do not seem to be statistically significant.

In fig. 3 the dimensions of the schools sighted in the different months are reported: they show a tendency of the fin whales to associate in the winter months, probably in correlation with the

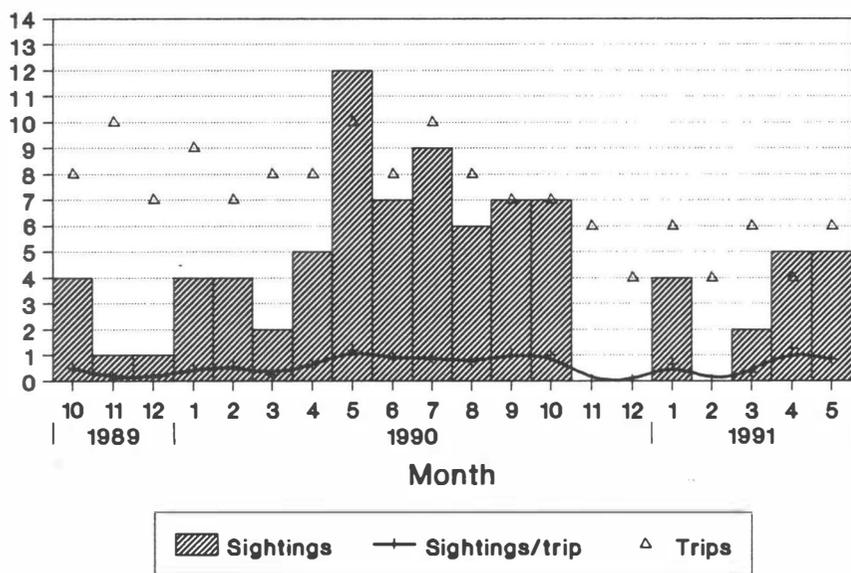


Fig. 2. — Sightings of *Balaenoptera* sp. in the Central Tyrrhenian Sea.

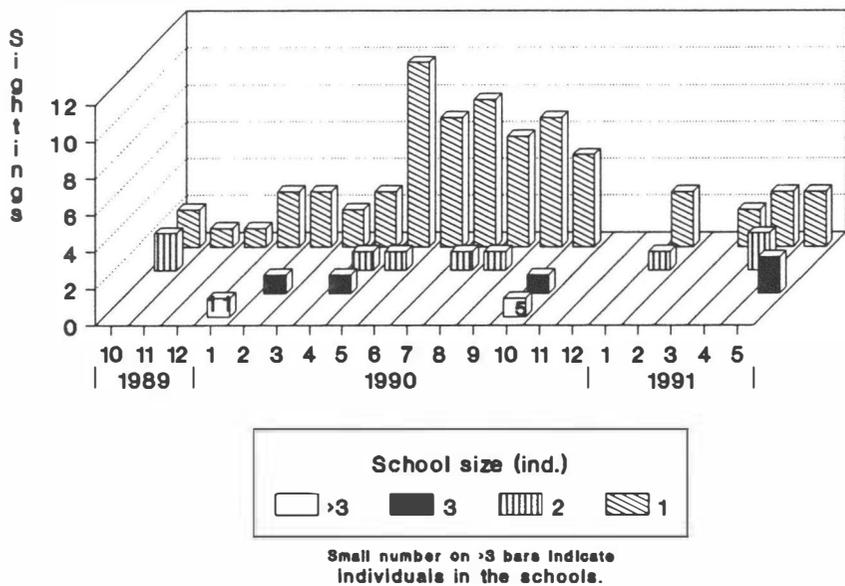


Fig. 3. — School size of *Balaenoptera* sp.

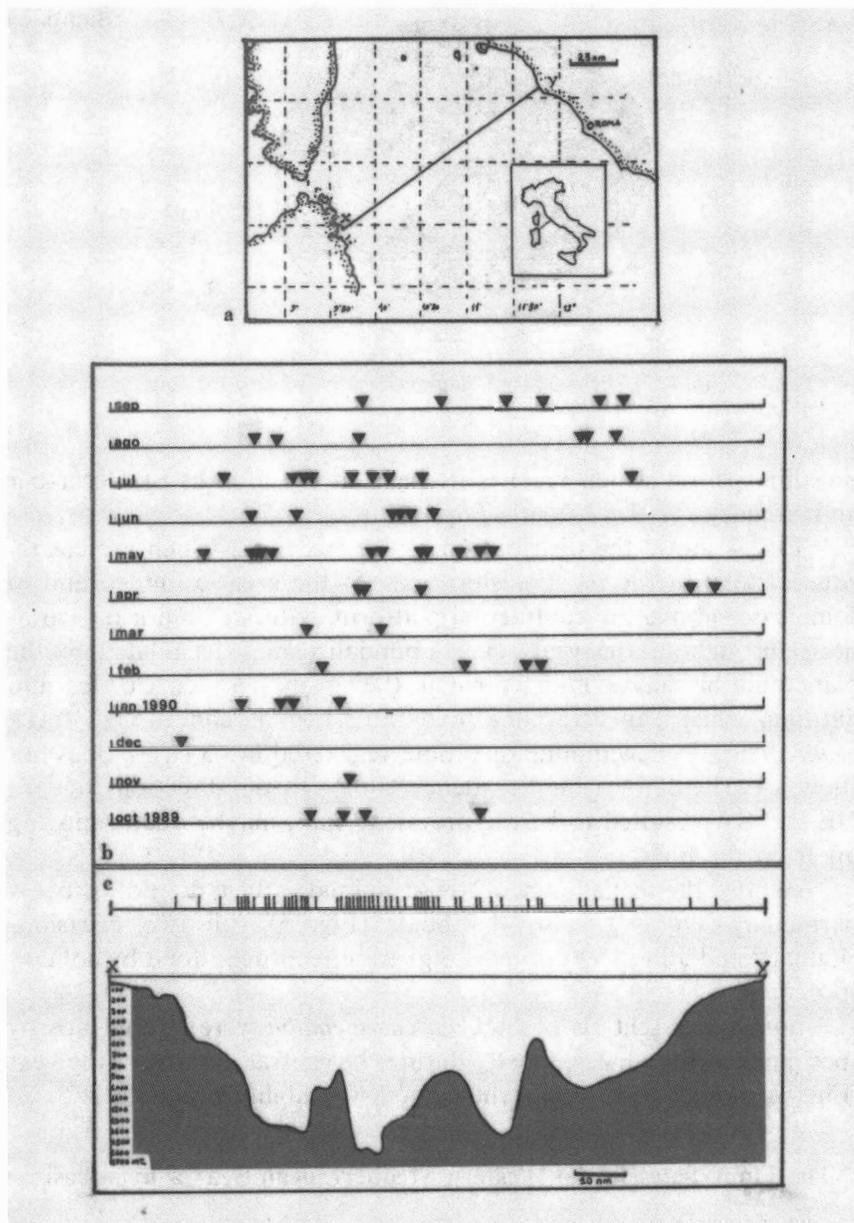


Fig. 4. — Geographical distribution of sightings of *Balaenoptera* sp. recorded in the Central Tyrrhenian Sea:

- The research area and the followed line transect;
- Monthly distribution in the first year of the research;
- Total distribution in the first year of the research and submarine profile.

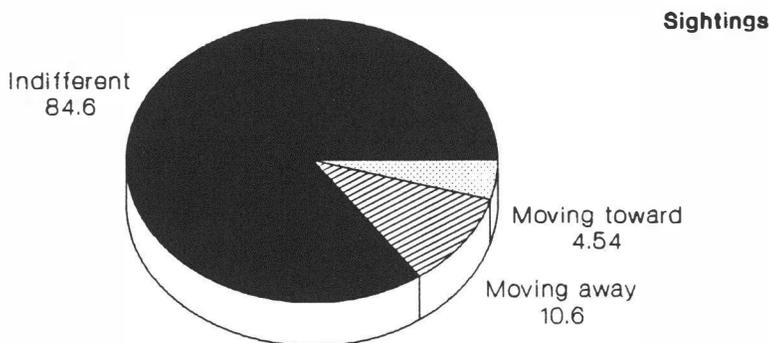


Fig. 5. — Behaviour of *Balaenoptera* sp. toward the ship.

breeding period which reaches its peak in the months of December and January for the Atlantic populations.

Fig. 4 shows the distribution of the sightings, which are clearly concentrated in the most western part of the area examined and in some cases above the continental platform, without significant variations throughout the year: such abundance may be related to the planctonic biomass coming through the straits between Corsica and Sardinia which can determine favourable trophic conditions (VIALE *et al.* 1988). The swimming direction, registered in 43 cases, does not show a particular seasonal tendency, although the directions toward NE and SW resulted to be the prevalent ones, maybe due to moving off from the boat.

As for the behaviour of these animals, they do not show a particular shyness toward the boats (Fig. 5): on two occasions (January and June 1990), breachings were recorded, done by solitary specimens.

Sometimes schools of *Stenella coeruleoalba* were sighted nearby specimens of fin whales, mostly during the central months of the year (Fig. 6), probably in areas where food was highly available.

The Fin Whales in the Western Mediterranean Sea: a hypothesis

With the data today available from the literature, in spite of the above mentioned limitations, and also with the data collected by the authors during their sighting campaign, it is possible to arrive at a hypothesis on the presence of this species in the western Mediterra-

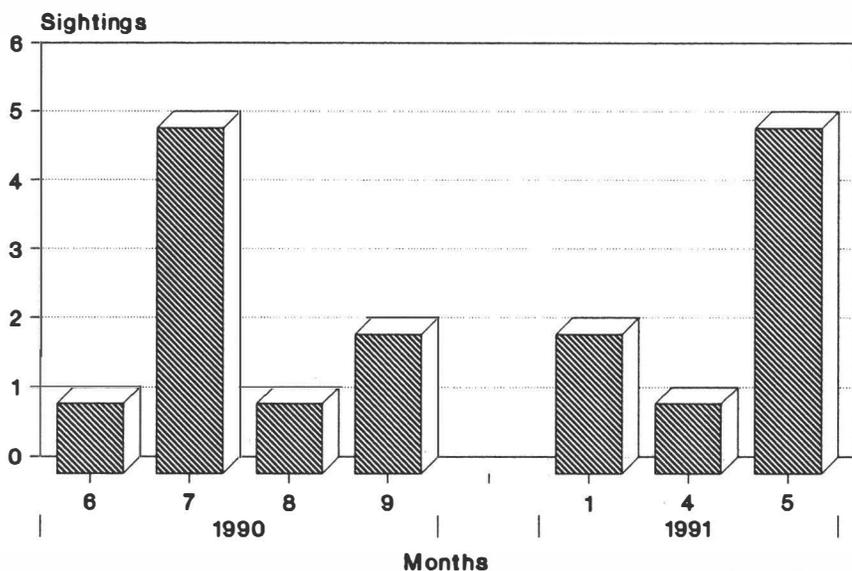


Fig. 6. — Occurrence of contemporary sighting of *Balaenoptera* sp. with *Stenella c.*

nean Sea: however, this hypothesis remains only at a speculative level and needs further verifications.

Considering that:

- The fin whales are present in the Mediterranean Sea throughout the year, never undergoing sensible variations in number, as it is evident from the distribution of the sightings and of the strandings;
- The recent observations of HASMHI (1990) in the Strait of Gibraltar did not point out any particular movement of large Cetaceans;
- The average dimensions of the new-born fin whales stranded on the shores along the Mediterranean Sea coast seem to be smaller than the dimensions of those of the same age in the Atlantic Ocean (DUGUY & VALLON 1977);
- The Mediterranean Sea, especially in some areas, seems to be not as oligotrophic as it was considered in the past (COSTE *et al.* 1988), thus it offers possibilities for an adequate development to all the components of the lower levels of the food pyramid that has the Mysticetes at its summit.

From this we can deduce that the fin whales of the Mediterranean Sea form one (or more?) live-in population that is relatively isolated from the populations of the Atlantic, or, rather, «a relatively homogeneous and self-contained population whose losses by emigration and accessions by immigration, if any, are negligible in relation to the rates of growth and mortality» as the Scientific Committee of the IWC (1977) has defined a «management unit» or «stock».

The theory proposed by EVANS (1987) on the existence of non migratory populations of Mysticetes and the isolation of seven fin whale stocks in the North Atlantic (IWC 1977; see also RORVIK & JONSGARD 1981) can support this hypothesis.

Probably the Strait of Gibraltar constitutes an effective barrier against large migrations, although there are many probabilities that small groups or isolated specimens occasionally enter and leave the basin, as it seems to happen for other species of large Cetaceans (BOLOGNARI 1951, for the Sperm whale).

Several aspects concerning the ecology of the fin whale in the Mediterranean Sea are still largely unknown. The main questions that arise regard:

- The number of specimens living in the basin and their presence in the eastern part of it;
- Eventual morphological (i.e. the dimensions and the blubber layer thickness) and ethological differences from the North Atlantic populations;
- Interchanges with those populations;
- Ways and reasons for movements of schools inside the Mediterranean Sea;
- The possibility that the Strait of Gibraltar is an effective barrier against large migrations entering and leaving the basin;
- The diet and the effective availability of food in the Mediterranean Sea.

ACKNOWLEDGEMENTS

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SIGHTINGS OF HARBOUR PORPOISES
(*PHOCOENA PHOCOENA*)
OFF THE ISLAND OF SYLT, F.R.G.

BY

H. KREMER *, L. KOCH **, B. BASCHEK ** & B. ADLOFF *

SUMMARY. — In autumn 1988, a pilot-project on sightings of harbour porpoises off the North Sea coast of the county Schleswig-Holstein, F.R.G., was implemented. This ongoing study utilized opportunistic observations made by conservationists, tourists and locals and was carried out in close cooperation with the conservancy society Schutzstation Wattenmeer with support from the Wadden Sea project of the World Wide Fund for Nature (WWF). The majority of the feedback (> 85%) came from the Isle of Sylt, where landbased observations were made within a region of up to 100 meters from the beach. The time of observations from Sylt could be correlated to the local tide with a maximum of observations during high water. Contradicting assumed offshore movements of this species during winter, the observations peaked in late autumn/winter. Despite of the non-quantifiable design of his initial stage of the project, it can be said that it is highly likely that the numbers of harbour porpoises in the immediate inshore-regions of Sylt have at least seasonally risen. The opportunistic sightings network was complemented by regular simultaneous countings since December 1990.

* * *

In autumn 1988, a pilot-project on sightings of harbour porpoises off the North Sea coast of the county of Schleswig-Holstein, F.R.G., was implemented. This was the first organized observation effort on cetaceans in German waters. The pilot-study utilized a leaflet, which combined information on harbour porpoises with forms for sightings and strandings. This leaflet was distributed by the National Park authority of the Wadden Sea Schleswig-Holstein and

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by numerous conservation-groups, namely the Schutzstation Wattenmeer e.V., which runs more than 12 information and conservancy centers in the vicinity of the Wadden Sea.

Encouraging conservationists, tourists and locals to report sightings on harbour porpoises, this ongoing study utilized opportunistic observations, which, by definition, can not precisely be quantified for observation effort. Work was supported by the Wadden Sea project of the World Wide Fund for Nature (WWF).

The majority of the feedback (> 85 %) came from the Isle of Sylt, where landbased observations were made within a region of up to 100 meters from the beach. Sylt is the westernmost island of Schleswig-Holstein and its west-coast is directly exposed to the North Sea, whereas the other islands are situated in the Wadden Sea, locked off from the North Sea by large sandbanks.

North and south to Sylt, strong tidal currents pass into the shallow areas of the Wadden Sea. Most waters east to Sylt are part of the littoral.

From the data of Sylt, the distribution of sightings could significantly ($p < 0.05$) be correlated to the local tide with a maximum of observations of ± 1 hour to high water. The reasons for this correlation are still unknown and need further investigations, e.g. for local variations of this phenomenon.

Contradicting assumed offshore movements of this species during winter, the observations peaked in late autumn/winter, while stranding numbers in this area continue to peak during summer (SCHULTZ & BENKE, 1991). It is interesting to note that in the Netherlands, observers noted a similar tendency in the seasonal variation of sightings (Kees Kamphuysen, pers. comm.).

Despite of the non-quantifiable design of this initial stage of the project, it can be said that it is highly likely that the numbers of harbour porpoises in the immediate inshore-regions of Sylt have at least seasonally risen. It is unlikely that the regular presence of harbour porpoises in this area during late autumn would have gone unnoticed by birdwatchers and conservationists prior to this investigation. No possible links could be found with the mass die-off of harbour seals, *Phoca vitulina*, in the North Sea during 1988.

The opportunistic sightings-network was complemented by regular simultaneous countings since December 1990.

In order to obtain effort-quantified data on the presence of harbour porpoises off Sylt, regular watches from fixed stations along

the west-coast off Sylt are carried out. Every 14 days, as many of the 18 stations as possible are manned simultaneously for an observation period of one hour. The project is coordinated by the Schutzstation Wattenmeer and involves volunteers from numerous organisations. The results from the simultaneous countings will be subject to a separate publication.

Finally, it should be mentioned that the results of this study do by no means suggest an increase of the population. Rather, the sightings off Sylt do indicate a surprising and possibly new pattern in the local and seasonal presence of *Phocoena phocoena*.

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RECENT STUDIES ON ABUNDANCE
AND TRENDS IN WHALE STOCKS
IN ICELANDIC AND ADJACENT WATERS

BY

Jóhann SIGURJÓNSSON*

SUMMARY. — Sightings surveys of large baleen whales in Icelandic and adjacent waters with special emphasis on blue, fin, sei, minke and humpback whales, were carried out during June-August 1987 and July-August 1989 onboard survey vessels and aircraft allocated by Iceland to the joint North Atlantic Sightings Surveys (NASS-87 and NASS-89). The results are presented and discussed, with particular reference to historical exploitation and the overall situation of the species in the North Atlantic. Based on these surveys, the estimated number of fin and minke whales in the East Greenland-Iceland-Jan Mayen area was 15,600 and 28,000, respectively; the estimate for sei whales in the area west and deep southwest of Iceland was 10,600, and that of humpback whales in Icelandic waters was 1,800. Relative indices of abundance for blue and humpback whales for the time period 1969-1988 show a steady increasing trend in the range of 5% (blue) and in excess of 10% per year (humpbacks). An index of abundance for fin whales west off Iceland indicates a stable population during the period 1962-1989. However, significant trends with time in biological parameters in the fin whale population harvested off Iceland have been observed in recent decades, including an increase in growth rate and corresponding decrease in age at sexual maturity in the 1950's and 1960's and a reversed trend in the 1970's and early 1980's. Also, in the time period 1967-1989 the relative fecundity in fin whales has varied considerably from year to year with an overall increasing trend in most recent years. These and other trends over time are discussed and compared with available information on environmental conditions in the area, particularly abundance of krill, the main food of fin whales and of capelin, consumed by humpback whales. A direct link was found between krill abundance and changes in growth rate in the fin whale population, while other factors such as dramatic changes of the ecosystem off Iceland in the late 1960's, introduction of industrial fishery for capelin off Iceland in the 1970's and increase in stocks of blue and humpback whales may be important factors still to be considered in more detail. Only weak relationship was found between abundance of blue, fin and humpback whales on the one hand and food abundance on the other,

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indicating that the available indices of whale abundance are more of a long-term indicators of stock changes rather than indicators of yearly variations in migration of the whales into the feeding grounds. The yearly fluctuations of apparent pregnancy rate in fin whales showed poor correlation with the available environmental variables. This was considered to be due to the complexity of the underlying mechanism for variation in reproduction in the species, which would not be explained alone by food abundance in the current or preceding seasons, but a combination of a number of these and other factors.

Introduction

After decades of over-exploitation of many of the stocks of large whales in different ocean areas, considerable research efforts have been devoted to studies on the status of the stocks and the future prospects. These studies have revealed a still depleted status of many stocks of the large whale species such as blue (*Balaenoptera musculus*) and fin (*B. physalus*) whales in the Antarctic Ocean (GAMBELL 1976, BUTTERWORTH & DUDLEY 1985, BUTTERWORTH & DE DECKER 1990). Other stocks such as the North Pacific gray whale (*Eschrichtius robustus*) and some of the North Atlantic stocks of humpback (*Megaptera novaeangliae*), fin and minke (*B. acutorostrata*) whales are at a much higher level (for gray whales see REILLY 1987 and IWC 1991a; for humpbacks see e.g. MITCHELL & REEVES 1983, KATONA & BEARD 1990; for fin see IWC 1991c, BUTTERWORTH & PUNT 1991; and for minke see IWC 1991b, 1991d), some having even reached their pre-exploitation level.

In the light of the depleted status of some of the species and stocks, the potential rate of increase in large whale stocks is of special interest. Two well-known examples of monitoring of trends in abundance in stocks of large whales by direct counts are the eastern North Pacific stock of gray whale and the Southern right whale (*Eubalaena glacialis*). In the first case, the annual rate of increase, based on fixed land-based look-out data series (REILLY 1987), was found to be 3.2% with an average annual catch of 174 whales (0.8% of the estimated stock size; IWC 1991a). In the latter case, the stock was monitored by regular aerial surveys off South Africa and the average annual rate of increase was found to be 6.8% over a period of 17 years (BEST 1990). The rate of increase in right whales (*E. australis*) off the Argentinean coast (R. PAYNE *et al.* 1990) and humpback whales throughout the North Atlantic (KATONA & BEARD 1990), based on repeated photoidentified animals, gave an annual net rate of increase of 7.6% and 9.4%, respectively.

All the above stocks were depleted to low levels by whaling operations. Very few data are on natural fluctuations in large whale populations or on the inter/intra-specific competition, since these often have been overshadowed by human influence after studies commenced. WHITEHEAD & CARSCADDEN (1975) showed considerable changes in inshore abundance of minke, fin and humpback whales off the Newfoundland coast during the period 1973-83, which evidently were linked with year-class strength of capelin (*Mallotus villosus*). P. M. PAYNE *et al.* (1990) also showed major changes in occurrence of several baleen whale species in the southern Gulf of Maine during the 1980's concurrent with dramatic changes in the abundance of sandlance (*Ammodytes* spp.) and calanoid copepods, which indicated interspecific competition. The dramatic changes in the species biomass in the Antarctic Ocean due to exploitation of whales and the subsequent increase in other vertebrate populations have also been a subject for studies of inter-species interactions (e.g. LAWS 1977a, 1977b & 1985, HORWOOD 1980).

Investigations have revealed major trends in growth rate and age at sexual maturity in the Southern hemisphere fin (LOCKYER 1972), sei (*B. borealis*) (LOCKYER 1974) and minke (*B. acutorostrata*) whales (MASAKI 1979, BEST 1982, KATO 1983, 1987, OHSUMI 1986a) and Northern hemisphere fin whales (LOCKYER 1981, OHSUMI 1986b). In all cases the data showed an increase in growth with time and corresponding decline in age at sexual maturity, where increased food availability was suggested as the main causative factor. GAMBELL (1973) also reported apparent changes in pregnancy rates of fin and sei whales in the Antarctic Ocean, which he correlated with an overall reduction in biomass of the large whales, while HORWOOD (1980) suggested that, apart from food surplus due to reduced whale stocks, the apparent improved climatic conditions from the 1920/30's onwards may be a significant factor in this context, although no direct relationships for any of the trends have been demonstrated. A more direct measure of the environmental impact on the fecundity was LOCKYER's (1986, 1987) analysis of fin whale fecundity off Iceland, which revealed close correlation between body condition, food resources and potential fecundity.

This paper reviews information available on abundance and stock sizes of three baleen whale species in Icelandic and adjacent waters, i.e. fin, sei and minke whales, which have been subject of thorough investigations in recent years, particularly as a result of the

joint international North Atlantic Sightings Surveys in 1987 and 1989 (NASS-87 and NASS-89) and the International Whaling Commission's (IWC) conduct of detailed analysis of the whale stocks (IWC 1990b, c). The results will be discussed in relation to historical exploitation and the overall situation of the species in the North Atlantic, based on surveys conducted simultaneously by other participating nations in the two joint surveys. Secondly, the paper will discuss data on trends over time in abundance of fin, blue, and humpback whales, that have been regularly monitored off Iceland by sightings and other methods during several decades. Thirdly, the paper reviews data on time trends in biological parameters in fin whales off Iceland, based on extensive investigations that have been carried out over a period of over 20 years. And finally, a comparative analysis of the observed trends is presented, incorporating data on the above time trends, and time series of data on abundance of prey in this ocean region.

Abundance of Fin, Sei and Minke Whales

Systematic sighting surveys is the main method used today to obtain information on absolute abundance in most whale stocks. The basic principle behind sighting surveys is quite simple, i.e. whales are detected either by naked eye or through binoculars from a specially equipped sighting vessel, the angle to bearing and distances to the sightings are recorded, and the number of each species per sighting made, is assessed. The search tracklines are randomly designed, and the abundance of each species is estimated by area according to the so-called line-transect methodology (see further HIBY & HAMMOND 1989). A modified version of this technique, the cue-counting method has recently been introduced in surveys conducted from aircraft (HIBY & HAMMOND 1989). For successful completion of the survey, we have found that of utmost importance is to have experienced crews on the surveys, because otherwise the basic assumption of all animals on the trackline to be detected is very likely to be violated, and consequently the estimate of abundance will be seriously negatively biased, unless specific corrections are being made. The degree of likely bias is, however, strongly dependent on the species and area under consideration. E.g. one would expect the assumption to hold true for the larger baleen whales, such as the fin whale (visible blow at large distances), while it unlikely holds for minke whale, which is

observed only in calm weather at close range, and does not have a visible blow. Corrections have been attempted for this species for shipboard surveys (IWC 1991d), while the cue-counting method applied on aerial data does not require such corrections, but requires data on surfacing behaviour of the animal.

In the surveys that have been conducted in Icelandic and adjacent waters in recent years, survey vessels have been used to cover the pelagic offshore waters (SIGURJÓNSSON *et al.* 1989, 1991a), while aerial surveys have been conducted in the coastal waters with easy access to airfields and relatively predictable weather conditions in and just outside the fjord areas (GUNNLAUGSSON *et al.* 1988, DONOVAN & GUNNLAUGSSON 1989). The reader is referred to these papers for further information on the conduct of the surveys.

In 1987 Iceland allocated three large survey vessels to the joint NASS-project during 24 June-27 July, and one aircraft. The timing of the survey and area covered (Fig. 1) was specifically chosen to cover the peak migration period of the two main target species in these waters, i.e. the fin and minke whale. Simultaneously, Denmark, Faeroe Islands, Norway and Spain allocated vessels and aircraft to cover areas elsewhere in the Northeast Atlantic (LARSEN *et al.* 1989, SIGURJÓNSSON *et al.* 1989, ØRITSLAND *et al.* 1989, LENS *et al.* 1989), totalling 8 vessels and 2 aircraft. In 1989 surveys were conducted from four Icelandic vessels during 10 July-14 August. The timing of the survey (2-3 weeks later than in 1987) and the emphasis on more southerly and deeper waters (Fig. 2) was designed to capture the late summer migration of the Denmark Strait stock of sei whales, the primary target species of the survey, into the area west and southwest of Iceland. In all 15 vessels and 2 aircraft scouted the eastern part of the North Atlantic in 1989, in surveys conducted by Denmark, the Faeroe Islands, Iceland, Norway and Spain (JOYCE *et al.* 1991, SIGURJÓNSSON *et al.* 1991a, ØIEN 1991, LENS 1991).

FIN WHALES

Figure 1 shows the survey area covered in 1987 and the distribution of fin whale sightings in the Icelandic NASS-87 survey. Fin whale was the most widely distributed and abundant large whale species encountered. The bulk of the animals were observed near or at the continental edge west and southwest off Iceland, in East Greenland waters and northeast of Iceland towards the Jan Mayen

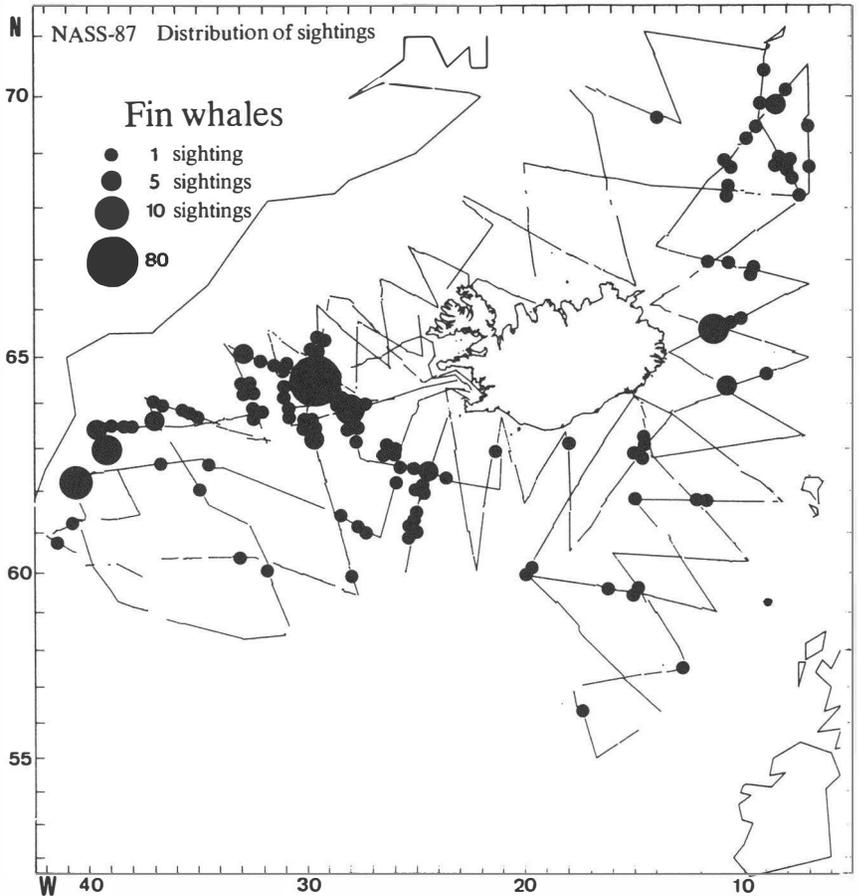


Fig. 1. — Distribution of fin whale sightings on board the Icelandic survey vessels, June-July 1987, with computer-drawn on-effort trackline.

island. Figure 2 shows the cruise track and distribution of fin whales during the 1989 survey, which went as far south as 50°N. Again major concentrations were found in the area between Greenland and Iceland, but in addition relatively high abundance was found deep southwest, south and southeast of Iceland, and also in the area south of 60°N, particularly within the geographical block 50-55°N and 25-35°W. This southern area is of special interest, since no systematic surveys have been conducted there before.

The Icelandic sightings data have been used to estimate the total abundance of fin whales in the areas surveyed in both 1987 and 1989

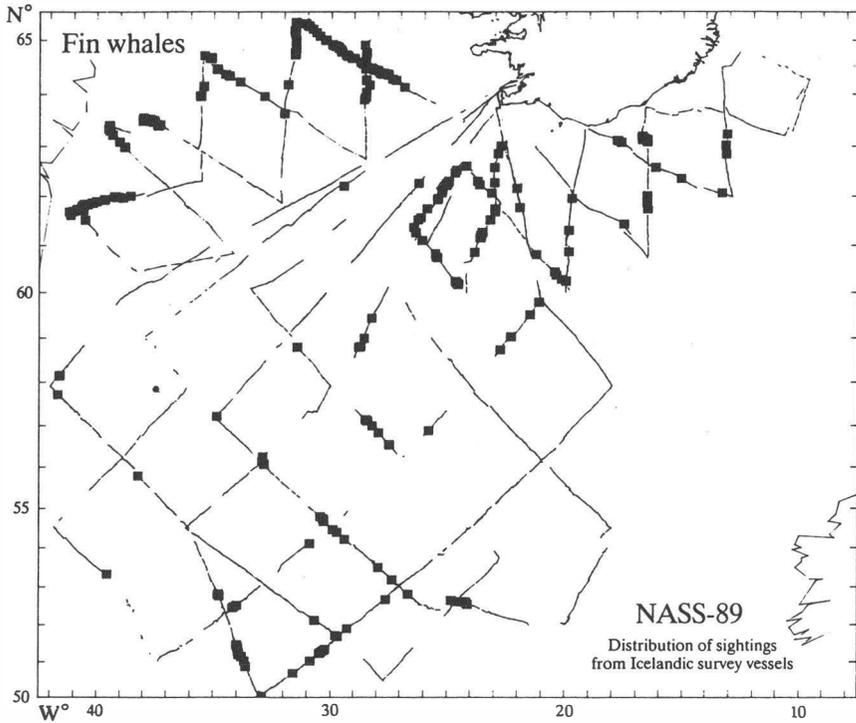


Fig. 2. — Distribution of fin whale sightings on board the Icelandic survey vessels, July-August 1989, with computer-drawn on-effort trackline.

Table 1

Estimates of abundance of North Atlantic fin whales by survey areas, based on NASS-87 and NASS-89 surveys with associated 95% confidence intervals of the estimates (see further details in text)

Area	Estimate	95% conf. int.
*NW Atlantic	10,818	5,387-21,723
W Greenland	1,046	520- 2,106
E Greenl. Icel. Jan Mayen	15,614	10,140-24,043
N Norway	1,476	846- 2,576
W Norway	340	85- 1,355
Faeroes-Br. Isles-Ireland	677	345-1,328
W Spain/Iberia	17,335	10,391-28,920
Total N Atlantic	47,306	n.a.

* No suitable sightings data available for the NW Atlantic; estimate based mark/recapture experiments.

n.a. = not available.

(GUNNLAUGSSON & SIGURJÓNSSON 1990, BUCKLAND *et al.* 1991a) and in other North Atlantic areas surveyed in the same years (ØIEN 1990a, b, BUCKLAND *et al.* 1991b). These were discussed and agreed upon by the special meeting of the IWC Scientific Committee on North Atlantic fin whales in early 1991 (IWC 1991c), except that off the Iberian coast, which was produced more recently by BUCKLAND *et al.* (1991b), based on the Spanish NASS-89 survey. Table 1 gives the estimates of abundance of fin whales by survey area with the associated 95% confidence intervals of the estimates. In absence of suitable sightings data from the Northwest Atlantic, a mark/recapture estimate (COOKE 1991), based on Canadian whale marking in the period 1965-72, is also given. Figure 3 shows the approximate areas the respective estimates refer to.

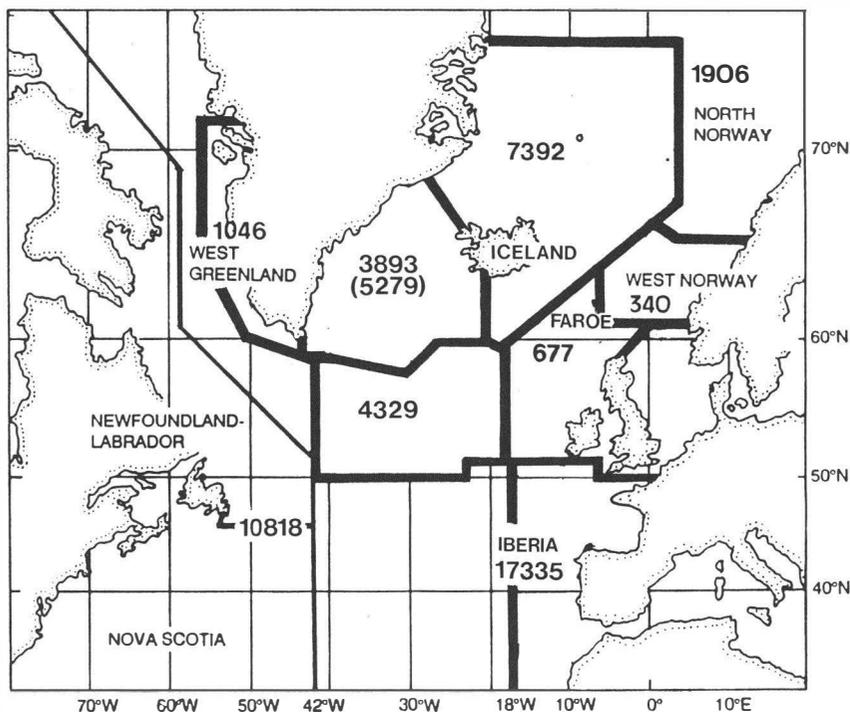


Fig. 3. — North Atlantic fin whales: estimates of abundance by survey area based on NASS-87 and NASS-89 international sightings surveys, except for Northwest Atlantic, which is derived from mark/recapture experiments (see further text and Table 1). Estimates given separately for 1987 and 1989 (in paranthesis) for the East Greenland-West Iceland area.

The total estimate of abundance for the entire North Atlantic Ocean is around 47,000 fin whales, with the major concentrations occurring in the East Greenland Iceland-Jan Mayen area (south to 50°N) and in the area west of Spain (Iberia), i.e. in the two recent main areas of exploitation. The mark/recapture estimate off the Canadian coast also indicates good numbers in the region, while the abundance off Norway and the Faeroe Islands, where whaling ended in 1971 (JONSGÅRD 1977), are relatively low, the stocks apparently still suffering from earlier exploitation. Considering the area between Iceland and Greenland, where whaling has been conducted for over 100 years, the estimate is 4,600 for the area north of 60°N (mean of 1987 and 1989); 8,900 if the area between 50 and 60°N is included. This is a similar order of magnitude as results of mark/recapture experiments carried out during the period 1965-84 in conjunction with the Icelandic fishery west of Iceland (SIGURJÓNSSON & GUNNLAUGSSON 1985). Fin whales were caught by several commercial operations throughout the North Atlantic Ocean earlier this century (JONSGÅRD 1977), the Icelandic fishery, the last one in operation, took an average annual catch of 234 animals in the period 1948-85 (SIGURJÓNSSON 1988).

SEI WHALES

Figure 4 shows the distribution and relative abundance of sei whales during the Icelandic NASS-89 cruise. The species was the second most common large whale species in the study area, while its distribution was rather restricted in space, with over 70% of the sightings being made in the latitudes 50-60°N (30-42°W) at the North Atlantic ridge. The remaining sightings were evenly distributed further north between Greenland and Iceland. Noteworthy was, that while fin whales were concentrated at the ice edge and at the steep continental slope off Iceland and Greenland, the sei whales were seen further offshore, where no fin whales were found. Only one additional sighting of sei whale was reported in the NASS-89 survey, i.e. in the area covered by the Faeroese survey vessel east of the Icelandic survey area (JOYCE *et al.* 1991).

Based on the sightings data, the estimate of abundance has been calculated (BUCKLAND, pers. comm.) as 10,607 sei whales ($ev = 0.266$) in the area surveyed by the Icelandic vessels in 1989. In recent decades this species has been very moderately exploited by

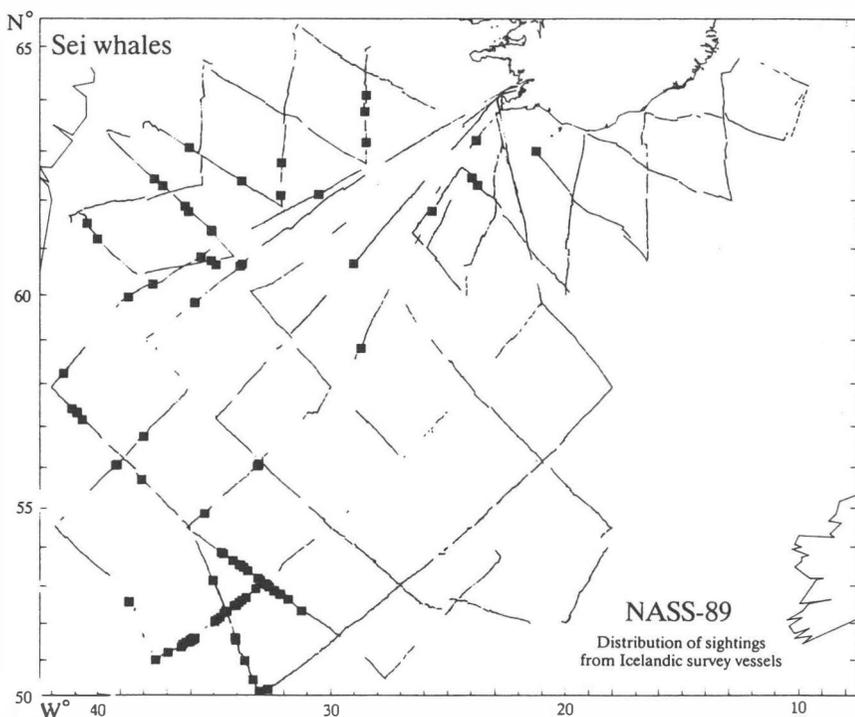


Fig. 4. — Distribution of sei whale sightings on board the Icelandic survey vessels, July-August 1989.

commercial operations (JONSGÅRD 1977), mainly by Canada (until 1972) and Iceland (until 1985), the average annual catch for the latter operation averaging 68 animals during 1948-85 (SIGURJÓNSSON 1988).

MINKE WHALES

Figure 5 shows the distribution of minke whales, the second target species of the Icelandic NASS-87 survey. In contrast to the fin whale, the sightings were mainly made on the banks relatively close to the shore, especially in Faxabay, southwestern Iceland. The species was also found in considerable numbers in the Denmark Strait (the narrow strait between Iceland and Greenland), off the Jan Mayen island, around the Faeroes and into the southern Norwegian Sea. For estimation purposes, aerial survey was conducted in the coastal waters (DONOVAN & GUNNLAUGSSON 1989), which confirmed the

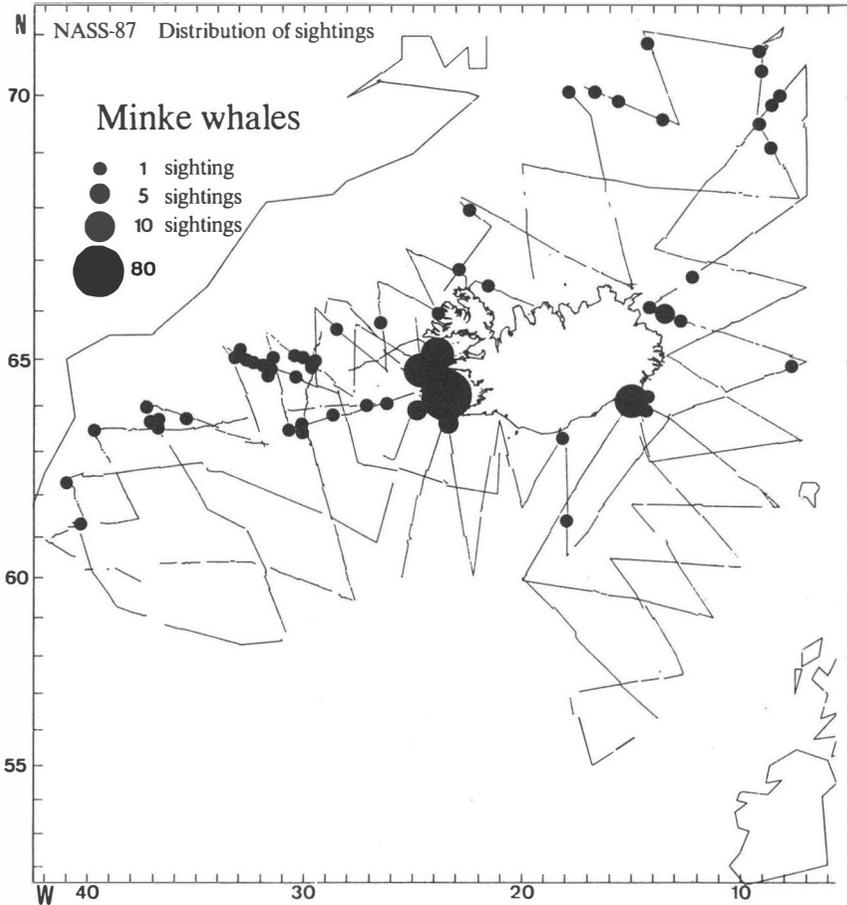


Fig. 5. — Distribution of minke whale sightings on board the Icelandic survey vessels, June-July 1987.

overall pattern obtained from the vessels. In 1989, minke whales were also observed throughout the survey area, but no aerial surveys were conducted that year, and the area north and northeast of Iceland was not covered. However, that survey demonstrated for the first time summer concentrations of this species between 50 and 55°N and the total absence of minkes in the deep waters between ca55°N and Icelandic coastal waters (GUNNLAUGSSON & SIGURJÓNSSON 1991).

