Gulf of Maine NEWS

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Research Provides Critical Insights for Protection of Marine Mammals

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The study of whale and dolphin biology began on the deck of whaling vessels in the 1800s, with captains and seamen jotting notes in logs, and, sometimes, publishing anecdotes in magazines or books. Descriptive whale biology developed significantly in the early 1900s, resulting in journals full of anatomical, osteological (skeletal), and sometimes even nutritional details. Yet, systematic observational field biology of the order *Cetacea* (whales, dolphins, porpoises) was almost non-existent until the mid twentieth century, and quantitative methodology for observational data lagged by a decade or more. A mere twenty years ago, taking photographs of whales was considered cutting edge science. This technique demonstrated that individual whales could be identified in most species. From individual identifications flowed new and heretofore unknown data: life tables, reproductive rates, and survivorship, also migration information and residence times. Recognition of the heterogeneity of sighting effort and its impact on population estimates resulted in increasingly sophisticated statistics derived from the photo identification and sighting data. Simultaneously, technological advances in tagging, genetics and acoustics created new venues for "observing" cetaceans, which, prior to these developments, were largely limited to the ocean surface. This new information began to reveal complex patterns of cetacean behavior. Researchers started examining factors affecting the distribution and movements of marine mammals, including significant work on ecology and human effects. Advances in tagging and acoustics now provide better information over

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Seals of the Gulf of Maine

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In the Gulf of Maine, there are two resident seal species and three other seal species found here primarily in the winter. Harbor seals (*Phoca vitulina*) and gray seals (*Halichoerus grypus*) have pups in the Gulf of Maine and are here year-round. Young harp seals (*Phoca groenlandica*) are frequent winter visitors (as evidenced by the frequency they are caught in sink gillnets), while hooded seals (*Cystophoca cristata*) and ringed seals (*Phoca hispida*) make rare visits from their normal ice habitats.

Harbor Seals

Harbor seals (*Phoca vitulina*) are widely distributed throughout the Pacific and Atlantic oceans. Of the six subspecies worldwide, the northwestern Atlantic harbor seal (*P. v. concolor*) is found along the New England Coast. It is common from Labrador to Rhode Island (Richardson 1976)

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longer periods of time, yielding data on underwater behavior unimagined a decade ago. Photo-identification and genetic studies are used to assess population structure and status for several species, and will prove critical for long-term monitoring. Recently, mathematical modeling has become a critical tool for estimating population parameters. As models increase in power and sophistication, new insights into whale and dolphin biology are appearing.

Looking to the future, the big advances in understanding cetaceans are likely to take place in two areas. First, research that combines modeling, field studies of food-web interactions, and oceanography, will generate new insights into questions about cetacean ecology. This will lead to the development of predictive models for cetacean distribution and movement, help identify characteristics of a cetacean "critical habitat", and support ancillary studies on diving and feeding physiology, evolutionary biogeography, behavior, and sensory physiology. Second, due to the dramatic increase in concern over human effects on marine mammals, we can anticipate a significant expansion of acoustic studies on this entire taxonomic group (which depends primarily upon sound for most activities). Today, the effects of human caused sounds are largely unknown. We can foresee an increased effort to understand the effects of pollutants upon marine mammals. Pervasive and persistent chemical compounds have been documented in cetaceans and pinnipeds (seals and walruses) worldwide, but few "effects" studies have been done. Other concerns will include the effects of shipping, fishing, bio-toxins, and coastal development.

One challenge confronting researchers and government managers is that marine mammals are long lived, slowly reproducing creatures. It takes a long time to get adequate information about such animals in order to understand their life histories, and an even longer time to understand population dynamics well enough to develop management strategies. The articles in this newsletter are mostly the result of long-term studies, and have been written by researchers who have committed many years of work to understand their study species. However, government and foundation funding is by and large an annual affair, with little commitment to the need for long-term support. Thus, critical and basic research about many animals that intersect with human activities are at the mercy of annual vagaries in government funding, short term funding cycles by foundations, and a lack of a comprehensive strategic plan for human and marine mammal cohabitation. Attention to these problems is urgently needed. Solutions will require both time and adequate resources. In the meantime, my colleagues and I remain fascinated by our mammalian cousins who survive in such a harsh world.

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and has been seen as far south as Florida (Bigg 1981). Breeding and pupping is normally restricted to areas north of the Maine/New Hampshire border (Temte et al. 1991). In winter, harbor seals are commonly found as far south as Long Island, New York (Waring et al. 1999).

The Maine harbor seal population has been increasing since the early 1980s. The annual rate of increase between 1981 and 1997 was 4.2%. Minimum number of seals observed was 10,543 in June 1981 and 30,990 in late May of 1997. Estimated pup production has increased from 676 individuals in June 1981 to 5,359 individuals in late May of 1997 (Gilbert and Guldager 1998). This increase has begun to slow, between 1981 and 1993 the population increased at 8.9%, while between 1993 and 1997 it grew at an annual rate of only 1.8%.

Harbor seals are generally considered to be animals of inlets, islands and reefs (Boulva and McLaren 1979). Haul-out sites are required in order to pup, molt, thermo-regulate and rest. Haul-out substrates vary with availability. Sandy beaches in California (Yochem et al.1987, Allen et al.1989), floating glacier ice in Alaska (Calambokidis et al.1986), and tidally exposed sand and mud flats in California and Oregon (Brown and Mate 1983, Allen et al.1989) are used as haul-outs. In Maine, harbor seals haul-out on rocky outcroppings and inter-tidal ledges off of the coast (Gilbert and Wynne 1984).

Harbor seal haul-out patterns closely reflect the tidal cycle in Maine. Tides in Maine up to 5.5 m expose more ledges and inter-tidal zones around coastal islands that are used by seals at low tide. Individual seals return to islands and ledges at the falling tide, and are left 'stranded' as the tide goes out, forming loose gregarious groups at low tide within the inter-tidal zone. As the tide returns, individuals return to the water (Richardson 1976).

