Research Results: Science to Support Effective Policy

Effective conservation efforts have their roots in science. We conduct and support research initiatives to better understand the threats to marine populations, habitats and ecosystems, and to inform our advocacy initiatives aimed at improving marine conservation policy.

The Secret Lives of Apex Predators: Tunas and Great White Sharks

The open ocean is the largest habitat on Earth, and the biology and ecology of large pelagic fishes like tunas and sharks are poorly understood. Yet these species face threats from poorly managed fisheries that allow unsustainable levels of exploitation.

Our collaboration with Stanford University's Hopkins Marine Station, the Tuna Research and Conservation Center, works to better understand pelagic fishes by building our knowledge of their basic biology, ecology and natural history—knowledge that is vital to protecting their dwindling numbers.

The Tuna Research and Conservation Center's home is a facility for maintaining open-ocean fishes located at Stanford University's Hopkins Marine Station next to the Aquarium. Established in 1994, it is the only place in the continental U.S. where live tunas are kept for research. Four 5,000- to 86,000-gallon tanks, each with its own life-support system, hold fast-swimming tunas that can ultimately grow to weigh hundreds of pounds.

A team of Stanford University and Aquarium scientists and students blend animal husbandry expertise with cutting-edge scientific research skills in a partnership that draws on each institution's unique strengths. Bluefin, yellowfin and skipjack tuna have all been successfully maintained and studied here.

Effective management of pelagic fish populations worldwide relies on understanding how environmental variability and evolutionary processes influence pelagic fish biology. The team conducts research in both laboratory and field settings, using a broad range of methods to study molecular, biochemical and physiological characteristics of various pelagic species. Staff and their collaborators have developed and deployed a range of electronic tracking devices to obtain detailed records of the short distance movements, long distance migrations and behaviors of open-ocean species in the wild.

The Tuna Research and Conservation Center currently focuses on Atlantic and Pacific bluefin tuna and white sharks. Our unique mix of laboratory and field research is yielding information needed to design ecosystem-based management policies and to ensure that these animal populations thrive.

Tag-A-Giant: Atlantic Bluefin Tuna

The spawning stock of bluefin tuna in the western Atlantic (*Thunnus thynnus*) is currently at an historic low despite more than 25 years of strict quotas and management. For more than a decade, Tuna Center scientists have traveled far and wide to solve this mystery. Through a remarkable and innovative program called "Tag-A-Giant" (TAG), they work in partnership with sport and commercial fishers from the Gulf of Mexico to the Gulf of St. Lawrence, and from Ireland to France, to attach electronic tags to tuna that are caught and then released. These tags are telling exciting new stories about the life history and biology of Atlantic bluefin tuna—providing knowledge that can help regulators better manage fisheries in the Atlantic Ocean, Mediterranean Sea and the Gulf of Mexico.

To study the movements and behaviors of Atlantic bluefin tuna, TAG uses electronic archival tags that are either surgically implanted in the tuna or attached to the outside. All tags gather environmental data such as water temperature, depth and geolocation. Implanted tags also collect data on the fish's internal temperature, but must be removed from the fish and returned to the lab for downloading and analysis. External tags release from the fish at pre-programmed times, float to the surface, and download their data to Argos satellites for transmission back to the lab. Over the past 12 years the program has tagged more than 1,000 fish and gathered data detailing 21,000 days in the lives of bluefin tuna.

These data revealed an important finding: there are actually two bluefin tuna populations in the Atlantic—one spawning in the Gulf of Mexico and another in the Mediterranean Sea. Recent genetic studies conducted by Tuna Center scientists corroborate the tagging data and indicate that there are indeed two discrete stocks that rarely, if ever, interbreed. The two stocks overlap on important foraging grounds in the north Atlantic with distinct movement patterns dependent on natal origin, season and year class. Transatlantic movements of western-tagged bluefin tuna reveal that the animals return to known eastern spawning areas in the Mediterranean Sea. Distribution of electronically tagged fish, when combined with U.S. pelagic longline observer and logbook catch data, identify hot spots for spawning bluefin tuna in the northern slope waters of the Gulf of Mexico and enable characterization of the environmental preferences of spawning fish (e.g., preferred sea surface temperature, bathymetry). A new mathematical model can predict where bluefin are most likely to be spawning in the Gulf at any given time by comparing real-time oceanographic data

collected by satellites and buoys to the habitat preferences identified through tagging. An area that falls within the preferred range of all the critical environmental parameters would be the most likely spawning ground.

Tagging of Pacific Predators: Pacific Bluefin Tuna

The Tuna Center team initiated archival tagging of Pacific bluefin tuna (*Thunnus orientalis*) in 2002, as part of the Tagging of Pacific Predators (TOPP) program. TOPP is a project of the global Census of Marine Life, a 10-year initiative to assess and explain the diversity, distribution and abundance of life in the oceans in the past, the present and the future. The TOPP program attaches electronic tags to a host of sea life, including sharks, fishes, sea turtles, sea birds, squid and marine mammals. To date, 417 archival tags have been deployed on Pacific bluefin tuna. Remarkably, 215 of these tagged fish (52 percent) have been caught and their electronic tags returned. This recovery rate is higher than expected and ranges up to an unprecedented 74 percent of tags deployed on wild bluefin in 2003, indicating high mortality in local fisheries. The vast majority of tagged bluefin tuna were recaptured off California and Mexico, while 15 were recovered on their return trip to spawn near Japan.

Combining the data from all recovered tags, we have garnered over 52,000 days of information on the movements, behaviors and habitat preferences of Pacific bluefin tuna, the largest electronic tagging data-set in the world. Seasonal movements off North America have indicated two distinct hotspot regions: bluefin tuna are farthest south in the spring when they are located off southern Baja California, Mexico; and farthest north in the fall when fish are found predominantly off central and northern California.