The IWC Scientific Committee completed its in-depth assessment of the stocks of North Atlantic minke whales in June 1990 (IWC 1991b), including a review of results of the joint NASS sightings surveys (ØIEN 1989, GUNNLAUGSSON & SIGURJÓNSSON 1990,

Table 2

Estimates of abundance of North Atlantic minke whales by IWC stock areas, with associated 95% confidence intervals of the estimates, based on NASS-87 and NASS-89 surveys (see further details in text)

Area	Estimate	95 % conf. int.
NW Atlantic*	n.a.	n.a.
W Greenland	3,266	1,790- 5,950
Northeastern	68,447	n.a.
Central	27,968	21,600-31,400
Total N Atlantic (-NW)*	99,681	n.a.

* No suitable sighting data available for the NW Atlantic.
n.a. = not available.

1991, HIBY *et al.* 1989). Some adjustments of the estimates were made in 1991 (IWC 1991d), due to more recent Norwegian experiments to estimate proportion of animals not seen on the trackline. Table 2 summarizes the findings of the Committee for three of the four conventional IWC stock areas (W Greenland coast stock area; Central stock area-covering the area between Greenland, Iceland and Jan Mayen; Northeastern stock area-Barents Sea, Norwegian coast, western coast of continental Europe) based on the sightings surveys. No comparable estimate is available for the US and Canadian coast minke whales, but the total estimate for the remaining part of the North Atlantic is around 100,000 animals.

Minke whales were exploited in all parts of the northern North Atlantic, mainly in the coastal regions, since early this century by Canada, Greenland, Iceland and Norway (JONSGÅRD 1974, MITCHELL 1974, KAPEL 1977, SIGURJÓNSSON 1982). At least three stocks are believed to inhabit the North Atlantic Ocean (IWC 1991b). The status of the Central and Northeastern stocks were evaluated recently (IWC 1991b), the first having apparently been only slightly reduced by the relatively small annual takes in recent years, while the latter was evidently more heavily exploited, although still counting about 70,000 animals.

Trends in abundance: Humpback, Blue and Fin Whales off Iceland

SIGHTINGS OF BLUE AND HUMPBACK WHALES 1969-88

SIGURJÓNSSON and GUNNLAUGSSON (1990) analysed blue and humpback whale sightings data collected onboard Icelandic whaling

vessels during the period 1969-88. After correcting for temporal and spatial variations in sighting effort and the effects of sighting conditions on the sighting rate, detailed time budget data kept onboard the vessels since 1979 showed an annual rate of increase of 5.2% and 14.8% for blue and humpback whales, respectively. A more crude index (number of whales observed/«working day») available since 1969 (see Fig. 6), showed a similar increasing trend in both species: 4.9% per year for blue whales (for the period 1969-88) and 11.6% per year for humpback whales (1970-88).

The authors concluded, after examining available information on the history of exploitation of both species and published information

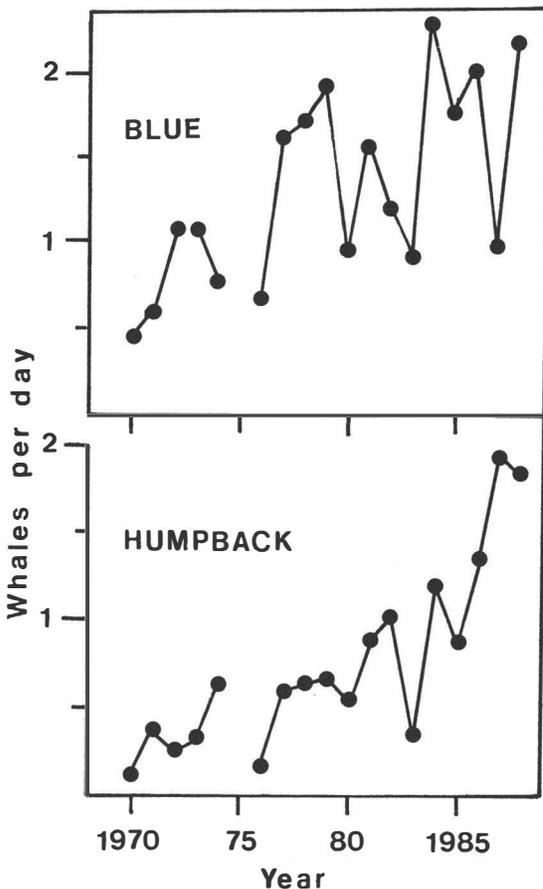


Fig. 6. — Sightings of blue and humpback whales west off Iceland (number of whales/«working day») made on board Icelandic whaling vessels during the period 1970-88 (no data for 1975).

on their historical and present occurrence, that the observed trend in the blue whale indicated a true increase in the population. With respect to the humpback whale, the authors did not preclude the possibility of some other factors, such as possible immigration of whales from other feeding aggregations, contributing in part to the apparent trend. Nevertheless, they considered the observed increase in both populations was at least in part attributable to the more than 30 years of protection of both species from commercial exploitation throughout the North Atlantic Ocean.

The increase in the humpback population is interesting in light of the estimated abundance from the NASS-87 survey, where some 1,800 whales were found in the area around Iceland (GUNNLAUGSSON & SIGURJÓNSSON 1990). KATONA & BEARD'S (1990) thorough review of photoidentified humpback whales in the North Atlantic, gave an estimated total population size of 5,500 whales for the Northwest Atlantic (including Iceland) with an annual rate of increase of 9.4% (1979-86). The relatively high rate of increase reported by these authors, indicates that the findings off Iceland and reported by SIGURJÓNSSON and GUNNLAUGSSON (1990), are indeed a reflection of true increase in the population. Considering MITCHELL & REEVES' (1983) estimate of the «initial» population size in the North Atlantic (4,700 whales), based on historical catch records, notwithstanding the possibility that their estimate may be downward biased due to absence of records of some whales caught, it appears as if the North Atlantic humpback population has reached near its pre-exploitation level.

CATCH/EFFORT RELATIONSHIP: FIN WHALES 1962-89

The catch/effort (CPUE) relationship in the Icelandic fin whale fishery has been investigated in several studies (reviewed by SIGURJÓNSSON 1988). It is based on analysis of log-books of all whaling vessels that were in operation since the early 1960's and the corresponding time budget data that have been collected since around 1980 (SIGURJÓNSSON *et al.* 1991b). The index refers to the standardized period of 10 June through 20 July each year and measures the average number of whales caught as the first whale (usually a fin whale) in a trip per hour searching for each season. No statistically significant trend over time was observed in the data series for the period 1962-89, while considerable between-year variations were found.

Trends in biological parameters over time: Fin Whales off Iceland

AGE AND GROWTH

Growth layers in the waxy ear plug of baleen whales are widely used for age determination. The number of growth layers and the so-called transition phase layers in the plug (i.e. transition from irregular unevenly spaced growth layers to more compact and evenly spaced layering), allow examination of changes in growth rates and corresponding mean ages at sexual maturity in year classes back in time. LOCKYER (1981) investigated such changes in growth rate and time trend in age at sexual maturity in fin whales caught off Iceland and reported an apparent decline for both sexes from 11 years in the pre-1945 year classes to 8 years in the 1970 year class, based on material collected from the Icelandic fishery in the period 1967-79.

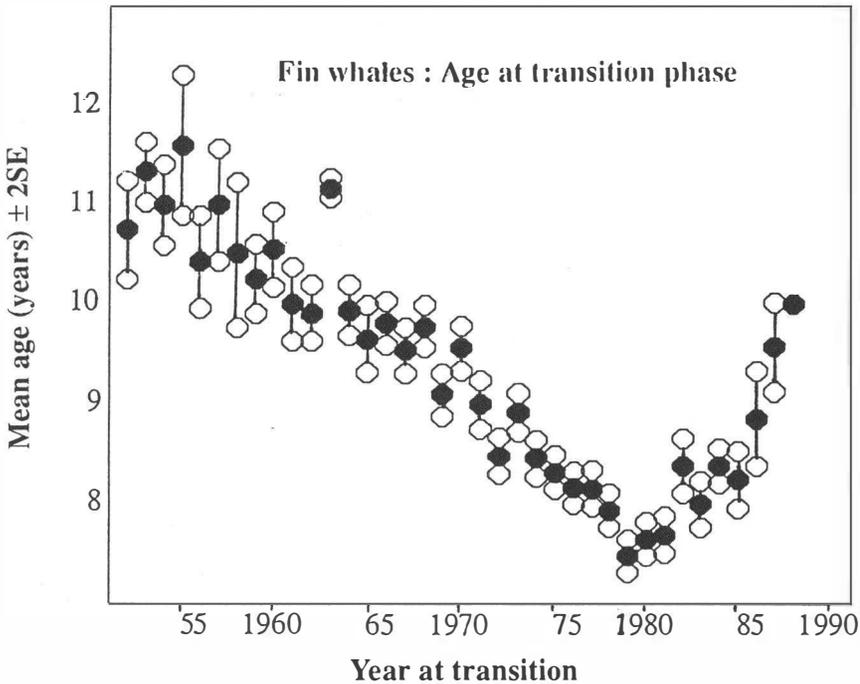


Fig. 7. — Trends in mean age (years) at sexual maturity in fin whales (both sexes combined) caught off Iceland by year of maturity for the period 1950-87, based on examination of ear plug growth layers and determination of transition phase in the plug (see also text).

Fin whales : Age at maturity (1st corpora)

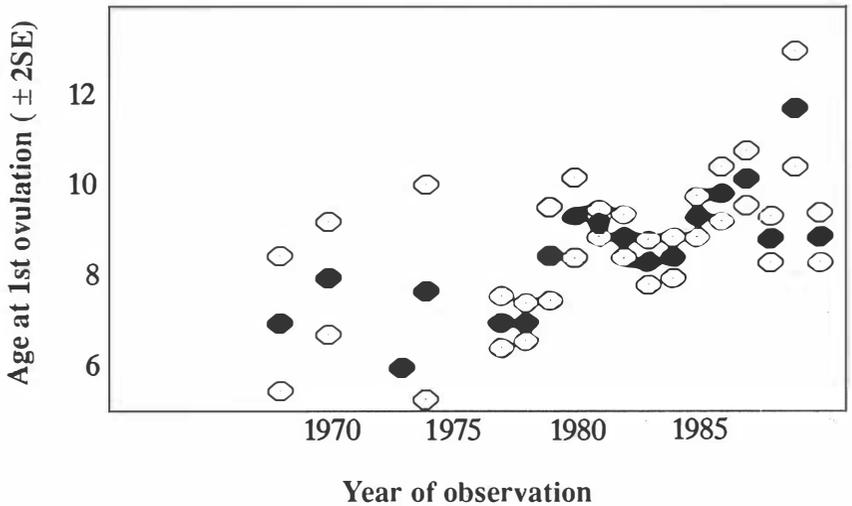


Fig. 8. — Trends in mean age (years) at sexual maturity in female fin whales caught off Iceland by year of observation, based on determination of mean age of first-time ovulators during the period 1967-89.

COOKE & DE LA MARE (1984), when discussing the apparent trends off Iceland, found the data were inconclusive. However, a revised analysis of the same data with an inclusion of data obtained in the period 1981-89 (Fig. 7), confirmed Lockyer's conclusion, but showed also a significant reversal trend in animals born after 1970, the age at maturity reaching 9-10 years for animals born around 1980 (KONRÁDSSON *et al.* 1991).

The observed reversal of trend in the transition phase was fully compatible with LOCKYER & SIGURJÓNSSON's (1990, 1991) findings in fin whales off Iceland, when mean ages at maturity were examined by direct biological observations on the catch during the period 1967 to 1989. In females (Fig. 8), the mean age at sexual maturity has risen from 6-7 to 9-10 years (depending on the method used); in males from 7 up to 11 years. A corresponding decrease in juvenile mean length at age over time was observed, which also is compatible with later attainment of sexual maturity, assuming a constant size at maturation. Thus it can be concluded, that major changes have taken place in growth rate of fin whales off Iceland during the past 40 years. This is the first time, that such reversal time trends in

biological parameters have been found in a large whale population. It is worth noting, that LOCKYER and SIGURJÓNSSON (1991) reported an indication of an increasing trend in growth rate in animals examined in the period 1985-89, although no firm conclusion can be made on this point at present.

REPRODUCTION

LOCKYER & SIGURJÓNSSON (1990, 1991) also made detailed studies on the relative fecundity of fin whales caught off Iceland during the period 1967-89, as measured by the proportion of mature females in the catch bearing an enlarged or active *corpus luteum* in the ovaries (Fig. 9). This was found to be almost identical to the apparent pregnancy rate (APR) in the stock.

The APR varied over the 23 year period, with a relatively low level during 1974-78, which coincided with relatively low foetal weight at length. There appeared to be an overall increasing trend in the APR in the late 1970's and the 1980's.

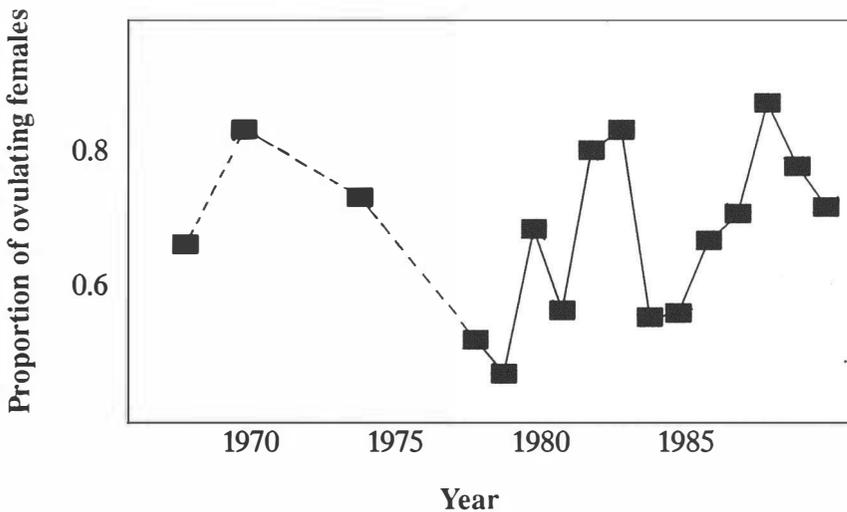


Fig. 9. — Apparent pregnancy rates in fin whales expressed as proportion of mature non-lactating females with an enlarged (active) *corpus luteum* in the ovaries, for the period 1967-89 (see also text).

Comparative analysis of observed trends and data on food abundance

In an attempt to throw some light on the observations made on abundance of whales and changes in biological parameters discussed above, regression analyses were performed using data on food abundance (euphausiids in three selected areas at or adjacent to the whaling grounds west and southwest off Iceland, and data series on 1-yr old capelin off Iceland), and data on stomach contents and blubber thickness of fin whales (examined at the land station in southwest Iceland) as explanatory variables. The parameters used were:

- Log-transformed indices of abundance of blue and humpback whales west and southwest of Iceland during summer, based on observations made onboard Icelandic whaling vessels (SIGURJÓNSSON and GUNNLAUGSSON 1990); available for 1970-74 and 1976-88;
- CPUE index (catch per unit effort relationship) for the fin whale fishery off Iceland, measured for all vessels in operation during 10 June-20 July each year as number of whales (mainly fins) caught as first whale in a trip per searching hour; available for the period 1962-89;
- Mean age (in years) at sexual maturity (t) by year of maturation (yt) in fin whales caught off Iceland based on transition phase readings in ear plugs, both sexes combined (see KONRÁDSSON *et al.* 1991); available for the period 1969-87 (Fig. 7), corresponding approximately to year classes 1959-77;
- Apparent pregnancy rate (APR) in fin whales 1967-89 (not including the years 1968, 1970-72, 1974-76), measured as proportion of mature females in the catch with an enlarged or active *corpus luteum* in the ovaries (Fig. 9);
- Stomach fullness in fin whales examined at the Icelandic land station during June-July, taken as proportion of animals (both sexes combined) with stomach half full or more;
- Mean blubber thickness in female fin whales examined at the Icelandic land station during July each year; measuring site: posterior ventral flank, V4 (see VÍKINGSSON 1990);
- Log-transformed indices of relative abundance of euphausiids for the months June through September as measured by the Continuous Plankton Recorder (CPR) scheme (see COLEBROOK 1975, LOCKYER 1986) in the area southwest (shallow waters) and south

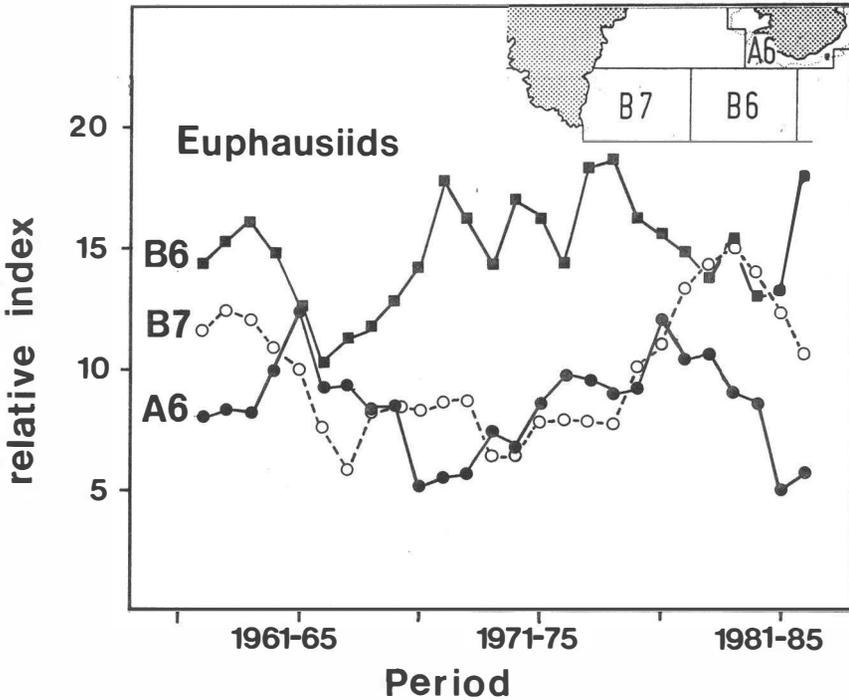


Fig. 10. — Relative indices of mean euphausiid abundance in three selected areas within or adjacent to the whaling grounds west and southwest of Iceland, Area A6, B6 and B7 (see top right corner), as revealed by the Continuous Plankton Recorder scheme; 5-year smoothed means for the months June-September 1957-86 (by the courtesy of the Sir Alister Hardy Foundation for Ocean Research, Plymouth, England).

of Iceland (CPR area A6, mainly on the Icelandic shelf north of 63°N and east of 25°W), in the deep waters to the southwest of Iceland (area B6, $59\text{--}63^{\circ}\text{N}$, $19\text{--}31^{\circ}\text{W}$), and between southern Greenland and Iceland (area B7, $59\text{--}63^{\circ}\text{N}$, $31\text{--}43^{\circ}\text{W}$), in the period 1957-86 (Fig. 10). In a few cases, data were missing for one or two months; then the average of the remaining months was used;

- Log-transformed index of capelin abundance (ton of 1-year old capelin in August each year), back-calculated from annual autumn/winter acoustic surveys by MRI research vessels (see VILHJÁLMSSON 1983, 1991) for the years 1977-89 (Fig. 11).

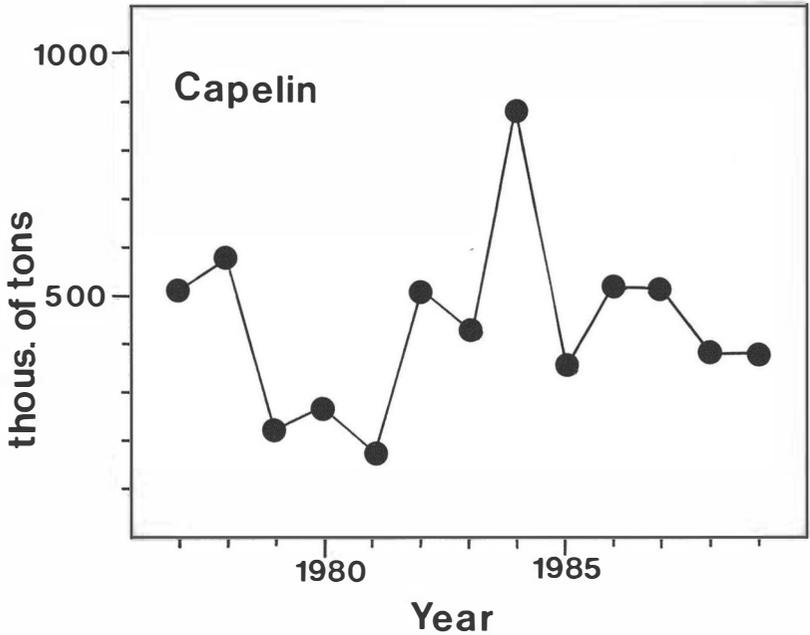


Fig. 11. — Mean August abundance (thousand metric tons) of juvenile (1-year old) capelin off Iceland based on yearly autumn/winter acoustic surveys 1977-89 (see VILHJÁLMSSON 1991).

ABUNDANCE OF BLUE, FIN AND HUMPBACK WHALES

Blue and Humpback Whales

In Tables 3 and 4 the results of the regression analyses for yearly abundance of humpback and blue whales are given. For both species there was a marked increase over the period 1970-88, and thus there appeared a strong correlation between the two species over time.

In all instances when humpbacks were related to year and a third variable (blue, CPUE, euphausiids, capelin, blubber thickness or stomach fullness of fin whales), the regression coefficient was significantly different from zero. This was mainly due to the substantial increase in the humpbacks during the period. However, when the year factor was eliminated, apart from the blue/humpback whale correlation, there was only found significant relationship between humpbacks and euphausiids in one of the three CPR- areas (area B7), and

Table 3

Regression analyses of annual trends in humpback whale abundance off Iceland and several explanatory factors for the period 1970-88

Variables			n	r	p	period
x	y	z				
yr	hump		18	.8245	***	1970-88
yr	hump	blue	18	.8309	**	1970-88
hump	blue		18	.7281	***	1970-88
yr	hump	cpue	18	.8269	***	1970-88
hump	cpue		18	.2112	NS	1970-88
yr	hump	cprA6	16	.7658	**	1970-86
hump	cprA6		16	.2078	NS	1970-86
yr	hump	cprB6	16	.7650	*	1970-86
hump	cprB6		16	-.0281	NS	1970-86
yr	hump	cprB7	16	.7870	**	1970-86
hump	cprB7		16	.5371	*	1970-86
yr	hump	stom	13	.7962	**	1973-88
hump	stom		13	-.2565	NS	1973-88
yr	hump	blub	13	.8250	**	1973-88
hump	blub		13	.5446	*	1973-88
yr	hump		12	.7167	**	1977-88
yr	hump	cap	12	.7178	*	1977-88
hump	cap		12	.2400	NS	1977-88

Variables: yr = year, period used depending on available variables; hump/blue = relative abundance of humpback/blue whales observed from whaling vessels; cprA6 = mean euphausiid abundance from CPR-plankton surveys in area A6; cprB6 and cprB7 = same, but in areas B6 and B7, respectively; cap = estimated abundance of 1-yr old capelin, based on annual acoustic surveys off Iceland; cpue = catch/effort relationship in the fin whale fishery off Iceland, 10 June-20 July, measured as number of whales (mainly fins) caught as first whale in a trip per hour searching; stom = freq. of half to full stomachs in fin whales examined June-July; blub = mean blubber thickness in July at the posterior ventral flank of female fin whales; *r* is the correlation coefficient and *p* indicates level of significance, where ***: $p < 0.001$; **: $p < 0.01$; *: $p < 0.05$; (*): $p < 0.1$; and NS: $p > 0.1$.

of humpbacks and blubber thickness in fin whales. The lack of trend in the fin CPUE data explains the lack of correlation between CPUE and humpback whale abundance. The euphausiid abundance in the three CPR-areas (Fig. 10) correlated in fact, very poorly, that shows how critical the selection of data series is in an analysis of this kind. While area A6 should best represent coastal (shallow) southwest to south Icelandic waters, the B6 and B7 are probably a better representation of the offshore waters near the traditional whaling grounds.

Table 4

Regression analyses of annual trends in blue whale abundance off Iceland and several explanatory factors during the period 1970-88

Variables			n	r	p	period
x	y	z				
yr	blue		18	.6708	**	1970-88
yr	blue	hump	18	.8309	***	1970-88
blue	hump		18	.7281	***	1970-88
yr	blue	cpue	18	.7425	**	1970-88
blue	cpue		18	-.1192	NS	1970-88
yr	blue	cprA6	16	.7390	**	1970-86
blue	cprA6		16	.2433	NS	1970-86
yr	blue	cprB6	16	.7259	**	1970-86
blue	cprB6		16	-.2165	NS	1970-86
yr	blue	cprB7	16	.7545	**	1970-86
blue	cprB7		16	.5804	*	1970-86
yr	blue	stom	13	.3164	NS	1973-88
blue	stom		13	.0019	NS	1973-88
yr	blue	blub	13	.7126	*	1973-88
blue	blub		13	-.1649	NS	1973-88

Variables: yr = year, period used depending on available variables; hump/blue = relative abundance of humpback/blue whales observed from whaling vessels; cprA6 = mean euphausiid abundance from CPR-plankton surveys in area A6; cprB6 and cprB7 = same, but in areas B6 and B7, respectively; cap = estimated abundance of 1-yr old capelin, based on annual acoustic surveys off Iceland; cpue = catch/effort relationship in the fin whale fishery off Iceland, 10 June-20 July, measured as number of whales (mainly fins) caught as first whale in a trip per hour searching; stom = freq. of half to full stomachs in fin whales examined June-July; blub = mean blubber thickness in July at the posterior ventral flank of female fin whales; r is the correlation coefficient and p indicates level of significance, where ***: $p < 0.001$; **: $p < 0.01$; *: $p < 0.05$; (*): $p < 0.1$; and NS: $p > 0.1$.

The relationship between blubber thickness in fin whales and humpback abundance, indicates that the food availability and preference of the two species is to some extent similar, although fin whales are apparently less piscivorous off Iceland during the summer season (the food mainly consisting of *Meganyctiphanes norvegica*; LOCKYER 1986, MRI unpubl. data) than elsewhere in the North Atlantic (see MITCHELL 1975). Furthermore, there is no evident relationship between humpback whales and abundance of juvenile capelin (preferred by humpbacks off Newfoundland; WHITEHEAD and CARSCADEN 1985), which one would have anticipated from the known

occurrence of juvenile capelin in summer, at least in some years, in the area between Greenland and Iceland (VILHJÁLMSSON 1983). But this is possibly simply due to the few data points available and the dramatic changes in the capelin stock (Fig. 11). The common appearance of humpback whales and capelin in the fishing grounds off Iceland during fall and winter has often been noted in recent years (MRI unpubl. data), and is in accordance with the general piscivorous feeding habits of the species in the North Atlantic (MITCHELL 1975). It should be added, however, that a significant relationship was found between capelin and euphausiid abundance in area B7 (leaving the year factor out for the period 1977-86; $r = 0.613$, $p = 0.059$). The same was the case for area A6 euphausiid mean for the current and preceding year ($r = 0.752$, $p = 0.012$).

The lack of correlation between blue whale abundance and the different parameters is even more striking than for humpback whales, the only significant relationship found (i.e. when the time factor was removed) was that of blue whales and euphausiids in area B7. Thus in general, the conclusion to be drawn from the relationships of the occurrence of both species with other parameters investigated, is that the indices are not measures of yearly variations of influx of the species into the whaling grounds west of Iceland caused by variations in food abundance, as was evident in the case off Newfoundland (WHITEHEAD & CARSCADDEN 1985) and the Gulf of Maine (P.M. PAYNE *et al.* 1990) baleen whales, but rather a long-term measure of true changes in these whale populations as discussed earlier in this paper.

Fin Whales

Some of the regression analyses made with respect to CPUE in fin whales are shown in Tables 3-4. Additional regression analyses did not show any significant correlations between fin CPUE and other parameters, except a marginal significance ($p < 0.1$) between CPUE and euphausiid abundance in area B6. This again indicates that yearly variations in food availability do not in general strongly influence the yearly occurrence of fin whales in the area west and southwest of Iceland, although one would assume that food availability would have long-term effects on the migration of whales into the area, as well as a general impact on the growth and development in the population (see below).

BIOLOGICAL PARAMETERS

Age at maturity

Table 5 gives the results of regression analyses of mean ages at maturity (t) by year of maturation (yt), based on examination of the ear plug transition phase, against average food abundance in the three CPR-areas for the approximate period from birth to sexual

Table 5

Regression analyses of annual trends in age at sexual maturity in fin whales caught off Iceland and their relation to food abundance for the approximate year classes 1959-77 (period of years of maturation 1969-87)

Variables			n	r	p	period
x	y	z				
t	yt		19	.0819	NS	1969-87 ¹
t	cprA6av	t	19	.4000	NS	1969-87
t	cprA6av		19	-.3496	NS	1969-87 ⁵
t	cprB6av	yt	19	.5277	(*)	1969-87 ⁶
t	cprB6av		19	-.3679	NS	1969-87 ⁴
t	cprB7av	yt	19	.4511	NS	1969-87 ⁷
t	cprB7av		19	.3070	NS	1969-87
t	yt		10	-.9418	***	1969-78 ²
t	cprA6av	yt	10	.9519	***	1969-78
t	cprA6av		10	.0662	NS	1969-78
t	cprB6av	yt	10	.9462	***	1969-78
t	cprB6av		10	-.7991	**	1969-78
t	cprB7av	yt	10	.9523	***	1969-78
t	cprB7av		10	.3507	NS	1969-78
t	yt		9	.9175	***	1979-87 ³
t	cprA6av	yt	9	.9216	***	1979-87
t	cprA6av		9	-.7807	*	1979-87
t	cprB6av	yt	9	.9335	**	1979-87
t	cprB6av		9	.0305	NS	1979-87
t	cprB7av	yt	9	.9488	**	1979-87
t	cprB7av		9	.6317	(*)	1979-87 ⁸

1. Approximate year classes 1959-77.

2. Approximate year classes 1959-70.

3. Approximate year classes 1971-77.

4. $p = 0.1212$.

5. $p = 0.1424$.

6. $p = 0.0735$.

7. $p = 0.1620$.

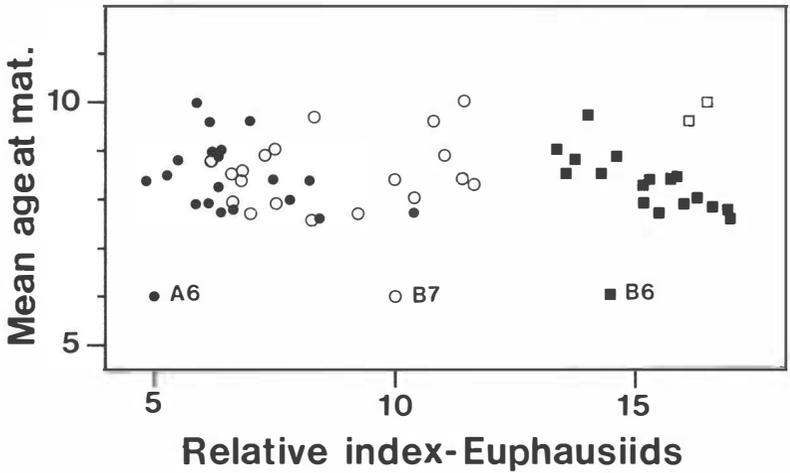
8. $p = 0.0680$.

Variables: t = mean age at maturity (in years) at any given year of maturation, yt , males and females combined, based on transition layer counts in ear plugs; cprA6av/cprB6av and cprB7av = mean abundance of euphausiids in areas A6/B6/B7 during the respective years approximately from birth to the attainment of sexual maturity.

maturity of the different year-classes. The lack of significance of the regression coefficients for t/yt for the period 1969-87 (approximate year-classes 1959-77) is in accordance with LOCKYER & SIGURJÓNS-SON'S (1991) and KONRÁDSSON'S *et al.* (1991) findings of reversal trend over time in age at sexual maturity as discussed above.

Considering the whole period 1969-87, the relationship between the different CPR-areas and the mean age at maturity, t , was not significant for any of the areas when the year factor (yt) was removed. A meaningful relationship of mean age at sexual maturity (t) and mean abundance of euphausiids in the period from birth to attainment of sexual maturity would be, that as the food becomes more abundant on average, the animals grow faster and reach maturity earlier and t would be low. Thus one would expect a negative correlation of t and the mean values of euphausiids in the respective periods of growth. As seen in Table 5 this was the case with respect to the t /euphausiid relationship for both areas A6 and B6, but not B7, while the regression coefficients were not significantly different from zero. An additional regression analysis was made on the t /euphausiid relationship in area A6 for the whole period, where instead of using mean t for each year of maturation and the respective mean abundance of euphausiids up to the year of maturation, the actual age at maturity for each animal was used and related to the mean euphausiid abundance in the respective years. This gave a very significant correlation ($p = 0.0002$, $n = 795$).

Table 5 also gives the statistics for the period split into two halves, the years of maturity (yt) 1969-78 and 1979-87, which correspond approximately to the year-classes 1959-70 and 1971-77, respectively. The regressions (yt vs. t) show that the t -trend with time was negative for the first part as the growth rate increased, while an increasing trend is evident for the latter part of the period, i.e. for animals born after 1970. For the first part a significant negative correlation was found between t and euphausiid abundance in area B6, and in the latter period for area A6. It could be argued, that the last data points in each series are biased because late maturing animals are under-represented. For area B6, the euphausiid data points for $yt = 1986$ and 1987 (see Fig. 12) are apparently «outliers». If these are excluded from the analysis, t and food abundance for the whole period up to and including 1985 are significantly negatively correlated ($p = 0.0001$); the same applies if only the years 1979-85 are considered ($p = 0.04$).



Apparent pregnancy rate

As seen in Figure 9, there appeared surprisingly high fluctuations between years in the apparent pregnancy rate (APR), but on average each mature cow had 1.3-1.4 calves per two year period. LOCKYER (1986, 1987) studied these fluctuations for the years 1977-84 and found them compatible with the body fat condition of the whales and the food resource (using the CPR-mean for the months July-September in area B7, and stomach fullness). VIKINGSSON (1990) analysed this further including data points upto 1988 as a part of a broader study of the energetic condition of different reproductive classes by means of anatomical measurements of blubber thickness and girths, as well as by chemical analysis of blubber and muscle tissues. He found pronounced yearly fluctuations in the energetic condition of the animals, which though were difficult to directly link to fluctuations in APR. The relationship between APR and blubber thickness (mean of two measurements M4 and V4, corrected for length of the animal, see VIKINGSSON 1990) was marginally insignificant ($p = 0.07$).

The APR upto 1989 was further investigated by the present author. This included examination of the relationship between APR and euphausiid abundance in the three areas A6, B6, and B7, capelin abundance, and stomach contents of fin whales the same year as well as considering the means for the same season and the preceding one. The relationship with mean blubber thickness in fin whales the same year (measured in females at site V4 only, see VIKINGSSON 1990) was also investigated.

Some of the results are given in Table 6. In general very poor correlations were found between APR and the «food» parameters, the only significant relationship revealed after the year factor was removed, was between APR and blubber thickness. When including the year factor, some significant correlations were found between APR in fin whales and capelin abundance. In general the food factors gave better statistics than the year/APR regressions alone.

Obviously, there are many factors affecting the reproductive success of the whales, and capturing these in a simple analysis of the APR and indicators of food supply is unlikely to yield conclusive answers as to the underlying reasons for the observed fluctuations. As discussed by LOCKYER (1987) and VIKINGSSON (1990), the fluctuations may very well be a result of feeding and other conditions on

Table 6

Regression analyses of annual trends in apparent pregnancy rates (APR) in fin whales caught off Iceland and their relation to food abundance

Variables			n	r	p	period
x	y	z				
yr	APR		16	.1016	NS	1967-89
APR	blub		16	.6619	**	1967-89
yr	APR		13	.5591	*	1977-89
yr	APR	cap	13	.6530	(*)	1977-89
yr	APR		12	.4770	NS	1978-89
yr	APR	cap-1	12	.6936	(*)	1978-89
yr	APR	stom	12	.7254	*	1978-89

Variables: APR = freq. of animals with an active corpus luteum in the ovaries; cap and blub as in Table 3; cap-1 mean values for the year of observation and the preceding year.

the grounds in more than one season. How far back in time and what additional factors could be used in studying this, needs further examination. Evidently, the inclusion of two-season effects of «food» parameters on the reproductive rate in the present study offered no further explanation of the between-year variations in APR. The only conclusion that can be drawn from this analysis, is that the whale itself, i.e. the monitoring of the body condition by anatomical or chemical analysis of the whale, seems the most promising means of exploring the factors affecting APR.

Conclusion

This paper shows that despite decades of exploitation the stocks of fin and minke whales (and probably sei whales) in the North Atlantic, particularly in Icelandic and adjacent waters, are still at high levels. It further demonstrates the recovery of two species of whales, blue and humpback whales, in the area after over 30 years of protection from commercial exploitation. The yearly fluctuations of main prey species of large baleen whales in the area between Greenland and Iceland do not seem to affect strongly the yearly migration of the whales into the grounds, although such factors undoubtedly have a major impact on the growth and development of

the populations as evident from the link found between food abundance and trends over time observed in age at sexual maturity in fin whales off Iceland.

The reduction of the fin whale stock the first years after the whaling off Iceland was resumed in 1948 is likely to have resulted in an increased food abundance per capita as suggested by LOCKYER (1981) and increased growth rate in the period 1950-70. However, the fin whale stock has been rather stable since the early 1960's (SIGURJÓNSSON *et al.* 1991b), so an increase in the stock can not have produced the reversed trends in growth and age at maturity in the 1970's. This needs therefore also be considered in a broader ecosystem perspective. The major changes in the marine environment around Iceland in the late 1960's (e.g. MALMBERG 1986), contributing to the collapse of several of the herring (*Clupea harengus*) stocks (JAKOBSSON 1969, 1985) and drastic changes of abundance of calanoid zooplankton (ÁSTTHÓRSSON *et al.* 1983) are for instance factors that are likely to have affected the livelihood of whales inhabiting these waters, either directly or indirectly. Major changes in year-class strength, growth and biomass of some fish stocks in Icelandic waters (MALMBERG 1986, STEINARSSON & STEFÁNSSON 1991) in the past 20 years, partly due to human exploitation, such as in the case of capelin (VILHJÁLMSOON 1983, 1991), must also play a role in this context. The large scale exploitation of capelin off Iceland commenced not until around 1970. This may have introduced an increase in competition between whales feeding on capelin, such as humpback and fin whales or between whales and fish species that were to shift to common food with whales due to shortage of capelin as a food. But, apart from such hypothetical suggestions, given that food supply is a limiting factor for the well-being of the whales, one would anticipate that both the increase in blue and humpback whales in recent decades may have significantly influenced the potential for growth in the fin whale population, since the three species exploit similar trophic levels.

All these factors and many others need closer examination, but also there is a need for improved understanding of the feeding strategies of the whales, including where exactly and when the animals feed. Monitoring animals by satellite tags over a prolonged period of time could assist in this. Improved quantitative sampling of the principal prey species, particularly of euphausiid species in Icelandic and adjacent waters, is also of primary importance for

future studies on interactions of whales and other marine life in this ocean area and for management of the resources in the future.

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DISTRIBUTION AND FOOD INTAKE OF SEABIRDS AND MARINE MAMMALS IN THE NORWEGIAN AND GREENLAND SEAS (JULY 1988)

BY

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SUMMARY. — During the ARK V/3 expedition of *RV Polarstern* in the Norwegian and Greenland Seas in July 1988, 360 half an hour counts for seabirds, pinnipeds and cetaceans were carried out. Results are presented as total numbers encountered and then converted into density and food intake. Total food intake was 2 kg fresh weight per km² per day: 1.1 for seabirds, with higher values in open water (1.4 in Atlantic water, 1 in Polar water), low value in the pack ice: 0.3, and intermediate level at the ice edge: 0.7; the main species were the Fulmar *Fulmarus glacialis* (0.6, mainly light morph), the alcids (0.36, of which 0.27 for the Brünnich's Guillemot *Uria lomvia*) and the Kittiwake *Rissa tridactyla* (0.07). The food intake by cetaceans (rough evaluation due to limited sample) was 0.3 kg/km²/day, with a maximum of 0.7 in Atlantic water. The food intake by pinnipeds was 0.6 kg/km²/day; they were mainly hooded seals *Cystophora cristata*, with a mean intake of 2.3 at the ice edge.

Introduction

In marine ecology, one still tends to give too little attention to the higher trophic levels—seabirds, pinnipeds and cetaceans.

The knowledge of seabirds is generally good as far as their breeding colonies are concerned (e.g. CROXALL *et al.* 1984), but less is known about their distribution at sea. Such data, however, provide important information, not only about the ecology of seabirds, but also about the ecological structure and the functioning of the

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ecosystems to which they belong (JOIRIS 1978; JOIRIS *et al.* 1982; CROXALL 1987).

The breeding populations of, for example, the alcids around the Norwegian and Greenland Seas are well studied and concern, in millions of pairs: 0.53 Razorbill *Alca torda*, mainly in Iceland; 2.5 Common Guillemot *Uria aalge* (of which 1.6 in Iceland and 0.75 in Bear Island); 4.9 Brünnich's Guillemot *U. lomvia* (2 in Iceland, 1 in Spitsbergen, 1 in Novaya Zemlya and 0.75 in Bear Island); 1.6 Little Auk *Alle alle* (1 in Spitsbergen); 0.12 Black Guillemot *Cephus grylle* and 4.3 Puffin *Fratercula arctica* (3 in Iceland and 1.3 in Norway) (NETTLESHIP & BIRKHEAD 1985).

Pinnipeds are mainly represented by ringed seal *Phoca hispida hispida* (0.1 to 3 observed per km² all zones of their distribution considered together: FROST & LOWRY in RIDGWAY & HARRISON 1981), hooded seal *Cystophora cristata* (230,000 observed moulting in the Denmark Strait: REEVES & LING in RIDGWAY & HARRISON 1981), bearded seal *Erignathus barbatus* (300,000 for the whole North Atlantic region, including the North, White, Barents, Kara and Laptev Seas: BURNS in RIDGWAY & HARRISON, 1981) and harp seal *Phoca groenlandica* (100,000 in the «West Ice», the Jan Mayen sector of the Greenland Sea: RONALD & HEALEY in RIDGWAY & HARRISON 1981, corresponding to an annual pup production of about 30,000, ICES 1990). The walrus *Odobenus rosmarus* is present in small numbers, with «no more than a few hundred individuals» for the East Greenland and Spitsbergen populations (HAY in RIDGWAY & HARRISON 1981).