The two annual peaks in haul-out numbers occur during the pupping and molting season (Sullivan 1980, Brown and Mate 1983, Kreiber and Barrette 1984, Allen et al.1985, Allen et al.1989). In Maine, harbor seals come inshore to have pups on islands and inter-tidal ledges in late May and early June. During the nursing period of roughly 24 days (Thompson et al. 1994), the mother/pup pairs tend to stay close to their birth sites and remain hauled out for longer periods of time (Thompson 1993, Jeffries 1986). High haul-out numbers during the first two weeks in August in Maine can be attributed to molting. While hauled out, hair growth is enhanced and warming of the skin accelerates the molting process (Hoover-Miller 1994). The number of seals hauled out at a given low tide during a peak haul-out season is likely to vary with year to year change in the timing of pupping and molting (Temte et al.1991). The number of seals hauled out on a given day may also be affected by the time of the daily low tide occurrence and weather conditions (Schneider and Payne 1983, Allen et al.1984, Stewart 1984, Yochem et al.1987, Kovacs et al.1990, Roen and Bjorge 1994, Frost et al. 1997).

Table 1
Harbor Seals in the Gulf of Maine

Year	1974	1981	1982	1986	1993	1997
Total Harbor Seals Counted[a]	5000+[b]	10,540	9,331	12,940	28,310	30,990

[a] These are total counts of seals on ledges and islands and do not account for the fraction in the water.
[b] 1974 data are from Richardson (1976), all other data are from Gilbert and Guldager (1998).

A female harbor seal matures at age 3-5. About 90% of the adult females have a single pup per birth event, born in May in Maine. The pup can enter the water soon after birth, but spends most of its time on land until weaning at 14 – 24 days after birth. The female loses 33 % of her mass during nursing, and does also feed during the latter stages of lactation (Bowen et al. 1992). Pups fast for 15-17 days after weaning (Muelbert and Bowen 1993), after which they begin feeding on bottom fish. An adult female breeds soon after weaning. Molting occurs in non-pups in late July and early August. Newborn pups weigh 10 kg, and adults weigh 75 to 120 kg, with males slightly larger than females.

Harbor seals are opportunistic feeders preying on available species of fish and invertebrates. Their most common foods consist of groundfish (i.e., hake and flounder), herring, and squid. Their diets, however, demonstrate significant flexibility and include other commercially important fish, such as alewife, cod, haddock, salmon, smelts, wolfish, etc. (Katona et al. 1993 and Olesiuk 1990). Comparisons of the stomach contents of seals, collected from the Bay of Fundy and the northeastern coast of Nova Scotia, with local prey abundances in these two habitats indicate that variations in the diets of harbor seals correspond with local prey availability. For example, the diets of harbor seals captured from the Bay of Fundy suggest the importance of winter flounder, hake, and alewife; three fish species common to this region. Along the Atlantic coast, an area where these species are less common, winter flounder, hake, and alewife did not comprise a significant portion of harbor seal diets (Bowen and Harrison 1996). Generally, harbor seals consume prey in the 10-13 cm length.

Harbor seals numbers in the Gulf of Maine have increased since the Marine Mammal Protection Act (Table 1). As the harbor seal numbers increased in the Gulf of Maine, the percent pups observed in the survey has also increased from 6.4% in 1981 to 17.3% in 1997 (Gilbert and Guladger 1998). This increase in productivity could be the result of less contaminant load, an increase in food availability, or perhaps fewer of the non-reproductive seals being in the area. Suitable habitat does appear to be a limiting factor in Maine as sufficient numbers of suitable ledges and small islands available for pupping (Kenney 1994). We anticipate harbor seal pupping to occur south of Maine in the near future.

Gray Seals

Gray seals (*Halichoerus grypus*) are found throughout the coastal areas of the North Atlantic Ocean. Gray seals are abundant and increasing in waters of Eastern Canada (Zwanenburg and Bowen 1990). There are relatively fewer gray seals in U.S. waters; although more gray seals are observed in recent summers than in the past and they are establishing more pupping sites in Maine and Massachusetts. Gray seals are generally considered to be inhabitants of remote, outer islands and ledges.

Gray seal pups weigh 15 kg at birth, 40 kg at weaning. Adult females weigh 100-180 kg and adult males weigh 200-300 kg. A female gray seal matures at age 3 to 5. Pups are born with white lanugo coat in January. Lactation lasts 17 days, and pups molt to spotted coat in 4 weeks. The adults breed soon after weaning. Molting occurs in non-pups from March through June. Gray seals also have wide-ranging food habits, including feeding on alewife, sand lance, herring, lumpfish, cod, place, and yellowtail flounder (Bowen and Harrison 1996).

The number of gray seals in the Gulf of Maine has increased in recent years. Richardson (1976) observed 50 gray seals in the summer of 1974, and we observed no gray seals in the harbor seal surveys that we have conducted until 1993, when we counted about 1,000. Gray seals have long been regular visitors in the late winter to the Nantucket area, some with tags indicating they were born on Sable Island, Nova Scotia (Gilbert et al. 1979). The gray seal population in Nantucket area is the remains of a larger population in the 1940s when many were killed for a bounty. Until 1979, a pup was born in this area only once every few years (Gilbert et al. 1979). Recently, more gray seal pups were born in this area (Rough 1995), and 200 pups were observed in 2000 (Waring, personal communication). In addition, there are two sites in Maine were gray seal pups are born (Gilbert, unpublished data). One site produced between 30 and 50 pups each year since 1994 and another site had at least 100 pups (based on incomplete aerial photography) in January 2000. The increase in gray seal numbers in Maine is likely related to the increase in gray seals at Sable Island, Nova Scotia. There, counts of pups have increased from less than 200 in 1962 to over 12,000 in 1987 (Zwanenburg and Bowen 1990). It is estimated that

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there were at least 143,000 gray seals in Canada in 1993 (Mohn and Bowen 1996).

Conservation Issues

The Marine Mammal Protection Act of 1972 states that "…such species and population stocks should not be permitted to diminish beyond the point at which they cease to be a significant functioning element in the ecosystem of which they are a part…" In New England, the harbor seals are definitely a significant functioning part of the ecosystem and have varied and significant interactions with people of the region. Many people enjoy seeing seals, and there are many tours where seals are a primary attraction. Yet the seals are often implicated as competitors for commercial fish species, and sometimes cause direct damage to gear.