There are currently no management measures such as quotas, seasons or size limits in place under international or U.S. domestic fisheries management bodies for bluefin tuna in the Pacific. Catch of this species is reported to the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). The ISC was established through an intergovernmental agreement between Japan and the U.S., and has members from coastal states and fishing entities in the north Pacific region. The data collected through the electronic tagging study can contribute critical information for development of a sustainable fishery management program.

Ecological Physiology of Tunas

Tunas are remarkable athletes. They travel vast distances at amazing speeds, with physical adaptations both inside and out that make their high performance possible. Over the past several years, the Tuna Center physiology team has focused on the cardiac physiology of tunas and related fishes. Understanding the mechanics of the heart is the key to understanding an animal's overall capabilities. Working at several different levels, from tissues to cells to individual genes, proteins and molecules, scientists are beginning to understand exactly how these extraordinary hearts deliver on the tunas' high metabolic demands made over a broad range of temperatures.

Studies of cardiac physiology started at the whole-heart level. The team measured temperature effects on the heart rate, stroke volume and cardiac output of both bluefin and yellowfin tuna (*Thunnus orientalis* and *T. albacares*). The hearts of both species are temperature-sensitive, with heart rate and cardiac output slowing at lower temperatures. However, the bluefin tuna heart is less temperature-sensitive and continues to function at much lower temperatures than that of the yellowfin. This difference helps to explain the thermal ecology of wild tunas, and why bluefin tuna routinely migrate and dive into much colder waters than yellowfin tuna. Cardiac performance also decreases significantly at high temperatures, which may explain why bluefin tuna are physiologically stressed in the warm waters of their Gulf of Mexico spawning grounds and experience relatively high and rapid mortality when hooked on fishing gear there.

Work at the cellular level helps researchers identify differences in cardiac function among tunas. Differences in the abilities of heart cells to move calcium may underlie the varying responses to temperature; bluefin tuna have at least two-fold higher calcium uptake, which increases cardiac contraction and therefore cardiac performance. Superior cardiac performance allows greater oxygenation of tissues, which is consistent with the bluefin's high metabolic rate relative to other tunas. Elevated metabolic rate is likely an essential component of the bluefin's ability to maintain a body temperature warmer than the surrounding water, which in turn allows bluefin to expand their thermal niche into colder waters. The physiology team is now taking this research to an even finer level, using genomics, biochemistry and electron microscopy to determine more specifically where the differences between these tuna species lie.

Management of Captive Tunas

Tunas are challenging animals to maintain in an aquarium or research setting because of their incredible size, strength and high metabolic rates. The Tuna Center has played a pioneering role in developing the techniques for collecting, handling, transporting, caring for and displaying tunas for research and exhibition. At any given time dozens of tunas representing three different species are swimming in the tanks at the Tuna Center and in the Aquarium's million-gallon Outer Bay Exhibit.

Recently, the team has applied gene markers for transcriptome expression, which reflects the genes that are being actively expressed at any given time. This will aid in assessing the condition of captive specimens in response to tank size, feeding trials and longevity in captivity. Characterization of gene and protein profiles for establishing the muscular condition and muscle color will lead to better techniques for rapidly assessing the quality and condition of the captive animals.

The genomic markers developed for the research animals can be applied to fish in the tuna aquaculture industry as well. This research is thus developing improved diagnostic techniques to provide information critical to monitor the growth, health and vigor of cultivated tuna stocks. The development of molecular technologies using the captive collections promises large breakthroughs for health and reproduction.

The tunas in our Outer Bay Exhibit allow for a different form of research as well. Growth in the exhibit can be monitored in relation to nutritional input and water temperature for several age classes of yellowfin and bluefin tunas over time. This information helps validate theoretical growth rates calculated for free-ranging tunas and is essential for calculating appropriate food rations for animals on exhibit.

Our captive tunas allow biologists and aquarists to improve husbandry and veterinary techniques. They also enable scientists to develop, test and improve electronic tagging techniques prior to deployment in the field.

Finally, our captive tuna population affords a unique environment for research applicable to aquaculture. The global bluefin tuna ranching and farming industry is now worth hundreds of millions of dollars per year. Current research is focused on diet and digestion efficiency as well as establishing a set of molecular and biochemical markers to assess the aerobic condition, fat content, sex and reproductive maturity of bluefin from biopsy samples.

Great White Shark Research

Great white sharks (*Carcharodon carcharias*) are important predators occupying a vital position at the pinnacle of the ocean's ecological food web. However, great white sharks have been listed as 'vulnerable' to extinction by the World Conservation Union (IUCN Red List of Threatened Species), and are protected under Appendix II of CITES, the Convention on International Trade in Endangered Species of Wild Fauna and Flora. Despite broad concern for their conservation, relatively little is known about their distribution and ecology. Our goal is to gain a better understanding of great white shark populations, as well as their migratory patterns, preferred habitats and physiology through tagging, photo identification and genetic analyses.

Our collaborative studies with Stanford University have revealed that adult great white sharks in central California coastal waters seasonally migrate thousands of miles offshore to the Hawaiian Islands and to a mid-ocean area halfway between Baja California and Hawaii dubbed by scientists as "The White Shark Café." Precisely why they visit these waters remains a mystery. When they return to the California coast they exhibit high site fidelity, consistently returning to the same local neighborhoods (pinniped rookeries) year after year.

We are now learning that great white sharks observed in California comprise a genetically distinct population. Our recent genetics data indicate that great white shark females in the northeastern Pacific have maintained long-term isolation from the other known great white shark populations (i.e. the major concentrations near South Africa in the southwestern Indian Ocean and Australia in the southwestern Pacific). Knowing that the population unit (northeastern Pacific) is distinct will enable us to census the population in order to determine its number, and know from year to year whether this population is increasing or decreasing. As an isolated population, it can be more vulnerable since it cannot be "rescued" or replenished via immigration from other populations. We will continue to study migratory pathways, habitat preferences and estimate the population size using photographic mark-recapture methods to insure that accurate and sufficient information is available for the effective management of great white sharks in the northeastern Pacific.