Among the large cetaceans, the sperm whale *Physeter macrocephalus* shows a very extensive distribution; in the North Atlantic an estimated population of 190,000 individuals is present, of which 60,000 are males (only males are present north of 45-50°N) (RICE in RIDGWAY & HARRISON 1989). The bottlenose whale *Hyperoodon ampullatus* is considered to be depleted in the North Atlantic, but the importance of this depletion is poorly known (MEAD in RIDGWAY & HARRISON 1989). The baleen whales are mainly minke whale *Balaenoptera acurostrata* (110,000 in the North East Atlantic: STEWART & LEATHERWOOD in RIDGWAY & HARRISON 1985).

The aim of this study is to determine the summer distribution at sea of seabirds and marine mammals in the North East Atlantic Ocean, and their ecological role in terms of food intake.

Material and methods

One of us (JTa) participated in the ARK V/3 expedition of the German icebreaking *RV Polarstern* in the Norwegian and Greenland seas, from July 6 till August 1, 1988 (Fig. 1).

Counts were carried out from the bridge, 17 m above sea level, during standard half hour periods, without any width limit. A total of 360 half hour counts were devoted to counting the higher trophic levels, when the ship was moving—but the difference between a moving and a stationary ship sometimes becomes very tiny in the closed pack! When the ship was stationary in open sea for hours, birds sometimes accumulated around her, apparently looking for shelter under the wind; up to more than 1,500 birds were so counted together around the stationary ship (*Fulmar Fulmarus glacialis*, Glaucous Gull *Larus hyperboreus*, Kittiwake *Rissa tridactyla*, Arctic Tern *Sterna paradisaea*, Skuas *Stercorarius sp.*, etc.), whereas counts by moving ship immediately before and afterwards showed the presence of less than 50 exemplars (Table 1).

In order to calculate densities, seabirds transect counts are often limited to a fixed width (300 m). We however considered that some species (e.g. Storm Petrel *Oceanites*, alcids sitting on the water) could not be quantitatively detected as far as 300 m away from the ship, and that other species can be detected at much larger distances (e.g. Gannet *Sula bassana*). Moreover in ice-covered areas, the ship tends

Table 1

Numbers of Fulmars and Gulls attracted by stationary Polarstern

Station number	Date 1988	Observation		Ship's speed (knots)	<i>Fulmarus glacialis</i>		<i>Rissa tridactyla</i>	<i>Larus hyperboreus</i>
		from	to		light	dark		
237 + 238	July 22	19.52	20.52	10.2	5	12	5	0
239 + 240	July 22	21.15	22.15	10.1	7	16	4	0
241 + 242	July 22	22.45	23.45	10	9	17	9	0
A *	July 23	6.00	6.05	0	100	120	400	6
B *	July 23	11.00	11.05	0	250	250	1,000	16
243 + 244	July 23	13.43	14.43	13.9	5	21	13	1
245 + 246	July 23	14.58	15.58	13.8	2	18	7	0
247 + 248	July 23	16.48	17.48	13.9	8	24	1	0

* 16 sea miles West of Spitsbergen.

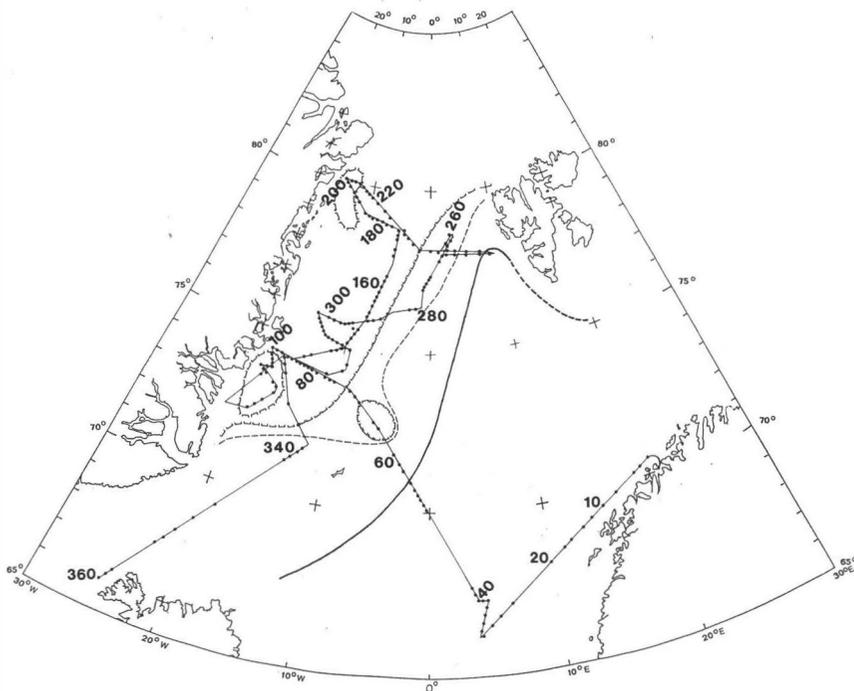


Fig. 1. — Map showing the route of *RV Polarstern* during the ARK V/3 expedition in the Norwegian and Greenland Seas, July 6 till August 1, 1988. The dots represent the position of the counts for seabirds and marine mammals. Each dot represents two successive half an hour counts. The limit between the main zones is also shown: Atlantic water, polar water, ice edge, pack ice, polynyas (see text).

to follow an easier route in open leads, where animals also tend to concentrate: this causes an important bias in the results, especially if the transect width is limited. In the case of marine mammals, the 300 m transect could not be applied for evident reasons. This is why we decided to count seabirds and marine mammals during transects with unlimited width. The actual width of the covered area was evaluated for each species on the basis of existing specific conversion factors (CROSSIN 1974; WIENS *et al.* 1978; BOURNE 1982; DIAMOND *et al.* 1986) and personal experience (JOIRIS 1989, 1991a, 1991b). During other cruises, both methods were compared and the results were strongly correlated (JOIRIS *et al.* in prep.). These factors take mainly into account the conspicuousness of the different species, depending on colour pattern, size and fizz. In order not to correct for other local factors such as light conditions, state of the sea, etc., the

conversion was not applied on every count separately, but on the mean (or median) value for a complete zone.

Problems in the determination of densities of seabirds are the existence of «followers» accompanying the ship, sometimes for long periods, and the possible movements of birds, e.g. between breeding place and feeding grounds or from one zone to another (migration). Such data cannot be expressed as density; they are not influenced by the speed of the ship and should not be extrapolated without causing a large overestimate of the density (see WIENS *et al.* 1978). Only the third type of observations concerns birds really belonging to the zone where they were encountered and were translated into density, knowing the ship's speed and evaluating the width of the transect actually surveyed. This concerns birds sitting on the water or showing local movements: no correction was introduced for locally flying birds (see GOULD *et al.* 1978; BURNHAM *et al.* 1980).

The results are interpreted as a function of the main water masses, which have been defined by their salinity and temperature, which correspond to differences in ecological structure (JOIRIS 1978; JOIRIS *et al.* 1982); in this study the available information was water temperature and our own data on the ice cover. We recognized four main zones:

- Atlantic water: $> 5^{\circ}\text{C}$ (as warm as 11.8°C closer to the Norwegian coast, but this category was geographically too limited to be used);
- Polar open water: less than 5°C with a minimal value of 1.4° ;
- Pack ice: ice floes or pack ice visible in all directions;
- Ice edge: in open water, with visible pack ice (at distances less than 15 km) or in the pack ice, with visible ice edge (less than 5 km) or marginal ice zone with low density of ice floes.

The category «polynya» could not be used in this study, because of the limited presence of the ship in polynyas and of a heavy mist causing no visibility conditions during a transect in the North East Water (East Greenland, 80°N).

Results and discussion

1. COMMENTS ON SELECTED SPECIES (see Table 2 and Figs. 2 to 12)

- The Fulmar *Fulmarus glacialis* was encountered everywhere but mainly in open Atlantic water, where the light morph was, as

Table 2

Total numbers of seabirds and marine mammals observed in the Norwegian and Greenland Seas in July 1988 (each count = half an hours)

		Zone	Atlantic	Polar	Ice	Pack	Total
Species	Number of counts	water	water	edge	ice		360
		69	27	46	218		
<i>Fulmarus glacialis (dark)</i>	Fulmar (dark)	94	34	172	450		750
<i>Fulmarus glacialis (light)*</i>	Fulmar (light)*	1,602	708	142	443		2,895
<i>Fulmarus glacialis (light)</i>	Fulmar (light)	45,602	708	142	443		46,895
<i>Sula bassana</i>	Gannet	3	0	0	0		3
<i>Stercorarius skua</i>	Great Skua	0	0	0	2		2
<i>St. parasiticus</i>	Arctic Skua	7	3	0	4		14
<i>St. longicaudus</i>	Long-tailed Skua	0	1	2	2		5
<i>Pagophila eburnea</i>	Ivory Gull	0	0	2	128		130
<i>Larus hyperboreus</i>	Glaucous Gull	20	0	3	23		46
<i>L. glaucoides</i>	Iceland Gull	6	0	0	0		6
<i>L. marinus</i>	Great Black-backed Gull	5	0	0	0		5
<i>L. fuscus</i>	Lesser Black-backed Gull	2	0	0	0		2
<i>L. argentatus</i>	Herring Gull	45	0	0	0		45
<i>L. canus</i>	Common Gull	3	0	0	0		3
<i>Rissa tridactyla*</i>	Kittiwake*	221	177	69	72		539
<i>Rissa tridactyla</i>	Kittiwake	2,821	177	69	72		3,139
<i>Xema sabini</i>	Sabine's Gull	0	0	1	3		4
<i>Sterna paradisaea</i>	Arctic Tern	25	5	0	9		39
<i>Alca torda</i>	Razorbill	86	0	0	0		86
<i>Uria aalge</i>	Common Guillemot	52	19	0	0		71
<i>Uria lomvia</i>	Brünnich's Guillemot	47	349	82	12		490
<i>Alle alle</i>	Little Auk	3	41	162	225		431
<i>Cephus grylle</i>	Black Guillemot	0	0	2	9		11
<i>Fratercula arctica</i>	Puffin	31	10	14	3		58
	Σ birds*	2,252	1,347	651	1,385		5,635
	Σ birds	48,852	1,347	651	1385		5,2235
<i>Orcinus orca</i>	killer whale	2	0	0	0		2
<i>Physeter macrocephalus</i>	sperm whale	4	1	0	0		5
<i>Hyperoodon ampullatus</i>	northern bottlenose whale	0	1	3	0		4
	whale sp.	1	0	0	0		1
	Σ whales	7	2	3	0		12
<i>Odobenus rosmarus</i>	walrus	0	0	0	1		1
<i>Phoca hispida</i>	ringed seal	0	0	2	29		31
<i>Phoca groenlandica</i>	harp seal	0	0	1	2		3
<i>Halichoerus grypus</i>	grey seal	0	0	1	4		5
<i>Erignathus barbatus</i>	bearded seal	0	0	0	3		3
<i>Cystophora cristata</i>	hooded seal	0	0	551	9		560
	seal sp.	0	1	3	48		52
	Σ pinnipeds	0	1	558	96		655
<i>Ursus maritimus</i>	ice bear	0	0	0	2		2

* Without taking into account an important concentration of Fulmars and Kittiwakes off Iceland (see text).

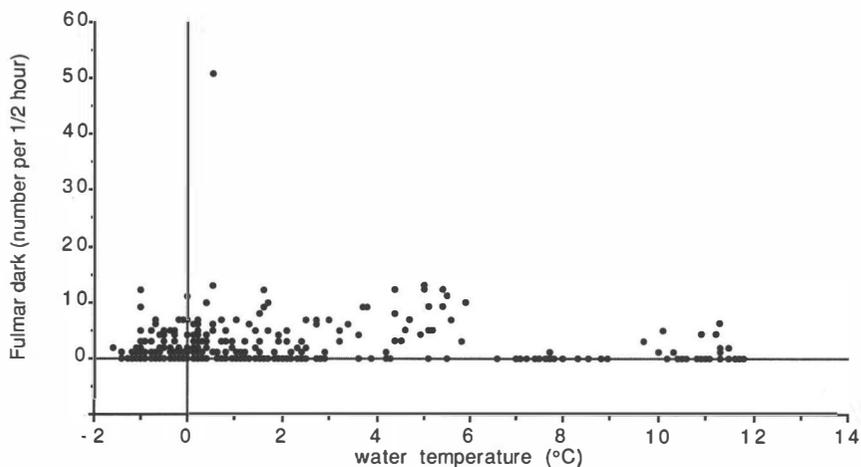


Fig. 2. — Numbers of Fulmar *Fulmarus glacialis*, dark morph, observed per half hour, as a function of the seawater temperature (degrees C).

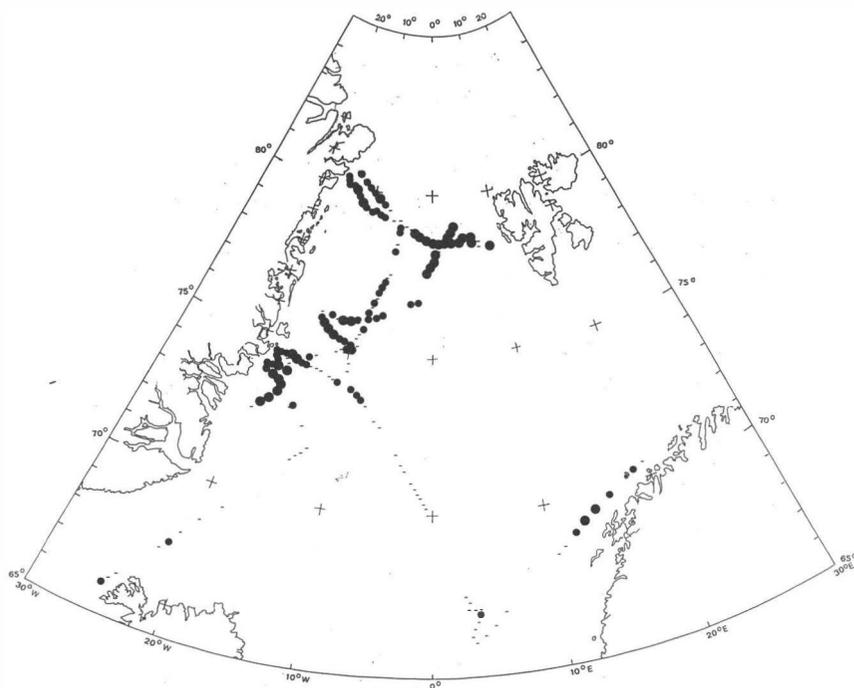


Fig. 3. — Map showing the distribution of the Fulmar *Fulmarus glacialis*, dark morph. Four classes: nihil; 1-5; 6-25; 26-125 birds per hour (see legend Fig. 1).

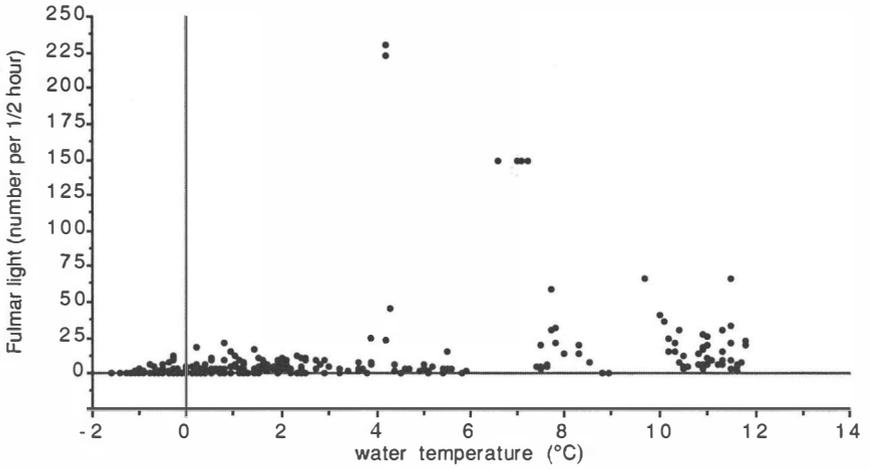


Fig. 4. — Numbers of Fulmar *Fulmarus glacialis*, light morph, observed per half hour, as a function of the seawater temperature, without taking into account an important concentration of 44,000 birds at four stations off Iceland (see text).

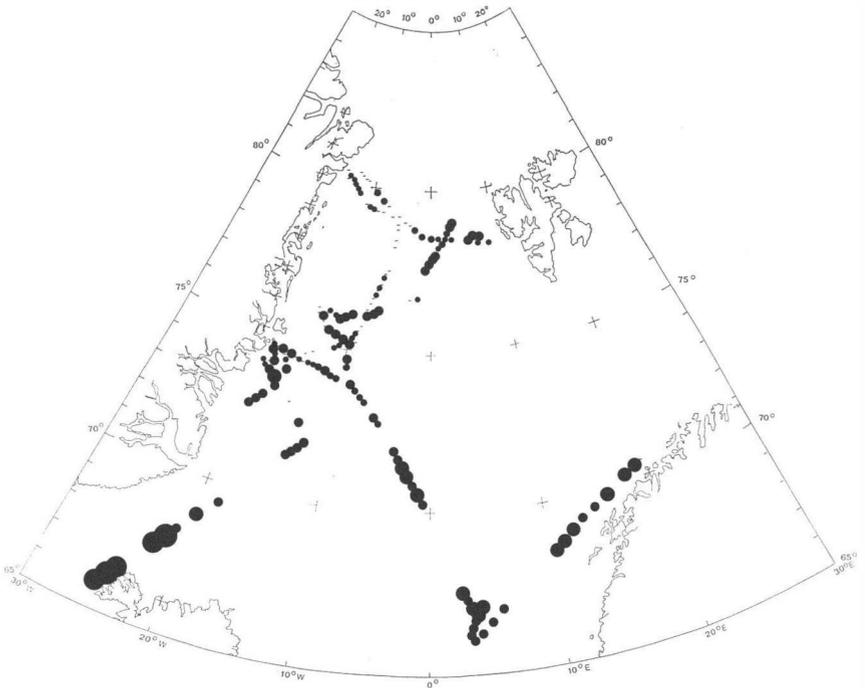


Fig. 5. — Map showing the distribution of the Fulmar *Fulmarus glacialis*, light morph. Five classes: nihil; 1-5; 6-25; 26-125; >125 birds per hour (see legend Fig. 1).

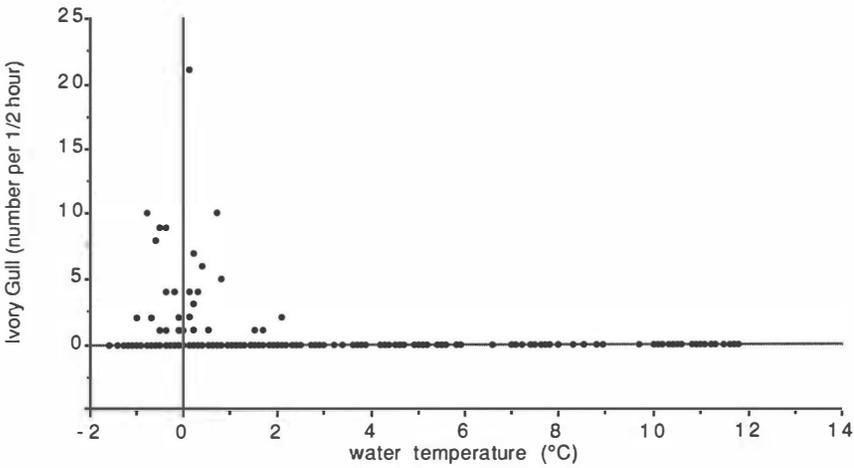


Fig. 6. — Numbers of Ivory Gull *Pagophila eburnea* observed per half hour, as a function of the seawater temperature.

expected, dominating the avifauna and represented more than 70% of the total; this figure becomes even much more important if a concentration of 44,000 birds were included (stations 355 to 358: Atlantic water off Iceland). The dark morphs were mainly present in Polar water, in Atlantic water with temperatures lower than 6°, at the ice edge and in the pack ice (Figs. 2-5). Fulmars were seldom observed feeding; this only happened in the leads of the pack ice, where they were swimming and picking food items (zooplankton?) under the water surface.

— Ivory Gulls *Pagophila eburnea* were encountered in low numbers only, in the pack ice zone (Fig. 6). Most of them were «local» birds sitting on ice floes in small flocks and difficult to detect, but by their black legs.

— The distribution of the Kittiwake *Rissa tridactyla* reflects its presence in all zones, with a clearly lower density at the ice edge and in the pack ice; from a total of 3,139 local birds encountered, an important concentration of 2,600 individuals was observed off Iceland at stations 354 to 358, together with the Fulmars, was considered as exceptional and was not integrated in the calculations. Kittiwakes were sometimes observed moving between breeding and feeding zones, but to a limited extent only: 309 moving birds in comparison with 3,139 local ones. A total of 43 sub-adults only were

encountered, 40 of them at the 60 first stations: this could reflect a geographical separation of the Kittiwakes as a function of age, or the end of the moulting period, so that all birds showed an adult summer plumage after July 10.

— Four Sabine's Gull *Xema sabini* were counted, concerning at least 3 individuals: 2 adults on an ice floe at station 212 and one adult flying south at station 220 on July 21, and a flying juvenile at station 238 on July 22.

— Among the alcids, the Common and Brünnich's Guillemots were clearly bound to open water: the former in Atlantic water, the second at higher density in Polar water and the ice edge (Figs. 7-10). The Common Guillemot was only present at two local (frontal?) zones, at seawater temperatures of 7 and 4° respectively, off the coasts of Norway and Iceland (Figs. 7 & 8).

— Almost as common as the Brünnich's Guillemot, the Little Auk showed high densities in Polar water, at the ice edge and, to a less extent, in the pack ice (Figs. 11 & 12). They were regularly observed swimming around ice floes and feeding in crevices where zooplankton might have been accumulating in melting ice.

A significant part of all counted alcids were moving, mainly along an East-West axis between their breeding colonies in Spitsbergen and their feeding grounds, and were not included in the calculations because they represent a flux rather than a density and, from the ecological point of view, do not belong to the zones they fly across. This was the case of Common Guillemot (71 local birds, 23 moving), Brünnich's Guillemot (490 local, 469 moving), Little Auk (431 local, 270 moving) and Puffin (58 local, 96 moving).

Juvenile Razorbill *Alca torda* (16 individuals) and Common Guillemot (8) were observed on August 1 only, at stations 355 to 358; no other species was represented by juveniles during this trip.

— The Black Guillemot *Cephus grylle*, a coastal bird, has been noted at 6 stations: the 11 birds were observed at, and close to, the ice edge.

All those data do fit with observations in a similar zone by MELTOFTE (1972) and MELHUM (1989). From a quantitative point of view, we compared our summer data with the observations of BROWN (1984) in February-March 1982 in the same region. He counted

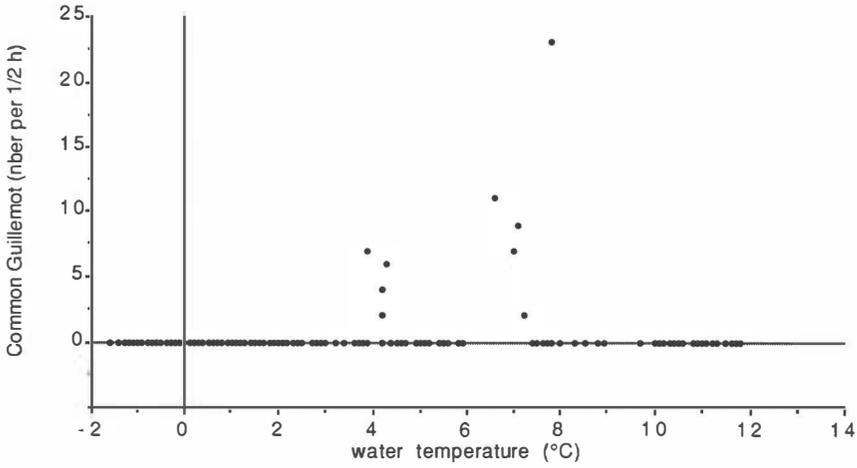


Fig. 7. — Numbers of Common Guillemot *Uria aalge* observed per half hour, as a function of the seawater temperature.

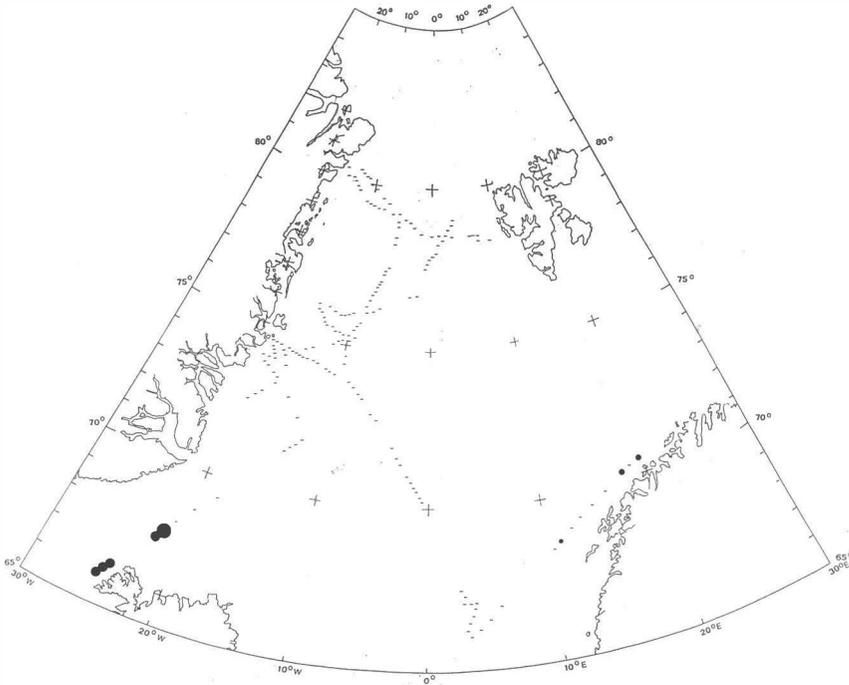


Fig. 8. — Map showing the distribution of the Common Guillemot *Uria aalge*. Four classes: nihil; 1-5; 6-25; 26-125 birds per hour (see legend fig. 1).

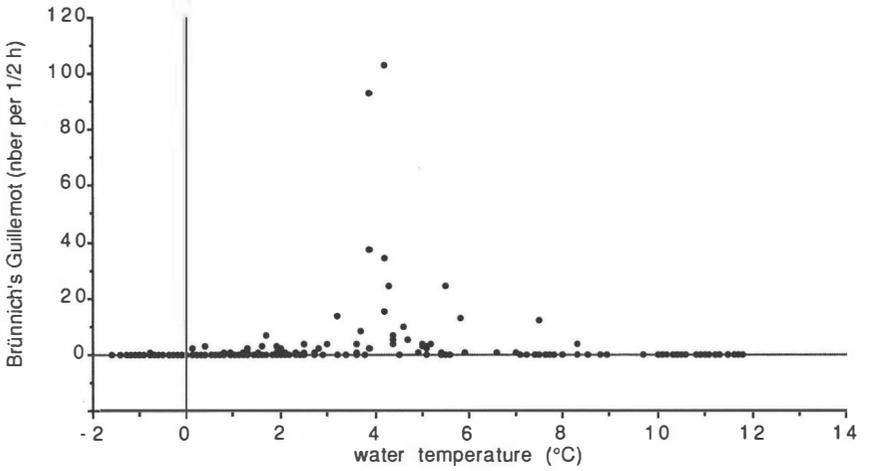


Fig. 9. — Numbers of Brännich's Guillemot *Uria lomvia* observed per half hour, as a function of the seawater temperature.

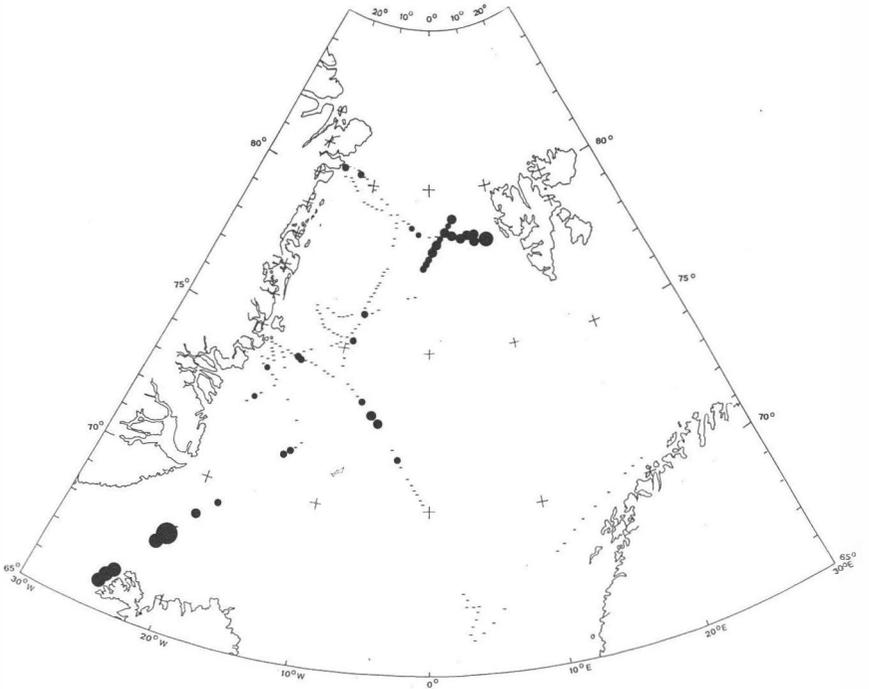


Fig. 10. — Map showing the distribution of the Brännich's Guillemot *Uria lomvia*. Four classes: nihil; 1-10; 11-100; >100 birds per hour (see legend Fig. 1).

comparable numbers of Fulmars : 0.4 to 1 birds per km, with maxima of 2 to 4 off the coasts of Spitsbergen, Iceland and Norway; the proportion of light morphs was however much higher in polar water, remaining as high as 10 to 25%. The density of Ivory Gull was slightly higher, with 0.1 and 0.3 birds per km in the northern zone and off Jan Mayen. Numbers of Kittiwake were comparable in the southern regions (0.8 per km), but lower in the northern polar water (0.01 to 0.1 instead of 0.65 in July). Numbers of Guillemots were much lower in February-April: he noted almost no Guillemot in Polar water with maxima of 0.1 to 0.5 off the coasts, while our July figures show mean values of 1.3 birds per km in Polar water. The distribution of Little Auk was similar, with 1.4 to 0.6 birds per km in February-March (0.15 to 0.54 in July) but higher values in the South: 0 to 0.8, and even 2.5 North of the Faeroes (0.01 in Atlantic water in July). This comparison shows that the results obtained by BROWN (1984) are basically similar to ours, the main differences in distribution reflecting differences between late winter distribution in February-March versus summer distribution in July.

In July 1973, a transect between Norway and Spitsbergen showed important concentrations of seabirds (Kittiwake, Razorbill, Little Auk and Guillemots) near the breeding colonies (BYRKJEDAL *et al.* 1974). The importance of such concentrations, however, was enhanced by the fact that main breeding colonies: Flugöy (Norway), Bear Island and Sörkapp (Spitsbergen) were approached during a very short, two-day trip.

— Only very low numbers of cetaceans were noted.

— Out of a total of 654, pinnipeds were mainly represented by 560 hooded seals *Cystophora cristata*, of which a concentration of 550 at station 265, on the ice edge. The other pinnipeds were lying on the ice along leads or crevices in which they dive and disappear when the ship approached.

An adult walrus *Odobenus rosmarus* was swimming between floes at station 142 (75° 20' N, 8° 58' W).

— The polar bear *Ursus maritimus* was encountered twice, at an interval of 83 hours and a distance of 160 km along the 79°N transect (stations 91 and 114).

2. FOOD INTAKE BY SEABIRDS AND MARINE MAMMALS

The results (Table 1) are expressed as numbers per count (per half an hour). They are then calculated as densities by using a specific conversion factor reflecting at which distance animals could be detected and the mean ship's speed in the different geographical zones. The density is translated into daily food ingestion by the equation

$$I = 0,191.W^{0.723}.N \quad (1)$$

where I is the ingestion in kg fresh weight/km²/day, W the individual biomass in kg, and N the density in numbers per km².

This equation is derived (SCHNEIDER *et al.* 1987) from the allometric formula of LASIEWSKI & DAWSON (1967) for the standard metabolic rate (SMR), a conversion factor of 2.8 SMR for calculation of the daily food requirement (KOOYMAN *et al.* 1982) and conversion factors of 1.33 for a 75% assimilation efficiency and of 6.37 kJ/g fresh weight. Fresh weight values should be divided by 10 in order to calculate carbon content.

The equation was established for seabirds, but the equivalent allometric relation for mammals ($Q = 70.W^{0.7325}$, in kcal/day) was considered similar enough to apply the same equation (1) to all homeotherms. Other equations such as food requirement = 4% of W /day, or the daily requirements already calculated for minke and fin whales (LOCKYER 1981) also provide values of the same order of magnitude.

Considering the important concentration of Fulmars and Kittiwakes off Iceland as a special phenomenon, and thus without taking these results into account, the calculated food intake by seabirds represents about 1.1 kg fw/km²/day, with higher values in open water (1.4 in Atlantic and 1 in Polar water), low values in the pack ice: 0.3, and intermediate level at the ice edge: 0.7 (tables 3 and 4). Our results (0.14 gC/m²/year in Atlantic water and 0.1 in polar water, if these summer values were extrapolated to the whole year) can be compared with data obtained in 1980 and 1981 in the southeastern Bering Sea: figures varied between 0.12 and 0.59 gC/m²/year, depending on the geographical zone and the year (SCHNEIDER *et al.* 1986).

The mean food intake by whales was 0.3, with a maximum of 0.7 in Atlantic water. This conclusion, however, depends on very low numbers of observations and therefore represents only a very rough evaluation.

Table 3

Calculated ingestion rate by vertebrates in the Norwegian and Greenland seas, July 1988
(kg fresh weight/km².day; species presenting values lower than 0.005 were omitted)
(see text)

Mean ship's speed (knots)	Specific conversion factor	Biomass (kg)	Zone				Mean
			Atlantic water	Polar water	Ice edge	Pack ice	
			8.80	11.10	7.10	7.40	
<i>Fulmarus glacialis</i> (dark)	2.4	0.70	0.06	0.04	0.20	0.11	0.10
<i>Fulmarus glacialis</i> (light) *	2.0	0.80	0.94	0.84	0.15	0.10	0.51
<i>Fulmarus glacialis</i> (light)	2.0	0.80	26.68	0.84	0.15	0.10	6.94
<i>Pagophila eburnea</i>	2.0	0.50	0.00	0.00	0.00	0.02	0.01
<i>Larus hyperboreus</i>	2.4	1.50	0.02	0.00	0.01	0.01	0.01
<i>L. marinus</i>	2.8	1.60	0.01	0.00	0.00	0.00	0.00
<i>L. argentatus</i>	2.4	1.10	0.04	0.00	0.00	0.00	0.01
<i>Rissa tridactyla</i> *	2.2	0.42	0.09	0.14	0.05	0.01	0.07
<i>Rissa tridactyla</i>	2.2	0.42	1.14	0.14	0.05	0.01	0.34
<i>Alca torda</i>	3.6	0.72	0.08	0.00	0.00	0.00	0.02
<i>Uria aalge</i>	3.6	1.00	0.06	0.05	0.00	0.00	0.03
<i>Uria lomvia</i>	3.6	0.92	0.05	0.82	0.18	0.01	0.27
<i>Alle alle</i>	4.0	0.16	0.00	0.03	0.11	0.03	0.04
<i>Fratercula arctica</i>	3.6	0.46	0.02	0.01	0.02	0.00	0.01
Σ birds *			1.40	0.95	0.73	0.28	1.09
Σ birds			28.18	0.95	0.73	0.28	7.78
<i>Orcinus orca</i>	0.3	4,000	0.08	0.00	0.00	0.00	0.02
<i>Physeter macrocephalus</i>	0.2	35,000	0.53	0.27	0.00	0.00	0.20
<i>Hyperoodon ampullatus</i>	0.3	3,000	0.00	0.07	0.19	0.00	0.06
whale sp.	0.2	10,000	0.05	0.00	0.00	0.00	0.01
Σ whales			0.67	0.34	0.19	0.00	0.30
<i>Phoca hispida</i>	0.3	50	0.00	0.00	0.01	0.02	0.01
<i>Phoca groenlandica</i>	0.3	125	0.00	0.00	0.01	0.01	0.01
<i>Halichoerus grypus</i>	0.5	200	0.00	0.00	0.01	0.01	0.01
<i>Erignathus barbatus</i>	0.5	200	0.00	0.00	0.00	0.01	0.00
<i>Cystophora cristata</i>	0.2	125	0.00	0.00	2.31	0.00	0.58
seal sp.	0.3	120	0.00	0.01	0.02	0.07	0.02
Σ pinnipeds			0.00	0.01	2.36	0.12	0.62

* Without taking into account an important concentration of Fulmars and Kittiwakes off Iceland.

Table 4

Synopsis of the main results obtained in the Norwegian and Greenland Seas in July 1988

Zone	Atlantic water	Polar water	Ice edge	Pack ice	Mean
Species number of counts	69	27	46	218	
Numbers per 1/2 hour					
<i>Fulmarus glacialis (dark)</i>	1.4	1.0	3.7	2.1	2.1
<i>Fulmarus glacialis (light) *</i>	23.2	20.8	3.1	2.0	12.3
<i>Fulmarus glacialis (light)</i>	660.9	20.8	3.1	2.0	130.3
<i>Pagophila eburnea</i>	0.0	0.0	0.0	0.6	0.2
<i>Rissa tridactyla *</i>	3.2	5.2	1.5	0.3	2.6
<i>Rissa tridactyla</i>	40.9	5.2	1.5	0.3	8.7
<i>Uria aalge</i>	0.8	0.6	0.0	0.0	0.4
<i>Uria lomvia</i>	0.7	10.3	1.8	0.1	3.2
<i>Alle alle</i>	0.0	1.2	3.5	1.0	1.4
other birds	3.3	0.5	0.6	0.3	1.2
Σ birds *	32.6	39.6	14.2	6.4	23.2
Σ birds	708.0	39.6	14.2	6.4	147.4
Σ whales	0.1	0.1	0.1	0.0	0.1
Σ pinnipeds	0.0	0.0	12.1	0.4	3.1
<i>Ursus maritimus</i>	0.0	0.0	0.0	0.0	0.0
Biomass (kg/km²)					
<i>Fulmarus glacialis (dark)</i>	0.20	0.20	1.00	0.60	0.50
<i>Fulmarus glacialis (light) *</i>	4.60	3.20	0.80	0.40	2.25
<i>Fulmarus glacialis (light)</i>	131.30	3.20	0.80	0.40	34.20
<i>Pagophila eburnea</i>	0.00	0.00	0.00	0.00	0.00
<i>Rissa tridactyla ' </i>	0.40	0.40	0.20	0.00	0.25
<i>Rissa tridactyla</i>	4.70	0.40	0.20	0.00	1.40
<i>Uria aalge</i>	0.40	0.20	0.00	0.00	0.15
<i>Uria lomvia</i>	0.20	3.40	1.00	0.00	1.15
<i>Alle alle</i>	0.00	0.00	0.40	0.00	0.10
other birds	1.00	0.20	0.00	0.40	0.40
Σ birds '	6.80	7.60	3.40	1.40	4.80
Σ birds	137.80	7.60	3.40	1.40	37.90
Σ whales	58.3	22.9	9.0	0.0	22.6
Σ pinnipeds	0.0	0.1	47.0	2.4	12.4
<i>Ursus maritimus</i>	0.0	0.0	0.0	0.1	0.0
total *	65.1	30.6	59.6	3.9	39.8
total	196.1	30.6	59.4	3.9	75.4
Ingestion (kg fresh weight/km².day)					
<i>Fulmarus glacialis (dark)</i>	0.06	0.04	0.20	0.11	0.10
<i>Fulmarus glacialis (light) *</i>	0.94	0.84	0.15	0.10	0.51
<i>Fulmarus glacialis (light)</i>	26.68	0.84	0.15	0.10	6.94

Table 4

Synopsis of the main results obtained in the Norwegian and Greenland Seas in July 1988 (follows)

Species	Zone	Atlantic water	Polar water	Ice edge	Pack ice	Mean
<i>Pagophila eburnea</i>		0.00	0.00	0.00	0.02	0.01
<i>Rissa tridactyla</i> *		0.09	0.14	0.05	0.01	0.07
<i>Rissa tridactyla</i>		1.14	0.14	0.05	0.01	0.34
<i>Uria aalge</i>		0.06	0.05	0.00	0.00	0.03
<i>Uria lomvia</i>		0.05	0.82	0.18	0.01	0.27
<i>Alle alle</i>		0.00	0.03	0.11	0.03	0.04
other birds		0.30	0.04	0.05	0.06	0.11
Σ birds*		1.40	0.95	0.73	0.28	1.09
Σ birds		28.18	0.95	0.73	0.28	7.78
Σ whales		0.67	0.34	0.19	0.00	0.30
Σ pinnipeds		0.00	0.01	2.36	0.12	0.62
total*		2.07	1.30	3.28	0.40	2.01
total		28.85	1.30	3.28	0.40	8.70

* Without taking into account an important concentration of Fulmars and Kittiwakes off Iceland (see text).

The food intake by pinnipeds was 0.6 kg/km²/day; they were mainly hooded seals at the ice edge, with a mean intake of 2.3 kg/km²/day at the ice edge and a maximum of about 100 kg/km²/day at station 265, if one accepts that they were feeding in the zone at this period of the year.

When such results are compared with data obtained in the Weddell Sea, Antarctica by the same way of counting and interpreting the data (table 5), the most striking conclusions are the lower values of food intake for seabirds: 1.1 kg/km²/day in the Arctic versus 17 in Antarctica (with 1.8 in open water and 25.7 in the Antarctic pack ice), as well as for marine mammals: 0.6 versus 7 for the pinnipeds, 0.3 versus 3.1 for the cetaceans. An important difference in whale distribution is their absence in Arctic pack ice, compared with the relatively high numbers of minke whale *Balaenoptera acutorostrata* in the Antarctic closed pack. In open water, on the contrary, whales were present in the Arctic, but absent in the Antarctic in early spring.

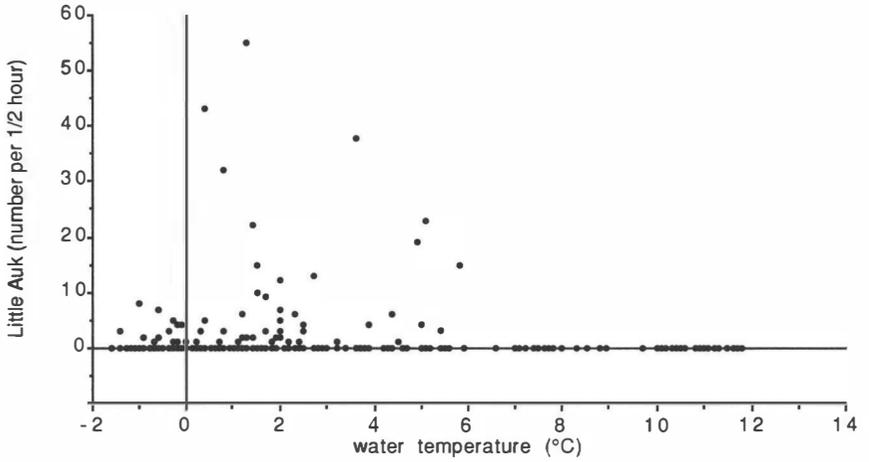


Fig. 11. — Numbers of Little Auk *Alle alle* observed per half hour, as a function of the seawater temperature.