Harbor seals were subjected to incidental shooting and were taken for bounty prior to the Marine Mammal Protection Act. In Maine, individual towns and the state would intermittently establish and abandon bounties for seals depending on available funds and political pressure. There was a bounty on gray seals in Massachusetts until 1964 (Gilbert et al. 1979).

Harbor seals are incidentally taken in a variety of fisheries, including sink gillnets, herring purse seine, halibut tub trawl, and lobster fisheries (Gilbert and Wynne 1985, 1987). Approximately two seal pups per port per year were recorded by mid-coastal lobstermen off Maine (Gilbert and Wynne 1985). Seals have been reported to rob bait from inshore lobster traps. Lobstermen claim that seals consume shedding lobsters, although food habit studies have not confirmed this.

Of these fisheries, the Gulf of Maine groundfish sink gillnet fishery is the most significant source of incidental mortality. Between 1994 and 1999, an average of 893 seals were taken each year (Waring et al. 1999). Most of the harbor seals taken were less than one year old (Williams 1999).

In Maine, the Atlantic salmon aquaculture industry is subjected to seal predation on fish in the pens. Although seals are present throughout the year, seal predation and net damage is most pronounced between February and April. While direct attacks on fish can result in injury and mortality to the farm stock, the mere presence of seals can create significant stress to the fish. In response to stress, the immune systems of fish become suppressed and the fish develop an increased susceptibility to disease.

In an attempt to alleviate the interactions of seals with finfish farms in Maine and throughout the world, numerous deterrent methods have been employed. As a result of the 1994 amendments to the Marine Mammal Protection Act of 1972, commercial fisheries, including the salmon aquaculture industry, are prohibited from the intentional killing of a marine mammal, except to protect a human life. Acoustical alarms have been developed for use in the aquaculture industry. Deterrence is accomplished through the emission of sounds that frighten and/or cause pain in the target animal(s). Acoustic harassment devices (AHDs) (Johnston and Woodley 1998) have been used by the North American aquaculture industry since the early 1980s. Currently, the most effective of all AHDs produce sounds of 10 kHz with outputs of 194 dB at 1m (NMFS 1996). When maintained, the AHD arrays are effective in reducing seal predation at pen sites. There are concerns about the impacts the noise has on non-target species, especially harbor porpoise.

Another means of deterring seals and other predators of the finfish aquaculture industry is through the deployment of predator nets. These nets are usually made of large, four-inch mesh, heavy nylon or polypropylene twine. Predator nets used to deter underwater predators such as seals are hung around the outside of the net-pen containing the fish stock to be protected.

In an effort to prevent escapement and minimize the interactions of farm-raised Atlantic salmon with wild stocks, The Maine Aquaculture Association, in 1998, created a "Code of Practice for the Responsible Containment of Farmed Atlantic Salmon in Maine Waters". According to current figures, 25% of all farm losses can be attributed to accidental releases due to storm damage and equipment failure. "The remaining 75% of non-disease related farm losses are associated with seal predation" which can result in the release of farmed fish (MAA 1998).

To date, harbor seals are the only seal species that have been reported to interact with Downeast salmon aquaculture. As gray seals increase in numbers, I anticipate that they will also attack pen sites in the future. With their larger body sizes, they could well be more efficient in exploiting weaknesses in nets. Another survey is planned in 2001, along with a radio-telemetry study to determine the fraction in the water. Interactions with aquaculture sites are being studied, and more work is being done to understand the food habits of the seals.

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Humpback Whales in the Gulf of Maine: Abundance, Stock Boundaries and Population Growth

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Introduction

Humpback whales (*Megaptera novaeangliae*) in the North Atlantic winter in the warm waters of the West Indies, where they mate and calve. There, humpbacks from all over this ocean mix spatially and genetically. In late winter, they leave the breeding grounds and return to largely separate summer feeding grounds in higher latitudes. These feeding areas include Iceland, Norway, Greenland, Labrador, Newfoundland, the Gulf of St. Lawrence, and the Gulf of Maine. Fidelity to a feeding ground is strong: a whale will go back to one area, such as the Gulf of Maine, for its entire life. This fidelity is maintained matrilineally (through the female line), with a particular whale's feeding ground determined by where its mother takes it during its natal year (Clapham and Mayo 1987). Recent genetics work using mitochondrial DNA has shown that, despite the lack of barriers in the ocean, this fidelity has persisted for long enough for it to be reflected in the genetic structure of the North Atlantic population (Palsbøll et al. 1995, Larsen 1996).

Humpbacks begin to reappear in the Gulf of Maine as early as March, and most of the population is back from the wintering grounds by May. This particular population has been extensively studied through photo-identification work since the 1970s (Clapham et al. 1993), and it is perhaps the best known population of large whales in the world. Each individual humpback can be readily identified by the pattern of black and white markings found on the underside of its tail (Katona and Whitehead 1981), which is usually raised during a deep dive. The tail pattern is much like a fingerprint in the sense that it uniquely identifies an individual animal. Some humpbacks from the Gulf of Maine have been observed every year since 1975, with many individuals seen hundreds of times, sometimes 1500 miles away in the West Indies in winter. The long-term study by the Center for Coastal Studies in Provincetown, Massachusetts, has documented numerous calves over the years, and many of the female calves have themselves grown up and produced offspring of their own, providing a wealth of information about humpback whale reproductive biology.

In 1992 and 1993, the Gulf of Maine population was one focus of a large scale of humpback whales known as Years of the North Atlantic Humpback (YONAH, Smith et al. 1999). This study brought together scientists from seven countries to investigate the abundance, population structure, migratory movements and social organization of humpback whales across their entire North Atlantic range, from the West Indies to the Arctic. Standardized sampling protocols were used throughout so that all data were comparable. The study collected photographs of approximately 3,000 individual humpbacks, and also gathered more than 3,000 skin biopsies for genetic analysis (Palsbøll et al. 1997). The study addressed questions relating to the North Atlantic population as a whole, as well as to the population characteristics and abundance of each feeding area (including the Gulf of Maine).