Satellite tagging technology is also enabling us to determine the critical habitat occupied by young-of-the-year great white sharks. In collaboration with Stanford University, the University of Hawaii, Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico (CICESE) and California State University, Long Beach, we are learning about a great white shark nursery area that extends from the Southern California Bight down throughout Baja California. In this region, sharks up to three years of age inhabit shallow coastal waters and frequently move between U.S. and Mexican territorial waters. These results indicate where young great white sharks are vulnerable to bycatch in coastal fisheries of both countries and highlight the need for transnational collaboration in creating effective management plans.

Recent evidence suggests that great white shark bycatch is indeed landed and sold. Over a three-year period, 40 mummified juvenile great white shark carcasses were found by our great white shark team and research collaborators in a desert dump site surrounding a fish camp in Baja California. The DNA associated with the teeth of these carcasses can be analyzed to help determine the population structure of great white sharks in California and Mexico. We will continue our sampling of great white shark carcasses within this region through our collaboration with researchers at Mexico's Laboratorio de Genética, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México and Laboratorio de Ecología Pesquera, Departamento de Oceanografía Biológica, CICESE, and colleagues at Stanford University. Eventually, we will incorporate these DNA results into the larger picture of overall genetic diversity and uniqueness of great white shark populations in northeastern Pacific waters (California and Mexico).

Future Directions for Pelagic Species Research

In the years ahead, we will continue to combine cutting-edge laboratory and field work to better explain the biology and natural history of pelagic fishes in their environment. Our captive tuna population also positions the Tuna Research and Conservation Center to be a global leader in improving the effectiveness and efficiency of aquaculture, including the burgeoning field

Close-up: Sal Jorgensen

As a boy growing up in Mozambique, Sal Jorgensen spent a lot of time snorkeling and fishing in the Indian Ocean. Still, the thought of the open ocean—beyond sight of the shore or the bottom—was both frightening and fascinating. So were the animals of that boundless world.

Today they've become his life's work.

As a postdoctoral researcher with Stanford University's Hopkins Marine Station and the Aquarium, Sal studies great white sharks as he tries to unravel the mysteries of their lives. He tracks the movement of great white sharks along the coast and across the Pacific, and the different ways they use coastal and open-ocean habitat.

"I find it amazing that great white sharks return to the same local neighborhoods along the northern California coast year after year," Sal says. "They regularly migrate 1,000 to 3,000 miles across the Pacific, traveling as far as the Hawaiian Islands, and can easily cross ocean basins. And they are not wandering aimlessly."

Sal and his colleagues have documented great white shark migrations by tagging adults off the Farallon Islands outside San Francisco Bay. Each fall, you'll find a small team of researchers on a tiny boat, tagging some of the largest predators in the ocean.

They've documented the fidelity of great white sharks to specific feeding grounds and sharks' precise migratory routes. They're developing a picture of their behavior in an area between Baja California and Hawaii that they've dubbed "The White Shark Café." Sal is also a key player on the Aquarium's great white shark research team, where he helps tag and track young great white sharks released after a few months on exhibit in Monterey.

Sal's enthusiasm is matched by his dedication to the mission behind the science.

"Sharks are in trouble, and their populations aren't capable of rebounding the way some other fish populations are," he says. "The fact that the shark is a demonized character in our minds prevents us from really focusing on the fact that they need our help.

"I want to use what we're learning to set the stage for an accurate census of the population. Then we can monitor great white sharks over time to ensure their protection."

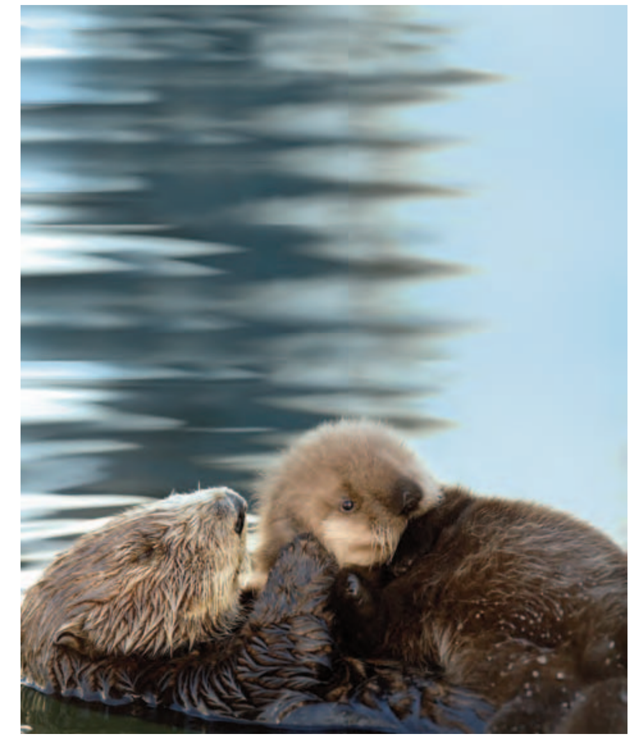
of closed lifecycle bluefin tuna culture, in which fish are raised from egg to market with no impact on wild tuna populations.

In the field, scientists and staff will continue to electronically tag large pelagic species in the Pacific and Atlantic Oceans. Overlapping data from tagging multiple species will allow better characterization of the ocean ecosystem and the interrelationships of species at the top of the food web. Predicative models based on oceanography and animal movement data will reveal how environmental cues affect the behavior of large open-ocean species. The models will make it possible to forecast out to longer time scales, offering a tool to examine the potential effects that global climate change will have on the distribution of pelagic species. Tagging data, including seasonal movement patterns and age structure of populations, will be used to further improve stock assessment methodologies in ways that will allow a more accurate estimate of wild fish populations. We can translate that knowledge into science-based management and conservation policies in both the Pacific and Atlantic.