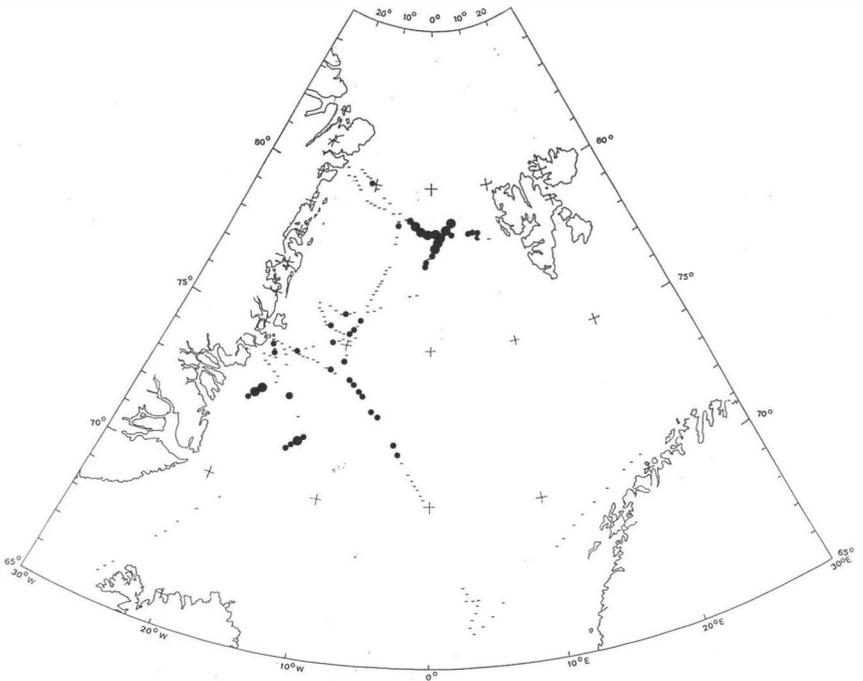


Fig. 12. — Map showing the distribution of the Little Auk *Alle alle*. Three classes: nihil; 1-20; 21-400; birds per hour (see legend Fig. 1).

Table 5

Synopsis of the main results obtained in the Weddell Sea, Antarctica in spring 1988

Zone	Antarctic zone*					Sub Antarctic & sub Tropical zones
	Open water	OMIZ	IMIZ	CPI	Mean	
Numbers/km²						
Σ penguins	1.13	4.15	6.74	32.57	20.69	0.04
Σ petrels + Fulmar	4.13	3.66	12.75	2.22	4.47	1.89
Σ albatross	0.06	0	0	0	0.01	0.23
other birds	0.80	0.17	0.76	0.29	0.43	0.80
Σ birds	6.4	8.1	20.4	35.2	25.8	3.1
Σ pinnipeds	0	0.16	0.23	1.26	0.79	0
Σ cetaceans	0	0	0	0.02	0.01	0.04
Biomass: kg/km²						
Σ penguins	4.6	15.0	23.7	141.0	88.7	0.1
Σ petrels + Fulmar	3.0	2.2	6.5	1.4	2.6	1.5
Σ albatross	0.2	0	0	0	0	1.0
other birds	0.2	0.1	0.6	0.3	0.3	0.2
Σ birds	7.9	17.3	30.8	143	92	2.8
Σ pinnipeds	0.2	9.2	17.7	182	52	0.2
Σ cetaceans	0	54	54	218	81	203
total	8.1	81	102	542	225	206
Food ingestion (kg fresh weight/km².day)						
Σ penguins	0.89	2.39	3.44	10.95	8.33	0.06
Σ petrels + Fulmar	0.82	0.69	1.47	0.50	0.82	0.58
Σ albatross	0.11	0.00	0.01	0.00	0.03	0.34
other birds	0.09	0.05	0.24	0.14	0.15	0.13
Σ birds	1.89	3.13	5.16	11.58	9.33	1.10
Σ pinnipeds	0.07	1.35	2.15	11.61	4.38	0.07
Σ cetaceans	0.00	3.59	1.60	8.89	3.52	17.73
total	1.97	8.07	8.92	32.09	17.24	18.90

* OMIZ: Outer Marginal Ice Zone; IMIZ: Inner Marginal Ice Zone; CPI: Closed Pack Ice.

Source: JOIRIS 1991a.

As a consequence, the total food intake by marine vertebrates is comparable in Arctic open water (1 to 2 kg/km²/day) and in Antarctic open water (1.8), but is much lower in the Arctic pack ice (0.8) than in the Antarctic (32). The mean values are 4 in the Arctic and 17 in the Antarctic. These differences might however be less marked, as far as seabirds are concerned, if the local concentrations of Fulmars

and Kittiwakes in Atlantic water off Iceland were integrated in the calculations.

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INTERACTIONS BETWEEN HUMANS AND DOLPHINS IN GALVESTON BAY, TEXAS

BY

T. HENNINGSSEN* & B. WÜRSIG**

SUMMARY. — More than 3 million people are living around the Galveston Bay in Texas. It is one of the most industrialized and polluted large bays in the United States. During a seven-month study in 1990, we investigated bottlenose dolphin (*Tursiops truncatus*) occurrence and activity patterns in Galveston Bay and adjacent waters of the Gulf of Mexico. We also focused on interactions with humans and at our research vessel's influence on the activity of the observed dolphins. Although there is a high amount of vessel traffic due to industrial, fishing, and private utilization, we found an unexpected high number of dolphins used the area. Dolphins are attracted to fishing activity (43 % of all sighted dolphins were associated with shrimp boats) and to human-made structures such as dredged channels and jetties, where prey often concentrate. However, the high boat traffic, frequent occurrence of oil spills (two major spills in 1990 alone), and other pollution may also have harmful effects. An exceptionally high mortality which occurred in the area in 1990 awaits necropsy and body tissue analysis, and has not yet been explained.

* * *

Interactions between humans and dolphins occur in many places around the world. Some of them are friendly in nature, like at the famous Monkey Mia Beach in Australia, but many of them are harmful or deadly for the dolphins. These animals are killed for human consumption, as food competitors, as bait, accidentally in various fishing activities or because of marine pollution. It is estimated that more than 1 million dolphins are killed every year (ENVIRONMENTAL INVESTIGATION AGENCY 1991). Pollution of

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the marine environment could especially be the major threat of the future for these animals.

During a seven-month study (April-October) in 1990, we investigated bottlenose dolphin (*Tursiops truncatus*) occurrence and activity patterns in Galveston Bay, and the adjacent waters of the Gulf of Mexico. The bottlenose dolphin is the most common cetacean species found along Texan shores and the only cetacean species seen during the study period, excluding the stranded spotted dolphin *Stenella attenuata*, melonhead whale *Peponocephala electra* and pygmy sperm whale *Kogia breviceps* sightings.

The study area is 2,100 square kilometers including Galveston Bay, a bay system of 4 neighbouring bays which total approximately 1,550 square kilometers, and the adjacent waters of the Gulf of Mexico which total approximately 550 square kilometers. There are only 2 small entrances to the bay system. The bays have mainly a muddy or fine sand bottom and are on average only 240 cm deep, whereas the adjacent waters have a middle sized sand bottom and are about 10 m deep. There are about 400 km of 13 m deep dredged channels for shipping traffic inside the bay system.

Galveston Bay is one of the most industrialised and polluted large bays in the United States. More than 50% of all chemical products produced in the United States are produced in this area, as well as 17% of the refinery of all oil produced in the entire Gulf of Mexico.

More than 3 million people live around Galveston Bay. There is a high amount of vessel traffic due to industrial, private (more than 120,000 private boats are registered in the four counties surrounding Galveston Bay) and fishing utilisation. It is also one of the main areas in the United States for the shrimp and oyster fishery.

We conducted our study from a small motor vessel at a speed of 10-12 m/h. We tried to cover the entire study area at least once per week. We used photo-identification to identify the dolphins individually by natural marks on their backs (DEFTRAN *et al.* 1990, WÜRSIG & JEFFERSON 1990). Every sighting of a singular or a group of dolphins was registered along with oceanographic and biological data. The locations of sightings were marked on a map with information about whether sightings were linked to human influence. Therefore, the sightings were divided into:

- Dolphins bowriding on ships;
- Dolphins close to jetties (< 100 m);

- Dolphins inside a dredged channel;
- Dolphins inside a dredged channel behind a shrimping boat;
- Dolphins behind a shrimping boat outside of dredged channels.

During the study period we had 412 sightings totalling approximately 2,991 dolphins. Of these, we identified 1,002 different individuals by photo.

Figure 1 shows that the dredged channels and the shrimp fishery are the main human influences which impact on the dolphins in this

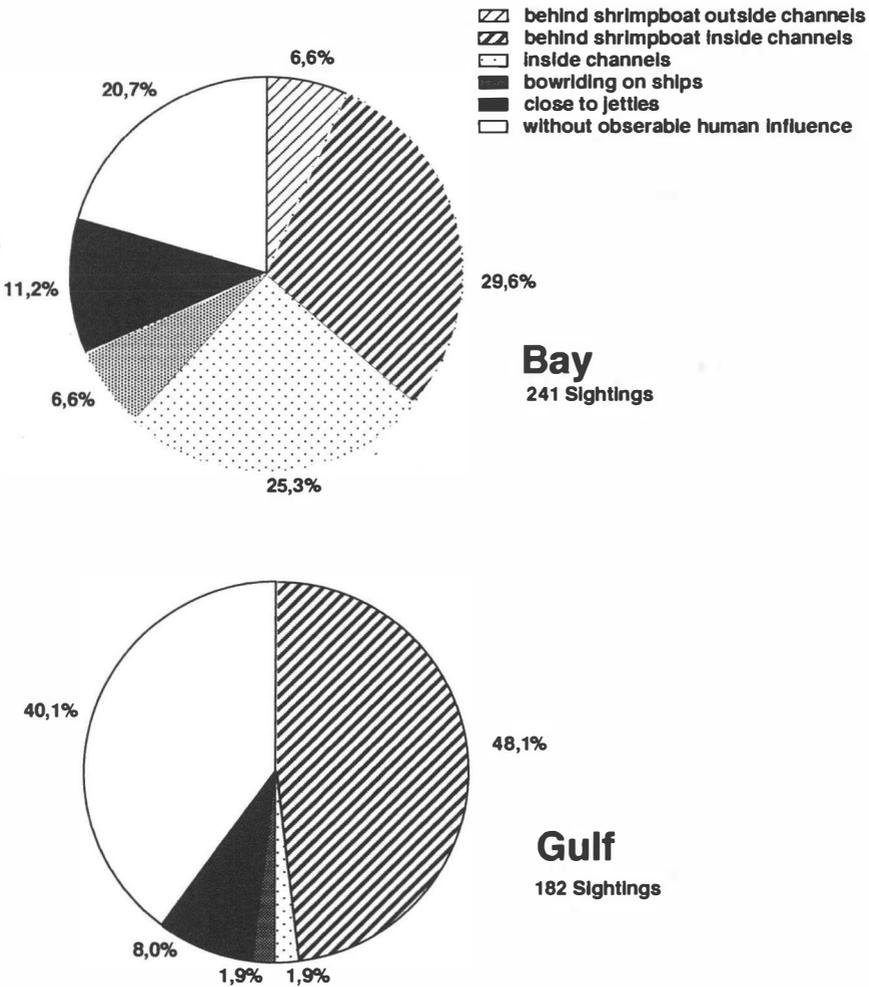


Fig. 1. — Human habitat association of bottlenose dolphins in Galveston Bay and in the adjacent waters of the Gulf of Mexico (Thomas Henningsen).

area. Only about 20% of the sightings within the bay and about 40% in the adjacent waters of the Gulf were without observable human influence.

We also investigated the influence of our boat on the animals. No change in their activity was counted as a neutral reaction to our boat.

A change in their activity, e.g. swimming away from shrimp-boats, a change in swimming direction, longer dives or aggressive behaviour were counted as negative reactions towards our boat. A positive reaction to our boat was if the dolphins played with our boat, e.g. bowriding or playing with the stern waves. From these data, 69.8% of all dolphins showed a neutral reaction to our presence, 8.7% a positive reaction and 21.5% reacted negatively.

Even though we were not a serious threat for these animals, which means they were in no real danger, we should try to develop better and less stressful methods of observation and identification for marine mammals.

We found an unexpectedly high number of bottlenose dolphins using an area of high human impact. These animals tolerate the disadvantage of disturbance and noise pollution from small boats and

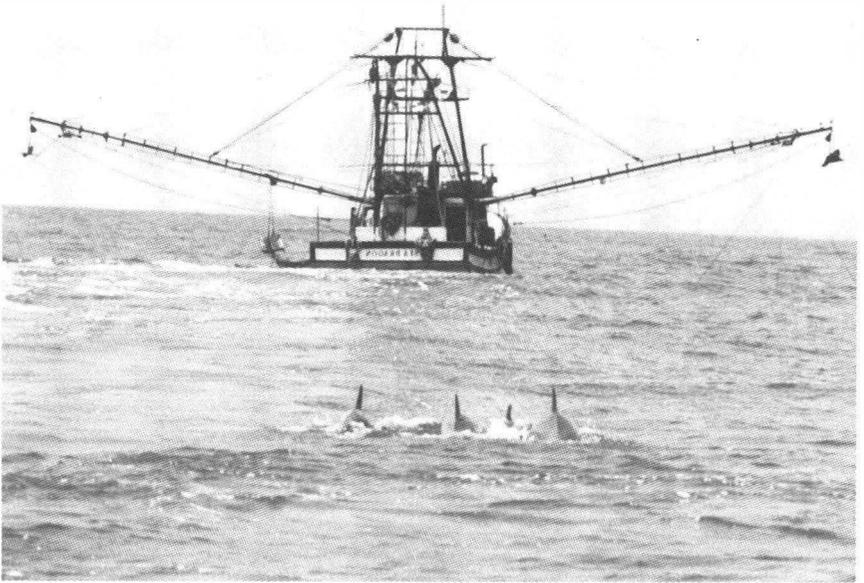


Fig. 2. — A group of bottlenose dolphins is following a shrimp boat near Galveston (Thomas Henningsen).

big ships, and also from industrial and harbour activities, for the advantage of a good food supply. Fish are often concentrated near structures like jetties and also in deeper dredged channels. The main attraction in this area for dolphins is the shrimp fishery. These animals follow the fishing boats and feed on discarded fish, but their main food source is from fish and crustaceans disturbed by bottom trawling nets. This had already been observed in various other places, such as California (LEATHERWOOD 1975) and Australia (CORKERON *et al.* 1990).

The main disadvantages in this area, probably not detectable by these animals, are the pollution and toxic components contained within their environment. The high concentration of heavy metals in the sediments (WHITE *et al.* 1985), added to a high number of toxic hydrocarbon compounds could cause severe damage to these animals in the future, as it is recognised that top predators such as dolphins accumulate these toxins in their tissues (GREENPEACE 1990). The fact that bottlenose dolphins do not avoid oil and its vapours was observed by us when two major oil spills occurred during the study period. Oil vapours are known to be very harmful for marine mammals as was found for sea otters after the Exxon Valdez oil spill in Alaska (OSBORNE & WILLIAMS 1990). We observed that the dolphins did not leave oil slicks for hours even when clean water was close by (SMULTEA, WÜRSIG & HENNINGSEN, unpubl.; SMULTEA & WÜRSIG 1991).

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SOME PHYSIOLOGICAL ADAPTATIONS OF CETACEANS

BY

F. BAGUET*

SUMMARY. — Cetaceans, including whales, dolphins and porpoises, are found in all oceans, their ranges extending from the warm tropical waters to frigid polar waters. Efficient thermoregulatory mechanisms permit these endothermic mammals to maintain a constant core temperature. A thick insulating layer of blubber and associated countercurrent vasculature, permit them to allow their skin temperature to approach that of the water, greatly reducing heat loss by conduction and convection. Cetaceans have a higher metabolic rate than would be expected for mammals of equivalent size based on Kleiber's analysis of terrestrial mammals. The respiratory pathway and lungs are modified in ways related to diving: lungs have cartilagenous rings along the bronchial tree, an arrangement which prevents the blood absorption of nitrogen from air stored in the respiratory tree during a deep dive. Oxygen stores are considerably larger in cetaceans than in terrestrial mammals: the blood volume is about 15 percent of the body weight compared to about seven percent for man. The oxygen capacity of the blood may be twice as much as in man. During enforced and voluntary diving, there is a complete cessation of liver and renal blood flow and a complete arrest of oxidative metabolism in both organs. As there is a simultaneous decrease of glycolysis, it turns out that these organs show a typical reversed Pasteur effect. It is concluded that Cetaceans, during diving periods, use some metabolic arrest mechanisms that lead the hypoperfused tissues in a hypometabolic state.

* * *

Cetaceans, including whales, dolphins and porpoises, are mammals specialized to spend their entire lives in the water. This specialization has proved quite successful in view of the many species of cetaceans that exist in the world's oceans, extending from the warm tropical waters to frigid polar waters.

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The greatest physiological problems for mammals living in an aquatic environment are referring to thermoregulation, pressure and hypoxia.

1. Thermoregulation

The specific heat of water per unit volume is 3,400 times that of air and its thermoconductivity is 25 times that of air. These figures indicate that water represents an enormous heat sink.

Since cetaceans are endothermic mammals that maintain a constant core temperature, they have evolved efficient mechanisms that prevent the heat loss by conduction and convection. They can either increase the metabolic rate to compensate for the heat loss or reduce the heat loss.

The metabolic rate has been measured in several species of dolphins (LAVIGNE *et al.* 1986) and large whales (KASTING *et al.* 1989). From this last work, it can be concluded that cetaceans appear to have an elevated metabolic rate. This is particularly evident in the largest whales that were studied in conditions that meet all the criteria for basal or standard metabolism.

The basal metabolic rate (BMR) increases as a function of the animal weight (W) according to the equation

$$\text{BMR} = 0.88 W^{1.06}$$

The weight exponent $1.06 \pm .09$ is significantly different from Kleiber's calculated of 0.75 for terrestrial mammals.

This exponent suggests that the metabolic rate in cetaceans may increase directly in proportion to their body mass (1.00) and not in proportion to surface area (0.67) which has been suggested as the main determinant in increases of metabolic rate in terrestrial mammals (surface law).

The very high metabolic rate of cetaceans is a real phenomenon and not the result of measurement or animal irregularities.

To reduce heat loss, cetaceans have effective mechanisms of heat conservation :

' a. A thick insulating layer of blubber and associated vasculature, permits the animal to allow its skin temperature to approach that of the water, greatly reducing heat loss by conduction and convection (YABLOKOV *et al.* 1974).

However, thermal conductance of the skin at 12-18°C reveals that it is equal or slightly greater than in humans. This suggests that the insulative properties of the cetacean integuments could be improved if it was vital to their survival.

Since heat retention is not maximized in these large whales, why do they have such high metabolic rates?

It is suggested that from the survival point of view of a mammal living in cold water, it may be better to be perpetually in a heat-excess situation when heat retention is seriously compromised, such as might occur with injury or illness.

b. Flippers and flukes lack blubber and are poorly insulated. Excessive heat loss from the blood is prevented by the special structure of the blood vessels, which are arranged in such a way that they function as heat exchangers. Each artery is completely surrounded by veins; heat is transferred from outgoing blood in the artery to incoming blood in the veins, and so, warm blood is returning to the body.

c. Evaporative energy loss is considerably reduced: the temperature of the air exhaled varies from about 23°C to 30°C (KASTING *et al.* 1989). Obviously, the whales exhale air at a temperature considerably lower than core temperature and unsaturated with regard to water vapor. The evaporative heat loss varies from 1 to 98 W, which is very low as compared to the convective loss varying from 2,789 to 235 W (watts).

2. Resistance to pressure

Cetaceans are air breathers, and as in all air breathers, the pressure increase involved in diving induces a deformation of all the cavities and increases the partial pressure of the gases present in these cavities.

Cetaceans can face high pressures by a large reduction of the cavities limited to the snout and the middle ear cavity. Moreover, the thorax is modified: the number of ribs is reduced and the lungs correspond to a lower percentage of the body weight than in terrestrial mammals. For an elephant, it corresponds to 2.55% of the body weight, while for a blue whale it is only 0.73% (KOOYMAN & ANDERSEN 1969).

Partial pressure of nitrogen must raise in blood and tissue when the animal dives as it is observed in man.

A high pressure of nitrogen has an anaesthetic effect, because, as it is soluble in lipids, it should increase the volume of lipids in the cell membranes and as a consequence it blocks the ionic channels present in the membrane.

It follows that nervous conduction in nerve cells is reduced or blocked.

Anatomical features suggest that nitrogen does not penetrate in the blood of cetaceans: the lungs have cartilaginous rings along the bronchiolar tree as far as the alveolar ducts. Muscle sphincters are present in large baleen whales at the mouths of the alveolar sacs.

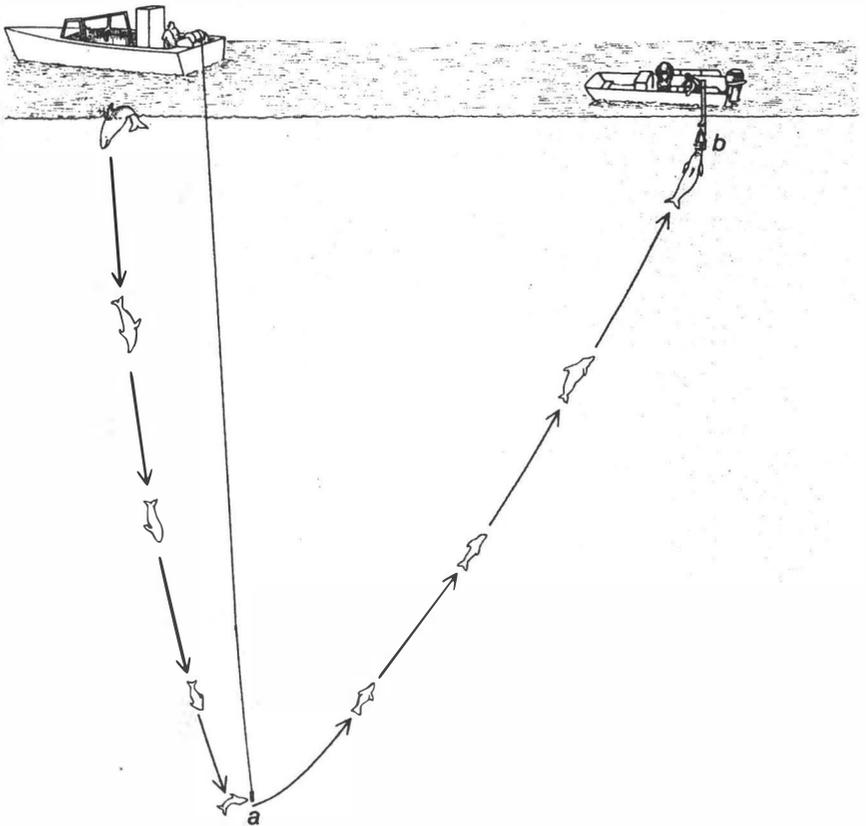


Fig. 1. — Deep-diving ability of the dolphin. A buzzer and a switch (a) were lowered to a depth of 150 meters. Turning the buzzer on was the signal to dive and switch it off. The dolphin then returned to the dinghy, to touch a second buzzer (b) and claim his reward.

With diving, the alveolar sacs collapse and air should be trapped in the bronchiolar tree where nitrogen could not escape to blood circulation.

However, direct measurements of blood nitrogen on diving dolphins do not confirm this conclusion based on anatomical observation.

Deep-diving ability of specimens of *Tursiops truncatus* was tested as reported in figure 1. A buzzer and a switch (a) were lowered to a depth of 100-150 meters. Turning the buzzer on was the signal to dive and switch it off. The dolphin then returned to the dinghy, to touch a second buzzer (b) and claim his reward. After a series of diving sequences, the dolphin swam onto a floating couch next to a boat containing a mass spectrometer; the experimenter pushed a gas-sampling needle through its blubber layer and into its muscle.

After 25 such dives of 1.5 minutes duration, with only brief surface intervals, the tissue PN_2 of the epaxial muscle at the end of the bout had risen to an apparent 2.1 ata (atmospheres) (RIDGWAY & HOWARD 1979).

Toward the end of a dive the N_2 tensions could be elevated to a level hazardous to the animal's health or that special tissue adaptations may be required to accommodate such tensions.

Such a high pressure of nitrogen has an anaesthetic effect, because, as it is soluble in lipids, it should increase the volume of lipids in the cell membranes and as a consequence it blocks the ionic

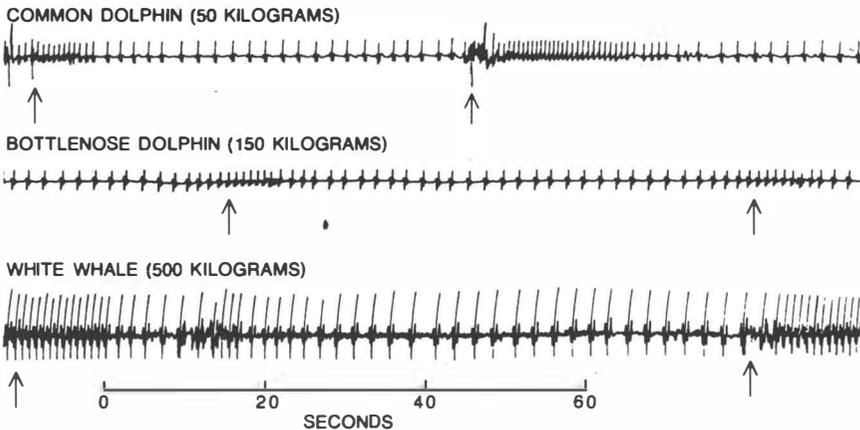


Fig. 2. — Toothed whale's heartbeats were recorded by telemetry and ultrasonic transmitter. Arrows indicate the start of diving in each instance.

channels present in the membrane. It follows that nervous conduction in nerve cells is reduced or blocked (WINTER & MILLER 1985).

It is possible that the thickness of the cellular membrane is different in cetaceans preventing the deleterious effects of nitrogen.

It can be concluded that the diving reactions observed on enforced dives, as reported by Scholander, is due to a stress or alarm reaction and has no physiological meaning, at least for short-duration divers.

However, during voluntary dives of long duration, *i.e.* more than 20 minutes, cetaceans show different reactions. Direct measurements of the oxygen consumption of diving animals, show that the metabolism is reduced to about 25 percent of the resting metabolism. This lower energy consumption is due to the arrest of the blood perfusion to the organs, especially liver and kidneys.

Under laboratory diving conditions, hepatic arterial flow is decreased to less than 1/20 of resting values. Similar degrees of liver hypoperfusion are obtained from flow meter measurements and also appear rather likely in voluntary diving (HOCHACHKA & GUPPY 1987).

On the other hand, following extreme insults (initial ischemia during tissue collection, a subsequent 50-min period of hypothermia, a further 60-min stabilization period of perfusion with physiological saline, then finally a 60-min anoxic period induced by curtailing perfusion), the oxidative metabolic rate of the kidney returns to normal almost instantly (ELSNER & GOODEN 1983).

A similar period of ischemia brings about irreversible damage, both to metabolism and to renal function in kidneys from terrestrial species (HOCHACHKA 1986).

As no oxygen debt is measured after ischemia, it means that no lactate is produced. This result implies a reversed Pasteur effect: interruption of oxygen supply to the organ involves a blockade of glycolysis. Such a metabolic arrest is described in some marine invertebrates which are able to survive in anoxia and in ectothermic as well as endothermic hibernators (STOREY 1988).

3. Conclusions

Two major conclusions can be made.

Firstly, marine mammals use the diving response to precisely regulate the rates and sites of utilization of fixed amounts of O₂ over fixed periods of diving time.

Secondly, metabolic arrest mechanisms (apparently involving a reversed Pasteur effect) are activated in hypoperfused tissues and organs to minimize end product accumulation.

Of the two best strategies used by ectothermic anaerobes, at least one (metabolic arrest) can also be harnessed by endothermic marine mammals.

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THE PERIPHERAL NERVE ENDINGS
IN THE SKIN OF THE HARBOUR PORPOISE
PHOCOENA PHOCOENA (LINNÉ 1758)

BY

G. BEHRMANN*

SUMMARY. — Harbour porpoises live in estuaries and coastal waters, which have a natural pollution. During their evolution, harbour porpoises have adapted to life in muddy water with reduced visibility. Their echolocation system is therefore highly developed, as well as their senses of taste, smell and touch. The nerve-endings of the touch sense are primarily situated in the skin, which is rubber-like, soft and smooth. It is interesting to know how sensitive the skin is. The integument possesses an epidermal layer up to 4 mm thick. The superficial layer with parakeraotic cells is up to ten layers deep, and can be up to 40 µm thick. The other epidermal layer has polyhedral prickle cells and extends peg-like into the cuticular layer. Melanocytes are accumulated in the stratum spinosum and in the thin basal layer. The whole integument is penetrated by myelinated and free merkelless nerve-endings, and many kinds of nervous corpuscles, as known from amphibians, fish, birds, mammals. These as well as new forms of nerve-endings are demonstrated and their possible function is discussed in relation to their morphology and location.

* * *

The epidermal layer is nearly 4 mm thick and penetrated by myelinated and merkelless free ending nerves, and many types of nervous end corpuscles, as known from amphibians, fish, birds, and mammals (MALINOVSKY 1986 & QUILLIAM *et al.* 1966). These, as well as up to 21 new forms, could be identified, but I assume that there exist even more.

In the dark area melanocytes (Plate 1, Fig. 1) are accumulated. They do not belong to the nervous system, but to prevent mistakes in determination, they are added. Cells of Langerhans (Plate 1, Fig. 2)

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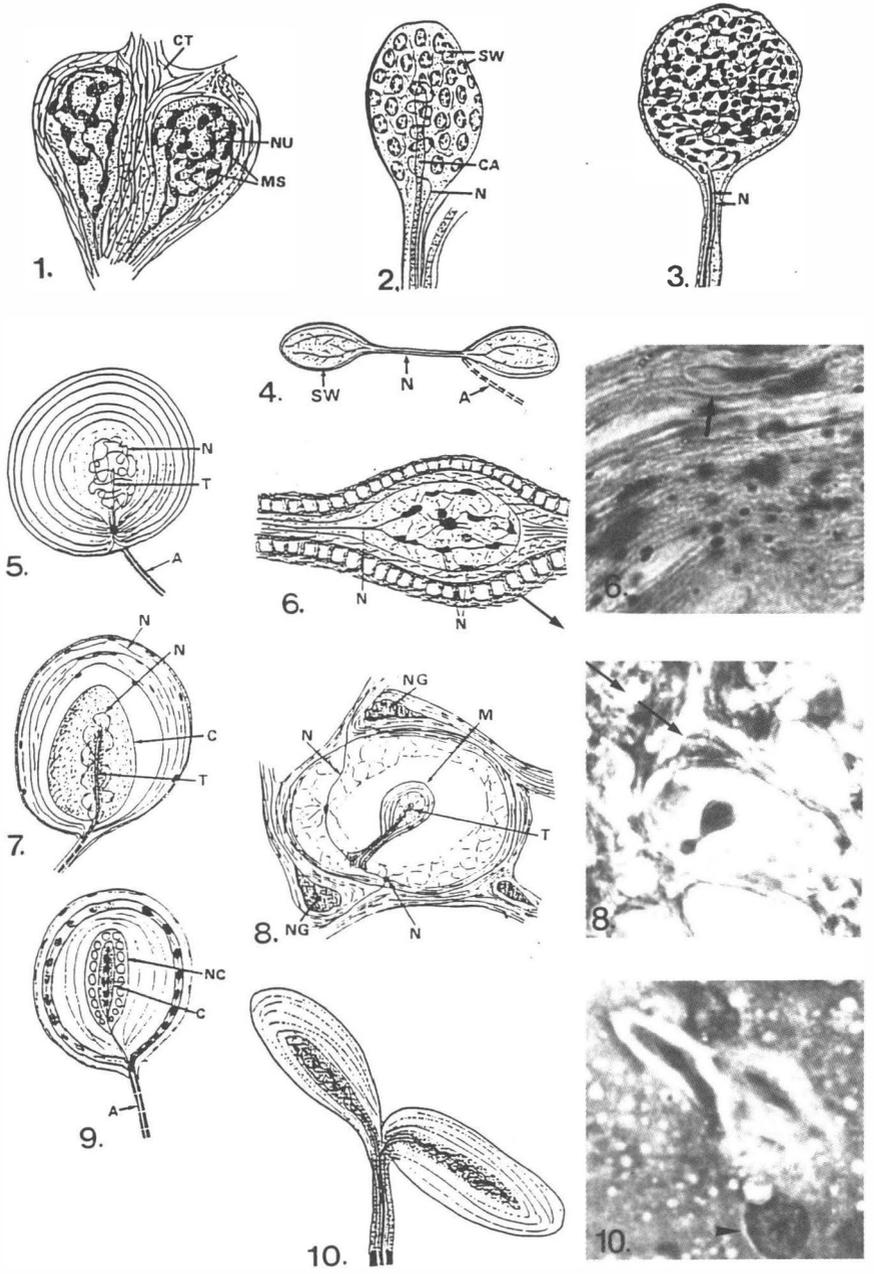
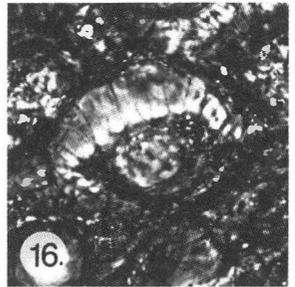
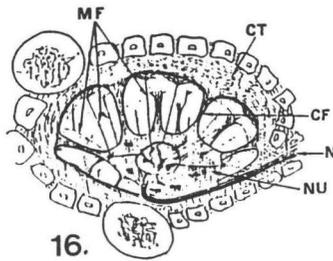
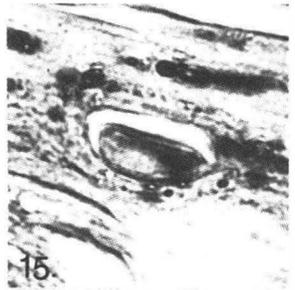
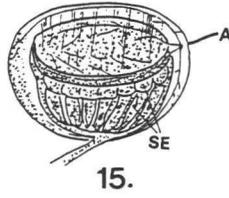
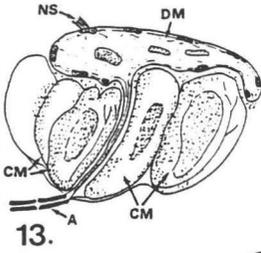
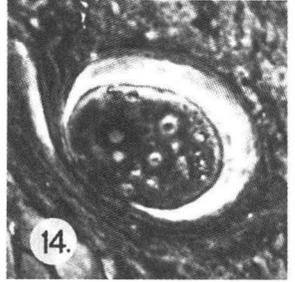
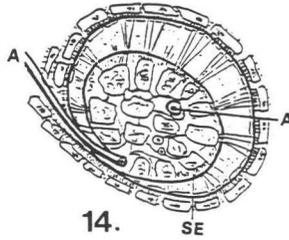
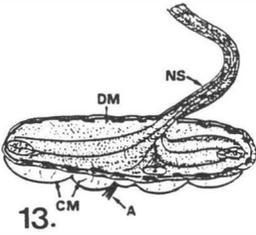
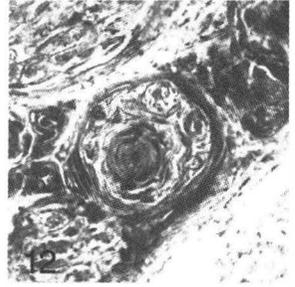
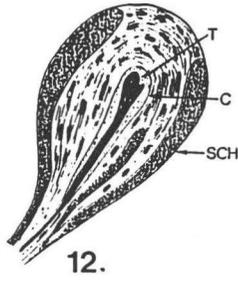
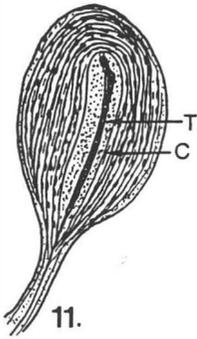


Plate 1

carry pigment-granules and are penetrated by neurites; they are therefore interpreted as neuro-vegetative cells. They have a length of up to 3 μm , are situated in the cuticle layer, and have a function within the immune system.

Primitive end corpuscles of Krause (1858) (Plate 1, Fig. 3) were found in many variations in all layers of the integument, frequently near, or in connection with other end corpuscles (10.◀, 18.◀, 21.NE). They have a diameter of up to 10 μm , and could be supply corpuscles. Nervous tandem corpuscles (Plate 1, Fig. 4) are known from the membrane of the sound bladder of frogs, two small swellings with a length of up to 3 μm , combined by a capillary and merkleless nerves.

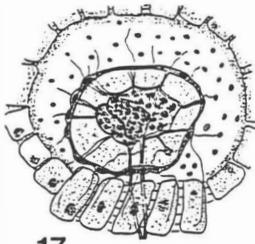
Numerous tandem end corpuscles are situated in the cornea of the tongue and in the upper epidermal layer of the nosehole. They perceive stretchings of the skin. Of the lamellated touch corpuscles seven types are clearly discernible (Plate 1, Figs. 5-10), Plate 2, Figs. 11 and 12). All lamellated touch corpuscles have a terminal nerve in the centre, surrounded by a core, which is covered by lamellae of connective tissue. They are all able to perceive the intensity of pressures. Up to ten lamellae have the variant of the Golgi-Mazzonian touch corpuscle. The roundish type 5 has a diameter of nearly 12 μm , and is situated in the whole skin. The oval type 7 can have a length of up to 30 μm , and is only found in the upper epidermal layers of the tongue and its papillae. A new variant of such touch corpuscles (Plate 1, Fig. 8) was discovered in the vessels of the swell corpus of the tongue papillae. With a length of only 6 μm it is the smallest known. In the connective tissue, covering the vesicles of the swell corpus, neuroglia cells (Plate 1, Fig. 6) are situated. They regulate the development of tissue. Lamellated touch corpuscles of Herbst (Plate 1, Fig. 9) were found in the upper epidermal layer of the tongue and have a diameter of up to 15 μm . Their longish core is surrounded by nerve cells. They are comparable to the touch corpuscles, which are situated in the bill of ducks (QUILLIAM 1966). With an extension of about 150 μm , the lamellated touch corpuscles of Ruffini (Plate 1, Fig. 10) are the greatest of this type. Two longish spray-like lamellated end corpuscles are in their structure comparable to the Golgi-Mazzonian touch corpuscles. They are situated in the epidermal layer of the tongue ground and in cutical layers of the accessory sacs of the nosehole. They are described as stretch corpuscles of birds and mammals (MALINOVSKY 1986). In deeper layers of



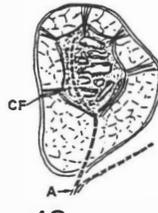
the cutis, near the muscles, Vater-Pacinian touch corpuscles are situated. They have 30 to 50 lamellae penetrated by a perineural network, and a big core. The biggest of this type (Plate 2, Fig. 11) could have a length of up to 5 mm. Slightly smaller is the type with nearly 20 lamellae and large Schwann cells, which has a diameter of nearly 60 μm and a length of up to 300 μm (Plate 2, Fig. 12). Such end corpuscles were found in subcuticle layers of the nose tip. Vater-Pacinian touch corpuscles can perceive strong pressures. Meissner corpuscles (Plate 2, Fig. 14) are situated in cutical layers of the whole skin and have a diameter of up to 100 μm . Out of a floating end corpuscle, composed of sensory cells, collagen fibrils extend to the tissue surrounding the capsule. The movement of the skin is mechanically transmitted to the sensory cells. A new type, perhaps a variant of the Meissner corpuscles, is situated in the parakeratotic and the epidermal layers, nearly 20 μm below the surface of the skin. The capsules have a length of up to 30 μm . The half roundish end corpuscle has a disk orientated in parallel to the surface. Out of the disk extend nerve fibres to the tissue of the capsule. The fibres transmit rapid tender surface load to the disk. Such end corpuscles may perceive turbulences which developed in time of fast swimming. A higher developed end corpuscle situated nearly 150 μm below the skin surface, especially in the skin of the forehead, is type 16. Out of the corpuscle, fixed by collagenous fibres to the tissue of the capsule, extend moss fibres, ramifying in the wall of the capsule. It has a length of up to 60 μm . In case of the moss fibres, such corpuscles are able to perceive tender vibrations and loads of the skin. Meissner touch corpuscles (Plate 3, Fig. 18) in the photograph accompanied by a corpuscle of Krause (\blacktriangleleft), have a diameter of up to 25 μm and are situated in all layers of the skin.

Grandry corpuscles (Plate 3, Fig. 17) are situated in the same area. The capsules have a diameter of up to 10 μm . Out of two or three primitive nervous end corpuscles extend nerve fibres penetrating the tissue of the capsule and endings in the cells around the capsule. «Grandry corpuscles are typical subepidermal endings in the beak of aquatic birds, are afferent units with rapid adaptation» (MALINOWSKY 1986).

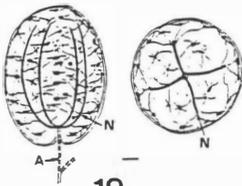
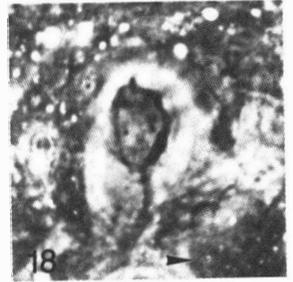
In the epidermis of the tip of the tongue and the papillae two types of ampulla-like nervous end organs were found. In a capsule with a diameter of nearly 12 μm , three oval sensory cells with a diameter of nearly 3 μm float (Plate 3, Fig. 20). An axon leads into the capsule,



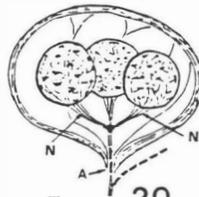
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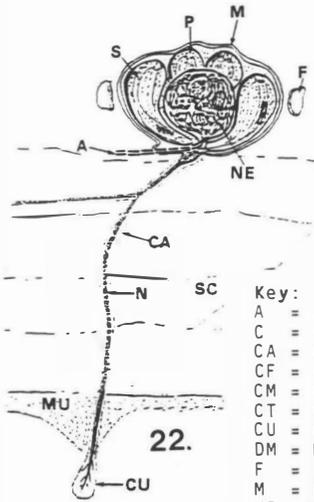
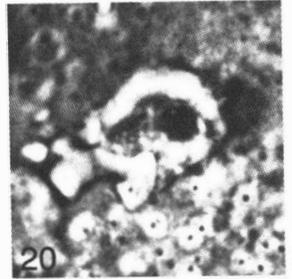
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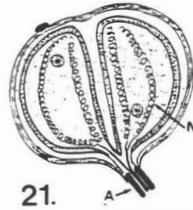
19.



20.



22.



21.



Key:

- A = Axon
- C = Core
- CA = Capillary
- CF = Collagenous fibres
- CM = Cell of Merkel
- CT = Connective tissue
- CU = Cupula
- DM = Disk of Merkel
- F = Foodcell
- M = Membrane
- MF = Moss fibres/Nerves
- MS = Melanosome
- MU = Mucosa

- N = Nerve/Neurit
- NC = Nerve cell
- NE = Nerve end-corpuscle
- NG = Neuroglia cell
- NS = Nerve strung
- NU = Nucleus
- P = Pore
- S = Secretory cell
- SC = Stratum corneum
- SE = Sense cell
- SW = Swelling
- SCH = Schwann cell
- T = Terminal nerve

and its nerve fibres lead to the ampoules (BEHRMANN 1988). Comparable organs are described in connection with electroreceptive organs of mormyrid fish (SZABO 1974). In the same area, oval ampulla-like organs (Plate 3, Fig. 19) with a diameter of a little more than 15 μm were situated (BEHRMANN 1988). The oval ampullae have a length of up to 10 μm and a diameter of up to 5 μm . The neurite leading into the capsule is ramified like a chandelier. The function of these organs is unknown. Well-known are the ampulla-like end corpuscles of Grandry. Comparable organs were found in the bill of ducks and in the tongue of woodpeckers (QUILLIAM 1966). Such corpuscles (Plate 3, Fig. 21) are situated in the tip of the lower lip and in the tip of the tongue. Two half-roundish ampoules form together an organ with a diameter of nearly 10 μm . The ampoules are penetrated by spring-shaped nerve terminals and primitive nerve fibres.