Prior to 2000, the North Atlantic humpback whale population was treated by the U. S. National Marine Fisheries Service as a single stock for management purposes under the Marine Mammal Protection Act (Waring et al. 1999). Indeed, earlier genetic analyses (Palsbøll et al. 1995), based upon relatively small sample sizes, had failed to discriminate among the four western North Atlantic feeding areas of Greenland, Newfoundland/Labrador, the Gulf of St. Lawrence and the Gulf of Maine (Iceland and Norway, by contrast, were clearly separate). However, genetic analyses often reflect a time scale that extends well beyond that commonly used by managers. Accordingly, the decision was made to reclassify the Gulf of Maine as a separate feeding stock for the most recent U. S. Stock Assessment Report (Waring et al. 2000). This decision was based upon the strong fidelity by individual whales to this region, and the attendant assumption that, if this sub-population was wiped out, re-population by immigration from adjacent areas would not occur on any reasonable management time scale. (There are, for example, very few documented movements of humpbacks from the Gulf of Maine to Newfoundland, the closest known feeding area to the north). This reclassification has subsequently been supported by new genetic analysis based upon a much larger collection of samples than those utilized by Palsbøll et al. (1995). These analyses have found significant differences in haplotype frequencies of the four western feeding areas, including the Gulf of Maine (Palsbøll et al. In prep.) Photographic data gathered by the YONAH project in the Gulf of Maine have been supplemented in subsequent years by information from annual directed cruises, primarily by the Center for Coastal Studies. These data, together with information from line transect and photographic surveys conducted by the Northeast Fisheries Science Center in Woods Hole, have been used to estimate abundance and population growth rate, and to assess boundaries for this population.

Stock Boundaries

One of the principal questions regarding the issue of stock boundaries concerns whether humpback whales observed on the Scotian Shelf are part of the Gulf of Maine population. During the summers of 1998 and 1999, the Northeast Fisheries Science Center conducted surveys for humpback whales in this region. The 1998 survey covered an area from Roseway Basin to Emerald Basin and Western Bank; the 1999 cruise repeated this coverage, but also surveyed further north and east as far as French Bank (approximately 44˚ 45' N, 61˚ 00' W, and

Humpback Whale. Photograph by Center for Coastal Studies

approximately midway between the Gulf of Maine and Newfoundland). Humpbacks were photographed and individually identified for comparison to catalogues from other areas.

Photographs from the 1998 survey have now been compared to both the overall North Atlantic Humpback Whale Catalogue and a large regional catalogue from the Gulf of Maine (maintained by the College of the Atlantic and the Center for Coastal Studies, respectively). These comparisons and preliminary matching of Scotian Shelf 1999 photographs have revealed a modest rate of exchange (around 20%) with the Gulf of Maine. In contrast, almost all humpback whales identified elsewhere in the Gulf of Maine (including from the southwestern shore of Nova Scotia and Bay of Fundy area) have been previously observed in the Gulf of Maine region. Although no Scotian Shelf matches have so far been made to Newfoundland, useful comparisons are compromised by the lack of field effort in that region in recent years.

Overall, while it is not possible to define the Gulf of Maine population by drawing a strict geographical boundary, it appears that the effective range of most members of this stock does not extend far onto the Scotian Shelf. Further analyses are underway to determine whether setting a boundary is at all feasible, or whether the non-zero exchange rate can somehow be accommodated in estimates of abundance.

Similar comparisons of photographs taken of humpback whales observed off the mid-Atlantic coast of the U. S. (New Jersey to South Carolina) show a much higher exchange with the Gulf of Maine. It seems likely that most of the animals recorded in the former area are Gulf of Maine whales. However, several individual humpbacks from the mid-Atlantic have been matched to Atlantic Canada (Newfoundland or the Gulf of St. Lawrence), so there is evidently some mixing of whales from different feeding grounds in this area. This phenomenon appears to also occur in harbor porpoise (*Phocoena phocoena*) off the mid-Atlantic states.

Abundance

Photographic identification data are often useful for estimating the size of a population. Statistical analyses of the Gulf of Maine humpback whale data suggest that there were 652 animals in the population in 1992. However, this is likely to be an underestimate because it does not take into account movement to the Scotian Shelf or other areas; the estimate is also likely to be negatively biased because of unequal sampling coverage throughout the Gulf of Maine region.

The second approach uses photo-identification data to establish the minimum number of humpback whales known to be alive in a particular year, 1997. By determining the number of identified individuals seen either in that year, or in both a previous and subsequent year, it is possible to determine that at least 497 humpbacks were alive in 1997. This figure is also likely to be negatively biased, again because of unequal sampling coverage.

In the third approach, data were used from a NEFSC line-transect sighting survey conducted in the summer of 1999 by a

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(Humpbacks continued)

ship and airplane covering waters from the Gulf of Maine and Georges Bank to the mouth of the Gulf of St. Lawrence. However, in light of the information on stock identity of Scotian Shelf humpback whales noted above, only the portions of the survey covering the Gulf of Maine were used; surveys blocks along the eastern coast of Nova Scotia were excluded. These surveys yielded an estimate of 816 humpbacks and we regard this as the current best estimate of abundance for Gulf of Maine humpback whales. However, given that the rate of exchange between the Gulf of Maine and the Scotian Shelf is not zero, this estimate is likely to be conservative and may need to be adjusted following further clarification of stock definition. The same issue applies to the mid-Atlantic area, which was not included in the estimate.

Population growth rate

Barlow and Clapham (1997) applied a population model to photo-identification data from the Center for Coastal Studies, and estimated the population growth rate of the Gulf of Maine humpback whale stock at 6.5%. It is possible to calculate a theoretical maximum for any humpback population using known values for certain biological parameters (Brandão 2000, Clapham et al. 2001). For the Gulf of Maine, data on these parameters (which include interbirth, interval, pregnancy rate, age at sexual maturity and sex ratio) come from the long-term photoidentification study. Using these data, a maximum population growth rate of 7.2% is obtained according to the method described by (Brandão et al. (2000), suggest that the observed rate of 6.5% (Barlow and Clapham 1997) is close to the maximum for this stock.

No more recent estimate of population growth is available for this population, but a reanalysis (applying the same modeling technique to updated photographic information) is planned for next year.

Outlook

Overall, the Gulf of Maine humpback whale population appears to be increasing strongly, despite continued mortality from human sources (notably entanglement and ship collisions). The status of this population will be reviewed as part of a comprehensive assessment of North Atlantic humpbacks, to be undertaken in 2001 by the International Whaling Commission.