In the near future, physiological studies will identify the unique characteristics behind the ecological differences among tunas and other active pelagic predators. Scientists will continue their genetic work on bluefin tuna and lamnid sharks. New microprocessor-based DNA analysis instruments in the physiology lab will provide new tools to examine reproduction in bluefin and assess the fitness of captive tuna populations.

The research team is also on the verge of developing a microsatellite-based identification test to distinguish between eastern and western Atlantic bluefin tuna. This will allow the team to monitor the migration of electronically tagged tunas of known stock origin, and monitor the trade of meat, knowing the stock from which it was caught. Our partnership with Stanford University puts the Tuna Research and Conservation Center at the forefront of open-ocean research. Its findings are doing much to reveal the mysteries of open-sea animals, and to help shape more rational and effective management policies to secure their future.

Sea Otters as Sentinels of Ocean Health:
Sea Otter Research and Conservation



Sea otters live at the interface between humanity and the ocean. With average diving depths of 30 to 60 feet, they typically occupy intertidal and shallow subtidal marine habitats along the Pacific Rim, from the Japanese Kurile Islands, across the Aleutian Archipelago and down the west coast of North America to southern California. With more than half of the U.S. population living in coastal counties, nearshore marine ecosystems are heavily impacted by human activity. Sea otters are voracious carnivores consuming 25 percent of their body weight per day of shellfish and other marine invertebrates. As apex predators, their condition reflects that of the ecosystem that supports them. Sea otters are sentinels of the health of their nearshore marine ecosystems.

Fur trading in the 19th and early 20th centuries nearly exterminated sea otters along the west coast of North America. Despite almost a century of full protection, sea otters in California (southern sea otters, *Enhydra lutris nereis*) are still threatened, and they number less than 20 percent of historical levels. Scientists are searching for reasons to explain the sluggish and uncertain recovery. Disease, contaminants, habitat degradation and other factors are prime suspects, but there is no single "smoking gun." Our Sea Otter Research and Conservation program, in collaboration with scientists around the world, is helping to unravel this mystery through field and captive research initiatives, innovations in sea otter care and management, conservation initiatives to enhance the wild population and educational outreach.

Despite its listing as a threatened population in 1977, under the Endangered Species Act, the number of southern sea otters remains disturbingly low, and true recovery remains uncertain. Studies have shown that increased death rates—not lower reproduction rates or emigration—are behind the population's stagnant and unpredictable growth. Research is underway to discover why so many sea otters are dying, as well as how we can manage and mitigate human activities that threaten them and the nearshore ecosystem on which they depend. We work in close partnership with colleagues at UC Santa Cruz, UC Davis, the California Department of Fish and Game (CDFG), the U.S. Geological Survey (USGS), the U.S. Fish and Wildlife Service, and many other institutions and public agencies to better understand the threats facing the southern sea otter and to identify actions that will lead to long-term population recovery.

With our collaborators, we are seeking to achieve the following five key conservation outcomes.

Sea Otter Conservation Outcomes

1. Answer the Question: Why Do Sea Otters Die?

Every dead sea otter tells a story. Each carcass, if not too decomposed, is a gold mine of information about the condition of the animal near death and the proximate cause of death. Carcasses are taken to the Marine Wildlife Veterinary Care and Research Center in Santa Cruz for postmortem study by a team of pathologists. Multiple causes of death are found in stranded dead sea otters, but infectious disease accounts for more than 40 percent of the mortalities—a rate much higher than would be expected in a healthy wildlife population. Other causes of death include shark-bite mortality, emaciation/starvation, intra-specific aggression, and direct human-caused mortality (e.g., boat strikes, gunshot wounds, fishing gear entanglement).

2. Answer the Question: How Do Healthy Sea Otters Become Sick?

One of our most important contributions to understanding the health of the sea otter population and its nearshore marine ecosystem is gathering data on the health and physiological condition of live sea otters. Live-stranded sea otters are brought to the Aquarium by our staff or personnel from The Marine Mammal Center headquartered in Marin County, California. Each live-stranded sea otter undergoes a comprehensive triage by our veterinary and animal care staff. These animals may be rehabilitated and returned to the wild, placed in a permanent captive setting or euthanized, depending on the health of the animal and its potential to contribute to population recovery. In all cases, the staff gathers data on the physiological condition of the animals—information that contributes to our overall knowledge of the health of the southern sea otter population.

We collaborate with scientists from UC Santa Cruz and the USGS in long-term studies of free-ranging individual sea otters to observe and document the transition from life to death, and to provide a more accurate assessment of the causes of mortality. Ongoing studies of the wild population and the surrounding marine ecosystem indicate that, at least in the center of the sea otters' range (near Monterey, California), limited food resources may contribute to exposure and susceptibility to disease. Data further indicate that food limitation leads to extreme variation in diet and foraging behavior from one sea otter to the next, and this in turn potentially exposes animals with different prey preferences to different diseases.

3. Answer the Question: What Risk Factors Do Sea Otters Face in the Wild?

Southern sea otters face a wide variety of hazards that put their lives at risk, some of which are caused or exacerbated by human activities, and some of which are naturally occurring. Exposure to infectious disease has increased due to introduced species and pathogens (e.g., non-native opossums on land carry a protozoan parasite, *Sarcocystis neurona*, which now gets into nearshore waters and causes lethal brain infections in sea otters), as well as alterations to the way water-borne pathogens enter the sea from land (e.g., more storm drains, fewer wetlands). Agricultural practices, urban development and human land-use patterns lead to increased flow of chemical contaminants and pathogens into the coastal ecosystem. The resulting contaminant burdens may compromise the immune system of sea otters and lead to increased susceptibility to disease. The reduced genetic diversity of southern sea otters as compared to their northern cousins (a result of an extreme genetic bottleneck prior to the sea otter fur trade) may further contribute to immune suppression. Nutritional deficiencies associated with food resource limitation and the resulting tendency of sea otters to specialize in their diets to just a few species may contribute to greater disease susceptibility. Finally, synergistic interactions among all of these factors represent an additional risk factor.