Two highly developed nervous organs were identified. Tactile disks of Merkel (Plate 2, Fig. 13, above the surface, below a cross section) consist of 4 to 7 tall Merkel cells and a longish disk, with a length of nearly 30 μm . They are situated in the parakeraotic layers of the upper and lower jaw, in the nose tip and in the opening of the blowhole. Such organs are described as specialized touch corpuscles. A new type of nervous organ was detected in the epidermis of the tongue tip. The organ is a combination of 5 to 8 nervous secretory cells and a nervous end corpuscle in the centre (Plate 3, Fig. 22). Out of the organ with a diameter of nearly 30 μm , leads a capillary with a length of nearly 50 μm to the surface. In the capillary, a nerve, extending out of the end corpuscle, draws to the surface, and ends in a gelatinous cupula. This organ could be a receptor of electric or magnetic waves (BEHRMANN 1990).

With the broad spectrum of nerve endings, the harbour porpoise, and perhaps other whales, have the best developed peripheral nerve system of all animals.

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THE USE OF COMPUTER TOMOGRAPHY IN ODONTOCETE MORPHOLOGY – PRELIMINARY RESULTS

BY

M. Garcíá HARTMANN*, C. KAMMINGA*,
A.I.J. KLOOSWIJK** & G. FLEISCHER***

The protrusions of the nasal passages, called airsacs, into the surrounding soft tissue are assumed to be involved in the echolocation system of toothed whales. Other functions have been postulated and in fact the airsacs are most probably part of a multifunctional system. In order to establish their importance, the airsacs have been studied in depth by several authors (MEAD 1975; LAWRENCE & SCHEVILL 1956; SCHENKKAN 1973; HEYNING 1989; HEYNING & MEAD 1990; GREEN *et al.* 1980) but, as AWBREY stated in 1990, «None of the experiments, so far, show how the structures implicated make clicks».

In recent years, modern anatomical techniques (such as X-ray computer tomography, magnetic resonance imaging, micro-cryosectioning) have been used to get a clear understanding of the complicated three-dimensional structure and possible functions of the airsacs and their surrounding tissue (AMUNDIN *et al.* 1988; AMUNDIN & CRANFORD 1990; CRANFORD 1988). In 1988, using X-ray computer tomography (CT) and magnetic resonance imaging (MRI), CRANFORD (1998) found hitherto undiscovered structures in the head of a spinner dolphin. Nevertheless, the aim of studies to date has always been qualitative. Our study will try to find a method to quantify the airsac volumes and thereby help to elucidate their function.

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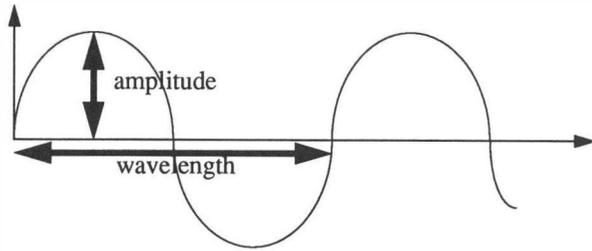


Fig. 1. — Wavelength is the length of the wave until it reaches its first zero point where it starts again. Amplitude is the height of the wave.

There is a clear physical relation between the size of an air volume and its reaction to sound of a specific wavelength (see Fig. 1 and Fig. 2). A quantitative study was needed to bring the properties of the echolocation click of certain species to relation with their airsac anatomy (HEYNING 1989). The whitebeaked dolphin (*Lagenorhynchus albirostris*, Gray 1846) uses a click as depicted in Fig. 3* with a dominant frequency of 65 kHz. Its airsac system is relatively simple

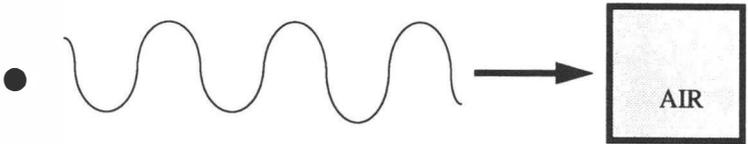


Fig. 2a. — If the wavelength is close to the dimensions of an air volume, the volume will resonate and amplify the sound.



Fig. 2b. — If the wavelength is longer than the dimensions of the air volume, the waves will go through the volume without being blocked.

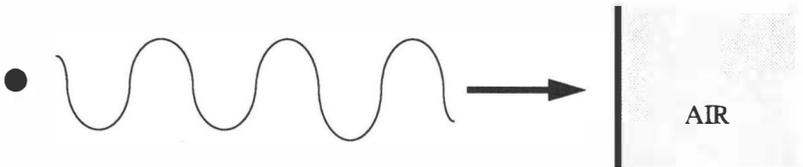


Fig. 2c. — If the wavelength is smaller than the dimensions of the air volume, the volume will block the sound and reflect it.

* All recordings shown in this publication were made by C. Kamminga.

and follows the usual pattern in most delphinids*. It is quite similar to that of the bottlenose dolphin (*Tursiops truncatus*, Montagu 1821). The harbour porpoise (*Phocoena phocoena*, Linnaeus 1758), however, uses a frequency spectrum with a two-component structure; one component at 20 kHz and a high frequency component on 110-130 kHz. The click of the harbour porpoise looks more complicated in structure and possibly shows inner reflections (see

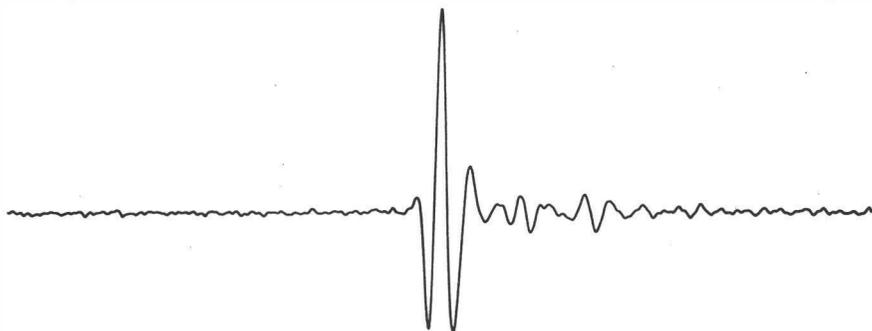


Fig. 3a. — Echolocation click of *Lagenorhynchus albirostris*. Unpublished recording, August 1982.

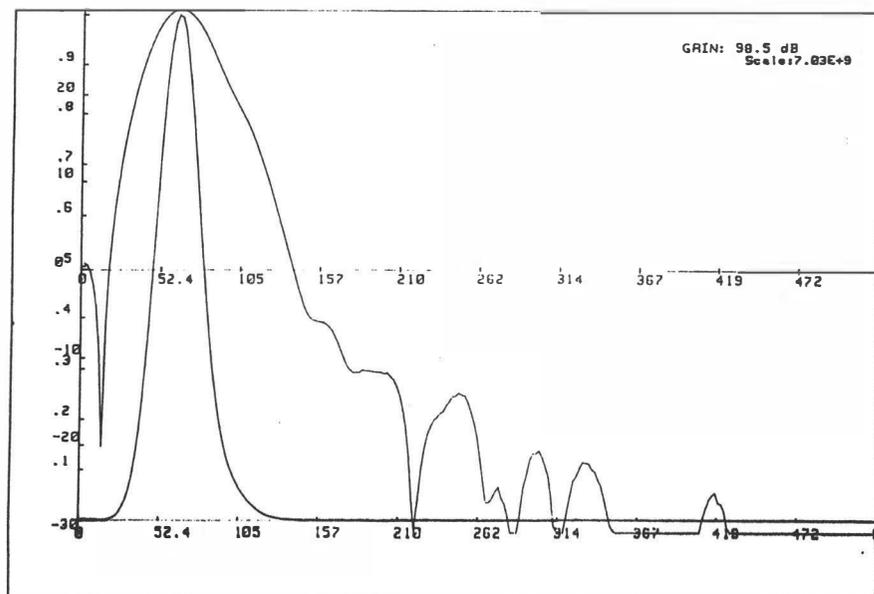


Fig. 3b. — Frequency spectrum of the click of *Lagenorhynchus albirostris*.

* We do separate the Delphinoidea into the distinct families of Delphinidae, Phocoenidae and Monodontidae for several taxonomical reasons, especially their air sac anatomy.

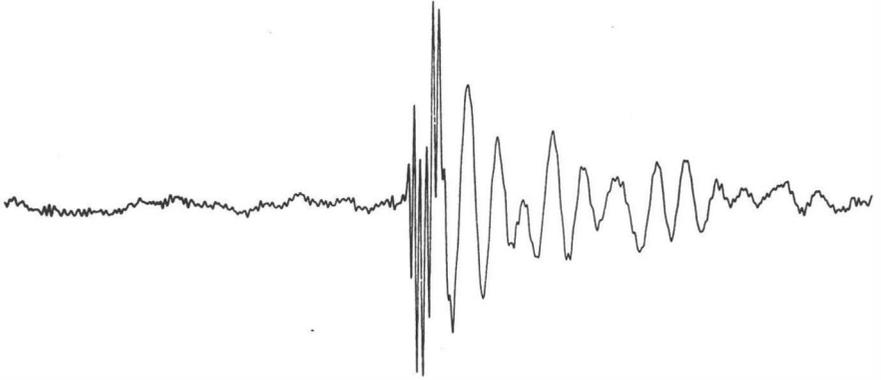


Fig. 4a. — Echolocation click of *Phocoena phocoena*.

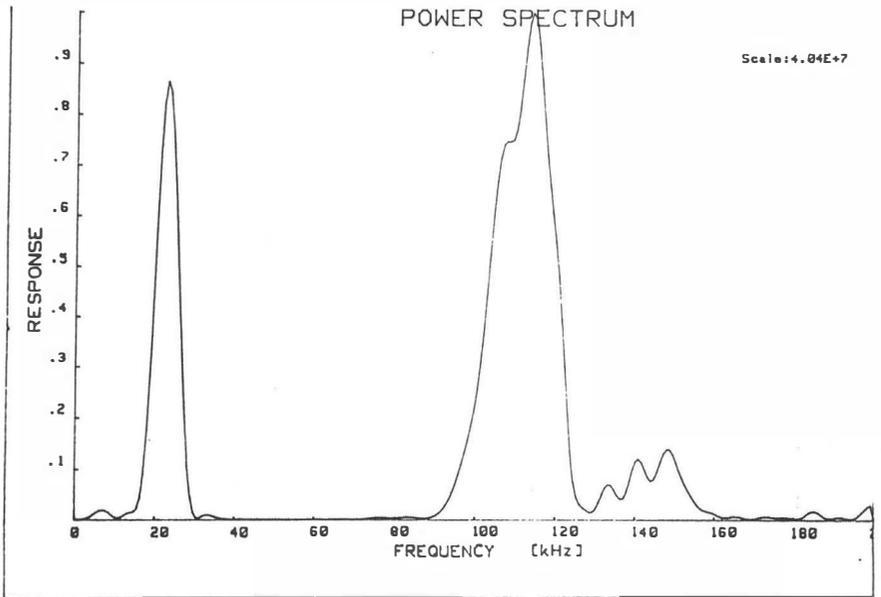


Fig. 4b. — Frequency spectrum of the click of *Phocoena phocoena*.

Fig. 4). The airsacs system of this species is much more complicated than that of the delphinids, with most distinctive features being the existence of a «Hintere Klappe» and big vestibular airsacs with an intrinsic muscle.

Methods

To be able to quantify the volume of the airsacs, first of all an accurate representation of these structures is needed.

We have applied several non-invasive methods to this problem with varying results (see Fig. 5). Every method proved to have its own advantages and disadvantages. X-ray computer tomography proved to be the best method for an exact representation of the air-tissue interface of the airsacs. The major disadvantage of this method is the loss of information about surrounding soft tissue. To achieve an image with both good soft tissue resolution and good air-tissue interface representation, a new method of fitting and combining CT and MRI images was presented by ANDREA (1990, 1991).

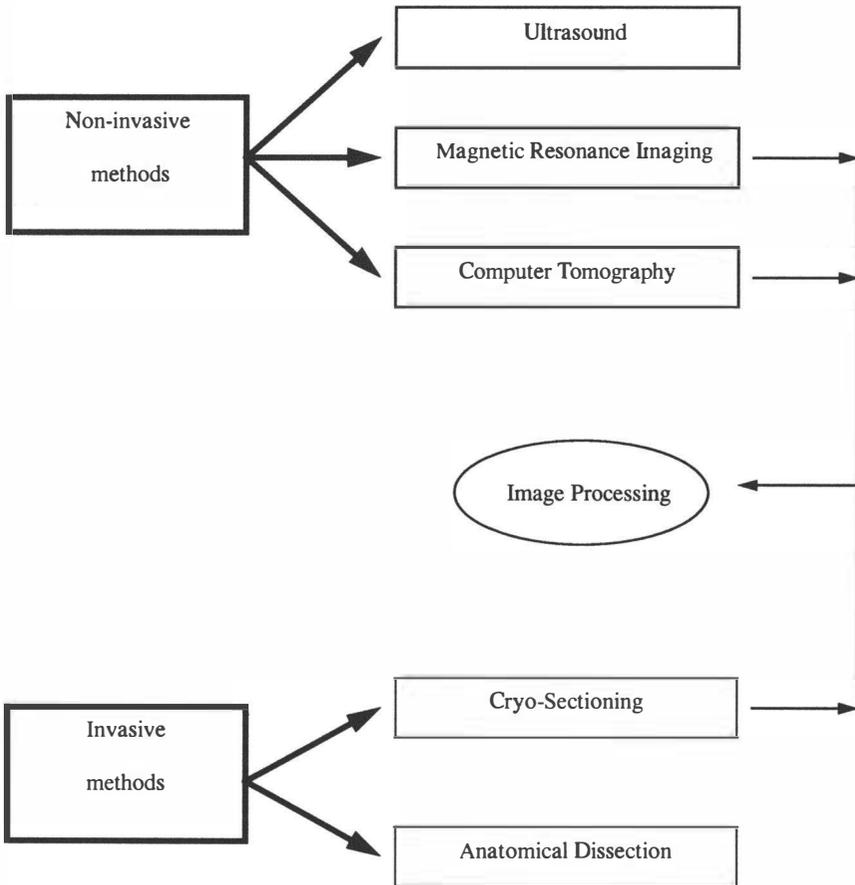


Fig. 5. — Methods studied for the quantification of the airsac volume in toothed whales.

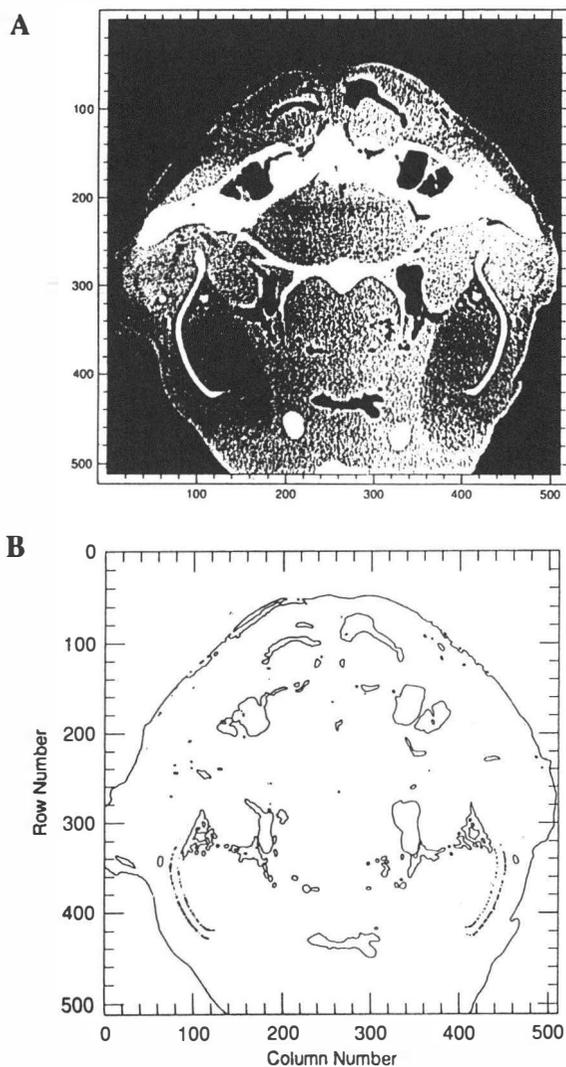
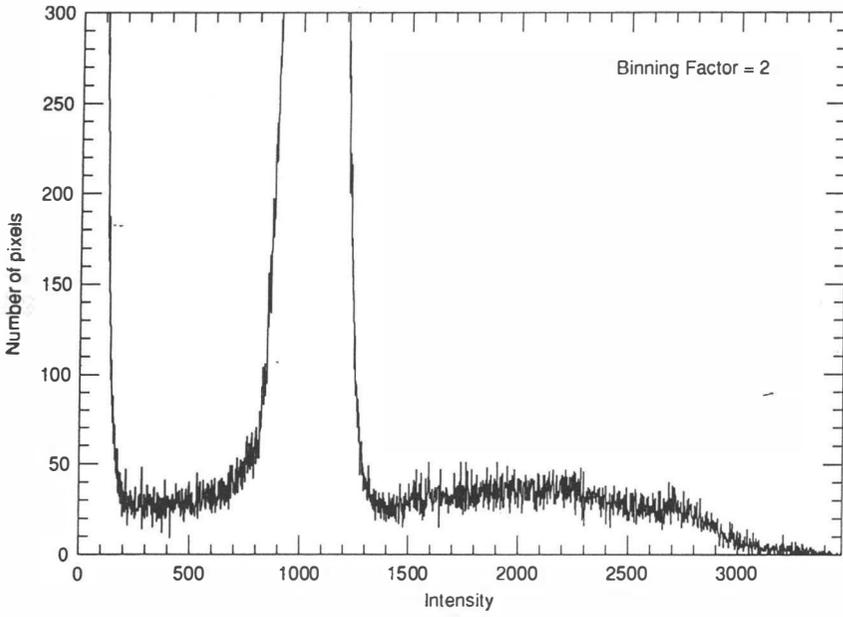


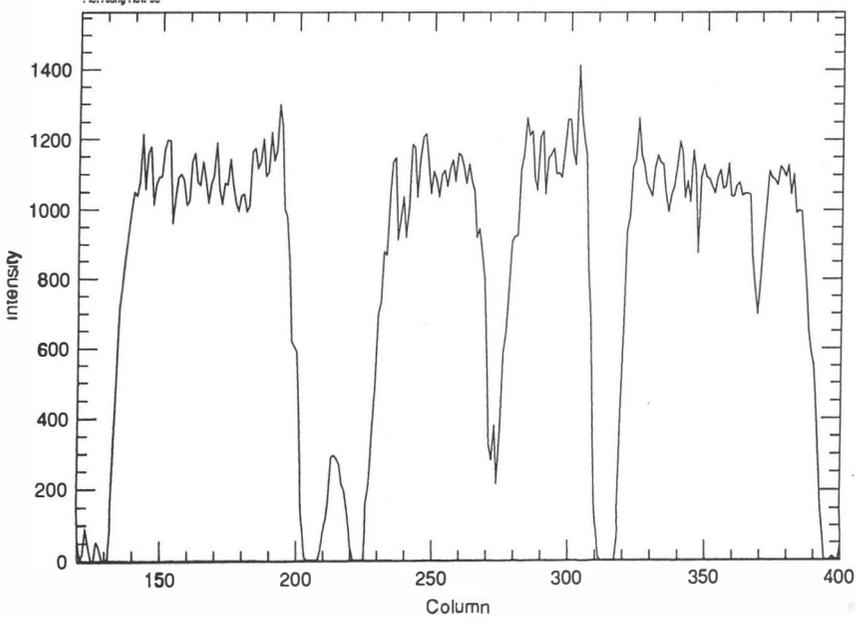
Fig. 6. — Image processing applied to the CT images:

- A. Original black and white CT image.
- B. Contour of all air-tissue interfaces in the image; the area of the entrance to the vestibular air sac (red) is 157 pixels.
- C. The histogram shows the distribution of pixel values (in Hounsfield values +1000) throughout the whole image.
- D. The plotting of one row of the image helps detecting the kind of tissue around an air sac.

C



D



For the CT scanning of a dolphin's head the airsacs are artificially inflated. Thus we are able to compare the passive air volume distribution with the post-mortem distribution in the relaxed airsacs. After the scannings, a «traditional» layer-by-layer anatomical dissection is performed on the heads to ensure the freshness of tissues and the absence of pathological changes. In one animal, cryosectioning of the whole head was performed.

The images gained by the scanners and the cryosectioning are processed by means of image processing techniques to get more information out of them than what is actually visible. These techniques provide the possibility to analyze the imaged structures, enhance certain features, find borderlines, and are used to calculate the air volume of the airsacs. Examples of such image processing are given in Fig. 6.

Material

The specimens used for this study are mostly stranded animals, few are bycatches. Whenever possible, we perform an autopsy ourselves to make sure that no disease afflicting the airsac system is present. Thus pathological changes in the airsacs were discovered in several cases. To my best knowledge at present, the type of pathological changes found in two cases have not been described previously. Another animal presented two tears in the melon tissue, clearly visible in both CT and MRI, but difficult to see in the melon itself without prior knowledge of it. The origin of this lesion is not clear at the moment.

The following species have been studied to date:

1. *Phocoena phocoena* (family: Phocoenidae);
2. *Lagenorhynchus albirostris* (family: Delphinidae);
3. *Kogia breviceps* (family: Physeteridae).

All animals used, with the exception of the *Kogia*, were adults (*Kogia* subadult). Some other species will be studied in the near future, as soon as we can get adequate material.

Preliminary results

X-ray computer tomography has proved to be not only a good qualitative investigative method for the airsac system of odontocetes, but to be suitable for quantitative investigation as well.

The combination of CT images with image processing techniques proved to give excellent results.

Because there are two passive closure mechanisms, the blowhole and the nasal plugs, we are able to inflate the airsac system in odontocetes and thus evaluate the passive air distribution in comparison with the relaxed *post mortem* situation which has been the basis for all studies of this kind so far.

Several interesting findings have been the result of the application of the methods described above, especially concerning the passive distribution of air among the airsacs. These will be the object of further investigation and future publications.

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HEALTH STATUS OF CETACEANS. VETERINARY ASPECTS

BY

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SUMMARY. — Environmental disturbances are blamed to be a major threat on sea mammals but defining the cause of a disease is one of the most difficult tasks in medicine and, although there is little doubt that at least some pollutants must affect sea animals, a precise assessment on their relative importance is extremely difficult on elusive, wild animals that cannot be examined. At least, they can be necropsied and pathologists, trained at observing gross and microscopic lesions, can obtain significant informations on the cause of a disease by performing necropsies and histopathological evaluations. Integrated with data on toxicology, microbiology and epidemiology; pathology can provide evidence for major and minor causes of diseases. Active international cooperation, creation of data banks, and multidisciplinary approach are our best chance to understand pathogenesis and to propose solutions for diseases of sea animals in general and for cetaceans in particular.

* * *

Environmental disturbances are thought to be a major threat on sea mammal populations. Heavy metals, organochlorines, oil, depletion of fish resources and noise are altogether blamed for contributing to the progressive disappearance of some species. It is tempting to draw immediate conclusions from data that relate human activities to biochemical or toxicological results. Is this a proper scientific approach?

Medical thinking teaches us that attributing a cause to a disease is a formidable task requiring, theoretically, the fulfilment of the so-called Koch's postulate: the suspected cause or etiologic agent must be present in all cases, it must be retrieved from all diseased or dead

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hosts, and, once given to experimental individuals, reproduce the disease in all its forms. Needless to say that, in most cases, meeting these requirements is a long, difficult, expensive and more than often frustrating task.

It is particularly the case with diseases of marine mammals which are, for most of them, elusive creatures, difficult to observe and impossible to examine. Occasionally, however, scientists have access to individuals found dead ashore, with variable post-mortal decay. These dead bodies are an extremely important material that should be made available not only to biologists but also to people with a medical training. In fact, another thing that medicine teaches us is to avoid the layman's most frequent mistake: to equate clinical signs of disease (symptoms) or death with a suspected cause (etiology), giving little attention to lesions.

Pathology, the scientific discipline of lesions understanding, is the cornerstone of theoretical medicine. Back to basic concepts, let us say that medicine has two major purposes that are not exclusive but that apply differently according to the species involved.

Clinical medicine is turned toward individuals and tries to cure diseases. The ultimate example is human medicine where, in the civilized world, the major cost of health care results from individual treatments, often given to elderly people or to terminal patients. That aspect of medicine raises questions with an ethical dimension that I have no competence to discuss. To remain in the field of sea mammals, asylums and re-conditioning centres belong to that kind of thinking and most of them are a respectable but, in the long run, futile initiative in regard to entire populations protection.

And this concept of populations brings us to theoretical medicine which purpose is to dissect mechanisms and to achieve a better understanding of diseases. To reach that result, observation and experimentation are uncomparable tools that bring medical scientists to do exactly the opposite of what they are there for: to reproduce diseases and to kill animals. That too has a strong ethical flavor that I don't want to discuss.

Experimental medicine is easy to perform on small, easily raised animals (mice, chicks, ...) that have little popular attractiveness or commercial value. In that regard, like humans and large domestic animals, sea mammals are to be seen as valuable individuals that deserve attention and cannot be experimented on. A major difference between sea mammals and humans or domestic animals is that their

diseases are not well enough understood yet and their lesions are not thoroughly worked out and described.

As veterinary pathologists, we are trained at observing lesions, and comparing them between species, our discipline being often referred to as «comparative pathology». Studying various species gives us an advantage at prospecting new fields such as wild or sea animals pathology, using our knowledge and experience of similar conditions in domestic species. Indeed, pathology is remarkably similar across the species barriers and, let us say, a pneumonia or an interstitial pneumonitis is very similar in humans, cattle, pigs, cats, and dolphins. More so, a proper evaluation of lesions can lead to consider a specific agent or a specific group of agents that typically induce that pattern of changes.

Remaining with the example of respiratory diseases, it is easy to observe that a dead sea mammal has big swollen red and humid lungs but it is more difficult, on gross observation, to differentiate passive congestion that can be due to circulatory failure (heart disease), to lung œdema that is often associated with asphyxiation, to hemorrhage that can be metabolic, toxic or traumatic, or to lung inflammation.

Following careful necropsy observations, histopathology or microscopic examination of lung tissue will give us additional information: so-called alveolar pneumonia is usually due to bacteria reaching the respiratory tract by inhaled air and interstitial pneumonitis is mainly associated with viruses or non-infectious agents such as inhaled or exhaled toxics and with immune-mediated hypersensitivities.

That example of the lung was particularly obvious with the massive death of dolphins that occurred along the Spanish coast of the Mediterranean Sea in 1990. Speculations of all kinds emerged as soon as mortalities were recorded. A veterinary pathologist, Dr. Domingo from the University of Barcelona, associated the lung lesions observed in these animals with an interstitial pneumonitis, very similar to canine distemper. Starting from there, the cause was searched for and a morbillivirus, similar to canine distemper virus, was identified. Now, the story is not complete since one can object that these animals were debilitated from the start. Indeed, it is known that the development of diseases can be multifactorial and result from an imbalance between the defense mechanisms of the host and the aggressiveness of the agent. Therefore, non-infectious agents could have sensitized the dolphins to preexisting viruses. Important infor-

mation can be collected on such a hypothesis by performing complete and additional necropsies. Record of similar lung lesions in dolphins necropsied in other instances, could indicate previous undiagnosed cases. Serum samples revealing the presence of specific antibodies could also sign the presence of the virus rampant in dolphin populations.

What is the Belgian contribution to the question of cetaceans' health status? In late 1989, at the initiative of the Ministry of Public Health and Environment, a cooperative program was created that grouped biologists and veterinarians from major scientific institutions and external collaborators. Initially subsidized by the Ministry and the EEC (G.D. XI), the group performs necropsies of sea mammals at the veterinary school of the University of Liège. Specimens are forwarded to the Royal Institute of National Sciences (Mr. Tavernier) for speciation, identification, measurements, aging, and skeleton preservation.

MM. Joiris and Milinkovich, respectively scientists at the Dutch and the French University of Brussels, collect data for heavy metal toxicology and genetic studies. Tissues are also sampled for parasitology, bacteriology, and virology at the veterinary school, and additional samples are collected for organochlorines concentration by Prof. Bouquegneau at the University of Liège, Ecotoxicology lab.

Belgium only has a 40 miles coast line and, so far, only 2 fresh bodies of the common porpoise (*Phocoena phocoena*) have been examined, a young, immature male and an adult female.

The first case, the female, was found dead in February 1990, with numerous chronic cutaneous scars and ulcers due to trauma.

Decreased fat layer indicated emaciation with evidence of severe weight loss. Opening the abdominal cavity, the liver was found to be enlarged, soft, and irregular, with about one hundred white, granulo-matous foci of fibrotic tissue and one 1 cm diameter cystic nodule. Histopathology revealed the massive presence of liver flukes (*Cam-pula oblonga*) with sections in adult parasites and typical operculated eggs. Lesion diagnosis was a cystic and hemorrhagic chronic parasitic cholangitis and multifocal subacute hepatitis.

Interestingly enough, adrenal glands were hypertrophic, nodular, and cystic, with empty cavities containing viscous fluid. On histopathology, the general structure of the gland was modified, and characterized by a loss of typical cortical layers architecture due to large hyperplastic nodules and cysts. Proposed lesion diagnosis was a

multifocal cystic adrenal hyperplasia. Cysts mostly involved the so-called fascicular layer of the adrenal cortex. That type of lesion has been previously described in grey and ringed seals chronically exposed to organochlorines. Also, rats chronically fed with polychlorinated biphenyls (PCB) have been observed to present zona fascicularis hyperplasia. These cells are responsible for cortisol secretion, a glucocorticoid adrenal hormone produced in high amounts during chronic stress.

Lymphoid tissue was also examined, since immunodeficient status often relates to lymphoid tissue atrophy and depletion. It has been reported, however, that marine mammals have a poorly reactive lymphoid system, most lymph follicles being in a resting stage. The fact remains that lymph nodes of that animal were characterized by rare cells, with evidence, in central areas of lymph nodes, of severe cellular depletion and occasional lymphocyte necrosis.

Identical lesions were observed in lymphoid tissue of the spleen.

Lymphoid tissue is responsible for the defense of individuals against pathogens, and severe lymphoid depletion can be indicative of chronic stress or chronic exposure to pollutants such as organochlorines or heavy metals, as observed in Guinea pigs orally exposed to PCB. In kidneys, lesions were most prominent in glomeruli where severe membranous glomerulopathy was diagnosed. Identical lesions have been described in diabetes mellitus, a common complication of Cushing's syndrome, a disease associated with adrenal cortex hyperplasia.

Lung lesions were characterized by congestion and œdema, possibly leading to asphyxy, probably occurring just before death. Bacteriology performed on various organs was non significant but heavy metals were extremely high for inorganic mercury content in fat, liver, and kidney.

A young, immature, male porpoise was also necropsied in February 1990. The animal was found entangled in fishing nets and had died of asphyxy. Lesions can easily be summarized in saying that it hosted massive infestation by cutaneous, hepatic, respiratory, and intestinal parasites.

Liver contained hundreds of parenchymal and biliary lesions of chronic hepatitis and cholangitis associated with *Campylobacter* sp. Intestine was the seat of subacute anterior and mid enteritis due to cestodes identified as *Diphyllobothrium* sp, lungs were massively

invaded by parasitic worms identified as *Torinurus convolutus* and *Pseudalius inflexus* and the skin was spotted with numerous proliferative chronic lesions due to parasite *Isocyamus delphini*.

Parasites resembling nematodes were also present in renal pelvis. However, mesenteric lymph nodes were diffusely reactive and the spleen was characterized by extramedullary hematopoiesis, indicative of regenerative anemia in most species.

We thought these lesions were very interesting since, in domestic animals, a massive parasitic infestation is seen in animals exposed to heavy concentration of larvae (mostly in overcrowded pastures), to unusual parasitic species, or debilitated by other pathogens. Since it is unlikely that porpoise concentrations have dramatically raised in recent years, it is possible that exposure to infective larvae has increased, for example through imbalances of fish populations or due to a diet shift toward heavily parasitized preys. Depletion of fishes by overfishing or due to other causes can be the starting point of such a process.

Also, early exposure to toxic agents, such as cited before, could be responsible for decreased defense mechanisms and subsequent inadequate clearance from parasitic larvae. Such a mechanism could be relevant in animals with immunosuppression.

As one can see, dead marine mammals are important for pathologists as well, and every single case brings its load of information. However, a general pattern can only emerge from lesions frequency, incidence and distribution. It is important therefore that in various countries, people perform the same procedures, record the same data, and store them in the same information banks. Dr. Kuiken at the Zoological Society of London has sent a proposal on an integrated necropsy procedure for sea mammals and for a potential exchange of information between countries.

A meeting will be held in Leiden, the Netherlands, in September 1991 to coordinate a programme that might be a unique opportunity to promote the importance of sea mammals necropsy.

Interdisciplinary collaboration, international interaction, cooperative studies between biologists and veterinarians are and will be mandatory in the future if one considers to handle the formidable task of identifying, understanding, and hopefully solving the frightening prospect of the progressive disappearance of marine mammals on this planet.

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ÉTUDES ANATOMO-PATHOLOGIQUES DES CÉTACÉS ÉCHOUÉS SUR LES CÔTES FRANÇAISES DE MÉDITERRANÉE EN 1990

PAR

D. VIALE, F. BAGAINI, S. FREMONT & A. M. ISETTI *

RÉSUMÉ. — Une forte recrudescence d'échouages du dauphin *Stenella coeruleoalba* débute en juin 1990 sur les côtes méditerranéennes d'Espagne, progresse vers le nord et atteint les côtes françaises en août; au total 140 cadavres identifiés en 1990 et 16 indéterminés (*Tursiops*, ou *Stenella*), certains perdus car le réseau de surveillance a été débordé. En Corse, le nombre d'échouages en 1990 est multiplié par 20 par rapport aux années précédentes, alors que le taux d'échouage ne change pas pour les deux autres espèces de dauphins. Les comportements observés des dauphins venant mourir à la côte dénotent une grande souffrance, en liaison avec les diagnostics d'encéphalite et de détresse respiratoire confirmés. Un paramyxovirus voisin de celui de la maladie de Carré et de celui de la rougeole a été mis en évidence dans un dauphin des côtes d'Espagne. Des échantillons de Corse sont également à l'étude actuellement à l'École vétérinaire de Lyon. Cependant les autopsies montrent une très forte variabilité de l'état général des cadavres, décrit par l'épaisseur du lard par exemple. Huit autopsies sont discutées ici. Au-delà des observations de pneumonie et bronchopneumonie liées à l'atteinte virale et constatées par plusieurs auteurs, le poumon montre à l'examen macroscopique des anomalies observées déjà les années précédentes et retrouvées sur *Tursiops truncatus*: atrophie totale de lobes entiers par affaissement du parenchyme et des bronches entre les deux plèvres, hépatisation de zones importantes, fragilisation du tissu pulmonaire au point d'enfoncer les doigts par rupture de la plèvre à la seule manipulation du poumon. Cette fragilisation est également constatée sur le foie et les téguments, et antérieurement observée chez *Tursiops*. Elle n'est pas spécifique du virus cité. Une épizootie classique décrit une relative homogénéité de l'état des cadavres et ne rend pas compte de la variabilité constatée sur notre échantillon. Cette forte variabilité avec l'âge, le sexe, l'état physiologique (croissance, puberté, etc.) suggère une action différentielle de facteurs tels que les polluants véhiculés par les chaînes alimentaires et capables de diminuer les défenses immunitaires.

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SUMMARY. — *Anatomo-pathological studies of dolphin carcasses found on the French Mediterranean coast.* — A renewed outbreak of beached dolphins, *Stenella coeruleoalba*, which started in June 1990 on the Spanish mediterranean coast, progressed towards the north and reached the French coast in August; in total 140 carcasses were found and the species identified, except for 16 (which could have been *Tursiops* or *Stenella*); some were lost as a result of the monitoring network being overloaded. In Corsica, the number of beached dolphins in 1990 was 20 times higher than the annual number for the six previous years, whereas there was no change for the two other dolphin species. The observed behaviour of these dolphins which came to die on the coast, is indicative of great stress related to encephalitis and confirmed respiratory distress. A paramyxovirus of the same strain as that of Carré's disease and measles was identified in one of the dolphins found on the Spanish coast. Corsican samples are at present being studied at the Veterinary School of Lyon. However, the biopsies show a very strong variability in the general condition of the dead dolphins, for example, the thickness of the blubber. Eight autopsies are reported here. In addition to observations made by several authors of pneumonia and broncho-pneumonia linked to the viral symptoms, the lung, under macroscopic examination, shows anomalies which were already noted in the previous years and found in *Tursiops truncatus*, total atrophy of whole lobes by collapse of the parenchyma and the bronchi between the two pleura, hepatization of important areas and the weakening of pulmonary tissue to the point where manipulation by hand of the lung causes the pleura to rupture. This weakening is also noted in the liver and integuments, and has been previously observed in *Tursiops*. It is not specific to the afore-mentioned virus. A classic epizootic disease demonstrates a relative homogeneity in the condition of the bodies and does not explain the observed variability in our sample. This strong variability in age, sex, physiological condition (growth, puberty, etc.) suggests a differential action of factors to the extent that the polluting agents, transported by the food chain, are capable of reducing immune defences.

Introduction

A partir de juillet 1990 les échouages de *Stenella coeruleoalba* se font de plus en plus fréquents sur les côtes d'Espagne entre Malaga et Barcelone (AGUILAR & RAGA 1991). Le phénomène gagne les côtes du Languedoc et de Provence en septembre (BOMPAR *et al.* 1991). En Corse, il débute en août et s'atténue en décembre, en se prolongeant début 1991. Au total sur les côtes de France, 140 dauphins bleu-et-blanc sont inventoriés, plus 16 comptabilisés sous le terme «dauphins indéterminés» mais qui sont probablement aussi des *Stenella* (DUGUY 1991). En fait, certains cadavres ont été repris par la mer avant d'être observés et traités, car le réseau d'observateurs a été débordé.

Sur les côtes de Corse, qui nous servent de base d'échantillonnage, nous avons comptabilisé un total de 20 *Stenella*, auxquels il faut

ajouter 6 spécimens rapportés dans la presse (20 échouages seulement sont donc notés dans DUGUY 1991). Le tableau 1 montre que le nombre d'échouages de cette espèce a été multiplié par 26 en 1990 par rapport à la moyenne des années 80, les échouages des autres espèces de dauphins restant relativement stables. Il s'agit donc d'une mortalité massive.

Cette forte mortalité est rapportée à une épizootie due à un virus. Un *Paramyxovirus* voisin de celui de la maladie de Carré et de celui de la rougeole a été mis en évidence sur un des dauphins échoués sur la côte d'Espagne (AGUILAR & RAGA 1991). Un spécimen échoué sur la côte provençale a permis d'identifier encore la présence du morbillivirus (CHAPPUIS 1991).

Sur un des spécimens échoués en Corse, les tests sérologiques du morbillivirus ont été positifs bien que le virus lui-même n'ait pas été mis en évidence. Les Laboratoires Mérieux de Lyon (Dr. Chappuis) sont actuellement organisés pour faire des tests sur les cétacés échoués sur les côtes françaises de Méditerranée.

Cependant une épizootie engendre généralement une relative homogénéité des cadavres. Elle ne rend pas du tout compte ici de la grande variabilité d'aspect et d'état physiologique des spécimens observés. Il nous semble donc opportun de rapporter les observations réalisées sur les animaux moribonds et sur les organes prélevés lors d'autopsies.

Matériel et méthodes

Le matériel autopsié provient, pour deux spécimens, de dauphins récoltés et traités par le Muséum d'Histoire naturelle de Marseille. Les six autres proviennent des côtes de Corse (1990-91) et ont été collectés par l'équipe Medicet (Université de Corse). Des réunions à Marseille et Montpellier avec les collègues espagnols ont tenté de normaliser les méthodes.

Les mensurations des cadavres et les observations externes sont réalisées suivant le protocole du Centre national d'Étude des Mammifères marins de La Rochelle, auquel elles sont adressées.

Le repérage des cadavres de dauphins nécessite la collaboration des services départementaux (Crossmed, Codis, pompiers, Gendarmerie, Affaires Maritimes), qui font converger les informations sur l'Université de Corse. Avec leur aide, les cadavres sont acheminés vers des chambres froides ou au laboratoire vétérinaire départemental

pour être autopsiés. Quand l'autopsie en laboratoire n'est pas possible elle est réalisée sur la plage même.

Des prélèvements d'organes sont réalisés et adressés à divers organismes.

Dans quelques cas, des bénévoles mobilisés nous ont aidés à relever la taille et le sexe, ou parfois seulement la localité.

Des études histologiques et des analyses de certains métaux sont faites ultérieurement.

L'ensemble des échantillons obtenus n'a pu à ce jour être étudié : des études ultérieures sont nécessaires. Nous livrons ici les premiers résultats d'autopsies.

Résultats

Le tableau 1 montre l'évolution du nombre d'échouages pour trois espèces de dauphins sur les côtes de Corse, durant la décennie 80.

Le tableau 2 récapitule en ordre chronologique la date et la localisation des cétacés échoués en Corse en 1990 : au total 2 *Physeter macrocephalus*, 1 *Balaenoptera physalus*, 2 *Tursiops truncatus*, 23 *Stenella coeruleoalba* et 7 «indéterminés» (il n'y a aucun *Delphinus delphis*).

Table 1

Notre échantillon d'échouages en Corse

	1975	1983	1984	1985	1986	1987	1988	1989	1990	1991
<i>Stenella coeruleoalba</i>	16	2	0	1	1	0	1	—	23	16
<i>Tursiops truncatus</i>	4	0	1	2	4	3	1	2	3	1
<i>Delphinus delphis</i>	0	0	0	1	0	0	0	—	0	0
Indéterminés	0	0	1	0	0	0	2	—	2	1

Fréquences des échouages de trois espèces de dauphins (*Stenella coeruleoalba*, *Tursiops truncatus*, *Delphinus delphis*) sur les côtes de Corse de 1983 à 1991, avec référence à l'année 1975, montrant que les nombres restent du même ordre. On note le manque de renseignements pour 1989, en raison d'un blocage de l'information par les Affaires Maritimes, suite à une campagne de presse sur l'effet des filets dérivants sur les Mammifères marins.