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North Atlantic Right Whales: An Update

Scott Kraus, New England Aquarium

Right whales are uncommon in most parts of the ocean, although the Gulf of Maine is host to four of the five known habitats in the North Atlantic. In the Bay of Fundy, one can see more than 50 at a time on a good day during the summer and early fall. Despite these local aggregations, the Atlantic right whale population is a mere fraction of its former size.

Right whales (*Eubalaena glacialis*) got their name from being the "right" whale to kill, because of the high yields of oil and baleen, and the fact that this slow moving species floated after death. Right whale hunting was started as a shore based fishery by the Basques over a thousand years ago, off northern Spain and western France. By the early 1500s the Basques had expanded their operations to the coasts of Newfoundland and Labrador, and for nearly a century they hunted right whales and bowhead whales (*Balaena mysticetus*) near the Strait of Belle Isle every summer and autumn. The Basque whalers killed between 25,000-40,000 whales between the years 1530-1610 (Aguilar 1986). In New England, right whale hunting started from colonial shore stations during the late 1600s, peaked in the early 1700s, and persisted at low levels until the early 1900s. In addition, the American pelagic whalers killed right whales at several locations around the North Atlantic until nearly 1900.

The discovery of petroleum in 1859 soon reduced the demand for whale oil as fuel for lamps and as a lubricant. However, baleen remained in great demand well into the 1900s and right whales continued to be valuable prey. Whaling for right whales continued up until 1935, when this species received international protection by the League of Nations. The original population size before hunting started will never be known with certainty. However, it is likely that by 1900 only a few dozen right whales remained in the western North Atlantic.

Distribution and Biology

In the western North Atlantic, individual right whales are wide ranging, and have been observed from Florida, to the Gulf of St. Lawrence, Newfoundland and southern Greenland. One known male traveled from Cape Cod to Norway in less than six months, and returned to the United States the following summer. Right whales sited in Iceland and Norway have been matched to animals seen in the western North Atlantic, and preliminary genetics data indicates that stock separation between east and west is unlikely. However, less than a dozen right whales are believed to survive in the eastern North Atlantic and that stock is considered nearly extinct.

Most right whales aggregate seasonally on one of five known seasonal habitats, all in United States or Canadian coastal waters (Winn et al. 1986). The primary calving ground is in the coastal waters of the southeastern United States during the winter months. Males and adult females without calves are rarely seen in that area, so an additional winter habitat has been hypothesized but remains unidentified. In the spring, aggregations of right whales are observed in the Great South Channel, east of Cape Cod, and in Massachusetts Bay. In the summer and fall, right whales are observed in the Bay of Fundy, between Maine and Nova Scotia, and in an area on the Nova Scotian Continental Shelf 50 km. south of Nova Scotia. At least one other summering ground location remains unidentified.

Right whales are skimfeeders on zooplankton, both at the surface and at depth, depending upon patch locations and density. They feed primarily on copepods but also occasionally on euphausiids. In the North Atlantic, right whale feeding grounds have been identified as areas of high concentrations of the copepod *Calanus finmarchicus*, specifically the larger stages (C4, C5, and adult) (Mayo and Marx 1990, Wishner et al. 1988). Feeding has been documented by observations of open-mouth skimming at the surface, or by the observation of feces in all four of the northern habitats in the western North Atlantic, but not in the calving grounds off the southeastern United States.

Right whales are usually seen either singly or in pairs, or in the case of courtship activity, in larger aggregations of closely interacting animals. Right whales engage in many typical whale behaviors, such as breaching, fluking upon diving, flipper slapping, and lobtailing. Courtship groups can be large and boisterous (up to forty animals), and appear to be multiple males competing for access to a single female. Researchers have speculated that right whale males engage in sperm competition, and that females actively solicit such competition among males. However, the timing of births and observed courtship activities do not match with the hypothesized gestation periods, so much remains unknown. Right whale sounds have been recorded, although the function of most sounds is poorly understood. They produce mainly moans in the range of 400 - 3200 Hz, and of 0.5-6.0 seconds duration, often with both pulse and tonal components.

Since 1980, North Atlantic right whale studies have been based upon the photographic identification of individuals from both aerial and shipboard surveys. Right whales are individually identifiable on the basis of distinctive patterns of thickened skin, called callosities. A total of 400 right whales have been cataloged in the North Atlantic, but because of known and estimated mortality, the population is currently estimated to number about 300 animals (Hamilton and Martin 1999). Despite an increase in documentation effort, fewer than five new adult individuals have been added each year to the cataloged population since 1985, suggesting that most North Atlantic right whales are known. On the basis of either sightings data or genetic techniques, the sex ratio of the population is known to be 50/50. The average age at sexual maturity for females is nine. Longevity remains unknown, although at least one North Atlantic female has a sighting history extending back to 1935 (60+ years).

The breeding location is unknown and the length of gestation is estimated to be about twelve to thirteen months. Most North Atlantic right whale calves are born in the winter months between early December and late March. Infant right whales grow rapidly, and calves attain eight to nine meters by the end of their first year. Nursing lasts ten to twelve months, although occasionally juveniles stay with their mothers up to seventeen months. Cows give birth to a single calf every three to five years. Calving intervals appear to have increased from slightly over three years in the 1980s to over five years by the late 1990s, but the causes of this increase are unknown (Kraus et al. 2000). This year (2001) appears to be a record for calf production by right whales, with thirty births recorded as of the middle of March. This stands in dramatic contrast to the previous year in which only one calf was born. Averaging out reproduction over the last twenty years yields an annual birth rate of about eleven, and there is no statistically significant increase or decline. The high variability in calving rates is perplexing, but a single banner year, while encouraging, is not a good indicator of the population's overall status.

N. Right Whale mother and calf. Photograph by Elizabeth Pike, New England Aquarium

Natural mortality rates are estimated at 17% for first year calves and about 3% for the next three years. Adult mortality rates are apparently very low - only three adults are known to have died of natural causes in this population since 1970. There may be low levels of predation by killer whales, although anecdotal reports of orca and right whale encounters suggest that right whales are more than adequately capable of defense.