Scientists rely heavily on comparative studies to sort out the underlying causes of sea otter mortality. For example, to investigate the importance of contaminants, we compare mortality patterns in areas of high contaminant exposure, such as Monterey, to areas of low contaminant exposure, such as Big Sur. We're also comparing mortality patterns in populations found in California, southeast Alaska, the Aleutian Islands, and the Russian Commander Islands. By carefully evaluating similarities and differences in risk factors and mortality patterns among these areas, scientists hope to isolate the factors that are most responsible for limiting sea otter recovery.

Understanding the fine details of sea otter population dynamics in both time and space is critical to understanding the risk factors that sea otters face today. For more than 20 years, our scientists have assisted the USGS and CDFG in monitoring the status and trends of the southern sea otter population. Each spring and fall, our staff and volunteers participate in aerial and ground-based counts of free-ranging sea otters that provide invaluable and statistically rigorous estimates of the entire population.

The results of the biannual counts indicate that overall population growth has been approximately three percent per year between 1988 and 2008, far less than the 17 percent per year population growth seen in some northern sea otter populations. Moreover, even this modest rate of increase has slowed over the past four years.

For southern sea otters to be considered for removal from threatened species status, the three-year running average during the spring census would have to exceed 3,090 sea otters. The 2009 three-year running average was 2,813 sea otters. More research and continued counts are required to determine whether the population is recovering.

4. Mitigate the Effects on Sea Otters of Potential Environmental Catastrophes

By living in the coastal zone, where human maritime activities are most concentrated, sea otters face the risk of environmental catastrophes such as oil spills, other contaminant spills and disease outbreaks. Sea otters are particularly susceptible to oil spills because they depend on their lush fur to stay warm. Sea otters succumb to hypothermia when their fur is soiled with even small amounts of oil. Oil spill modeling studies indicate that oil spills off California are a near certainty, and that a large spill could decimate the southern sea otter population. Data from the 1984 T/V *Puerto Rican* spill and the 2007 M/V *Cosco Busan* spill in San Francisco support these predictions.

It is critical to maintain and enhance the capacity to respond effectively to unexpected and unpredictable environmental disasters. One of the many lessons learned from the 1989 *Exxon Valdez* oil spill response, as well as subsequent less-catastrophic spills, is the importance of maintaining a cadre of people trained to handle affected wildlife. Our staff and volunteers provide a resource should such a need ever arise. The expertise of our staff and volunteers is not limited to basic sea otter handling and husbandry. With our scientific and wildlife collaborators, we are constantly seeking ways to improve washing techniques, post-washing care, medical management, anesthesia and captive nutrition.

5. Improve and Advance the Quality of Veterinary Care Provided to Sea Otters in Both Captive and Field Research Settings

The Monterey Bay Aquarium is the undisputed center of sea otter veterinary medicine expertise. We are unique in handling large numbers of live sea otters facing a wide range of health challenges. Our staff views every live-stranded sea otter as an opportunity to gain new insight into the medical and surgical management of the species. The broad demographic range of live-stranded sea otters and the variety of diseases presented provide an unprecedented opportunity to further our understanding of the cause and development of disease in sea otters. For example, we apply state-of-the-art technologies used in domestic animals to sea otters for the diagnosis of common causes of sea otter mortality, such as acanthocephalid peritonitis, reproductive tract disease and coccidiomycosis. Efforts are currently underway to combine existing tests with sea otter-specific ones to better understand the more cryptic and perplexing diseases such as protozoal encephalitis (toxoplasmosis and sarcocystosis) and cardiomyopathy.

Aquariums and zoos around the world currently display more than 100 sea otters, and more display programs are on the way. While most are exclusively "exhibit display animals," some, including those at the Monterey Bay Aquarium, are active participants in a variety of scientific research projects. In addition, dozens of wild sea otters are handled every year by marine mammal scientists in conjunction with research into the status of sea otter populations and the nearshore ecosystems they inhabit.

Close-up:
Michelle Staedler

If you want to understand the family history of sea otters in Monterey Bay, just ask Michelle Staedler. The research coordinator with our Sea Otter Research and Conservation program knows several generations of otters, which she's been studying in the field for the past two decades.

When you're trying to crack the mysteries behind the slow recovery of this threatened population, it's valuable to know their life stories—and the stories of their mothers, grandmothers and great-grandmothers.

"I enjoy sitting quietly and observing nature 'do its thing' and adapt in spite of us," Michelle says.

From years of patient observations, she's documented how mother otters pass food preferences along to their offspring, and how those preferences continue through the generations.

"It's one small piece of the puzzle as we try to determine the underlying causes for the slow growth of the southern sea otter population," Michelle says. "Does food specialization carry consequences for the survival and development of pups? Are there different nutritional advantages for one pup over another if mom has a different diet specialty? Will a pup raised on a diet of abalone and crab develop survival skills sooner than one with a different type of preferred diet, or does it really matter at all?"

There are no clear answers—yet. But the quest has Michelle returning to the field, year after year.

When she's not observing mother-pup feeding and foraging behavior, she may be flying aerial surveys to count California otters, or studying foraging behavior and population dynamics and the overall health of Alaska's sea otter population.

"The otters keep me going, because they always teach me something new," Michelle says. "I've been watching them for more than 23 years and they still fascinate me. And I'm constantly amazed at how rugged they are, and how much they can endure."

For all the fascination she derives from her work, something larger motivates her to stay with it.

"I intend to contribute to figuring out why sea otters are still struggling to recover," she says. "I'll know that they're thriving when I can get to know more mother-daughter lines—when we can see prey preferences passed on to great-great-great-granddaughters!"

The advances and improvements in veterinary care we've developed are not just being used by other aquariums and zoos. They are also being applied in field research settings. Enhanced anesthetic protocols and monitoring methods, use of minimally invasive surgical techniques and improved methodology for implanting tracking transmitters are examples of such advances.