Tableau 2

Date et localisation des cétacés échoués en Corse en 1990

23.04.90	Cachalot			Ostriconi Palasca								
14.08.90	Indéterminé			Calvi								
15.08.90	Indéterminé			Ste Lucie de Moriani								
18.08.90	Stenella coeruleoalba		2 m	Bonifaccio				Sem. Pertusato				
20.08.90	Indéterminé		1,02 m	Calvi, Argentella				P. Jego PNRC				
07.09.90	Stenella coeruleoalba		1,70 m	Propriano								
20.09.90	Stenella coeruleoalba		1,70 m	Ostriconi Palasca				Equipe MEDICET				
21.09.90	Indéterminé		1,35 m	Ostriconi Palasca				Equipe MEDICET				
23.09.90	Stenella coeruleoalba		1,58 m	Ostriconi Palasca				Equipe M				
24.09.90	Stenella coeruleoalba		1,50 m	Pietrosello Corticchiavari								
07.10.90	Stenella coeruleoalba		1,50 m #	Folelli				Equipe MEDICET				
28.10.90	Stenella coeruleoalba		1,87 m	Nonza				F. Lemoine				
28.10.90	Stenella coeruleoalba		1,69 m	Nonza				F. Lemoine				
28.10.90	Stenella coeruleoalba		1,70 à 2 m	Nonza				F. Lemoine				
02.11.90	Stenella coeruleoalba		1,88 m	Santa Maria Pogghiu				F. Lemoine				
02.11.90	Stenella coeruleoalba		1,91 m	Ajaccio				F. Lemoine				
05.11.90	Indéterminé			Sagone								
05.11.90	Stenella coeruleoalba		1,70 m	Cargèse								65 kg
05.11.90	Stenella coeruleoalba		2 m	Tiuccia, Sagone								63 kg
10.11.90	Cachalot			Centuri				Presse				blessé
10.11.90	Stenella coeruleoalba			Canari								
10.11.90	Stenella coeruleoalba			Canari				F. Lemoine				
10.11.90	Stenella coeruleoalba			Canari				F. Lemoine				
15.11.90	Stenella coeruleoalba			Canari				F. Lemoine				
05.12.90	Stenella coeruleoalba		2 m	Sartene				Pêcheurs				
06.12.90	Indéterminé		1,70 m	Bastia Marana								
06.12.90	Tursiops truncatus		1,15 m									
08.12.90	Balaenoptera physalus		18 à 20 m									
15.12.90	Tursiops truncatus		1 m #	Ajaccio								
18.12.90	Stenella coeruleoalba		1,50 m	Port Bastia								
20.12.90	Stenella coeruleoalba		1,96 m	Bastia Marana								
29.12.90	Stenella coeruleoalba		2 m	Bastia								
30.12.90	Stenella coeruleoalba		2 m	Ajaccio								
31.12.90	Stenella coeruleoalba		2 m	Bastia Marana								
18.12.90	Indéterminé		2 m #	Ajaccio								
15.12.90	Stenella coeruleoalba		1,56 m	Mâcimaggio								
				Calvi								

Les diverses espèces de cétacés échouées en Corse en 1990, par ordre chronologique d'échouage. Les colonnes de gauche à droite fournissent la date; l'espèce échouée; la taille de l'individu; la localité de l'échouage; le sexe; l'origine de l'information; des remarques sur l'état du dauphin.

Tableau 3
Caractéristiques des 9 cadavres de Stenella coeruleoalba autopsiés

Cadavres de S.c. par date et par lieu	Sexe	Longueur	Poids	Epaisseur lard	Caractéristiques du lard	Parasites	Etat nageoire dorsale	Caractéristiques externes	Observations
20.09.90 Ostriconi Frémont	mâle	176	—	—	—	—	rien d'anormal à signaler	a souffert par la chaleur	prélèvements
Muséum Marseille	mâle	207	—	< 1 cm	du dos jaune huileux, flasque	kystes dans lard. (phyllob.)	flasque, renversée	—	—
Muséum Marseille	mâle	185	—	< 0,8 cm	huileux pas blanc	—	idem	—	testicules 12 cm
28.10.90 Nonza Corse	fem.	187	60 kg	0,5 cm	—	nbx dans lard partie génitale	—	—	rostre cassé très maigre
28.10.90 Nonza Corse	mâle	169	40 kg	presque pas	flasque, huileux	<i>Monorhyncha</i> partie génitale	enroulée, flasque	pénis 8 cm	rostre cassé côtes saillantes
02.11.90 Ajaccio	fem.	191	63 kg	1,5 à 2 cm	blanc tonique	<i>Penella</i>	ferme et droite	très bon état de conservation	traces de ventouses de calmar
02.11.90 Santa Maria di Pogghiu (Campoloro)	fem.	188	65 kg	> 1 cm; 1 cm ventre	—	2 <i>Penella</i>	idem	marques de morsures sur l'aileron	—
01.02.91 à Ste Lucie Frémont	mâle	187	—	2 cm	blanc-jaune	—	droite	—	des dents n'ont pas poussé
28.01.91 Marana Bastia	?	206	?	< 0,5 cm	non huileux	—	normale	trous de prédatations peau écorchée	blessures à la mandibule

Liste des 9 cadavres de *Stenella coeruleoalba* qui ont été étudiés et autopsiés. Ils sont identifiés par un numéro qui reproduit la date de leur échouage, sauf pour les deux dauphins qui font partie de la collection du Muséum de Paris. Le 9^e (28/01/92) a été autopsié par la Direction des Services Vétérinaires de Haute Corse, et les prélèvements adressés à l'École Vétérinaire de Maisons-Alfort qui a diagnostiqué le morbillivirus et une encéphalite. Les autres autopsies réalisées par nos soins indiquent dans diverses colonnes les caractères observés.

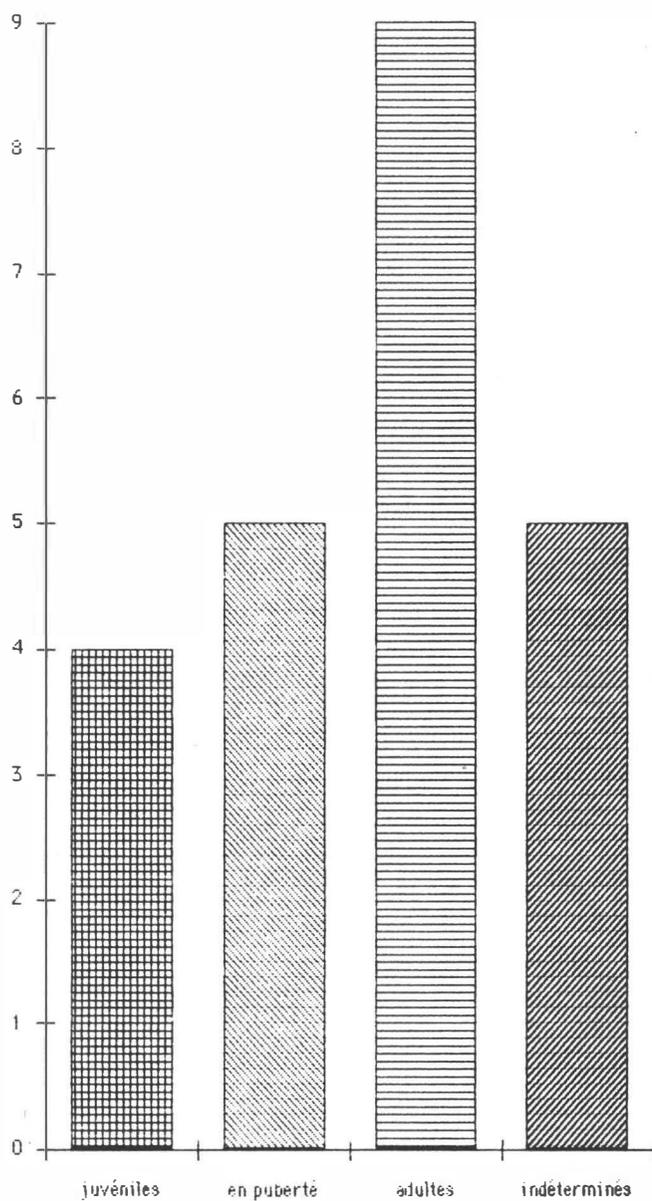


Fig. 1. — Histogramme de tailles (donc d'âges) des *Stenella coeruleoalba* échoués sur les côtes de Corse en 1990-91 (26 individus).

1^{re} classe = juvéniles;

2^e classe = individus en phase de puberté;

3^e classe = jeunes adultes;

4^e classe = taille non signalée.

Le tableau 3 rapporte, pour 9 spécimens autopsiés (dont un par la Direction des Services vétérinaires de Haute Corse), les caractéristiques observées.

La fig. 1 situe les 26 cadavres échoués en Corse dans un histogramme de tailles.

L'aspect des organes à l'autopsie sera commenté plus loin.

Discussion

Le tableau 1 montre qu'il s'agit d'une mortalité inhabituelle (fréquence multipliée par 26). La mortalité de *Tursiops truncatus* reste forte également depuis plusieurs années : il s'agit d'une espèce côtière dont la population est bien moins importante que celle de *Stenella* — mais, étant côtière, ses cadavres ont plus de chances d'être retrouvés sur les plages.

Cette forte fréquence d'échouages pourrait être accidentelle, due à des filets dérivants comme ce fut par exemple invoqué en 1989, quand des centaines de *Delphinus delphis* ont été retrouvés sur les plages atlantiques, de Cap Breton à la Vendée (DUGUY 1990). Dans le cas présent, comme nous l'avons dit plus haut, la mortalité massive est attribuée à une épizootie par virus. Dans quelques cas l'agonie, qui a pu être décrite, révèle une grande souffrance : le dauphin est observé se précipitant contre les rochers, ce qui explique les fractures de la mâchoire observées dans 3 cas sur 8. Ce comportement est à relier au diagnostic d'encéphalite qui a été plusieurs fois rapporté (PICARD, com. pers.; BOMPAR, com. pers.).

Le tableau 2 montre que l'augmentation des échouages de *Stenella* en Corse a débuté en août et que son maximum est atteint en novembre. Il est opportun de remarquer qu'à cette date apparaît aussi une hécatombe de poissons touchant six espèces démersales parmi les plus communes et quelques espèces pélagiques. Cette mortalité massive de poissons consommés par *Stenella coreruleoalba* et *Tursiops truncatus* leur crée un problème d'approvisionnement en nourriture, ajoutant une difficulté supplémentaire aux conditions de disette constatées dans les eaux du bassin nord-ouest méditerranéen. Cette mortalité de poissons n'est pas localisée : elle apparaît sur les côtes catalanes et provençales dès le mois de juin et gagne les côtes italiennes et même algériennes. Elle atteint son maximum en septembre en Corse, où l'IFREMER diagnostique une pastorellose. Une

telle épizootie de poissons est-elle la conséquence d'une altération du milieu ou d'une oligotrophie généralisée? La production en Méditerranée nord-occidentale de 1988 à 1991 a, de fait, été profondément modifiée. AGUILAR & RAGA (1991) attribuent dans les eaux catalanes ce déficit de production au déficit d'apports pluviaux, donc de sels nutritifs, en 1990. BETHOUX *et al.* (1990) constatent que l'augmentation de température de l'eau superficielle se répercute sur celle de l'eau profonde, dont ils démontrent qu'elle a augmenté de 0,16°C. D'autre part des modifications de la circulation générale en Méditerranée créent dans le bassin nord-ouest méditerranéen des conditions de production primaire très faible, tout à fait différentes de celles de 1988 (Programme national Frontal du C.N.R.S. – TOMOFRONT : travaux en cours).

Il apparaît donc dès 1989 de grandes modifications du milieu et des difficultés d'approvisionnement pour les grands Mammifères marins, qui sont probablement une des causes de la *variabilité d'aspect des cadavres*.

Cette variabilité constaté est de plusieurs types. D'une part, l'état de fraîcheur des cadavres est très variable: certains sont morts au large et nous parviennent, avec les téguments abîmés, plusieurs jours après leur mort, d'autres au contraire viennent mourir à la côte. Indépendamment de ce fait, les animaux sont d'un état de maigreur très variable (beaucoup plus variable que chez les dauphins observés échoués les années précédentes). Dans 2 cas sur 8, le dauphin est si maigre que ses côtes saillent sous la paroi externe du corps. L'état du tégument et la tonicité de la paroi varient très fortement, en même temps que la tonicité générale de l'hypoderme et de la musculature et que l'épaisseur du lard. Cette dernière varie de 20 mm (épaisseur normale) à 4 mm. L'hypoderme graisseux est normalement blanc et rigide. La charpente fibreuse du lard est très importante chez les cétacés car elle leur confère leur rigidité extérieure. Ici, le lard est le plus souvent flasque, il a perdu sa couleur blanche, il est jaune et huileux. Cependant le tableau 3 signale un cadavre qui avait conservé son hypoderme normal et la rigidité de sa paroi externe.

Enfin, en relation avec la modification du tégument et du lard, signalons d'une part le caractère flasque de la nageoire dorsale, qui finit par s'enrouler sur elle-même et d'autre part l'importance du parasitisme externe. Le tableau 3 signale deux observations du copépode parasite *Penella* ainsi qu'un nombre important de kystes de *Phyllobothrium* dans le lard et la musculature externe.

Variabilité de l'âge. L'âge détermine-t-il une sélection face au virus? L'histogramme 4 comporte, outre la classe des indéterminés, trois classes de tailles: les juvéniles de moins de 1,58 m de longueur; les animaux en puberté de 1,58 à 1,75 m; les adultes au delà de 1,75 m (à noter qu'il n'y a pas de taille supérieure à 2 m). La classe la mieux représentée est celle des jeunes adultes.

Variations de poids. En se reportant aux courbes taille/poids (ROUX 1984), le poids moyen à 1,65 m est de 65 kg, et à 2 m de 100 kg. Or dans notre échantillon, les tailles de 1,80 m et 1,90 m correspondent à des poids de 63 kg; on note même 40 kg pour un individu de 1,60 m (Tableau 3). Cela dénote un amaigrissement de 20 à 33 % du poids corporel.

ASPECT MACROSCOPIQUE DES VISCÈRES À L'AUTOPSIE ET EXAMENS HISTOLOGIQUES POUR DEUX D'ENTRE EUX

Le *poumon* est l'organe le plus touché, ce qui est logique dans le cas d'une épidémie par le virus de la maladie de Carré. Dans un cas sur huit la plèvre montre des caractères de pleurésie. Dans tous les cas le poumon montre une forte hétérogénéité de couleur et de structure: des zones rouge plus foncé sont infarciées, hépatisées; quelques zones se distinguent par une couleur rosé vif et par l'aspect gonflé des alvéoles. Dans trois cas sur huit, des lobes entiers du poumon ont disparu par affaissement du parenchyme et disparition des bronches: il reste la plèvre. Cette atrophie peut correspondre à une atélectasie par compression ou obstruction, mais ce qui la caractérise est qu'il s'agit de zones très larges.

La même anomalie a été observée chez les *Tursiops* des côtes de Corse dès 1985. On en tire deux hypothèses: ou bien cette atrophie du poumon n'est pas liée au morbillivirus; ou bien le morbillivirus a atteint les *Tursiops* des côtes de Corse dès 1985.

L'examen histologique réalisé sur les *Stenella* Sc 09-90 et Sc 02-91 montre pour le premier une altération bronchiolique et une pleurésie, et pour le second une forte infiltration de cellules lymphocytaires dans le parenchyme. Il s'agit d'une pneumonie interstitielle (BAGAINI 1990). Notons que deux pneumonies avaient été diagnostiquées sur des *Tursiops* en 1988 (collab. M. Riera, Direction des Services vétérinaires de la Corse du Sud). D'autre part un des poumons observés présente une caractéristique: il se déchire sous la pression des doigts, il n'a plus l'élasticité ni la résistance qui permet-

tent normalement à un poumon d'être étiré et manipulé même sur des cadavres de plusieurs jours.

Le *foie*: dans un cas sur huit, il est maintenu contre le diaphragme par une multitude d'adhérences cristallines. De telles cristallisations indentées ont été trouvées antérieurement chez plusieurs espèces (VIALE 1977). Dans deux cas sur sept, le foie n'a pas sa consistance habituelle: il s'affaisse sous la pression des doigts avec un crépitement. L'examen histologique montre deux cas de très nombreux granules dans les espaces du système porte; MARTOJA & VIALE (1977) ont montré qu'il s'agit d'une fonction de détoxification du méthylmercure sous forme de sélénure mercurique. En effet le mercure et le sélénium ont été mesurés dans cet échantillon, qui contenait 162,8 mg de mercure et 6,54 mg de sélénium par kg de poids frais. De tels accrochages cristallins agraffent entre elles les anses intestinales, qui dès lors ne paraissent pas libres et ne glissent pas à l'ouverture de l'animal.

La charge de polluants métalliques est forte. Nous avons testé deux échantillons sur huit en ce qui concerne le foie et le poumon: la charge en plomb est de 5,89 mg dans le foie et 0,075 mg dans le poumon, celle en cadmium de 3,48 mg dans le foie et 0,243 mg dans le poumon, par kg de poids frais.

Le cadmium est éliminé par le *rein*, où il entraîne des néphropathies. Or les reins observés ici ne sont apparemment normaux que dans deux cas sur huit; dans les six autres ils sont flasques, les réticules ne sont plus contigus mais disloqués les uns des autres, reliés par un conjonctif lâche, très encombré de sang noir. De telles néphropathies sont à relier à une hypertrophie et une hypertonie cardiaques observées dans trois cas sur cinq.

Conclusion

Au total les symptômes majeurs présentés par les dauphins sont pulmonaires. Ceci confirmerait le tableau classique des atteintes décrites chez le chien dans la maladie de Carré. Les stades ultimes à encéphalite, décrits chez le chien, sont également signalés chez les dauphins.

Les autres organes des dauphins autopsiés révèlent des atteintes antérieures à l'attaque du morbillivirus, et parfois chroniques comme celles liées à la charge en métaux toxiques Hg, Pb, Cd. La fragilisation des tissus et l'amaigrissement ne sont pas forcément dus à

l'attaque par le morbillivirus: certains dauphins sont morts sans accuser de perte de poids importante. On peut en tirer deux hypothèses de travail. Soit le virus agit très différentiellement sur les *Stenella*: certains sont foudroyés (cas de la femelle du 02/11/90); certains au contraire sont malades très longtemps et meurent cachectiques. Soit le virus a atteint des groupes de *Stenella* très différents par leur état général, certains souffrant déjà de malnutrition et ayant entamé leurs réserves graisseuses. Dans ce dernier cas, la disparition du lard a pour conséquence une libération des toxines qui y étaient mises à l'écart, comme les pesticides, ce qui occasionne une diminution des défenses immunitaires. Les métaux toxiques sont remobilisés, pouvant expliquer des atteintes neuro-psycho-motrices à relier aux comportements anormaux signalés ci-dessus.

Les modifications importantes du milieu marin en Méditerranée nous font pencher pour la seconde hypothèse: elles sont telles qu'elles auraient suscité des perturbations facilitant l'action du virus.

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THE PARASITES OF CETACEANS

BY

J. A. RAGA & J. A. BALBUENA *

SUMMARY. — The metazoan associated with cetaceans constitute a peculiar, little-diversified fauna in comparison with other vertebrate groups. The endoparasites (Trematoda, Cestoda, Nematoda and Acantocephala) had to face the ecological and evolutionary changes brought about by the return of their hosts to the marine ecosystem. Some ancestral parasitic groups, which became practically extinct among terrestrial mammals, were preserved in the process (e.g. pseudaliid nematodes). However, other helminths were acquired from marine vertebrates, mainly fishes and birds (e.g. tetrabothriid cestodes). In addition, several crustaceans were able to adapt to live on cetaceans, which represents the only case among mammals. This resulted in the establishment of new relations that range from phoresis and commensalism to parasitism.

Introduction

Parasitism constitutes a kind of association between two individuals, which occurs in nature more frequently than it has been generally realized. Parasites of marine mammals show several peculiarities as a result of their hosts' colonization of the aquatic environment. This process brought about an ecological isolation from the rest of the mammals, which in the case of cetaceans, dates from the early Tertiary (BARNES *et al.* 1985).

Part of the endoparasitic helminths (trematodes, cestodes, nematodes and acantocephalans) of cetaceans possibly had a terrestrial origin, so that they had to adapt to the pressures of the new environment, resulting in a tight host-parasite co-evolution. The preservation of archaic parasitic taxa, which have practically disappeared among terrestrial mammals, such as the lungworms of the

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family Pseudaliidae (ANDERSON 1982), illustrates the isolation of this helminth fauna. Other helminths were acquired more recently, after the cetaceans' adaptation to sea-life. The mechanism involved is known as «host-capture» and implies that parasites of other marine vertebrates, more commonly fishes and sea birds, were able to colonize and adapt to live in cetaceans (HOBERG 1987a, 1987b; BUSH *et al.* 1990).

Likewise, cetaceans could establish a series of new associations (parasitism, commensalism, phoresis, etc.) with crustaceans. With the exception of some occasional reports in pinnipeds, these relationships between crustaceans and cetaceans are unique among mammals. In the case of some mysticetes, the crustacean fauna can reach a sizeable volume. In this context, TOMILIN (1977) considers that whales and their associated crustaceans form an «itinerant biocenosis».

Helminths

ENDOPARASITES

Apart from some sporadic reports of fungi and protozoans (see ARVY 1982; DAILEY 1985; GERACI & ST. AUBIN 1986), most endoparasites of cetaceans correspond to helminths.

The trematode species of cetaceans belong to nine families (Fig. 1). Three of them, Brauninidae, Pholeteridae and Nasitremitidae, include species that parasitise cetaceans only. In addition, most species of the family Campulidae occur in cetaceans, although some are found in pinnipeds and sea otters.

Most trematodes occur in the digestive tract: liver, hepatic and pancreatic ducts, stomach and intestine. However, the species of the genera *Nasitrema* and *Hunterotrema* parasitise the air sinuses and lungs respectively.

The life-cycles are completely unknown, although it can be assumed that, in addition to molluscs, other organisms can intervene as intermediate hosts.

Generally, trematode infections in cetaceans are not severe. Sometimes, however, they can produce severe pathologies due to their location, their somatic migrations or their high numbers. Light pathological manifestations caused by liver flukes, such as Campuli-

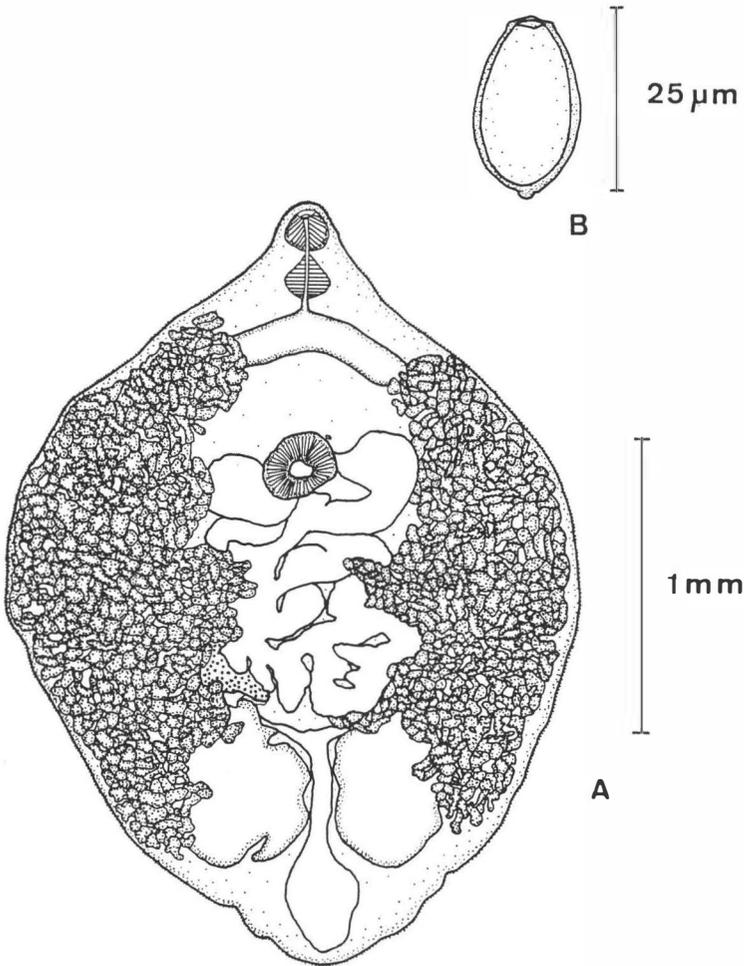


Fig. 1. — *Pholeter gastrophilus* (Kossack, 1910):
A) entire specimen, B) egg.

dae species, consist of duct obstructions and fibrosis, forming hepatic cysts. The latter is commonly observed in harbour porpoises, *Phocoena phocoena* (L., 1758), in the North Atlantic produced by *Campula oblonga* (Cobold, 1858) (RAGA *et al.* 1989). *Pholeter gastrophilus* (Kossack, 1910) causes irritation, haemorrhages and fibrosis in the stomach submucosa as noted in different Atlantic and Mediterranean odontocetes (RAGA *et al.* 1985). By far, the most

severe pathologies are produced by *Nasitrema* spp. in odontocetes in the Pacific and South Atlantic Oceans. These worms are often associated to brain or otic lesions (DAILEY & RIDGWAY, 1976; DAILEY & STROUD 1978; DAILEY & WALKER 1978; RIDGWAY & DAILEY 1972; HOWARD *et al.*, 1983; WALKER *et al.*, 1984; GERACI & ST. AUBIN 1986; MORIMITSU *et al.*, 1986, 1987).

The cestodes parasitic in cetaceans belong to three families: Tetrabothriidae, Diphyllbothriidae and Phyllobothriidae. The first one consists mainly of parasites of sea birds although some occur in cetaceans and a few in pinnipeds. Diphyllbothriids parasitise a wide range of mammals, both marine and terrestrial, and some birds, but the life-cycles, when known, are associated to aquatic ecosystems. The members of the family Phyllobothriidae occur in cetaceans as larval (plerocercoid) stages. Most adult phyllobothriids are parasites of fishes.

Usually, tetrabothriids and diphyllbothriids appear in the intestine, but some species occur in the stomach and liver (DAILEY & BROWNELL 1972). Phyllobothriid plerocercoids form cysts located either in the blubber layer, in the case of *Phyllobothrium delphini* (Bosc, 1802), or in the abdominal mesenteries, in the case of *Monorygma grimaldii* (Moniez, 1889).

The life-cycles of these tapeworms are not known in detail. In the case of those using cetaceans as definitive hosts, it has been proposed that zooplanktonic and benthic crustacea might be involved as first intermediate hosts, and cephalopods and fishes, as second intermediate or paratenic hosts (WARDLE *et al.* 1974; HOBERG 1987a, 1987b). Concerning those forms occurring as larval stages, BAER (1932) postulated that the definitive hosts of these species might be selacian fishes. Currently, this opinion is commonly shared by many other authors, e.g.: DELYAMURE (1955), DOLLFUS (1964), WILLIAMS (1968), TESTA & DAILEY (1977). Sharks may become infected either by predation or by scavenging of cetaceans. Infections may be facilitated by the high latency of these worms after the cetaceans' death and their abdominal location in these hosts.

The tapeworms of cetaceans do not seem to produce severe pathologies. In some cases, however, mass infections can cause mechanical obstruction of the intestine. Light alterations of the intestine walls due to the attachment of the scolex of *Strobilocephalus triangularis* (Diesing, 1850) are also known (Fig. 2) (DAILEY & PERRIN 1973, DAILEY & STROUD 1978, RAGA 1985, DAILEY 1985).

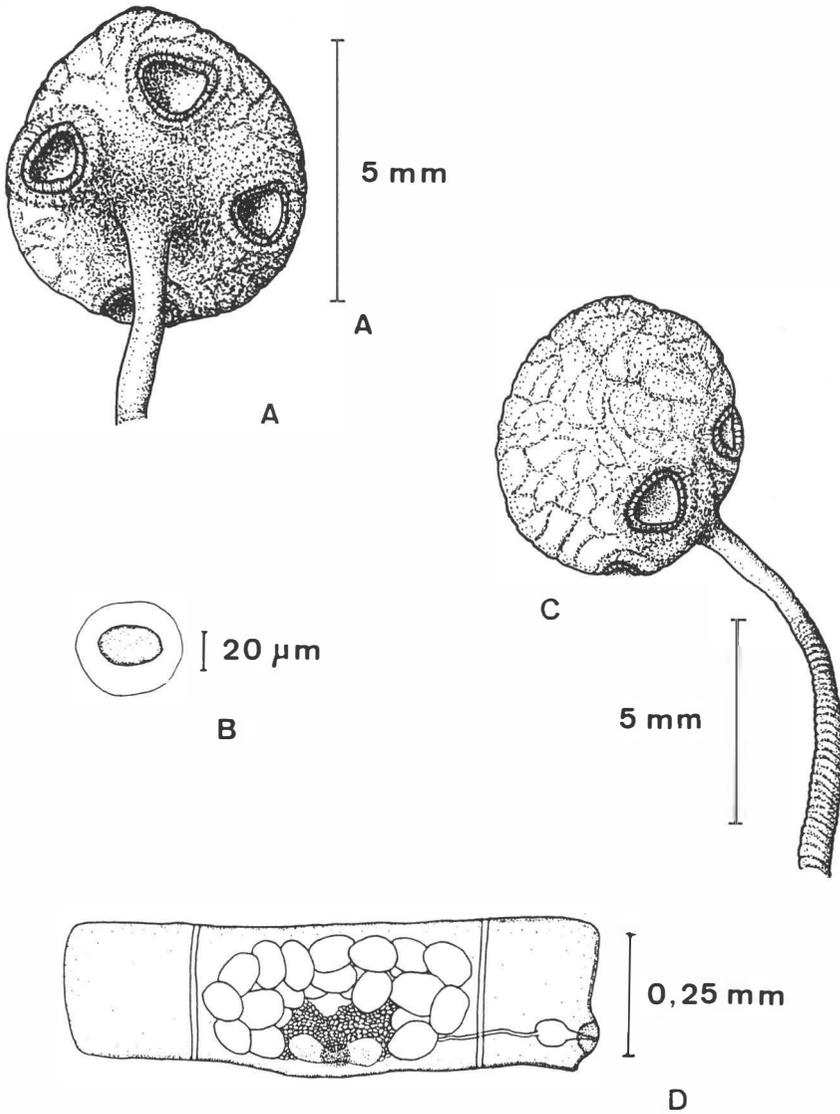


Fig. 2. — *Strobilocephalus triangularis* (Diesing, 1850):
 A) scolex ventral view, B) egg, C) scolex lateral view, D) proglotid.

In addition, diphylobothriid infections in humans have been related to vitamin B₁₂ depletion (VON BONSDORFF 1977).

The highest prevalences of tapeworms correspond to phyllobothriids. These larval forms are distributed world-wide and show no

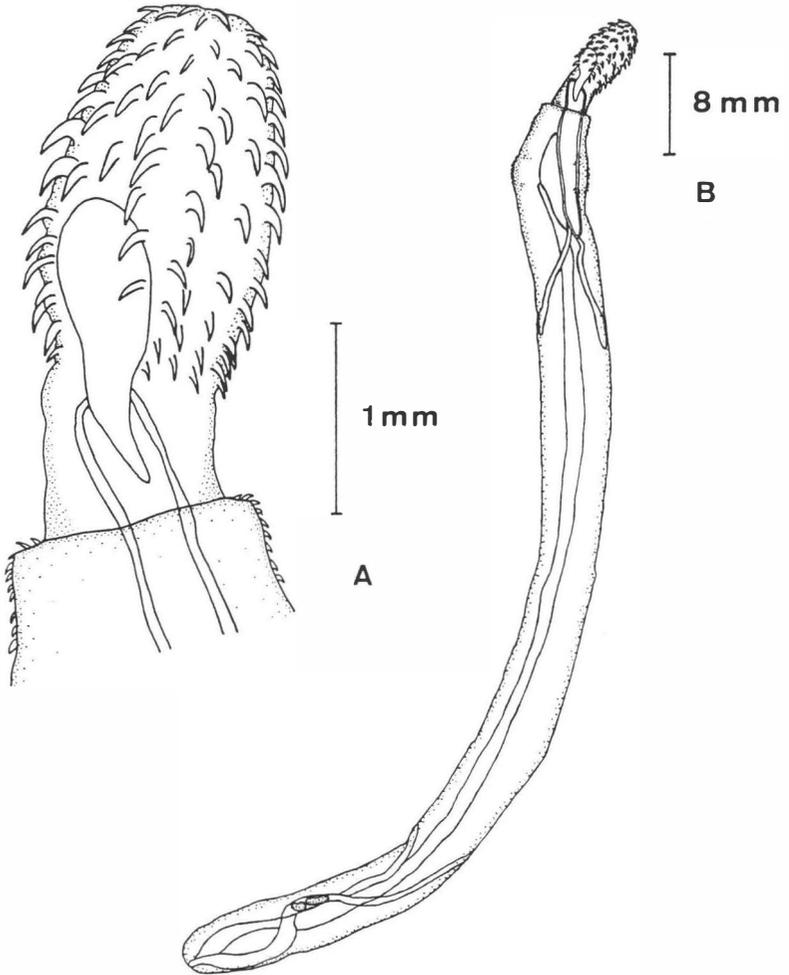


Fig. 3. — *Bolbosoma vasculosum* (Diesing, 1819):
A) proboscis, B) complete male, lateral view.

specificity at all. Prevalences apparently increase with host age. In dolphins of the genus *Stenella* in the tropical Pacific, it has been shown that calves and juveniles are practically free of these parasites, whereas they become more common in subadults, almost all adult individuals being infested (DAILEY & PERRIN 1973). However, these infestations seem to have little effect on the hosts (RIDGWAY & JOHNSTON 1965, HOWARD *et al.* 1983).

Acanthocephalan parasites of cetaceans belong to the family Polymorphyidae. Most species belong to the genus *Bolbosoma* (Fig. 3), although some species of *Corynosoma*, a genus common in pinnipeds, have also been reported. The usual location of these worms is the intestine although occasionally they can occur in the stomach.

The life-cycles of *Bolbosoma* species are unknown. However, given their close phylogenetic relationship with those of the genus *Corynosoma*, it can be assumed that the life-cycles may be similar to that known for *C. strumosum* (Rudolphi, 1802) (DELYAMURE 1955). Accordingly, a crustacean (amphipod or isopod) may be used as first intermediate host and a teleost as second intermediate host. In fact, juvenile forms of *B. vasculosum* (DIESING, 1819) have been reported in fishes (DELYAMURE 1955).

Acanthocephalans can occur in high densities in cetaceans. For instance, 1,319 *Bolbosoma turbinella* (Diesing, 1851) specimens were recovered from 20 cm² of intestinal mucosa of a sei whale, *Balaenoptera borealis* (Lesson, 1828) (DELYAMURE 1955). Nevertheless, the alterations caused by these parasites are usually restricted to local injuries, light inflammation and ulcers provoked by the attachment of the proboscis to the intestine walls (HOWARD *et al.* 1983).

The nematodes of cetaceans can be classified into three families: Anisakidae, Crassicaudidae and Pseudaliidae. The last two parasitise cetaceans exclusively (Fig. 4). There are also occasional records of other species. *Trichinella spiralis* was reported in the muscles of the white whale (*Delphinapterus leucas* L., 1758) in the Arctic (RAUSCH 1970). The pathogeneity of this nematode in marine mammals is unknown (GERACI & ST. AUBIN 1986).

Anisakid nematodes occur in the stomach and intestine; crassicaudids, in the kidneys and genito-urinary organs, placenta, mammary glands, muscles and pterigoidian sinuses and pseudaliids are usually located in the lungs, air sinuses and heart.

Unlike in the rest of nematodes of cetaceans, the life-cycles of anisakids, particularly that of *Anisakis simplex* (Rudolphi, 1809), are known in detail. This is possibly due to the economic and public health impact of these nematodes. The presence of larvae in commercial fishes produces significant economic losses. In addition, these larvae can infect humans through the ingestion of raw or improperly cooked fish, resulting in serious pathologies (OSHIMA & KLIKS 1986, OSHIMA 1987). The first larval stage is found free in the marine environment. Subsequently, planktonic crustaceans become infested.

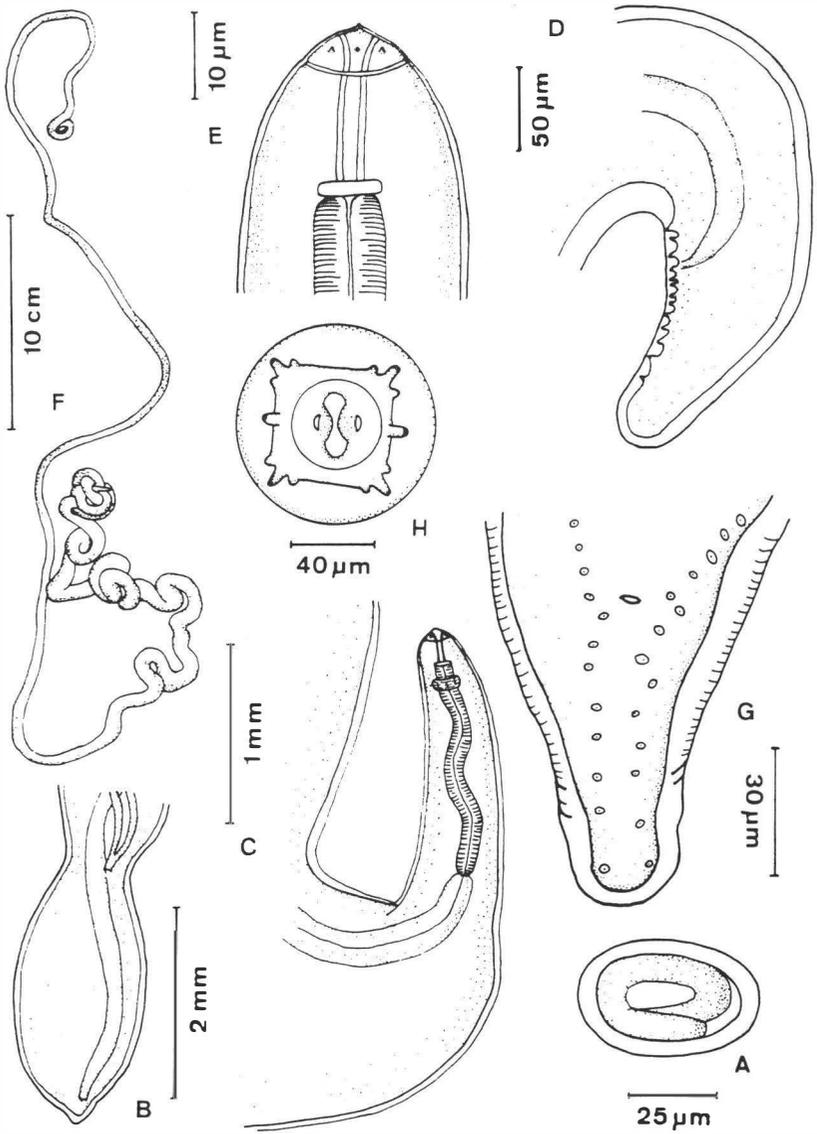


Fig. 4. — *Crassicauda grampicola* (Johnston & Mawson, 1941):
 A) egg, B) tail of female, ventral view, C) head of male, D) tail of male, lateral view, E) head of male, lateral view in detail, F) complete male, lateral view, G) tail of male, ventral view, H) head, anterior view.

Later on, the larvae are transferred to teleosts or cephalopods preying on these crustaceans, but it is unclear if these teleosts or cephalopods act as second intermediate or paratenic hosts. Finally, marine mammals are infected by eating infested fish or squid (OSHIMA 1972, SMITH & WOOTTEN 1978).

Anisakid infections are common in cetaceans, specially in certain areas. For instance, *A. simplex* is frequently and abundantly found in odontocetes of the North Atlantic (SMITH & WOOTTEN 1978, DESPORTES 1985). These parasitosis can produce mechanic obstructions, gastric ulcers and other gastro-intestinal disorders (COWAN 1967; YOUNG & LOWE 1969; SMITH 1989).

The action of the pseudaliids on their hosts can be severe (WOODARD *et al.*, 1969; MCCOLL & OBENDORF 1982; MARTINEAU *et al.*, 1986). These worms can produce obstruction of the bronchi and bronchioles. In addition, some species characteristically embed the cephalic region into the lung parenchima. It has been postulated that the lungworms *Skrjabinalius cryptocephalus* Delyamure 1942 and *Stenurus ovatus* (Kühn, 1829) may be an important factor regulating the populations of common dolphins, *Delphinus delphis* L. 1758, and harbour porpoises, *Phocoena phocoena* (L. 1758), in the Black Sea (DELYAMURE 1955). A similar hypothesis was proposed for various Mediterranean dolphins (RAGA *et al.* 1987), including the striped dolphin, *Stenella coeruleoalba* (Meyen, 1833), population affected by an epizootic in 1990 (AGUILAR & RAGA 1990).

Possibly, the crassicaudids are among the parasites producing the most severe pathologies in cetaceans. In the populations of fin whales in the Northeast Atlantic (Iceland and Iberian Peninsula waters), renal infections with *Crassicauda boopis* Baylis 1920 are common. In this case, the nematodes produce lesions in the kidneys and in other organs due to somatic migrations of the larvae (LAMBERTSEN 1986, RAGA & AGUILAR unpublished data). Some *Crassicauda* spp. can damage the cranial bones of odontocetes (DAILEY & PERRIN 1973, ROBINEAU 1975, DAILEY & STROUD 1978, RAGA *et al.* 1982, RAGA 1987). According to some authors, infections by *Crassicauda* spp. can be an important factor regulating some dolphin (PERRIN & POWERS 1980, WALKER *et al.* 1984) or rorqual whale populations (LAMBERTSEN 1986). In addition, it has been proposed that nematodes of this genus infecting the mammary glands can jeopardise the reproductive success of schools of Atlantic whitesided dolphins (*Lagenorhynchus acutus* Gray, 1828) (GERACI *et al.* 1978) and, perhaps, of

long-finned pilot whales (*Globicephala melas*) in the North Atlantic (RAGA & BALBUENA in press).

Crustaceans

COMMENSALS

The copepod *Balaenophilus unisetus* Aurivillius, 1879 (family Harpacticoidae) represents a good example of commensalism (Fig. 5).

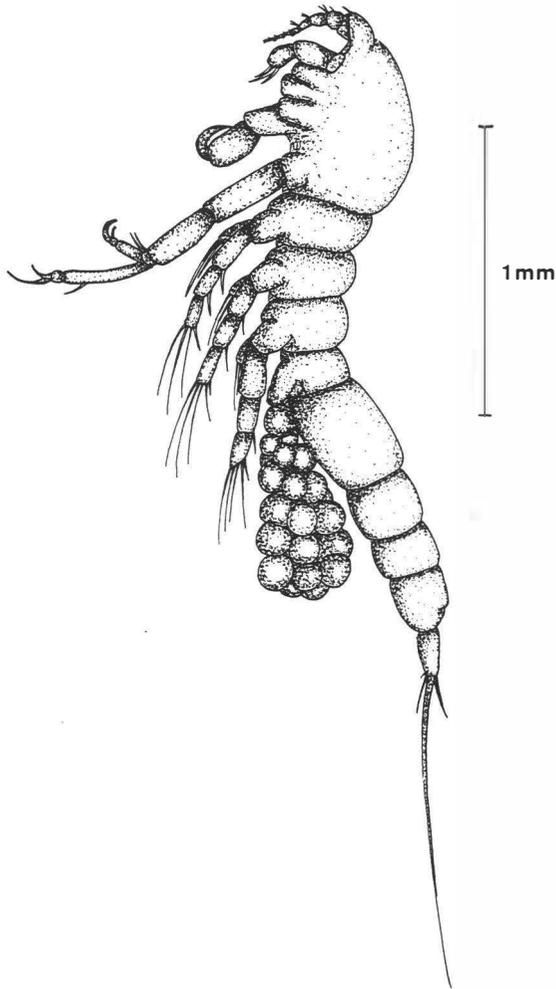


Fig. 5. — *Balaenophilus unisetus* (Aurivillius, 1879): ovigerous female, lateral view.