Human activity is the primary known cause of deaths in North Atlantic right whales. About 36% (17/47) of all mortality in this species is due to collisions with large ships, with an additional 6% (3/47) due to entanglements in fishing gear (Knowlton et al. 2000). The remaining deaths are either neonates (considered natural mortality) or are from unknown causes. Further, about 60% of all right whales in the North Atlantic display scars from entanglement in fishing gear sometime in their lives. Vertical lines from lobster and crab pots and groundfish gillnets appear to be primarily responsible. Extensive efforts in the United States are underway to develop alternative fishing methods and strategies for managing shipping to reduce kills of right whales. Because most of the known right whale habitats occur within the Gulf of Maine, entanglement mitigation research efforts are particularly focussed in this area.

Prospects for the Future

North Atlantic right whales are protected in the United States by the Endangered Species Act (ESA) and the Marine Mammal Protection Act, and internationally by the International Convention on Whaling, and the Convention on Trade in Endangered Species. In the United States, the National Marine Fisheries Service has developed a recovery plan under the mandate of the ESA, and national teams to implement that plan have been meeting for several years. In Canada, a recovery plan for right whales has just been released by the Dept. of Fisheries and Oceans and the World Wildlife Fund, and an implementation team is being convened there as well.

The urgency for these teams to function proactively cannot be understated. Recent population models show right whales under current conditions going extinct in less than 200 years (Caswell et al. 1999). An effective conservation program for right whales will require cooperation and action from many federal and state agencies, scientists, industry, and non-governmental conservation groups. Further, international cooperation is essential as this population range spans national boundaries. There are three clear priorities.

The first priority is the reduction of ship/whale collisions. This effort requires the attention of all the implementation teams. The deep basins of the Gulf of Maine concentrate not only the food that sustains right whales, but also the primary threat to their survival—ships. The Bay of Fundy shipping lanes go right through the Grand Manan Basin feeding and courtship area. Similarly, all ship traffic between Boston (or other Gulf of Maine ports) and southern destinations must transit through the Great South Channel in order to avoid Georges Bank. In the southeastern U.S., three ship channels track directly through the heart of the right whale calving ground. Collision with ships is the greatest source of human-induced mortality for this species (Kraus 1990), claiming at least one or two North Atlantic right whales annually along the east coast of North America. Given the small population size and low birth rate, this may account for a significant reduction in the growth rate of the remaining population of North Atlantic right whales.

The second priority must be reducing the incidence of entanglements in fishing gear. The gear-entanglement problem frustrates managers and scientists as much as the problem of ship-whale collisions does. Many of the animals have been able to escape from entanglements on their own, although it is not known whether injuries sustained during those entanglements compromise longer-term survivorship. Fixed fishing gear is distributed broadly both nearshore and offshore all along the coast of North America. Records of entanglements from Newfoundland to Florida show no clear pattern that might inform a management strategy, other than seasonal closures of known whale habitats to risky fishing gear. Nevertheless, with industry cooperation, progress is being made on 'whale-safe' fishing gear, some of which is being tested as this is written.

The third priority is perhaps the thorniest. We must examine whether reduced habitat availability, chronic or newly introduced pollutants, and acoustic disturbance from vessel traffic are slowing the population's recovery. There is no point in saving right whales from the direct kills of shipping and fishing if their homes have been lost to the increasing urbanization of the ocean. Whales can certainly tolerate a certain amount of habitat degradation, just as humans can. However, we don't know when or if these factors are affecting reproduction, feeding, and survival of right whales. Some studies on these topics are being started by the International Fund for Animal Welfare, Woods Hole Oceanographic Institution, Dalhousie University, and the New England Aquarium.

The contemporary right whale losses will be much more difficult to mitigate than directed take by historical hunting. For right whales, the prohibition on hunting has been very effective, but accidental deaths due to collisions with ships and entanglements in fixed fishing gear could very well push the species to extinction (Katona and Kraus 1999). The responsibility for killing North Atlantic right whales has broadened from a small group of whalers to a much larger group, which includes all of us who eat seafood, purchase foreign autos, petroleum, appliances, or any other products which arrive on ships.

This species the rarest large whale in the Atlantic Ocean and perhaps the rarest in the world. Because of the historical circumstances that led to their low numbers and the ongoing anthropogenic mortalities, their prospects for survival into the next century are questionable. Northern right whales are perhaps the longest running example of humanity's failure to manage marine species, whether from directed hunting or losses due to other human activities. Nevertheless, the North Atlantic right whale is being increasingly studied, and researchers and managers have identified a number of actions that could be taken to save it. Well-directed and effective measures to reduce mortalities and improve habitat will be needed to pull this species back from the edge, but there is a good chance we can do it. And I believe our grandchildren will thank us for our efforts.

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(continues page 14)

Assessing the Circumstances Surrounding Collisions between Right Whales and Vessels: New Technology Provides a 'look' and 'listen' from the Whale's Perspective

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Mark P. Johnson and Peter L. Tyack, Woods Hole Oceanographic Institution

The northern right whale, *Eubalaena glacialis*, is the most endangered whale, numbering fewer than 300 animals. The population appears to be in decline and the reproductive rate is approximately half that of recovering populations of southern right whales, *E. australis* (Best et al. 1999); indeed, the North Atlantic right whale is under significant threat of extinction if current conditions persist (Caswell et al. 1999; Clapham et al. 1999).

Collisions with vessels are the most serious cause of human-induced injury and mortality among this highly endangered whale. Between 1970-1999, ship strikes were responsible for sixteen of the eighteen deaths known to be caused by humans (Marine Mammal Commission 2000); these sixteen ship strikes accounted for over one-third of the forty-five known right whale fatalities (Knowlton and Kraus in press). Caswell et al. (1999) further state that reducing human-caused mortality is essential if this population is to remain viable. A significant obstacle to developing targeted measures to mitigate ship strikes is our ignorance of the precise behavioral problems or conditions that lead to a collision.