Sea otters on exhibit in aquariums and zoos are subject to not only the requirements for veterinary care mandated by the Animal Welfare Act as enforced by the U.S. Department of Agriculture, but also the more stringent requirements of the Association of Zoos and Aquariums (AZA), as well as the moral and ethical standards of the various institutions, and the public that supports them. We provide hands-on training in sea otter medicine, anesthesia and surgery for veterinarians from aquariums and zoos around the world, including the Georgia Aquarium; Aquarium of the Americas, New Orleans; Oceanario Lisboa, Portugal; Aquamarine Fukushima, Japan; Ocean Park, Hong Kong; and the New York Aquarium.

Future Directions for Sea Otter Research and Conservation

The southern sea otter population growth rate has stalled. Sea otter mortality, and not reproduction, continues to explain this trend. And there is still no single identified major cause to explain the elevated mortality. Rather, there are many possible contributing factors, acting alone or in combination with others. Thus, research focusing on risk factors to sea otter health will be the focus of our program for the next three to five years. Specific areas of interest include:

- Improving our understanding of risk factors southern sea otters face by comparing sea otter populations in Russia, Alaska and California.
- Improving our understanding of the role of maternal nutrition in development and weaning success of offspring.
- Developing advanced telemetry technology to increase the variety and quality of data collected from free-ranging sea otters, and to minimize the health risks to sea otters carrying telemetry devices.

Research and Conservation Focusing on Ocean Wildlife in Our Care

The Aquarium is home to more than 31,000 animals and plants representing some 553 different marine and freshwater species. They are exhibited in naturalistic settings that inspire a sense of awe and wonder about nature, and that connect visitors with their place in the natural world. As a conservation organization, we support research initiatives and other activities to protect the wild relatives and the ecosystems of species in our care, and to minimize the impacts of our collecting activities on wild populations and ecosystems.

Wild Bird Rehabilitation

In cooperation with the SPCA of Monterey County, the Oiled Wildlife Care Network, and the San Francisco Bay Oiled Wildlife Care and Education Center, our Husbandry aviculture team rescues, rehabilitates and releases a variety of local shorebirds and seabirds. Between 2006 and 2008, we participated in the rehabilitation of more than 120 birds representing 25 species.

The primary focus of our wild bird rehabilitation efforts is the western snowy plover (*Charadrius alexandrinus nivosus*). The Pacific coast population was designated as threatened under the Endangered Species Act in 1993 due largely to habitat destruction, conflict with human recreational uses in vital nesting areas, and destruction of eggs, chicks and breeding adults by non-native and native predators.

We work with local and regional parks, and avian conservation groups to rescue abandoned, threatened or damaged eggs and chicks during the snowy plover breeding season. These are then incubated as needed and reared for release. Since 2000, we have reared 71 chicks, including 41 that hatched from eggs; 51 of these chicks were fledged, banded and released at remote Monterey Bay beaches.

The expertise and experience of our aviculture staff proved to be vitally important in the response to two recent oil spills in California. The November 2007 accident involving the M/V *Cosco Busan* in San Francisco Bay affected sea birds in central and northern California and a concurrent "mystery spill" involved seabirds in Monterey Bay. Working with the Oiled Wildlife Care Network our team cared for incoming sick and stressed oiled birds. We prepared them for the long and stressful washing process by stabilizing them with fluids and food to help them gain the strength needed to survive the washing.

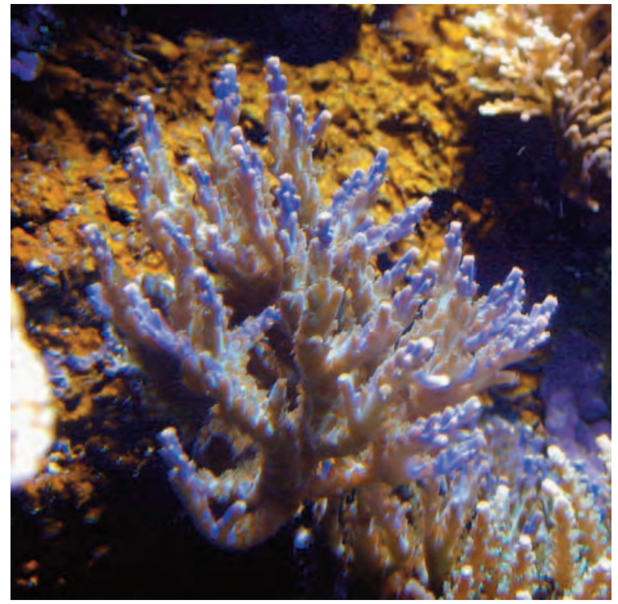
Propagation of Seahorses

Seahorses rank among the most popular aquatic species for public and home aquariums worldwide. Additionally, they are collected in huge numbers and dried for sale as souvenirs and curios, and for use in traditional Chinese medicine. As a result, seahorse populations have been devastated globally. In 2004, all seahorse species were listed as threatened by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

To help ease the pressure on wild populations and to enhance the genetic diversity of seahorses in public aquariums, our Husbandry biologists are culturing a variety of seahorse species. Our aim is to perfect seahorse culture techniques, breed and rear enough seahorses to meet our own exhibit needs, and provide surplus animals to other accredited facilities.

Despite the challenges involved in seahorse propagation, we have succeeded in breeding five species and have reared captive-bred offspring of three species (*Hippocampus erectus, Hippocampus whitei* and *Hippocampus breviceps*). With the expansion of our exhibition of seahorse species, we are applying our captive breeding efforts to other species.

Propagation of Tropical Corals



Elevated seawater temperatures, ocean acidification, siltation, coastal development, vessel damage and collection of corals for the curio and aquarium trade threaten coral reef systems throughout the world. Living corals are part of our exhibits and we strive to minimize our impact on wild coral populations.

Our corals come from captive propagation here at the Aquarium, or from illegal coral shipments confiscated by the U.S. Fish and Wildlife Service. We've propagated more than 30 coral species and regularly ship colonies to other public aquariums throughout the United States and abroad.