This species is found between the baleen plates of rorqual whales, feeding on micro-organisms. Its life-cycle occurs entirely in the buccal cavity of the whales. Apparently, the abundance of *B. unisetus* is related to water temperature, being higher in warm waters. Whereas several thousands of these organisms per animal are usually found in fin whales, *Balaenoptera physalus* L., 1758, off the Iberian Peninsula, in contrast the species is absent in baleen whales from the Antarctic (VERVOORT & TRANTER 1961, BANNISTER & GRINDLEY 1966, RAGA 1985).

PHORONTS

Phoront species on cetaceans represent a short number of barnacles of the families Balanidae, Coronulidae and Lepadidae. Some genera, such as *Coronula* and *Xenobalanus*, occur in cetaceans only (Fig. 6). The first data about the life-cycle of these barnacles were provided by GRUVEL (1920). This author described the juvenile forms of *X. globicipitis* Steenstrup 1851, beginning with the attachment of the *cypris* larva to the skin. It seems that the larva initially produces an irritation of the epidermis prior to developing a chitinous shell. Similarly, the different developmental stages of *Cryptolepas rhachianecti* Dall, 1872 on the grey whale, *Eschrichtius robustus* (Lilljeborg, 1861), have also been described (SAMARAS & DURHAM 1985).

The areas of attachment of these barnacles vary according to the species. *X. globicipitis* occurs on the edges of the flukes, flippers and dorsal fin more frequently on odontocetes than on mysticetes, specially in warm waters (PILLERI 1970, RAGA & SANPERA 1986). *Conchoderma auritum* is found on hard surfaces, such as the shell of other barnacles (*Coronula* sp. or *Cryptolepas* sp.), baleen plates or teeth (the latter specially propitiated by jaw malformations) (CLARKE 1966). *Conchoderma virgatum* is not usually found fixed to the skin, it attaches to other crustaceans (*C. auritum* or *Pennella* spp.) instead. Unlike these species, *Coronula* spp. are typically found on mysticetes, specially on the humpback, *Megaptera novaengliae* Borowski, 1781, and right (*Balaena glacialis* Müller, 1776) whales. *C. rhachianecti* is specific to the grey whale, often occurring massively on specific parts of the body (rostrum, flippers, etc.). These zones are thought to be exposed to the maximum waterflow generated by the swimming movements of the whales. In addition, these barnacles show an

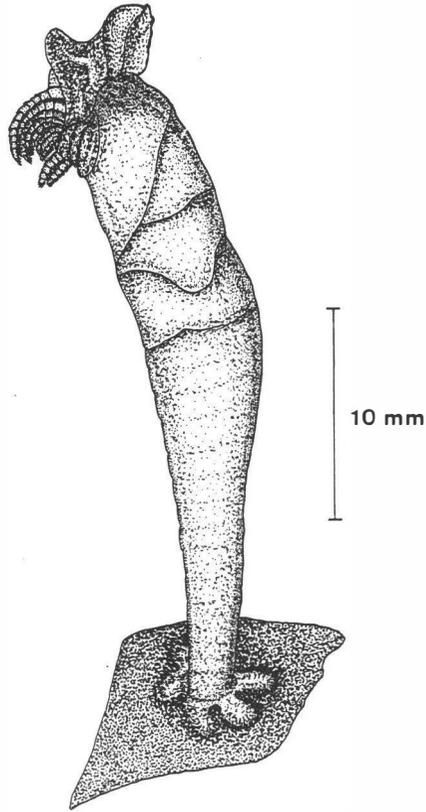


Fig. 6. — *Xenobalanus globicipitis* (Steenstrup, 1851): complete specimen fixed on cetacean skin.

orientation and alignment pattern presumably related to increasing feeding efficiency (KASUYA & RICE 1970; SAMARAS & DURHAM 1985).

ECTOPARASITES

Two parasitic crustacean groups occur on cetaceans: copepods of the family Pennellidae and amphipods of the family Cyamidae.

The species of the genus *Pennella* parasitise several marine vertebrates, including fishes, turtles and cetaceans. Among the latter, they occur more commonly on mysticetes. Usually, the prevalences are low although these parasites become more common at low latitudes (MIZUE & MURATA 1951; RICE 1963). Ovigerous females

are attached to different body areas of cetaceans, particularly on the back and belly. These females embed their cephalic region into the blubber, attaining the muscle layer, and producing an inflammatory reaction. The parasite feeds on exsudates and blood, but it seems that the damage caused is not very important. It commonly consists of small haemorrhages around the attachment zone.

Cyamids, also known as whale-lice, parasitise cetaceans only and constitute the only amphipod group adapted to parasitism (Fig. 7). The life-cycle occurs entirely on the host since there are no actively-swimming stages. There is a remarkable host-specificity among those species that parasitise mysticetes, but not among those that occur on odontocetes. Usually, a given cetacean species does not harbour more

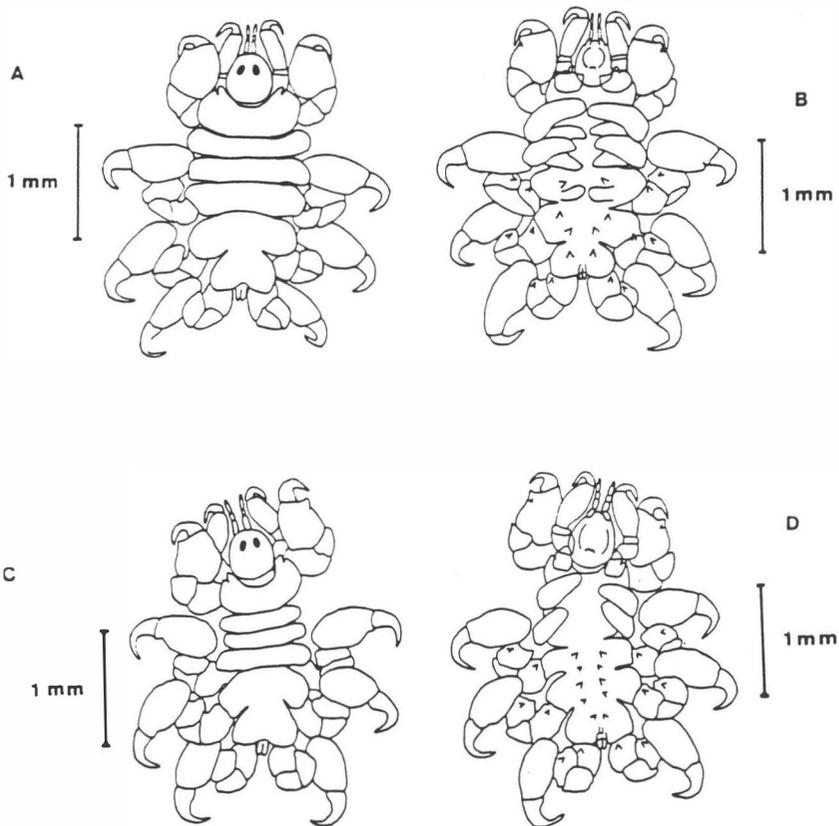


Fig. 7. — *Syncyamus aequus* (Lincoln & Hurley, 1981):

A) dorsal view of female, B) ventral view of female, C) dorsal view of male, D) ventral view of male.

than one whale-lice species, but if this happens, they tend to occupy different locations.

Whale-lice show several morphological adaptations, particularly powerful hooked appendages and strong ventral spines, meant to guarantee fixation on the skin of cetaceans. The abundance of whale-lice seems to be inversely proportional to the swimming speed of the host species. In slow-moving whales, several thousands of cyamids per animal can occur, whereas in odontocetes, particularly in medium-sized or small species, whale-lice are assumed to form sparse populations. In this case, they tend to occur around the natural openings (blowhole, eye folding, mouth, genital slit and anus), where they can shelter themselves from the strong currents set up by the host's swimming. Occasionally, however, mass infections can occur on unhealed wounds or scars where cyamids find shelter and abundant food from inflammatory exudates and blood (LEUNG 1970). Recent evidence suggests that, in the case of *Isocyamus delphini* (Guérin-Ménéville, 1837) on long-finned pilot whales, *Globicephala melas* (Traill, 1809), the latter fact is related to behavioural characteristics of the whales. *I. delphini* is more abundant on sexually mature males than on the rest of individuals. In addition, mass infections always occur on those males and on unhealed wounds. Since the pilot whale is a gregarious species with a polygynous social system, it seems that sexual fights would result in an increased incidence on wounds and scars on adult males. This might provide suitable places for nourishment and reproduction of whale-lice, thereby accounting for the higher abundance on these individuals (BALBUENA & RAGA 1991).

It has been observed that certain barnacles of large whales, such as *C. rhachianecti*, provide additional shelter for some species of the genus *Cyamus* (LEUNG 1976; SAMARAS & DURHAM 1985). In some instances, cyamids are able to feed around and underneath the barnacle until it is eventually detached (SAMARAS & DURHAM 1985).

In some cases, it has been shown that the life-cycles of cyamids are closely related to the biology of their hosts. The life histories of the species occurring on the grey whale (*Cyamus scammoni* Dall, 1872), *C. ceti* (L., 1758) and *C. kessleri* (Brandt 1873) are known with some detail. In this case, there is a synchrony between the whale-lice cycles and the migration of the grey whales, from the Bering Sea to Baja California. In autumn and winter, during the

whales' reproductive season off Baja California, mating and hatching of whale-lice takes place, so that, when the northward migration of the whales starts in early spring, the cyamid larvae are fairly developed and about to attain sexual maturity (LEUNG 1976).

Whale-lice are thought to feed on epidermic tissue, algal filaments and debris from the skin, but it seems evident that the outer layers of the skin constitute the main item (ROWNTREE 1983). These organisms cause certain damage to the whale skin, specially the larvae, which are known to encase themselves into the skin for food and shelter (LEUNG 1976, SAMARAS & DURHAM 1985).

Occasionally, other crustaceans have been reported on cetaceans, but it is unclear whether they are common to these hosts. The harpacticoid copepod *Harpacticus pulex* Humes 1964 was found on a captive bottlenose dolphin, *Tursiops truncatus* (Montagu 1821) (HUMES 1964). Likewise, certain isopods occurred on Hector's dolphins (*Cephalorhynchus hectori* Van Beneden, 1881) and franciscanas [*Pontoporia blainvillei* (Gervais & d'Orbigny, 1844)] (BOWMAN 1971; BROWNELL 1975).

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TOXIC ALGAE BLOOMS AS A THREAT TO CETACEA

BY

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SUMMARY. — The stranding of dead marine mammals is of concern especially when it occurs on a large scale. Among the possible lethal agents, one that could be important but seems to have been underestimated is the consumption of food tainted by toxins, mainly the dinoflagellate toxins that accumulate in filter feeders (molluscs, pelagic fishes). Toxic blooms are increasingly reported even in waters not previously affected. Routine warning networks were set up in different parts of the world to prevent pathological or lethal consequences in humans consuming seafood (mussels mainly). Cases of ichthyotoxicity also occurred, ruining fish farming operations. Since the preys of odontocetes and also of seals might potentially be toxic, it seems reasonable to assume that toxins accumulated in the food web could result in massive and local mortalities of marine mammals. Literature is scarce about this but cases such as the *Megaptera novaeangliae* (Borowski 1781) strandings in the Cape Cod region (N.W. Atlantic) after eating pelagic fish contaminated with Saxitoxin clearly shows that this mechanism may occur. The increase of toxic blooms could enhance mortality of marine mammals. Therefore, routine investigations of strandings should include sampling of corpse tissues, stomach content and if possible living preys in order to investigate for the presence of paralytic (P.S.P.) toxins.

Introduction

Environmental disturbances such as the massive development of microalgae leading to blooms or « red tides » are becoming more frequent and widespread.

The poisoning of humans through eating seafood tainted by toxic algae has been known since biblical times but is rather restricted in space and time.

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In tropical marine communities «ciguatera» poisoning of fish is familiar to local fishermen. In the case of shellfish, earlier, scattered outbreaks in many parts of the world have affected human consumers. The rise (observed in Asia, America and Europe) in the number of incidents of human poisoning, and even mortality, resulting from the consumption of tainted molluscs can be explained by the expansion of shellfish aquaculture and the related increase in consumption. This led to the setting up of monitoring and warning systems able to stop the harvest, and/or ban the trade of suspected products, in order to protect consumers. The basic tools for this are surveys by marine fisheries laboratories, for tracking the toxic species in the plankton on which the shellfish feed, and quality controls on the seafood carried out by the official sanitary services.

These painstaking efforts, as well as the increase in consumption, may explain part of the increase in reports of algal blooms and poisonings. However, the situation seems to be even more dramatic than previously thought. Recently more such events have occurred at a more widespread level and more algal species appear to have become toxin producers, some of them growing to bloom densities. Knowledge of the toxins is still in its infancy; different families of chemicals are involved and lead to a variety of poisoning mechanisms such as the «ciguatera» type, the paralytic, neurotoxic, diarrhetic and amnesic types.

Well documented reviews of this rather broad new field have been published by SHUMWAY (1989, 1990). At least 20 genera of 6 taxonomical groups contain potentially harmful toxic species. They include the dinoflagellates responsible for the paralytic poisoning often referred to as PSP (Paralytic Shellfish Poisoning) toxins. These are related to the saxitoxins of which 18 different molecular structures have already been recognised (SULLIVAN 1988).

Besides the fish poisoned by the «ciguatera» and the infected shellfish which poison humans, other phytoplankton feeders, and consumers higher in the food chain, could well be poisoned also. Logically there is no reason to exclude other routes by which these toxins may be carried through the food webs. Data of this sort are almost non-existent, however, although they should be taken into account when attempting to explain mass deaths of fish-eating cetaceans and, perhaps, also seals.

Toxins and the food chains

FILTER-FEEDING MOLLUSCS

Most of the available data describing the levels of toxins in marine organisms, both in the natural environment and during experiments, are concerned with plankton feeding bivalve molluscs.

Along the Pacific coasts of North America, the PSP toxins have affected the commercial harvesting of bivalves for a long time. The monitoring programmes which have now been running for many decades provide a unique set of data describing the increase in levels of infection from the late 1970's (NISHITANI & CHEW 1988). The highest recorded values reached 30,360 μg toxin/100 g shellfish meat. During a similar monitoring in British Columbia starting in 1964 the following peak concentrations were measured (CHIANG 1988):

Bay Mussels	5,000 μg toxin/100 g shellfish meat
Butter Clams	9,600
Cockles	1,120
Manilla Clams	4,000
Mussels	30,000
Oysters	1,900

This range of values agrees with that found in the adjacent US States for the same period.

On the East coast of the USA, the leading state for the harvest of marine bivalves is Maine. An intensive monitoring programme (SHUMWAY *et al.* 1988) showed that the toxin season lasted from late summer until October. The highest toxin concentrations found in economically significant species were:

Mussels	13,500 μg toxins/100 g shellfish meat
Scallops	3,800
Soft Shelled Clams	> 500
Surf Clams	4,993

Experimental contaminations carried out *in vitro* on different commercial molluscs in Europe (LASSUS *et al.* 1989) show that the maximum level of contamination is species-specific as well as the time needed to reach this level:

Scallops max.: 2,700 μg PSP/100 g reached after 15 days exposure;
 Mussels max.: 1,200 μg PSP/100 g reached after 12 days exposure;

Oysters max.: 100 μg PSP/100 g reached after 11 days exposure;
Clam max.: 100 μg PSP/100 g reached after 18 days exposure.

In the North Sea, a British survey in 1968-77 noticed PSP concentrations in mussels up to about 25,000 μg toxin/100 g mussel meat (AYRES & CULLUM 1978).

All the toxin concentrations given as examples above are found almost regularly today in one or another part of the shellfish production grounds. These extreme, but not uncommon, levels are far above the threshold levels used by seafood sanitary officials to close the shellfish industry: 80 to 100 μg toxin/100 g in Maine (SHUMWAY 1988) and 80 μg toxin/100 g in Europe (LASSUS *et al.* 1989). The gap between these values gives a measure of the importance and extent of the potential for poisoning, especially since detoxification rates are rather low, taking weeks or months, as shown by SHUMWAY (1989, 1990).

Plankton filter feeders other than commercial bivalve molluscs could well become toxic in a similar way and this could lead toxins higher up the food chain to affect the carnivorous components. Data on these steps are very scarce and scattered.

HERBIVOROUS PLANKTON

In addition to the benthic marine ecosystems, the major trophic role of microalgae in marine environments is related to the pelagic food web. Laboratory work by WHITE (1981) indicates that a variety of planktonic herbivores can act as toxin vectors.

From a fish-kill linked with PSP poisoning, which involved sand eels (*Ammodytes* spp.) feeding on cladoceran plankton, WHITE (1984) suggested that toxins must have passed through these zooplankters. Similar suggestions had already been made by WHITE (1977, 1979) in relation to the mortality of herring grazing on pteropods which had accumulated dinoflagellate toxins. Blue fish and menhaden mortality could also result from the transfer of toxins through zooplankters (WHITE 1982).

The only experimental data on the potential of zooplankton grazing to transfer toxins results from experiments in which low concentrations of PSP toxic algae were given to zooplankters (larvae and post-larvae of capelin and herring) (GOSSELIN *et al.* 1989). They showed a build-up of the toxins, reaching saturation after 12 hours, and poisoning the larvae with deleterious effects on their further development.

PELAGIC FISH

Contamination of Atlantic mackerel (*Scomber scombrus*) during an outburst of PSP toxic algae in the Bay of Fundy revealed a build-up of toxin reaching 40-288 μg toxin/100 g liver tissue and 2-75 μg toxin/100 g intestinal tissues (HAYA *et al.* 1990). One month after the algae ceased to be present in the environment, significant levels of toxin still remained in the liver.

Toxicity experiments (WHITE 1984) gave LD₅₀ values for PSP activity on herring, pollock, winter flounder and Atlantic salmon. The *per os* LD₅₀ values ranged from 40 to 76 μg toxin/100 g fish. Recent investigations (GERACI *et al.* 1989) of Atlantic mackerel caught at sea after a PSP toxic algal bloom gave the following concentrations:

0 μg toxin/100 g in the muscles,
52 μg toxin/100 g in the viscera,
153 μg toxin/100 g in the liver,

the mean concentration for entire fish being 80 μg toxin/kg fish.

ACCUMULATION OF TOXINS IN THE FOOD WEB

PSPs produced by dinoflagellates have been shown to contaminate the food chain and accumulate in different organisms for which, with the exception of economically important bivalves, information and data are still scarce.

Mass mortalities in the marine environment

FISH KILLS

The fish species involved in mass mortalities due to PSP material and referred to above, are sand eels, herrings, menhadens and mackerel, all of them pelagic planktivores. The link between toxic algae, grazing zooplankters and planktivorous fish has also been demonstrated experimentally. Important fish mortalities have also occurred in marine aquacultures, for example in the Skagerak where recently there were massive mortalities of salmon in pens and cages (LINDAHL & DAHL 1990).

MASS MORTALITIES OF FISH AND SHELLFISH PREDATORS

Mass mortalities are not infrequent in the marine environment. In addition to planktivorous fish, such events have been recorded for many carnivorous animals, even large top carnivores such as whales, that actively feed on fish or squid. The link between the development of toxic dinoflagellates, at the base of the chain, and the mortality of carnivores at the top of the chain has been established in only a limited number of cases:

Birds:	MCKERMAN & SCHEFFER 1942; COULSON <i>et al.</i> 1968; BICKNELL & COLLINS 1973; ARMSTRONG <i>et al.</i> 1978; HOCKEY & COOPER 1980; NISBET 1983; WHITE 1984; KVITEK & BEITLER 1988; WORK <i>et al.</i> 1991.
Foxes:	KEYES 1965.
Sea otters:	KVITEK 1991.
Fur seals:	KEYES 1965.
Cetaceans:	
Humpback whales:	BEACH 1988; GERACI <i>et al.</i> 1989.
Bottlenose dolphin:	GERACI 1989.

Mortalities and strandings of cetaceans

Many explanations have been advanced for mass mortalities and strandings of Cetacea. None appears to be fully satisfactory. Cetaceans, dominating the food web, are largely devoid of predators. Their longevity is considerable and, besides senility and individual diseases, there appears to be no strong and evident reason why an entire herd should become depressed, swim ashore and die *en masse*. Poisoning due to feeding on contaminated prey does, however, seem a rational alternative explanation for this astonishing behaviour.

Since the prey of odontocetes, and also those of seals, might, as shown above, be potentially toxic, it seems reasonable to assume that toxins accumulated all along the food chain could result in poisonings

leading to mass mortalities. Since these are social animals, including when feeding, symptoms affecting members of the herd and eventually death due to poisoning, could be synchronous. Differences may arise from differences in individual susceptibility and thresholds related to the activity of the toxin (age, size, quantity of contaminated food eaten...). The case of the humpback whales *Megaptera novaeangliae* (Borowski 1781) that were stranded in the Cape Cod region of the NW Atlantic (GERACI *et al.* 1989), after eating pelagic fish (mackerel) which were demonstrated to be potentially contaminated with PSP toxins (Saxitoxin), clearly shows that this mechanism may occur.

In addition to this unique description of an evident link between contaminated prey and strandings, other evidence could be drawn from the literature. One such could be the statement by ODELL *et al.* (1979) of the fact that among false killer whales (*Pseudorca crassidens*, Owen 1946) strandings may occur at the same time in contiguous regions. The same authors also report the case of a false killer whale stranding where all members of the herd were helped to swim back to the sea and where a similar number of whales were stranded again during the next month, on different beaches in the same vicinity. This leads to the thought that strandings could be associated with a synchronous and ineluctable illness or behaviour leading to mortality. Poisoning seems to explain this much better than disease.

Another example supporting the idea of poisoning is the observation of the stranding of a female bottlenose dolphin (*Tursiops truncatus*, Montagu 1821) and her suckling, showing that the juvenile died much earlier (TOMILIN 1957, WOOD 1979).

The link between strandings and poisonous food seems also to be in agreement with the earlier review of TOMILIN (1957) who expressed the opinion that strandings of top carnivores, such as false killer whales (which turn to feed on fish when squids are in short supply offshore), are in some way related to feeding.

Conclusions

The strandings and mass mortalities of marine mammals are of concern, especially when they occur frequently and in large numbers. Among the lethal agents one which seems to be important but largely underestimated, is the consumption of food contaminated by toxins,

mainly the dinoflagellate toxins which accumulate in the food web through the planktivorous filter-feeders (molluscs and pelagic fish).

Toxic blooms are increasingly reported even in waters not previously affected, including temperate and cold waters where cetaceans (and seals) are normally living. This increase in the occurrence of toxic blooms, together with the reduction of squid and fish stocks, could increase the mortalities of marine mammals.

Little has yet been done to elucidate or confirm this hypothesis. The tools for measuring the concentrations of the toxins are now available and routine investigations of strandings should include sampling of corpse tissues, liver and stomach contents, etc. If possible, living prey should be caught in the vicinity at the time of the stranding in order to investigate, among other things, the presence of paralytic (PSP) toxins.

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CETACEAN MASS MORTALITIES AND THEIR POTENTIAL RELATIONSHIP WITH POLLUTION

BY

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1. Introduction

In recent years there has been an increase in the frequency and apparent severity of mass mortalities affecting marine mammals. Considerable concern has been voiced that ubiquitous pollution could be contributing to these incidents. The extent, duration and severity of these epizootics are doubtless affected by many interacting factors; included amongst these could be ambient and preceding climatic conditions, high population density, and changes in species distribution, as well as the nature of the diseases concerned (DIETZ *et al.* 1989, LAVIGNE & SCHMITZ 1991, SIMMONDS, in press).

Since 1987 there have been at least five mass mortalities in marine mammal populations: 1987-1988—a minimum of 2,500 bottlenose dolphins died on the eastern seaboard of the U.S.; 1987-1988—some 8,000-10,000 endemic seals died in Lake Baikal, Siberia; 1988—some 18,000 harbour seals died in the North Sea; 1990—several hundred bottlenose dolphins died in the early months of 1990 in the Gulf of Mexico and, most recently, in the summer of 1990, several thousand striped dolphins died in the Mediterranean (DIETZ *et al.* 1989, GERACI 1989, MCKAY 1989, AGUILAR & RAGA 1990, SIMMONDS, in press). All these events (except perhaps that in Siberia) occurred in waters adjacent to highly populated and industrialised coasts. In addition, there is evidence of unprecedented mortalities in the sperm whale populations of the N.E. Atlantic.

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2. The seal mortalities

2.1. THE EUROPEAN SEAL EPIZOOTIC

Seals and dolphins have many aspects of their biology in common. Both are top predators—feeding largely on fish—and both use insulating blubber stores in a similar way. Seals, however, are easier to study and consequently substantially more is known about the effects of contaminants on them. The 1988 seal epizootic which occurred in Northern Europe is particularly well documented. The event generated tremendous debate about the role of pollution in this and other mortalities (SIMMONDS 1991).

Comparison with the past history of epizootics in seals (something which is not true of dolphin species), showed « striking differences between this [1988 seal epizootic] and earlier events, in terms of mortality rate, rapidity and range of spread » (DIETZ *et al.* 1989). The rapid advancement of the disease in the seal herds clearly indicated a non-resistant population (DIETZ *et al.* 1989) exposed to a highly pathogenic disease (SIMMONDS 1991).

An investigation, funded by Greenpeace with analyses carried out by the British Institute of Terrestrial Ecology, Monks Wood, compared the pollution burdens of harbour seals, *Phoca vitulina* (Linnaeus, 1758), which died during the epizootic in eastern Scotland and the Norfolk Wash (SIMMONDS *et al.*, in prep.). Mortality clearly varied between seal colonies in the UK. It was high off Norfolk (as elsewhere in Europe about 50-60% of the population died) but low, if not negligible, in Scotland (HARWOOD 1989, 1990 and NERC 1989) (table 1). The pollution study found that the Scottish harbour seals sampled had far lower levels of contaminants in their tissues than those from Norfolk (table 2).

Table 1

Population trends post-epizootic

West Scotland, Skye to Mull	+ 3%
Orkney	+ 6%
East Scotland (Moray Firth)	- 15%
Norfolk Wash	- 48%

Sources: HARWOOD 1989, 1990; NERC 1989.

Table 2

Contaminants in blubber samples from harbour seals which died during the seal epidemic of 1988-89

i) On the East coast of Scotland (Concentration in ppm) (9 seals sampled)	
Contaminants	Mean concentration
Mercury	0.03
DDE	1.37
PCBs	0.11
<i>Age:</i> 6 were classed as yearlings/pups 2 as «sub adults» and one is unknown	
ii) From Norfolk (14 seals sampled)	
Mercury	0.212
HCB	0.014
DDE	2.07
Dieldrin	0.031
PCBs	7.17
HCH	0.131
TDE	0.02
DDT	0.24
<i>Age:</i> All seals were classed as yearlings or pups except for one adult.	
Another recent report, (LAW <i>et al.</i> 1989) found the following in a similar group of young Norfolk harbour seals (10 seals sampled)	
HCB	0.004
DDE	3.1
PCBs	23.0
(other organochlorines were also detected)	

The two groups of seals were of similar ages and all died during the 1988 event but the Wash samples had a mean DDE (the stable metabolite of DDT) blubber concentration (2.07 ppm) almost twice that of the Scottish seals (1.37 ppm). PCBs were also more concentrated (mean 7.17 ppm, compared with a value of 1.03 ppm found in only one out of the 9 Scottish seals sampled). In fact, of all the organochlorine compounds which might have been detected, only DDE and, in a single individual, PCBs were found in the Scottish animals.

Following intensive scientific and public speculation, a morbillivirus was isolated from the seals. After initial confusion with Canine Distemper Virus, it was identified as a new virus «Phocine Distemper Virus» (PDV). If PDV had not reached Scotland in 1988, or had

reached significantly fewer Scottish seals than elsewhere, then the lower mortality observed there might be more easily explicable. This was not the case, however, as similar proportions of the surviving populations in Scotland and Norfolk were found to have been infected (HARWOOD *et al.* 1989).

Surviving seals carrying PDV-antibodies show that infection did not inevitably lead to death and, even in seals which ultimately died, sudden death was by no means always the case. Some seals survived for many days in a debilitated condition. Typically they had pneumonia-like symptoms and were unable to feed. This would have caused them to mobilise lipids from their blubber-stores and, indeed, depleted blubber layers were observed in some of the seals sampled (SIMMONDS 1991). This acute mobilisation of lipids would also have caused an accelerated release of lipophilic compounds (such as PCBs and DDT) from their blubber.

Once present in raised concentrations circulating in the seals' bodies, these toxic contaminants may have had very significant effects—producing an additional stress, which for some seals, tipped the balance from recovery from PDV-infection to death. So, the data indicate that seals from Scottish colonies were indeed not only less contaminated than those living off more polluted coasts but that they also had a higher survival rate.

2.2. OTHER SEAL MORTALITIES

Several other seal epizootics have been reported this century and the environmental factors which have been linked to these are outlined in Section 4.4. Too little is known about pollution in Lake Baikal presently to comment on its possible implications for the recent die-off of the Baikal seal, *Phoca sibirica* (Gmelin, 1788). Nevertheless, in 1987-88 about 10% of the original population of 80,000 to 100,000 died. A similar virus to PDV has been implicated in the mortality (DIETZ *et al.* 1989).

3. Cetacean mortalities

3.1. THE MEDITERRANEAN STRIPED DOLPHIN MORTALITY

Very similar recent mass mortalities are now known to have occurred in two dolphin species. The most recent and probably largest of these was in the western Mediterranean.

Since the summer of 1990 abnormally high numbers of dead and dying striped dolphins, *Stenella coeruleoalba* (Meyen, 1833) have been washing ashore on Mediterranean coasts. The first few dolphins were found on beaches near Valencia, in early July, but the full gravity of the situation was not realised until later in the year (AGUILAR & RAGA 1991). By the end of October the number recorded from Spanish coasts had reached four hundred. They also stranded on French and Italian shores as the mortality spread, comprising, in total, some 700 recorded strandings. Only a small proportion of the dead will have been washed into shore as the striped dolphin is a deep water species, normally living far off the coast. The mortality is, therefore, believed actually to have involved several thousand dolphins.

The Spanish Oceanic Institute, Greenpeace, ICONA and others initiated a programme to collect dolphin bodies for pathological and toxicological examination. The Universities of Barcelona and Valencia co-ordinated. Initial epidemiological studies indicate that the event seemed to spread rapidly eastwards, perhaps matching the pattern of dolphin migration. The dead and dying animals exhibited a range of symptoms. Lesions, attributable to viral infection, were present in lungs, nerve tissue and the lymphatic system (AGUILAR & RAGA 1991).

Furthermore, despite sporadic strandings of other dead cetaceans at much the same time and in the same area, it was clear that only one species was affected and that it was suffering a very high mortality rate. A survey of the remaining populations out to sea (AGUILAR *et al.* 1991) found only very depleted schools in the region. So, in terms of severity, species-specificity and symptoms this mortality resembled the 1988 seal epizootic. Once again suggesting the presence of a highly infectious, pathogenic agent and a susceptible population. A morbillivirus was proposed as the cause and this led to fears that the highly endangered Mediterranean monk seal, *Monachus monachus* (Hermann, 1779), might also be threatened (PAIN 1990). However, whilst a morbillivirus has since been found in the dead dolphins, pathology has revealed a complex picture (AGUILAR & RAGA 1990) which indicates that factors including, but not limited to, a morbillivirus infection were involved.

Morbillivirus infections are generally fast-acting but the dolphins seemed to have been in poor condition for some time prior to the infection. Lipid reserves were around 45% of the value expected in

healthy striped dolphins. Parasite burdens were very heavy, including numbers of ectoparasites, indicating that the striped dolphins had probably been debilitated (swimming slowly) for a relatively long period of time. Furthermore, practically every dolphin examined had significant liver lesions which did not appear to have been caused by a morbillivirus infection.

Earlier studies on striped dolphins in the Mediterranean revealed high levels of contaminants in their tissues. Toxicological studies on the dead dolphins from this mortality, however, (conducted by the Department of Animal Biology, University of Barcelona) revealed even greater contaminant concentrations (especially PCBs) (AGUILAR & RAGA 1990). The earlier studies had found average blubber concentrations of 326 ppm (AGUILAR & PERRIN 1989) but, in dolphins from the 1990 epizootic, values exceeding 2,500 ppm were recorded. Aguilar and Raga have put forward the hypothesis that the high body burdens of PCBs produced immunological deficiencies making the animals more vulnerable to infection and, once the infection had been initiated, less capable of combating it.

The mobilisation of lipids which preceded the mass mortality is likely to have been caused by an earlier infection (or some other stressing event). The liver damage (a lesion not compatible with being of viral origin) would then have been caused by elevated levels of PCBs released from the blubber into their general body circulation.

The high concentrations of PCBs found in the dead dolphins in 1990 may be there because depletion of lipids in the blubber not only released the PCBs but also caused those remaining in the depleted blubber layer to become more concentrated. It is also possible, of course, that it was the more highly contaminated individuals within the population which died and then washed ashore.

Alex Aguilar of Barcelona University (cited in LUKE 1991) noted, however, the poor nutrient status of the western Mediterranean Sea preceding the mortality. The weather pattern seemed to be unusual with less water mixing than normal and low rainfall causing comparatively little nutrient-bearing run-off to enter the sea. This, in turn, could have reduced the abundance of the dolphins' normal prey species. Low prey abundance could, in turn have led, or contributed, to the dolphins' initially poor condition prior to morbillivirus infection. A schematic diagram showing the events which may have led to the mortality is given in figure 1.

The potential contribution of «natural» toxins to this mortality,

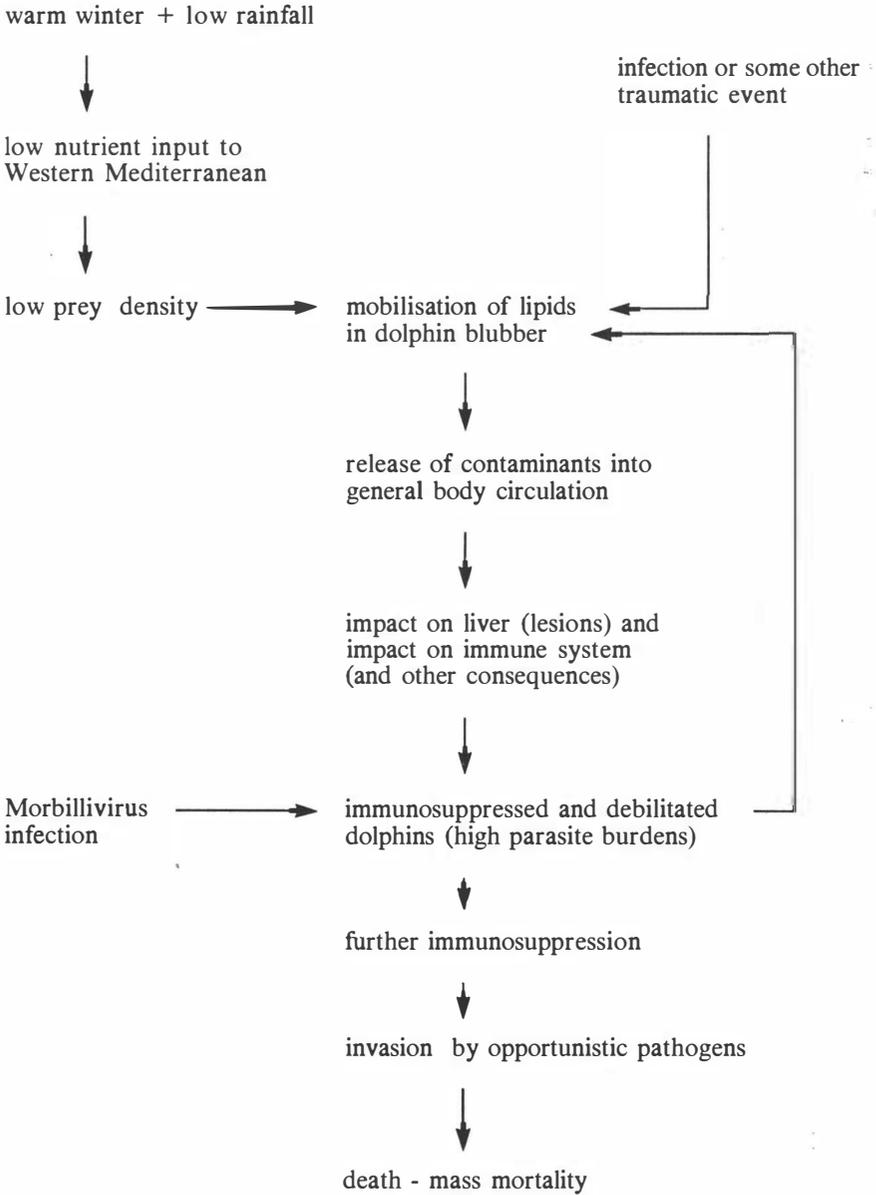


Fig. 1. — Events which may have led to the death of several thousand striped dolphins in the Mediterranean in 1990-1991.

specifically those produced by some phytoplankton, has also been considered (AGUILAR & RAGA 1990). The Mediterranean at this time, however, was not only relatively nutrient poor but there was no contemporaneous record of major algal blooms.

3.2. THE US EAST COAST DIE-OFF

In June 1987, unprecedented numbers of Atlantic bottlenose dolphins, *Tursiops truncatus*, Montagu, 1821, began to wash ashore along the coast of New Jersey, USA, and the US National Oceanic and Atmospheric Administration (NOAA) established a team to investigate. Over 740 bottlenose dolphins stranded along the Atlantic coast during the 11 months that followed. Again only a fraction of the dolphins which actually died are thought to have come ashore and more than half of the inshore migratory population are believed to have died. The die-off progressed southwards in a wave of strandings of dead and dying individuals, following the course of the dolphins' migration in the autumn and winter of 1988. The whole event generated great media interest and public sympathy and concern and the researchers in their final report on this mortality noted that, at that time, «the event was unparalleled» (GERACI 1989).

The dolphins suffered a range of disturbing symptoms. They commonly had large open «crater» lesions on their heads and in their mouths (GERACI 1989). On some animals, considerable areas of skin were found to be sloughing off, exposing reddened dermis—associated with the breakdown of blood vessels. These and other symptoms seemed to be the result of massive bacterial and fungal infections, which were also identified as the final cause of death of many of the dolphins. Related oedema was found in many organs and blood-tinged fluid in the thoracic and abdominal cavities. Whilst significant, the bacterial and fungal invasions appeared (as in many other disease events) to be opportunistic secondary infections.

In fact, many of the dolphins' symptoms were in accord with immune system dysfunction. Lymphoid follicles in the spleen, lymph nodes and intestine were found to be depleted (GERACI 1989). This is again comparable with the 1988 seal epidemic when it was secondary pathogens which, in the majority of cases, ultimately caused death (SIMMONDS 1991).

It was not until February 1989 that NOAA announced the investigation's conclusions at a major press conference. The researchers said that the dolphins were poisoned by eating fish tainted by a naturally-occurring toxin, «brevetoxin», from «red tide» algae (NOAA press conference and reported in MCKAY 1989). The basic evidence for this was that the toxin was found in eight out of seventeen dolphins which were tested. Pollution was at that time categorically rejected as a significant factor in the die-off.

The investigators' final report (GERACI 1989) was released later, in April, and repeated the algal poisoning theory. The hypothesis was that part of a «red tide» (a poisonous algal bloom) was transported to the East coast of Florida by the Gulf Loop Current—Florida Current—Gulf Stream system. Such an event had actually been recorded in the autumn of 1987, although the toxin was found three months earlier in stranded dolphins in Virginia. Planktivorous fish migrating north could, the investigators suggested, have consumed algae from an earlier and undetected bloom. Dolphins, also moving north and feeding on these fish (or their predators) were then exposed to the toxin over a prolonged period, with effects only starting to become manifest as they reached the mid-Atlantic coast.

Not all dolphins could have been poisoned by directly eating fish because brevetoxin was also found in the livers of 3 nursing calves and must have been transferred to them in their mothers' milk (GERACI 1989). In this respect, therefore, brevetoxin was proposed to

Table 3

Problems with the «brevetoxin theory»

- | |
|--|
| <ol style="list-style-type: none"> 1. Evidence of brevetoxin intoxication is limited. Brevetoxin only detected in 8/17 carcasses and 3 fish (one inside the stomach of a dolphin). 2. All lesions found in the 240 carcasses examined were synonymous with PCB intoxication. Including some which are relatively specific for PCB toxicity. 3. Brevetoxin is not known to attack organs or cause lesions. 4. High concentrations of organochlorine contaminants were found in the dolphins. 5. PCBs are known to be immunosuppressive and brevetoxin has not been reported to have such an effect. 6. Dolphins have been exposed to algal toxins for thousands of years and are therefore likely to have metabolic pathways to degrade them. 7. Red tides are common in the Gulf of Mexico along with the same species of dolphins but no previous similar events have been reported. |
|--|

After MARTINEAU 1989.

be acting rather like fat-soluble contaminants (such as PCBs) which can also be passed on in milk.

The brevetoxin-poisoning hypothesis was apparently without precedent, although in the final report it was presented as the trigger for the die-off rather than the sole cause. A number of significant problems exist with this theory and these are summarised in table 3. The known effects of brevetoxin and PCBs are compared with the effects observed in the dolphins in table 4.

It is reported that the investigators, at an early stage, decided to ignore the implications of the animals' contaminant burdens (MCKAY 1989). A memorandum dated August 1987 between government scientists carried the instructions that «no special attention will be drawn relative to these data [PCB and pesticide levels] and that a blanket statement will be made that the levels of these components were not out of the ordinary».

A Congressional hearing on the conclusions of the die-off investigation was held in May 1989. The hearing found that the conclusion released to the world's press—death by natural causes—was less definitive than it had appeared (MCKAY 1989). In fact,

Table 4

Pathology of bottlenose dolphins from the 1988 US die-off and comparison with known effects of PCBs and brevetoxin

<i>Symptom</i>	<i>Previously reported as inducible by</i>	
	<i>Brevetoxin</i>	<i>PCBs</i>
Parakeratosis (thickening of superficial skin)	Unknown	Yes
Liver		
— severe hepatic lipidosis	Unknown	Yes
— single cell necrosis	Unknown	Yes
Immune system – lymphoid depletion	Little known (does not impair immunity in mice)	Yes
<i>Basic known effects on mammals</i>		
	<i>Brevetoxin</i>	<i>PCBs</i>
	Potent neurotoxin	Potent immune suppressors
	Haemolytic agent	(and see other tables)

After MARTINEAU 1989.

however, although the algal-poisoning theory was challenged, the notion that brevetoxin alone was responsible had already been widely reported by the world's press.

One other interesting discovery about the US dolphins (which seemed to have been made between the February press conference and release of the final report) was that serological titres to a morbillivirus were raised in six out of 13 blood samples examined. Bearing in mind the other recent morbillivirus infections in marine mammals, this deserves more investigation. Morbilliviruses are difficult to detect. The presence of detectable antibodies in only a proportion of animals does not preclude the possibility that they were all infected by one of these highly pathogenic agents. Similarly, the significance of the high contaminant burdens of the dolphins cannot simply be dismissed.

3.3. THE GULF OF MEXICO MORTALITY

A subsequent mortality of the same species has occurred in the Gulf of Mexico between January and May 1990 (MCKAY, pers. comm.). No report has yet been produced on this event although several hundred dead animals are thought to have come ashore. Again, many others may have been lost at sea—some to the local shark population.

Initially, during the winter, there was speculation that an exceptionally cold spell in the Gulf might be responsible. The animals, however, went on stranding at abnormally high levels for several months after this. It should also be noted that brevetoxin-producing blooms are a common occurrence in the Gulf, but not off the US East coast. Dolphins, however, seem to have co-existed with them in these comparatively warm waters for millennia without mortalities being induced. What is new here, however, is the heavy industry which now lines the shores and estuaries of the region and which pumps its wastes into the sea.