One solution to the ship strike problem is to keep vessels away from right whales, as is currently being attempted through 'early warning system' advisories to mariners. Most estimates of the detection rate for current visual monitoring surveys, however, indicate that fewer than 50% of the whales are likely to be detected under the best of conditions, and none in bad weather or darkness. Passive acoustic monitoring may increase the detection rate, especially at night or times of reduced visibility. However, our preliminary data indicate that right whale vocal activity useful for detection and localization is very low. It remains to be seen how many additional whales would be detected using a combination of visual and passive acoustic monitoring. Another option is to search for whales using ship-borne forward-looking active sonar. Several marine mammal monitoring sonars have been developed, but they currently offer detection ranges insufficient to alter the course of a large ship traveling at ocean speeds (~15-25 knots) in time to avoid a whale. Moreover, the potential benefit of these systems must be weighed against the impact of the noise they would generate in frequency bands that are important to other cetaceans, e.g., Atlantic white-sided dolphins, harbor porpoises (Au 1993; Miller et al. 1999).

Mitigation measures are difficult to design without the knowledge of how a whale behaves in the presence of an approaching ship. While we assume that right whales can physically hear the sounds produced by vessels based on the frequencies of sounds they produce, there are several different conditions that make it difficult for a whale to hear or locate an approaching ship. One condition involves basic acoustics: when a whale is near the sea surface, little sound energy will reach it because of the pressure release at the surface and

Figure 1. The DTAG, housed in its molded plastic fairing, is non-invasively attached to a right whale via three suction cups. The tag package is oriented approximately in line with the whale and at a slight down angle, which makes use of the water flow to force the suction cups down onto the whale. The radio beacon antenna extends out the back of the fairing. When the package releases it floats with the tail up so the antenna is out of the water, which facilitates package recovery.

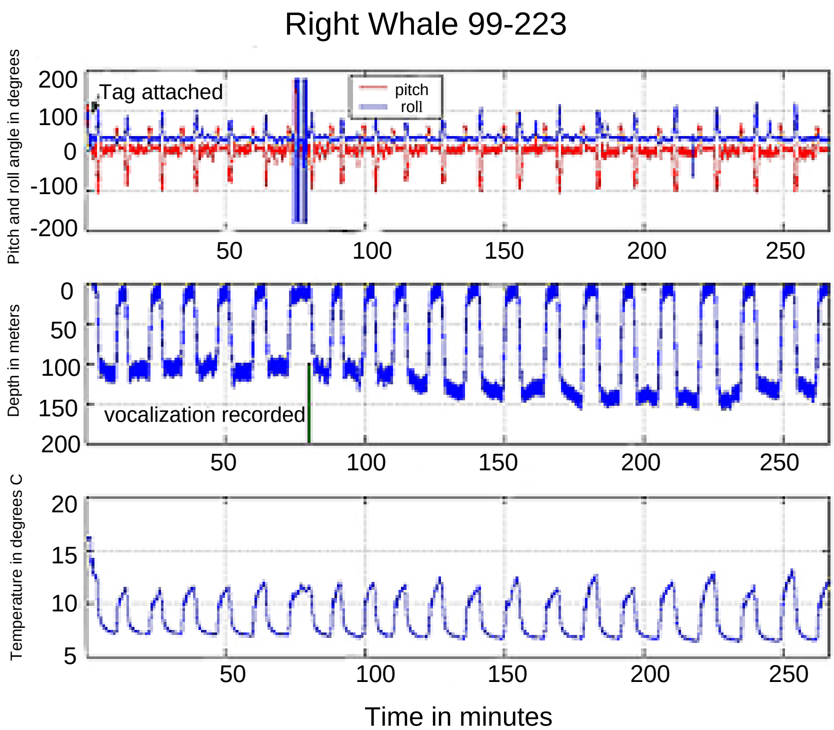
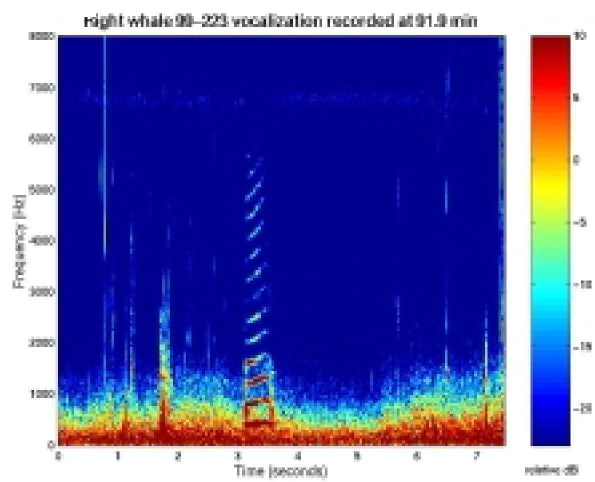


Figure 2. (left) The sensor data set from a whale tagged in 1999. The top panel shows the pitch and roll of the whale, calculated from the accelerometers; the pressure sensor data are used to calculate the water depth shown in the middle panel; and water temperature is shown in the bottom panel. Note the regularity of the diving behavior.

because of absorption and scattering of sound due to air bubbles (Medwin and Clay 1998). This means that a whale near the surface is less likely to hear a low frequency sound that is quite loud at depth. Another condition has to do with sound localization: whales may have difficulty determining the source direction of low frequency continuous ship noise, especially in a reverberant underwater environment (Spiesberger and Fristrup 1990). A third condition is more behavioral: whales may habituate to the gradual amplitude increase of noise from an oncoming ship, and so not recognize it as a threat. These factors may combine to hinder successful avoidance responses of whales particularly in environments with high ambient noise levels such as Cape Cod Bay and the Bay of Fundy, two extensively utilized habitats of northern right whales. There may also be behavioral conditions in which the whale does not respond appropriately. Sleeping whales, for example, might not wake to hear an oncoming ship, or whales engaged in some behaviors such as social aggregations may be so intent on their activity that they do not interpret the noise of an oncoming ship as a great enough threat to break-off from their activity. Until we learn the circumstances that increase the likelihood of a collision, we cannot develop more targeted mitigation measures.