Jellies Propagation and Research

Jellies play vital roles in coastal and open ocean ecosystems and are increasingly affecting human activities. Also, more aquariums are exhibiting jellies because visitors are attracted by their beauty, grace and otherworldly appearance. While many jelly species are abundant in the wild, their populations fluctuate greatly and are often episodic. Our husbandry biologists have learned to propagate jellies in the laboratory both to minimize our need to collect from the wild, and to contribute to basic knowledge of these intriguing animals.

In addition to developing husbandry methods for jellies that are now used by aquarists worldwide, our biologists have described the life cycle for four species of jellies displayed in the Aquarium: the purple-striped jelly (*Chrysaora colorata*), Pacific sea nettle (*Chrysaora fuscescens*), the egg yolk jelly (*Phacellophora camtschatica*), and the cross jelly (*Mitrocoma cellularia*). This knowledge has helped our jelly team to have a constant supply of healthy jellies by determining the optimum conditions required to grow jellies from polyps to adults. We are now looking at how environmental factors like temperature affect benthic life history stages of jellies with an eye toward better understanding their bloom ecology.

Our jelly aquarists are exploring the possibility of displaying deep sea jellies, and have logged many hours at sea searching for likely candidates. To date, our staff has discovered two species of deep sea jellies that are new to science: *Amphinema rollinsi*, for which we have described the full life history, and the wigdroid jelly, *Earleria* n. sp., which we are working to describe and which can be seen on display in our Tiny Drifters Gallery. Husbandry biologists are also in the process of describing the life cycle of the deep sea palm tree jelly, *Ptychogena californica*.

Humboldt Squid Research

The Humboldt squid (*Dosidicus gigas*) is a large, active predator that reaches up to six feet in length, weighs up to 110 pounds and feeds on a staggering array of prey items, many of which are commercially important. Its range is expanding in both the northern and southern hemispheres at an alarming rate, earning increased media attention due to its effects on commercial fisheries, and its charismatic and at times pugilistic nature. As part of an international team of collaborators including Stanford University, the Monterey Bay Aquarium Research Institute, NOAA and the Centro de Investigaciones Biológicas del Noroeste, La Paz, Mexico, we are working to better understand the biology and ecology of the Humboldt squid. Additionally we are working to develop protocols for successful *in vitro* culture so that we may one day be able to raise Humboldt squids for display.

Ocean Sunfish Research

The biology and ecology of the ocean sunfish (*Mola mola*) is poorly understood. The largest of all bony fishes can reach an astonishing 3,000 pounds or more; the world record is 5,071 pounds. In the wild, this fish lives in temperate and tropical oceans worldwide. On exhibit, it is hugely popular with our visitors. Although we have successfully displayed this species for more than 20 years, its life in the wild remains shrouded in mystery.

In 2008, we undertook a research collaboration to more thoroughly study ocean sunfish in Monterey Bay. We know that they are seasonal visitors to bay waters, but where do they travel when they leave the bay? Do the same animals return annually? What do they eat? How deep do they dive? Through a program of tagging and tracking both wild and released animals via satellite, coupled with genetic analyses, we are working to find answers to these and many other questions about these bizarre and intriguing fish.

Elasmobranch Research

Sharks and rays, or elasmobranchs, are visitor favorites at the Aquarium, but wild populations are threatened by human activities, especially commercial fishing. Their slow growth rates, small litter sizes and late age at first reproduction combine to make them particularly susceptible to overexploitation. We know little about the biology and ecology of most elasmobranch species because of their secretive nature and their low economic value.

We display ten species of sharks and rays. Collaborating with scientists worldwide, we conduct research to better understand the biology and ecology of the species in our care, and to display new species. In addition to our great white shark research initiatives (see pages 12-13), current research focuses on sevengill sharks, cookie cutter sharks and mobulid rays.

Sevengill sharks (*Notorynchus cepedianus*) have been on display in our Monterey Bay Habitats exhibit since we opened in 1984, yet we know little about their basic biology and ecology (e.g., movement patterns, population size and structure). We are collaborating with scientists at the Moss Landing Marine Laboratories and the Seattle Aquarium to tag sharks in San Francisco Bay, an important nursery area for sevengills, and to collect tissue samples for DNA analysis. Preliminary results indicate that sevengill sharks travel long distances. Sharks tagged and released in Willapa Bay, Washington were recently reported in San Diego, California—1200 miles away—by hydrophone receivers. They show very strong site fidelity, returning to the same coastal wetland habitat year after year.

Cookie cutter sharks (*Isistius brasiliensis*), among the strangest and most highly specialized sharks in the world, are candidates for display in our renovated Outer Bay exhibit. With a snout and mouth modified to take perfectly round chunks of blubber and flesh from marine mammals and fishes, these sharks are a mystery to biologists and have never been displayed by any aquarium. In collaboration with scientists at California State University, Long Beach and the Hawaii Institute of Marine Biology at the University of Hawaii, we are undertaking research to quantify habitat preferences, seasonal movement and distribution patterns, and population structure. Results from this research, which we initiated in 2008, will improve our overall understanding of this mysterious shark and will help us develop husbandry methods and protocols for public display.

Mobulid rays (mantas and devil rays) are also high-priority species for display in our Outer Bay exhibit. These magnificent creatures reach wingspans of more than seven feet and are breathtaking in their grace and beauty. While little is known about their life in the wild, we do know that they are the target of an intensive and expanding artisanal fishery in the Gulf of California. Anecdotal reports suggest that populations there have declined dramatically over the last 20 years. *Mobula japanica*, a candidate for display in our renovated Outer Bay exhibit opening spring 2011, is a pan-tropical species that appears seasonally in the Gulf of California and is listed as "near threatened" in the 2008 IUCN Red List of Threatened Species. We are involved in collaborative field research with scientists from the University of California, Santa Cruz to better understand this threatened population. Thirteen individuals of *M. japanica* were

Close-up:
Aimee Greenebaum

At the Monterey Bay Aquarium, one woman leads the charge for all things bird-related–Aimee Greenebaum, the associate curator of aviculture. Aimee is responsible for the entire bird collection, and she manages a dedicated team that keeps snowy plovers, blackfooted penguins and long-billed curlews happy and healthy.