3.4. THE HUMPBACK WHALE DEATHS

Other marine mammal mortalities similarly, hypothetically, linked to algal toxins are very rare. Between November 1987 and January 1988, however, 14 humpback whales, *Megaptera novaeangliae* Borowski, 1781, were stranded dead along the beaches of Cape

Cod Bay and the northern Nantucket Sound. In this case, researchers reported that the whales died after eating Atlantic mackerel containing saxitoxin (another algal poison) (GERACI *et al.* 1989).

Again, a complex scenario resulting in algal-poisoning of the whales was proposed, along with the idea that yet another marine mammal species is vulnerable to a ubiquitous marine toxin. «Saxitoxin» was found to be present in fish sampled at the time and place where the whales were feeding. Extracts from whale kidneys (in 3 out of 8 kidneys sampled), livers (4/7) and stomach contents (7/9) caused «mortality characteristic of STX [saxitoxin] in mice» but STX was not identifiable using standard diagnostic-analytical (HPLC) techniques, nor was it detected in New England shellfish or plankton sampled in the vicinity and at the time of the mortality. The researchers propose that either the fish carried STX from planktonic sources in the St. Lawrence Gulf to Cape Cod in October-November or the toxin in the mackerel was actually a bacterial metabolite.

Overall, the idea that cetacean mortalities relate to the occurrence of algal toxins in their environments seems, for the present at least, to be based on scant evidence. By contrast, evidence for pollution having a significant impact on the health of marine mammals is considerable and reviewed in Section 4 following.

3.5. THE SPERM WHALE STRANDINGS

Before moving on to the toxicological evidence, however, it is important to note that the list of recent marine mammal mortalities is probably not complete. This may be true of whales, in particular, which could die at sea and never be found. There is some evidence that another significant mortality of a great whale species has occurred because abnormally high numbers of sperm whales, *Physeter macrocephalus* Linnaeus, 1758, have stranded in recent years on European and Norwegian coasts (CHRISTENSEN 1990 and BERROW *et al.* 1991).

Details are as follows: in 1988, in Norway, 27 stranded (and 9 were observed drifting offshore); in Sweden 1; Denmark 1; Belgium 1 and on the Faroe Islands 2. Making a total of 32. Similarly in 1990 on UK and Eire west coasts approximately 12 stranded and in Norway 20—making again a total of 32.

Data on previous levels of sperm whale strandings is scant but the reported levels of these whales stranding on British coasts (where

there has been an observer system since 1913) indicate that only 12 stranded between 1913 and 1966. Strandings schemes have been incomplete elsewhere but there may have been an overall increase in British sperm whale strandings this century, with a significant increase since the 1950s (BERROW *et al.* 1991). This could reflect an increase in the density of these whales in the NE Atlantic but researchers have also noted that the 1990s strandings should not simply be interpreted in this way. CHRISTENSEN (1990) has posed the question of whether these mortalities relate to other recent marine mammal die-offs.

The stranded sperm whales were in too poor a condition for any pathological investigation, but the possibility that one of the «great whales» has also been involved in an epizootic has significant implications for their conservation and must not be ignored. There is no reason to hope that the bigger whales are exempt from the factors causing mass mortalities in other marine mammal species. Unfortunately, little is known about the amount of contamination in any of these larger species. Baleen whales, as filter feeders, may be lower on the trophic web and, perhaps, do not accumulate such high concentrations of pollutants. This would not, however, be true of the other large «toothed» species—including the sperm whales.

4. The toxicological evidence

4.1. THE PCB STORY

A considerable amount is known about the kind of compounds which preferentially accumulate in the ample fatty tissues of many marine mammals. Most is probably known about the PCBs (the polychlorinated biphenyls). It is important to note that this is only one group of chemicals but they are, in many ways, typical of this class of persistent yet highly biologically active chemicals presently of greatest concern with respect to marine wildlife—the halogenated hydrocarbons.

Brief consideration of the PCB family (209 compounds) will help explain their significance. The compounds differ from each other according to the number and position of chlorine atoms in the molecule. They are poorly or non-degradable, accumulate in the food chain and are «toxic» (JOHNSTON & SIMMONDS 1989, VAN DER GAAG & MARQUENIE 1991). PCB-mixtures are used in a range of

Table 5*A summary of PCB toxicity*

<i>Type of Effect</i>	<i>Examples</i>
Liver toxicity	— Liver function disturbed — Enzyme systems activated — Hormone metabolism altered
Immuno-toxicity	— Atrophy of lymphoid tissue — Increased disease susceptibility
Neurotoxicity	— Behavioural changes and «reduced intelligence»
Reproductive impairment	— Increased abortions — Reduced fertility — High embryonic mortality — Birth defects
Skin damage	— Chloracne
Cancer promotion	— Increased malignancies

Source: SAFE 1984.

products where chemical stability is important and some also have useful dielectric properties. PCBs are, therefore, found in flame-resistant coatings, drilling equipment, fluorescent light ballasts and transformers. Commercially available mixtures are often contaminated with very toxic dibenzofurans and PCB mixtures which have been exposed to high temperatures also contain these highly toxic and persistent compounds.

More than two thirds of the estimated global production of PCBs (an estimated 2 million tonnes) is presently still in use in industrialised countries. Shortly, much PCB-containing equipment will reach the end of its useful life and many scientists feel that the threat from the ultimate release of these substances is extremely acute. Dutch scientists (VAN DER GAAG & MARQUENIE 1991) have noted the following:

An uncontrolled release of only part of this 'chemical time bomb' would mean a world-wide threat to vulnerable animal species. Predators at the top of food webs in aquatic ecosystems would be the first victims.

Furthermore, Japanese researchers have estimated that even if as much as 50% of the world's existing PCBs were to be destroyed in the next ten years, a reduction in PCBs in marine mammals would only occur far off in the 21st century.

PCBs are ubiquitous environmental contaminants, which spread world-wide primarily in 2 ways; via atmospheric and by aquatic transport. About 1-10% of global production is estimated to have so far reached the oceans (VAN DER GAAG & MARQUENIE 1991). Areas where sedimentation occurs are likely to be especially badly impacted by water-borne contaminants. It is, therefore, no surprise that PCB concentrations are particularly high in seals and sea birds, for example, in the Wadden Sea. PCBs and related compounds are, however, even detectable in remote polar regions in wildlife and even the indigenous human populations. PCBs, chlordane-related compounds, DDT and other organochlorines, for example, are even detected in arctic cod, polar bears and ringed seals (MUIR *et al.* 1988).

4.2. THE TOXIC EFFECTS OF PCBs

It is already widely acknowledged that fish- and shellfish-eating top predators (potentially including humans) are the major group at risk. Put simply, this is because mammals and birds consume highly contaminated food and accumulate PCBs (and related compounds) in their fatty tissues and elimination of PCBs is very limited except during reproductive processes (VAN DER GAAG & MARQUENIE 1991). Birds, for example, mobilise their fat stores to produce eggs and thus fat-soluble or «lipophilic» contaminants may be deposited inside the eggs in substantial quantities. Similarly, mammals utilise lipids in their adipose stores during gestation and lactation. PCBs and other compounds liberated at this time may be transmitted in high and even potentially lethal concentrations to offspring.

Consideration of the toxic effects of PCBs on mammals is a complex issue (see SAFE 1984, MARTINEAU *et al.* 1987, JOHNSTON & SIMMONDS 1989, and VAN DER GAAG & MARQUENIE 1990). One problem is the variety of PCBs (and other contaminating compounds) present in the original commercial mixtures which are released to the environment. Moreover, the composition of PCBs found in the environment, including in animal tissues, differs from those in the original commercial mixtures because of various transformation and degradation processes. The more highly chlorinated PCB compounds tend to persist.

In laboratory studies PCB mixtures have been shown to cause a wide range of responses in animals, these are summarised in table 5.

Table 6

Evidence of impact of organochlorines on the reproductive systems of mammalian species

- | |
|---|
| <ul style="list-style-type: none"> i. microsomal enzyme induction leading to hydroxylation of steroids such as oestrogens (various species) ii. various impacts on the female reproductive tract (rats) iii. prolonged oestrous cycle—decline in number of implanted ova (mice) iv. incurred foetal deaths (sows) v. embryonic resorption, abortion, stillbirth, irregular menstrual cycles (rhesus monkeys), (embryonic resorption also recorded in mink) vi. development of ovarian-like tissue in embryos (gulls) vii. induction of testosterone hydroxylase (rats) viii. duplication of DDT effects by oestrogen (chickens) |
|---|

After SAFE 1984.

They have been found to impair significantly the immune function of chickens, ducks, guinea pigs, mice, rats, monkeys, rabbits and seals and reproductive effects in another range of species (see Table 6 and Safe, 1984). Further reproductive effects have also recently been found in humans and should be added to this list: a possible correlation has been found between miscarriages and levels of circulating PCBs (LEONI *et al.* 1989) and a similar «hypothesis of correlation» exists between late haemorrhagic disease in new-born babies and organochlorines in mother's milk (KOPPE & OLIE 1989).

Other human developmental problems mediated by exposure to pollution have been revealed by an intensive study of fish consumers around the Canadian Great Lakes (FEIN *et al.* 1984 and THOMANN *et al.* 1987). The Great Lakes system is highly contaminated and the ingestion of fish caught there was found to lead to significant PCB exposure in the womb, related to subsequent low birth weight, small average head circumference, shortened pregnancy duration and in new-born infants poor autonomic and reflex functioning. Moreover, further infant exposure occurs via mother's milk.

Returning to wildlife, GILBERTSON (1989) has noted that «over the past twenty-five years there has been increasing evidence of outbreaks of diseases among fish and wildlife (epizootics) which could not be attributed to conventional etiological agents, such as microorganisms and parasites». These events are linked to environmental

Table 7

Examples of wildlife events thought to be associated with PCB or related compounds

<i>Problem</i>	<i>Location and Species</i>
Fish disease (various symptoms)	Irish Sea plaice, flounder and dab; US Dover sole, starry flounder, Atlantic tomcod, striped bass, English sole, Canadian cod, Swedish hag fish, Baltic salmon, flounder, herring. Riverine trout (Rhine), Great Lakes trout, coho salmon, white sucker and goldfish.
Bird disease (various symptoms —notably embryonic and developmental problems)	Great Lakes: Herring gulls, black-crowned night-heron, ring-billed gull, common tern, Caspian tern, Foster's tern. British peregrine falcons, sparrow hawks and golden eagles, American peregrine falcons, bald eagles and ospreys.
Mammal disease (freshwater only reproductive failure and associated population decline)	US wild and ranched mink US otters

After GILBERTSON 1989.

halogenated hydrocarbon (especially organochlorine) contamination and summarised in table 7.

Added to this list should be the recent work of MASON (1989) who has concluded that pollution has played a major role in the decline of a number of otter populations, especially in Western Europe. He noted that otters are «the top carnivores of wetland ecosystems» and «as such the most vulnerable of animals to pollution and can be considered indicators of the health of the wetland environment».

What applies to otters, applies equally, or perhaps even more so, to other aquatic fish eating mammals. Bio-accumulation occurs along their food chain—fat-soluble compounds accumulate in the upper microlayer of the oceans and in particulate matter (including plankton). This is ingested by microfauna which in turn is eaten by larger animals and then fish. At each step contamination levels increase several fold. Ultimately concentrations of fat-soluble bio-accumulative materials thousands of times higher than those in the surrounding environment are reached. These materials are not locked

away in the animal's blubber but a dynamic situation exists with respect to the rest of the animal's body (REIJNDERS 1980). Exchange is increased when lipids are mobilised.

4.3. DETOXIFICATION MECHANISMS

As has already been noted, some PCB compounds are more frequently encountered in biological samples than others. A study of PCBs present in seal food compared with seal blood, for example, showed a significant difference (BOON *et al.* 1987), indicating metabolism of some PCB compounds. The precise effects of metabolism on actual PCB toxicity is, however, unclear. Metabolites can either be rapidly excreted («detoxification»), or the more stable metabolites (and/or highly reactive intermediates) may cause adverse effects «intoxication» (or «poisoning»).

One enzyme system—the cytochrome P-450 monooxygenase system—is a central catalyst in the oxidative metabolism and elimination of organic xenobiotics. There are more than 150 forms of cytochrome P-450 and each catalyses the metabolism of a comparatively specific group of lipophilic substrates. PCBs can interact with the cytochrome P-450 system in several ways: as inducers, substrates and inhibitors. Organochlorines and other chemicals which induce microsomal enzymes are classified according to their induction activities. Those behaving like the drug phenobarbital are classed as «PB-inducers» and those like methylcholanthrene as «MC-inducers». In rats, PB-type chemicals have been found to induce hepatic cytochromes P-450 a, b and e and MC-type induce a, c and d. PCBs, however, cause mixed-type induction activity as some are PB-inducers and others MC-inducers (SAFE 1984). In seals the mixed function oxidase induction activity referred to as the CYP2B subfamily (the same as that induced by the model compound phenobarbital) is much lower than that observed in other species.

Cetaceans, however, actually seem to lack the CYP2B group entirely (BOON *et al.*, in press). Harbour seals and cetaceans appear to be only able to metabolise PCBs of certain types (technically—those with *o*, *m* vicinal H-atoms in combination with at maximum one ortho-chlorine atom) (BOON *et al.*, in press) and seals have a significantly greater capacity than cetaceans to metabolise certain PCB compounds (those with vicinal H-atoms in the *m* and *p* positions). Similarly, data from a study of chlorinated biphenyls in

the tissues of some marine mammals from the North Sea and Atlantic Ocean, indicated that seals had a greater ability to metabolise these compounds than porpoises. Open sea cetaceans were the least capable (DUINKER *et al.* 1989).

The capacity of small cetaceans to metabolise PCBs has also been considered by Japanese researchers (TANABE *et al.* 1988). The spectrum of PCB compounds accumulated in the tissues of several species of higher animals (including humans) was compared with those in Dall's porpoises, *Phocoenoides dalli* (True, 1885) and the data suggest that in most higher animals, PCB-breakdown proceeds in a similar way but that small cetaceans had a significantly lower ability than the others. Comparison of two enzyme systems based on a «metabolic index» (which is based on tissue ratios of certain PCB compounds) indicates, again, that the important CYP2B enzyme subfamily is missing in cetaceans. The Japanese researchers noted that «... small cetaceans may be vulnerable to the reproductive effects of these chemicals because of a deficiency of PB-type enzymes and low activity of MC-type enzymes also» (TANABE *et al.* 1988). Direct examination of the specific profile of liver microsomal cytochrome P-450 in dolphins and whales, not surprisingly, also reveals very low activity of two parts of the enzyme system (WATANABE *et al.* 1989).

In addition to their detoxification function, the P-450 enzymes are also important in the synthesis and/or metabolism of endobiotics, such as fatty acids, steroids and prostaglandins. The relationship between their presence, concentration or absence and other aspects of animal's metabolism needs further investigation. Every investigation conducted so far, however, indicates that seals and even more so cetaceans, are especially vulnerable to the accumulation and toxic effects of halogenated hydrocarbons.

4.4. OTHER EVIDENCE FROM WILD MARINE MAMMALS

In seals, studies on reproductive failure in the Baltic and Wadden Seas and in Liverpool Bay in the UK, have been correlated in the field and in the laboratory with the presence of PCBs and DDT (REIJNDERS 1980, 1986, BAKER 1989); reduced blood levels of retinol (a precursor for vitamin A) and thyroid hormones in seals fed heavily PCB-contaminated fish caught in the Wadden Sea (BROUWER *et al.* 1989); and various deformities in seals reported from the highly-

polluted Baltic (ZAKHAROV & YABLOKOV 1990). The most dramatic increase in DDT and PCB levels in the Baltic occurred after 1955. Skulls from seals born before 1940 were compared with those from animals born after 1960. Thirty-seven characters were studied and the more recent sample had increased levels of asymmetry in almost every one.

Examples of reproductive failures in marine mammal populations linked to organochlorine contamination have recently been reviewed (ADDISON 1989) and are summarised in table 8.

Table 8

Reproductive failures in marine mammals linked to organochlorine contamination

<i>Locality and Species</i>	<i>Symptoms</i>
1. Californian Sea Lions	Premature births
2. Baltic grey and ringed seals	Population decline Uterine occlusions
3. Dutch Wadden Sea harbour seals	Population decline Reproductive failure
4. Canadian (St. Lawrence) Beluga whales	Population decline Various pathological abnormalities Cancers

Source: ADDISON 1989.

Whilst a detailed chain of events showing how whole organisms respond to PCBs has not been established (ADDISON 1989), changes in circulatory hormone levels in harbour seals, experimentally exposed to high PCBs by their diet, have now been found (BROUWER *et al.* 1989). So the mysterious mechanisms between causes and effects (pollution and reproductive failure) are now being determined.

Considering mass mortalities in marine mammals themselves as evidence of pollution's impact on these animals is perhaps a circular argument. Many different factors have been put forward as significant contributors to epizootics (see table 9). In any disease event a complex series of factors will interact controlling the expression of the disease, including its severity and spread. Some factors may be considered «natural», such as the density of the afflicted population; others «unnatural» such as pollution-induced immuno-suppression. Examination of the list of recent mortalities (table 9) shows that of

Table 9

Factors, other than pollution, postulated as associated with marine mammal mass mortalities

Mortality				Factor			
Date	Location	Species	Approx. Size	A	B	C	D
A. SEALS AND OTHER PINNIPEDS							
1918	Iceland	Harbour seal	1,000	+	-	-	-
1955	Antarctic	Crabeater seal	3,000	+	+	-	-
1978	Bering Strait	Walrus	1,200	+	-	-	-
1979/80	New England	Harbour seal	500	+	+	-	-
1987/88	Siberia	Baikal seal	8,000	+ ?	-	-	+
1988	European	Harbour seal	18,000	+	+	-	+
B. CETACEANS							
1987/88	US (E. coast)	Bottlenose dolphins	2,500	-	-	+	+
1990	US (Gulf of Mexico)	Bottlenose dolphins	300	-	-	-	-
1990/91	Mediterranean	Striped dolphins	7,000	?	-	-	+
<i>Key</i>							
A = Mortality preceded by 3 months when air temperature higher than the ten year average;							
B = Population known to be at high density;							
C = Algal bloom associated;							
D = Morbillivirus associated.							

Sources: DIETZ *et al.* 1989, GERACI 1989, LAVIGNE & SCHMITZ 1990, and AGUILAR & RAGA 1990.

the five which have occurred since 1987, at least four (and perhaps the other one in Siberia as well) occurred along highly contaminated coastlines.

4.5. OTHER EFFECTS REPORTED IN WILD DOLPHIN POPULATIONS

a. Japanese research

A study made on striped dolphins showed that abnormalities in lipid metabolism (fatty livers) occurred in individuals with relatively high PCB and DDT burdens (KAWAI *et al.* 1988). Other Japanese research has found a direct relationship between increasing residue

levels of PCBs and DDE in the blubber of oceanic Dall's porpoises and decreasing blood testosterone concentrations (SUBRAMANIAN *et al.* 1987). The results indicated that even in oceanic species, present levels of organochlorines are causing imbalance in sex hormones and consequently reproductive abnormalities. The levels of DDE in the blubber correlated with this effect were less than 20 ppm—which compared to existing levels in control species is quite low.

b. South African research

COCKCROFT *et al.* (1989) have recently made a major investigation into organochlorines in 105 bottlenose dolphins from the coastal waters of South Africa. They found the same pattern that had been reported from other small cetaceans; organochlorine burdens are closely related to age until animals reach sexual maturity, thereafter there is a marked drop in concentrations in females whereas males continue to accumulate these compounds throughout their lives. They also calculated the quantities and period of the passage of organochlorines to calves (table 10). As shown, rapid transfer of high

Table 10

Organochlorine transfer in South African dolphins

1.	Almost 80% of the organochlorine burden of a female bottlenose dolphin is passed to her first born calf.	
2.	Assuming 20% concentration of organochlorines in mother's milk and calf consumption of four litres/day —	
a)	Milk will contain	2.7 ppm PCBs 2.25 ppm DDT 0.08 ppm dieldrin
b)	Input to calf/day	10.8 mg/day PCBs 9 mg/day DDT 0.32 mg/day dieldrin (approx. 4% of mother's total burden/day) (total load transfer occurs in seven weeks)
c)	Burdens in 2 month old calf	= > 30 ppm PCBs and DDT 1 ppm dieldrin
[This is all based on mother's burden of only 13.5 ppm PCBs, 11.25 ppm DDT and 0.38 ppm dieldrin].		

Source: COCKCROFT *et al.* 1989.

concentrations of organochlorines occurs in mother's milk. The speed of transfer may constitute a greater risk than the levels themselves might indicate. Dolphin calves may also be more susceptible to PCB toxicity at this stage of their lives, as they may have comparatively poor immune response. The researchers noted that the contaminants could actually lead to «a possible mortality of first born calves and a concomitant reduction of male reproductive efficiency» which would probably vary according to the organochlorine burden of animals in each area. As in other mammals, organochlorine compounds are also transferred via the placenta to developing dolphin foetuses (TANABE *et al.* 1982) and enzyme activities are reported to be even lower in cetacean foetuses than older animals (WATANABE *et al.* 1989). It should be noted that the concentrations found in southern hemisphere animals are likely to be far lower than those in cetaceans living in more polluted waters.

c. The Cardigan Bay dolphin calf

The significance of contaminants in European bottlenose dolphin calves was recently illustrated in Cardigan Bay, Wales (WWF 1988, MORRIS *et al.* 1989). During a detailed ecological study of a resident group of bottlenose dolphins in the Bay, in August 1987, a calf was born to one of the adult female members. The development of the calf seemed normal but in June 1988 it was found floating offshore dead. The corpse was examined and blubber thickness seemed normal and hepatitis was the immediate cause of death. It was not possible, however, to determine if this was of toxic or viral origin. Extremely high levels of organochlorine compounds were found in the fat-rich tissues of the calf, lending support to the theory that pollution was to blame (i.e. in the blubber 290 ppm wet weight total PCBs, 150 ppm wet weight total DDT). Levels were comparable to those reported in the very highly contaminated Belugas of the St. Lawrence Estuary, Canada, and seals in the Dutch Wadden Sea. The researchers noted that they had not anticipated finding such high concentrations (although there are apparently no previous studies of contaminants in dolphins in Cardigan Bay or the adjacent waters of the Irish Sea). The calf had, throughout its brief life, remained within a home range of not more than 200 square miles and would still have been obtaining part of its nutrients from its mother's milk—the most likely source of its high contamination burden.

d. Research on St. Lawrence Belugas

Some of the most acutely polluted cetaceans in the world are the St. Lawrence beluga whales, *Delphinapterus leucas* (Pallas, 1776). These form a small population restricted to parts of the Gulf of St. Lawrence and the St. Lawrence estuary (SERGEANT & HOEK 1988). Their numbers have decreased dramatically during the present century. Initially, heavy hunting reduced the population from about 5,000 to several hundred. This pressure lessened appreciably in the 1960s and the beluga has been fully protected since 1979 but the population has never recovered. Researchers have suggested that «organochlorine contamination should be considered as a prime cause for the low recruitment observed in this population» (MARTINEAU *et al.* 1987).

The reproduction rate of the St. Lawrence belugas is half, or less than half, of that estimated for Arctic animals (SERGEANT & HOEK 1988). Concentration of PCBs in the beluga adipose tissues range from 5.7-576 ppm and, not surprisingly, the whales have also been found to be suffering from a range of pathological abnormalities including bladder cancer (MARTINEAU *et al.* 1985) which is rare in animals.

5. Conclusions

The evidence presented in this paper is summarised in table 11. What it shows is that certain ubiquitous pollutants—which preferen-

Table 11

Pollution and Epizootics

- | |
|---|
| <p>A. Considerable evidence exists that organochlorines impact animals in a variety of ways—particularly affecting the immune and reproduction systems;</p> <p>B. Marine mammals accumulate such materials in their substantial fatty tissues and pass them in substantial quantities to their young;</p> <p>C. Marine mammals (particularly small cetaceans) seem to be even more vulnerable to organochlorines than terrestrial mammals;</p> <p>D. Sick marine mammals are likely to mobilise their lipid stores—thereby releasing extra quantities of organochlorines into their disease-stressed bodies;</p> <p>E. There is evidence of this (D) in the 1988 seal epidemic and the 1990 striped dolphin mortality and possibly the E. coast dolphin die-off;</p> <p>F. The frequency of marine mammal die-offs seems to have increased in recent years and they appear to be centred along highly industrialised coasts;</p> <p>G. Levels of implicated substances (i.e. PCBs) are set to increase in coastal waters.</p> |
|---|

tially accumulate in marine mammal tissues—are known commonly to produce a range of detrimental effects in a variety of species. There is no reason to hope that these effects will not also be induced in marine mammals. Indeed, consideration of their biology and metabolism leads to the belief that seals and cetaceans are an especially vulnerable part of this planet's wildlife.

Diseased animals are clearly affected by many stresses in addition to those imposed directly by a primary infection (such as a morbillivirus). Many factors—for example their nutritional state prior to infection—will have a significant role in determining both an animal's initial susceptibility to infection and its subsequent ability to recover once infected. Any dysfunction in an animal's immune system will make it more vulnerable to infection and less able to recover. Toxic substances released into the body of a sick animal may contribute to the overwhelming of vital organs (which may already be damaged by infection). The liver, for example, would be important in removing from an infected animal's system the toxic products of invading bacteria. Elevated levels of PCBs would be expected to interfere with critical liver functions.

At the time of writing (July 1991) it seems most unlikely that the Mediterranean striped dolphin mortality can be simply explained in terms of a morbillivirus infection. Furthermore, the earlier US East coast bottlenose dolphin die-off has just been brought under the spotlight again in a recently released paper. This new investigation into chemical residues in dolphins involved in the die-off, conducted by the U.S. Environmental Protection Agency, far from supporting the natural «brevetoxin» theory, concludes the following:

The data reported here show that the U.S. mid-Atlantic bottlenose dolphins are contaminated with high concentrations of PCBs and PBBs [polybrominated biphenyls], strong immunosuppressive agents, as well as other toxic pesticides... [and] ...yet unidentified polychlorinated and polybrominated chemicals. Although the impact of these contaminants is not fully known, their role as causative agents in this recent mass mortality must be considered... (KUEHL *et al.* 1991).

In fact an increase in disease and even severe epizootics could actually have been predicted from the data available a few years ago. This is exactly what has happened. Now what is being forecast is the possible pollution-induced extinction of marine mammals in coastal waters (CUMMINS 1988, MARQUENIE 1990). It is time to act to prevent this.

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ECOTOXICOLOGY OF STABLE POLLUTANTS IN CETACEANS: ORGANOCHLORINES AND HEAVY METALS

BY

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Among marine organisms, cetaceans are known to contain high levels of stable pollutants in their tissues. However, these high levels depend not only on the contamination of the environment they are living in, but also on several other ecological and physiological factors, so that it is often quite difficult to assess the real health risk associated to the observed pollutant concentrations. The concentrations of stable pollutants recorded in marine mammals have been reviewed by WAGEMANN & MUIR (1984) and by THOMPSON (1990).

The homeothermy developed by cetaceans implies that these animals take up great quantities of food, so that both their position in the food web and the contamination level of the preys are a first important factor determining their own contamination level. As a rule, Mysticeti (planktophagous) are less contaminated than Odontoceti (high-order carnivores). The case of cadmium is particularly interesting in this regard since marine fishes are particularly lowly contaminated by the metal while cephalopods contain very high levels, which clearly influences the cadmium contamination levels of cetaceans feeding on these animals, as shown in Table 1.

The pollutant concentration of cetaceans depends moreover on both the considered organ and the age of the animal. When considering heavy metals, their concentrations are higher in the liver than in

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Table 1

Cadmium concentration of different species of cetaceans and main composition of their diet

Cd concentration in the liver ($\mu\text{g/g}$ WW)		Diet (increasing cadmium concentration)	
0.2	O harbour porpoise	Fish	
0.9	O beluga	Fish	
1.5	M bowhead whale	Crustacea/Pteropods	
5.6	O bottlenose whale		Cephalopods
6.3	O striped dolphin	Fish/	Cephalopods
32.0	O narwhal	Fish/Crustacea/	Cephalopods
50.5	O ziphius		Cephalopods
69.4	O pilot whale	Fish/	Cephalopods

O : Odontoceti

M : Mysticeti

(Cadmium data have been compiled by THOMPSON 1960).

the kidney, except in the case of cadmium. The concentrations of heavy metals are always lower in muscle than in the two organs cited above. When considering the effect of age, one must distinguish essential and non essential elements. In a same population, iron and zinc remain constant with age, whilst copper decreases during the first year and remains stable later. These metals are fairly well controlled, at variance with non essential ones whose concentration increases with age. Low levels of lead are found in cetaceans: most of the pollutant is brought to the animal during lactation, so that in youngest animals, the lead content of the tissues increases; after that, the concentration remains stable: lead is diluted in the animal; in oldest animals, when the growth in length and in weight has stopped, a slight increase in the lead concentration of the tissues is observed again. The cadmium content of cetaceans increases with age but such an increase is particularly important when mercury is considered (see e.g. JOIRIS *et al.* 1991). The mercury increase in cetaceans mainly results from a sequestration of the pollutant in the organism under a detoxified form (see e.g. BOUQUEGNEAU & JOIRIS 1988): mercury is absorbed from food mainly as methylmercury, a slow mineralization phenomenon occurs, under the form of tiemannite (HgSe) in the lysosomes of the liver (MARTOJA & BERRY 1980). A close relationship between mercury and selenium in the liver of marine mammals is consequently observed (KOEMAN *et al.* 1973).

A close correlation between organochlorine residues and age is also found in cetaceans, but, in this case, the pollutant increases with age in males, while it decreases in females following an elimination of the pollutant load by lactation (ABARNOU *et al.* 1986, AGUILAR & BORRELL 1988).

It appears therefore that the pollutant content of cetaceans is depending on many factors other than the contamination of their environment: feeding habits, metabolism, detoxification, age and sex. All these parameters are to be considered if we want to describe a mean contamination level for a population of marine mammals and if we want to estimate the associated health risk and a potential reproductive failure. According to WAGEMANN & MUIR (1984), a critical limit of 100-400 $\mu\text{g/g}$ WW Hg in the liver could be considered toxic and 50-200 $\mu\text{g/g}$ PCBs in the blubber would correspond to low reproductive rate and premature parturition. Considering mercury, striped dolphins in Japan and porpoises in the North Sea have reached such concentrations; however, potential detoxification by metallothioneins and selenium should be considered. Considering PCBs, striped dolphins, porpoises and pilot whales of French coasts, North Sea and Californian coasts must be considered as too much contaminated.

The heavy metals other than mercury, till now, seem to be harmless for cetaceans. However, it must be kept in mind that their control, detoxification and elimination are energy consuming.

Much further research is needed, and particular attention should be paid to mercury: high loads are often observed but it is supposed to remain harmless as far as methylmercury is mineralized and stored as tiemannite. The PCB loads are much more dramatic in several areas, since they reach a level similar to the one which is responsible for a reduction of fertility in seals.

A mean contamination level for a population of marine mammals is quite impossible to determine without taking into account the age distribution of the sampled animals, their sex and the intracellular speciation of the pollutants.

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A PROJECT ON
DYNAMICS OF THE RIVER DOLPHIN POPULATION
IN LAKE JANAUACA, AMAZONAS

BY

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Motivation

The deforestation along the banks of the rivers in the Amazon basin and the substitution with extensive cultivated areas has caused the disappearance of the fish species which fed on the fruit and seeds of the original trees. Consequently, the dolphins of the Amazon (*Inia geoffrensis* and *Sotalia fluviatilis*) can no longer find the food they need.

The construction of dams in Brazilian territory has threatened aquatic mammals because, by isolating entire populations, it impedes the genetic interchange indispensable for the survival of the species.

Substances such as DDT, FCB's and the mercury present in high percentages in rivers seriously alter the food chain with repercussions on the health of the cetaceans.

Accidental deaths caused by fishing-nets have become a very frequent phenomenon among these mammals.

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According to PERRIN (1989), the *Sotalia fluviatilis* populations in Brazil are at risk, and in IUCN's Red Data Book, BEST & DA SILVA (1989) recommend that the *Inia* be considered a «vulnerable» species.

Objectives

To carry out an in-depth and direct analysis of the movements of both species of dolphins during the entire hydrological cycle in the region; to study the parameters on age, life-span, growth, abundance, distribution, reproduction, identification of stocks and accidental death caused by fishing-nets.

These studies will enable suitable plans to be drawn up for preserving these animals, of which very little is known about their biology and ecology.

Research in this field has been recommended by OEA (1978), FAO (1979), UNEP (1979) and, more recently, by PERRIN (1989) and IUCN/SSC (1989).

The project will have a three-year duration starting in November 1991.

Area of Research

Lake Janauaca is about 60 kilometres from Manaus in the state of Amazonas. It varies in depth from five to seven metres, with a maximum of 12 metres. It is situated on the right bank of the Rio Solimoes and is permanently connected to it through a natural, very narrow canal, permitting observation of the dolphins entering and leaving the lake. This lake has also been chosen as a study area because the composition of its water undergoes significant changes during the year.

Methods

Five observation posts will be set up to study the movements of dolphins, one at the mouth of the canal leading to Lake Janauaca and four inside the lake. Scholars will occupy these positions, supplied with the appropriate technical forms to compile. Floating accommodation on the lake, capable of comfortably housing 16 people, will constitute the logistics base, scientific laboratory and centre

for processing the collected data. In particular circumstances and when possible, dolphins will be captured to extract teeth, take fat and blood samples and examine morphological data. The dolphins will be marked before being freed again.

Other studies will also be carried out on the local flora and fauna and the aquatic environment.

Anticipated results

1) A contribution to safeguarding and managing species of Brazilian fauna, and in particular those threatened by the present environmental degradation.

2) Improving and developing scientific knowledge of fauna species in the Amazon basin to implement a cultural interchange between different countries.

3) Publishing the results of the studies.

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LIGURIAN SEA SANCTUARY: A WAY TO PROTECT MEDITERRANEAN CETACEANS

BY

F. FABBRI*

1. Introduction

In 1989 Greenpeace Italy launched «Operazione Cetacei», a survey program aimed both at raising public awareness about cetaceans and at investigating the major factors threatening them. After the initial year the same project was extended to France, Malta and Spain in order to develop an overall picture of the Mediterranean cetofauna and determine technical measures to ensure the maintenance of those characteristics of marine environment which maintain the presence of cetaceans.

The importance of the Ligurian Sea as a feeding and breeding ground for some of the Mediterranean cetacean species prompted Greenpeace to carry out a specific research in this area.

2. Materials and methods

The research campaigns were carried out by Greenpeace, using rented sailing boats, following pre-established routes in linear transects.

Natural Sciences final year students, on board during the whole research period, made the sightings. They were helped by other students and researchers already involved in studying cetaceans. During 579 research hours the presence of cetaceans was noted and when possible, they were photographed to help later «photo-identifi-

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cation research». All studies were made without any noise and with total respect for the cetaceans and their livelihood.

3. Cetacean fauna in the Ligurian Sea

Five species out of twelve present in the Mediterranean Sea were sighted from Greenpeace vessels in this basin. Five others are reported from the literature.

Greenpeace vessels sighted striped dolphin (*Stenella coeruleoalba*), Risso's dolphin (*Grampus griseus*), common dolphin (*Delphinus delphis*), bottlenose dolphin (*Tursiops truncatus*) and fin whale (*Balaenoptera physalus*). While five other species such as minke whale (*Balaenoptera acutorostrata*), sperm whale (*Physeter macrocephalus*), Cuvier's beaked whale (*Ziphius cavirostris*), long-finned pilot whale (*Globicephala melas*) were sighted (GIORDANO 1988; NOTARBARTOLO *et al.* 1990; GANNIER & GANNIER 1990) as well as killer whale (*Orcinus orca*) (CAGNOLARO & PODESTÀ 1991). Cetaceans were particularly abundant in the Western part of the basin, although some significant sightings were reported from the Eastern and Southern side, especially for common dolphin (*Delphinus delphis*).

4. The importance of the Ligurian Sea for cetaceans in the Mediterranean

The presence of fin whales during the winter and in summertime could demonstrate that the Mediterranean population of this species is at least partially resident in the Ligurian Sea basin (GANNIER & GANNIER 1989, 1990). The recent recovery of a fin whale foetus also demonstrates that this basin is a calving area for this species (CAGNOLARO *et al.* 1986).

The most commonly encountered species is the striped dolphin as noted from our own research work (Fig. 1) and as confirmed by others (NOTARBARTOLO DI SCIARA *et al.* 1990; GIORDANO 1983). The suitability of the Ligurian Sea for the striped dolphin reproduction has also been pointed out (GANNIER & GANNIER 1990).

Sperm whales are present during the winter season in the Western part of the Ligurian Sea. The presence of newborns in this area demonstrates that it is a breeding and feeding place for this species (VIALE *et al.* 1988).

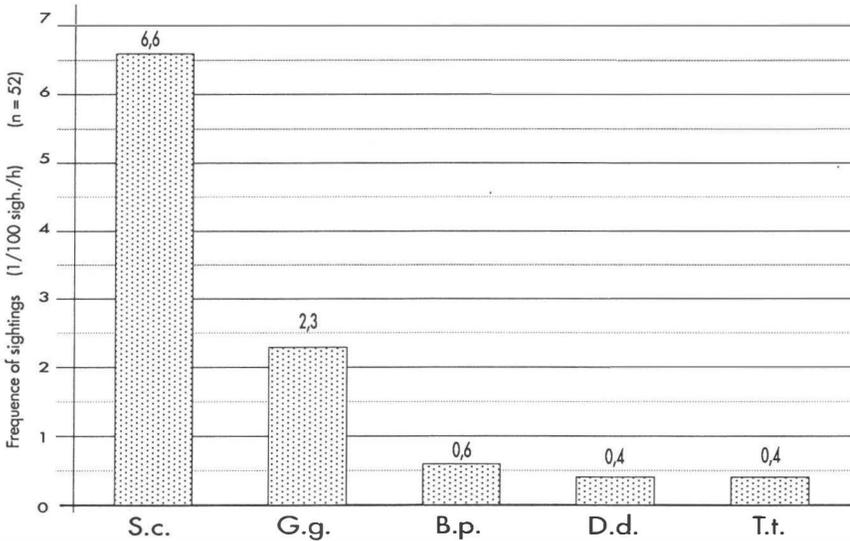


Fig. 1. — Frequency of sightings in the Ligurian Sea.

5. Threats to the cetaceans in the Ligurian Sea

Due to a convergence of different factors, there are many human activities that may be harmful for the cetacean populations in the Ligurian Sea.

This area is one of the most important for commercial maritime traffic. Accidents, such as that which occurred in late April with the tanker *Haven*, illustrate the scale of this threat.

Furthermore, some places have high concentrations of pollutants because of discharges from industrial plants into the sea, as occurs at Cogoleto where the concentration of chromium is the highest in the Mediterranean.

The Ligurian Sea is also very important for tourism, especially during summertime, when many pleasure boats go around the basin and some offshore competitions are organized. Fin whales, because of their behaviour, are the most exposed species to accidents with boats (DUGUY *et al.* 1983; DI NATALE & MANGANO 1983; DUGUY & VALLON 1977).

Finally, the use of driftnets in the area leads to the death of a lot of cetaceans (MAGNAGHI & PODESTÁ 1989) while some others are

directly killed in order to sell the dried dolphin meat called «musciame» (CURREY *et al.* 1990).

6. The possibility of declaring the Ligurian Sea Marine Sanctuary and minimum measures needed to be adopted

Taking into account the importance of the Ligurian Sea as a feeding and breeding area for a lot of Mediterranean cetaceans and considering the IWC statements related to the urgency of protection for the striped dolphin Med population heavily threatened by drift-nets and depleted by a major die-off in 1990, and its concerns for the health status of the sperm whale population (IWC/UNEP 1990), Greenpeace has proposed the following:

— Italy, France and Monaco shall adopt an international agreement to create a Marine Sanctuary (UNEP Mediterranean Action Plan, 1987) recognizing the importance of the area, identified as that within the ideal line from Cannes (Lat 43°41' N Long 07°01' E) to St. Floraint (Lat 42°41' N Long 09°18' E) and from Bastia (Lat 42°42' N Long 09°27' E) to Talamone (Lat 42°33' N Long 07°01' E) (Fig. 2), as a breeding and feeding area for the Mediterranean cetacean populations;

— The contracting parties will adopt at least the following measures:

1° Prohibition of the use of driftnets in the Sanctuary area;

2° Making every effort to promote the release of any animal inadvertently captured and which is alive and in good health;

3° Promoting habitat protection including taking measures to curb activities which negatively impact on the marine environment and measures to prevent, reduce and eliminate the release of dangerous substances which are harmful to the species concerned;

4° Carry out co-ordinated and benign research into the population biology of the cetaceans species as a basis for planning further management measures and initiatives. Areas for studies may include:

— Age composition, reproductive and health status;

— Causes of bad health and death;

— Contaminant analysis;

— Stock identity;

— Reproductive biology;

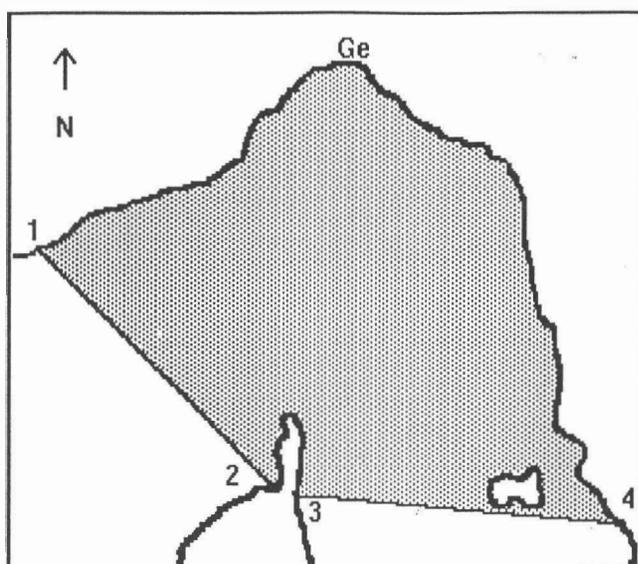


Fig. 2. — Area proposed as Marine Sanctuary.

Legend: 1. Cannes
2. St. Floraint
3. Bastia
4. Talamone.

— Estimation of population densities and distribution.

5° Conduct information and public awareness campaigns to elicit support for the above mentioned activities, in particular to encourage the public to report sightings, strandings and by-catches.

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CONCLUDING STATEMENTS AND RECOMMENDATIONS OF THE SYMPOSIUM

The Belgian Royal Academy of Overseas Sciences and the Chair Jacques-Yves Cousteau of the Free University of Brussels (V.U.B.) organized an International Symposium entitled « Whales: Biology-Threats-Conservation » which examined several aspects of the biology, population status and conservation of the cetaceans (whales, dolphins and porpoises), the largest mammalian order adapted totally to life in an aquatic environment.

The Symposium drew attention to several factors which are a cause of concern with respect to the conservation of cetacean populations. In particular this include: the kill of hundreds of thousands of cetaceans per year in fisheries operations; the effects of pollutants, particularly organochlorines, which can affect reproductive success and make cetaceans more vulnerable to mortality from viral, bacterial and other diseases.

The Symposium calls for increased support for research and monitoring on the biology, pathology, ecotoxicology and population dynamics of cetaceans and for the adoption of measures to reduce the threats to cetacean species.

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