To investigate the circumstances surrounding collisions between ships and right whales, we are using a new highly integrated digital acoustic recording tag, the DTAG. The solid-state tag combines digital sound recording with a broad suite of sensors including pressure, compass heading, acceleration, and temperature. By simultaneously sampling the sound at the animal's location together with behavioral and

Figure 3. (below) A vocalization recorded from a whale tagged in 1999. The rich harmonic structure of this sound captured by the DTAG is not normally available with other recording methods due to the low levels of the higher harmonics. This favorable signal to noise ratio also allows analyses of sounds made by other whales and boats in the area.



physiological cues from the sensors, the tag provides an unambiguous connection between sound exposure and response. The DTAG is attached to right whales via a non-invasive mechanism consisting of a molded plastic fairing and three suction cups (Figure 1). The tag is delivered with a cantilevered pole, developed by Moore et al. (in press) to measure the blubber thickness of right whales. Data from the sensor suite show a whale's diving/swimming behavior (pitch, roll, and heading) as well as the depth and temperature of the water (Figure 2). Acoustic data recorded by the tag have an excellent signal to noise ratio, which provides great detail of the structure of the sounds produced by the focal (i.e., tagged) whale (Figure 3) as well as recordings of sounds made by other whales in the area. Sounds from focal whales can be distinguished from those produced by nearby animals by several factors including the received level, the absence of reverberation, presence of significant high frequency harmonic components, and, in some cases, small concurrent perturbations in the pressure signal. The tagged whale is followed throughout the experiment by way of a radio beacon incorporated into the plastic fairing (Figure 1) and a directional antenna array on the observation vessel; the radio beacon also allows us to recover the tags when they release. The tags release from the whale via our timed mechanism incorporated into the tag, by being dislodged during contact with another whale, or by some other release of the suction, e.g., natural skin sloughing.

To study how right whales respond to the sounds of approaching vessels, we play controlled sound sources to tagged whales and record their response, both from the observation vessel and on the tag. Observations from the ship can be made only when the whale is at the surface, but these data provide detail not obtainable by the tag, e.g., number of whales in the area. Observations also assist with the interpretation of complex motor behaviors recorded by the tag, e.g., social surface active groups, or SAGs (Kraus and Hatch in press). In addition, due to the tag's ability to record the sounds made by ships and whales in the area, we have data from many 'natural' experiments, as whale watch or research vessels approach and/or pass a tagged whale, the sound exposure and whale's response are recorded on the tag To obtain controlled, quantitative samples, however, we play pre-recorded sound stimuli to tagged whales and observe and record their response both from the observation vessel and on the tag. Exposing multiple animals to the same standardized (e.g., duration sound pressure level) stimuli will allow robust statistical analyses of responses.

The DTAG can document motor responses on at least three time scales. A whale's behavior may change, for example, on the order of seconds with an erratic dive or other startle behavior such as violent rolling that can occur when a whale is distressed (Weinrich 1999); similar active rolling behavior occurs during SAGs. On time scales of minutes a whale may change its regular dive pattern, for instance, by spending more time at the surface, or it may change its activity such as abandoning a social bout. Finally, at the outer limit of our ability to detect a disturbance reaction, a whale may abandon a particular area, a change that would occur over a period of hours. All three of these types of changes can be captured by the DTAG. The high sensor sampling rate (> 20 samples/sec) is sufficient to resolve the shortest duration behavioral events such as a roll or rapid dive. A change in regular dive pattern would be evident on many of the sensors (e.g., pressure, pitch, roll), and a directed departure from an area would be recorded by the magnetometers We have collected tag data from fifteen whales (six in 1999 and nine in 2000) and have conducted playback experiments to 2 (2000). We hope to at least double our sample size during 2001 and 2002 field work in the Bay of Fundy and perhaps Cape Cod Bay. We know that ship strike mortality must be reduced if this species is to survive (Caswell, H. et al. 1999), and the increased speed of modern vessels exacerbates the ship strike problem (Laist et al. 2001). Understanding how whales respond to an approaching ship will be invaluable in designing effective collision mitigation measures, and the data collected by the DTAG are beginning to provide insight into the behavior of right whales in the presence of potentially lethal ships.

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Calendar

May

1 GoM Council Monitoring Workshop, Portsmouth, NH
contact: Laura Marron, lmarron@des.state.nh.us

3-4 RARGOM Board meeting, Portland ME
contact: Genie Braasch, braasch@dartmouth.edu

13-15 Bioinvaders workshop, Univ. Kings College, Halifax, NS
contact: Lara Gibson, g.lara@eudoramail.com

22-25 GoM Council Working Group and Council meeting
Bar Harbor, ME, contact: gom_sec@world.std.com

June

1 Oceans Day

10-15 Gordon Research Conference "Coastal Ocean Circulation", Colby Sawyer College, New London, NH

17-20 Open Ocean Aquaculture IV, St. Andrews, NB,
contact: ooa@usm.edu

18-20 Coast GIS '01: Managing the Interfaces, Halifax, NS
http://www.coastgis.org

21-22 Gulf of Maine Environmental Information Exchange,
Halifax, NS, contct: Paul Boudreau, www.gominfoex.org

July

15-19 Coaatal Zone '01 Conference, Cleveland, OH,
http://www.csc.noaa.gov/cz2001/

Gulf of Maine Aquarium Launches a Website for the Fishing and Research Communities

Courtney Coles, Gulf of Maine Aquarium

Fishresearch.org was launched by the Gulf of Maine Aquarium in December, 2000. The goal of Fishresearch.org is to produce partnerships between fishermen and scientists. As a comprehensive online resource for collaborative fisheries research, Fishresearch.org serves as a one-stop information source for people who seek information about fishing vessels available for research charter or scientists interested in partnering with fishermen on collaborative fisheries research projects. In addition to this primary function, the Fishresearch.org website provides detailed lists of research priorities, funding sources, internet weather sources, online fish prices, and advisory documents written by scientists and fishermen experienced in the collaborative fishery research arena for colleagues who are considering this type of endeavor.

Currently, the database includes information about 35 fishing vessels (ranging in length from 21 to 99 feet), and 21 research scientists (their scientific profiles and research projects). The Gulf of Maine Aquarium seeks additional participants for this project. The Aquarium plans to continue to cultivate relationships with those interested in contributing to the site, and develop the database to include a broader pool of scientists and funding sources responsive to collaborative fisheries research proposals.

Fishresearch.org was developed through partnerships among the Gulf of Maine Aquarium and Northwest Atlantic Marine Alliance (NAMA), CREnvironmental, Commercial Fisheries News, and McFish, Inc. Fishresearch.org is funded by the Maine Department of Marine Resources, Gulf of Maine Council on the Marine Environment, and the Henry P. Kendall Foundation.

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