"Some people might think a bird is a bird, and that they're all alike," Aimee says. "I know better. Each species is unique, and I have to use a different method to care for each and every one of them. Part of the job I enjoy is helping our visitors to see and appreciate those differences. I feel that's one of the best ways we can get people interested in saving them. For example, I want to help people learn more about snowy plovers. They're a special type of shorebird and deserve to share our beaches."

Saving snowy plovers (a threatened species) and other shorebirds is one area where her work with exhibit birds intersects with our field conservation efforts. Each year, we rescue stranded shorebirds, or raise eggs and chicks abandoned by snowy plover parents whose nests are disturbed. Most of the chicks are returned to the wild.

In between feedings, cleanings, public programs and caring for rescued birds behind the scenes, Aimee finds time to train her favorite charge, a clever Laysan albatross named Makana. After working with Makana for almost two years, she's forged a bond of trust so that Makana can comfortably meet visitors on the Aquarium floor during a daily education program about plastics pollution and its impact on albatross and other ocean birds.

For Aimee, it's a joy to inspire people through their encounters with Makana.

"In my career, I've worked with well over 100 species of birds and she is by far my favorite," she says. But she's quick to add that, "All our birds are here as ambassadors for the birds out in the wild. We need everybody's help to clean up the mess people have made in all of the ecosystems.

"I feel one of the best ways to help the birds in the wild is to not only teach people about the birds but also give them the tools to help the wild birds."

tagged with electronic data-logging tags in the Gulf of California during 2004-2007. Preliminary results indicate that *M. japanica* move out of the Gulf and into the Pacific during late summer/early fall. Resolving these seasonal movement patterns and identifying aggregating areas are key to the conservation of this species.

Visiting Investigator Research and Collaborations

The combination of Monterey Bay's diverse marine habitats, flora and fauna coupled with the Aquarium's extensive living collection offers rich opportunities to advance knowledge about the biology, ecology and conservation of organisms and systems under our care. We welcome research proposals from scientists around the world who can take advantage of these research opportunities. All research proposals are reviewed by our Research Committee and evaluated on the basis of scientific merit and feasibility.

Current visiting investigator research projects include:

- Effects of the future high-CO_2 ocean on marine animals (Barry, J., Monterey Bay Aquarium Research Institute, mbari.org/benthic/)
- Contaminant levels in sharks (Blasius, M., California State University, Long Beach)
- Serological screening for cardiac disease in wild southern sea otters (Bremer, D., University of California, Davis)
- Movement patterns of juvenile white sharks in coastal waters of Australia (Bruce, B., CSIRO, cmar.csiro.au/tagging/whitesharks/tracks/how.html)
- Ecology and conservation of mobulid rays: an integrated approach (Croll, D. and Newton, K., University of California, Santa Cruz, bio.research.ucsc.edu/people/croll/)
- Pathogenesis of *Streptococcus infantarius* subspecies *coli* valvular endocarditis in sea otters (Edgar, K., University of California, Davis)
- Toward a mission configurable stealth under-water batoid (Fish, F., West Chester University, darwin.wcupa.edu/~biology/fish/research/index.html)
- Visual implant alpha numeric tagging of small amphibians (Hemingway, V., University of California, Santa Cruz)
- *Mola mola* population genetics study (Karl, S., University of Hawaii, hawaii.edu/HIMB/faculty/karl.html)

- Mechanism of the monoxygenase activity of hemocyanin (Kieber-Emmons, M., Stanford University)

- Detection of domoic acid in sea otter urine using Enzyme-Linked Immunosorbent Assay (ELISA) (Lane, J., University of California, Santa Cruz)

- Movement patterns, behavior, husbandry and fishery interactions of cookie cutter sharks (Lowe, C., California State University, Long Beach, csulb.edu/labs/sharklab/index.shtml)

- Evaluating individual dietary specialization in sea otters via analysis of fatty acids and stable isotopes (Ralls, K. and Oftedal, O., Smithsonian Institution, nationalzoo.si.edu/SCBI/AquaticEcosystems/SeaOtters/)

- Autonomous tissue sampler (Raymond, E., Monterey Bay Aquarium Research Institute, mbari.org/mars/science/eits.html)

- Evolution and functional morphology of the gills of high-performance fishes (Wegner, N., University of California, San Diego)

- *Mola mola* atrophic level (Zeidberg, L., Stanford University, gilly.stanford.edu/louzeidberg.html)

- Phylogeography and adaptive evolution of old world river otters (Belfiore, N., University of California, Berkeley)

- Applications of reproductive sciences for otter conservation (Bateman, H., Center for Conservation and Research of Endangered Wildlife, Cincinnati Zoo & Botanical Garden, cincinnatizoo.org/earth/CREW/otter.html)

- African spotted-necked otter fecal study (Bateman, H., Center for Conservation and Research of Endangered Wildlife, Cincinnati Zoo & Botanical Garden, cincinnatizoo.org/earth/CREW/otter.html)

- High resolution DNA marker panel specific to the southern sea otter (Ernest, H. and Kurushima, J., University of California, Davis, vetmed.ucdavis.edu/vgl/wildlife/projects/otters.html)

- A study of shark ontogeny using stable isotope analysis (Kim, S., University of California, Santa Cruz, es.ucsc.edu/~skim/research.html)

- The effects of fishing-related barotrauma on the visual acuity of rockfishes (*Sebastes* spp.) (Rogers, B., California State University, Long Beach, csulb.edu/labs/sharklab/students/current_grad.shtml)

- Aerobic capacity in immature sea otters: a foundation for successful transition from pup to juvenile (Williams, T., University of California, Santa Cruz)

Moon Jelly
Aurelia aurita