An Investigation of Behavioral Differences in Captive Sevengill Sharks and Implications for Dive Safety Management

Vallorie Hodges*, Jenna M. Walker

Oregon Coast Aquarium, 2820 SE Ferry Slip Road, Newport OR 97365, USA
vallorie.hodges@aquarium.org
* corresponding author

Abstract

The Oregon Coast Aquarium (OCAq) in Newport, OR hosts nine captive broadnose sevengill sharks, Notorynchus cepedianus, in its largest exhibit, Open Sea. Most in-water husbandry activities are carried out by volunteer divers trained in the hazards of aquarium diving and captive animal care. In 2009 the 800,000 gallon fsw exhibit underwent a 3°F increase in average water temperature to accommodate plans for the introduction of a species of ocean sunfish. Between 2007 and 2011 the total increase in temperature was 7°F. Sevengill shark behavior was recorded throughout this temperature increase and a change in general behavior was noted. As a result of the observed shift in shark swimming patterns, changes to diver protocol were incorporated. These included training and testing the proficiency of divers to accurately identify individual sevengills, knowledge of habits unique to individual sevengill sharks, and post-dive shark behavior documentation as mandatory requirements in the OCAq volunteer diving program.

Keywords: dive safety management, diving with captive sharks, Notorynchus cepedianus, risk management, sevengill shark behavior

Introduction

The risk of diving with captive sharks in aquaria has led to the development of numerous safety practices implemented by dive programs around the globe (Hodges and Frierson, 2008). Ideally research and husbandry diving tasks are designed to consider the welfare of all animals as well as the safety of divers (Smith et al., 2004). Risk management models are common within the scientific diving community and can be important tools in ensuring the achievement of these goals (Richardson, 2004). This paper explores a specific case study at the Oregon Coast Aquarium where changes in captive sevengill shark behavior were noted, and as a result, adjustments in dive safety protocol were made.

It is believed that the observed shift in sevengill shark swimming patterns was primarily due to an average water temperature increase that was implemented to facilitate the planned introduction of ocean sunfish into the OCAq Open Sea exhibit. Temperature has been known to directly effect metabolic rates among sharks but its relationship with other activities such as digestion, resting, and swimming behavior is less known (Boisclair and Tang, 1993; Schmidt-Nielsen, 1997). Tullis and Baille (2005) demonstrated that when Chiloscyllium plagiosum, whitespotted bamboo sharks, originated from thermally stable environments they struggled to metabolically compensate from environmentally altered temperatures. Shuttling behavior is a recognized example of variation in shark swimming patterns as organisms move across thermal gradients in order to optimize physiological processes (Casterlin and Reynolds, 1979; Hopkins and Cech, 1994; Sims et al., 2006; Di Santo and Bennett, 2011). Wild populations of N. cepedianus enhance their physiological
performance by using temperature as a cue for selecting and avoiding particular habitats with shifting prey distributions (Heupel and Simpfendorfer, 2008). Temperature variability is also commonly associated with coastal migrations among sharks and can help signal reproductive behavior (Springer, 1967; Heupel and Hueter, 2001; Sims et al., 2003; Skomal et al., 2004; Bonfil et al., 2005; Hussey et al., 2009; Knip et al., 2010).

Of the five shark species within the Open Sea exhibit at the OCAq, *N. cepedianus* are the most dominant, and though not recognized as a particularly aggressive species, pose the highest potential safety risk for divers, primarily due to their size, width of the mouth and morphology of dentition. Seven-gill sharks are commonly identified by their seven paired gill openings, broad head, dorsal spot patterns, and large anal fin (Peron, 1807; Barnett et al., 2012). *N. cepedianus* are high order marine predators found in shallow coastal waters, estuaries, bays of temperate seas ranging from 48-68 °F and are associated with areas of high biological productivity and upwelling (Ebert, 1991; 2003; Barnett et al., 2010). They primarily feed on sharks, especially the genus *Mustelus*, batoïds, teledonts, cephalopods, and marine mammals (Ebert, 1991; Braccini, 2008; Barnett et al., 2010). Seven-gills are exposed to high fishing pressure due to their coastal zone habitat and are especially vulnerable to longline fisheries in South Africa (Compagno et al., 2005; DaSilva and Burgener, 2007). In North America seven-gill sharks can be found from Baja, California to southeast Alaska with important nursery and birthing grounds existing in Humbolt and San Francisco Bays (Ebert, 2003). While there are several publications of *N. cepedianus* ecology from South Africa, Tasmania, southern Australia and Argentina, little is known about their behavior and movement patterns within their North American range (Ebert 1989, Lucifora et al., 2005; Braccini, 2008; Barnett et al., 2010; Williams et al., 2012).

Methods

The Oregon Coast Aquarium is located in Newport, OR, USA (44° 37’N x 124° 2’W). The OCAq’s Open Sea exhibit is representative of the epi-pelagic habitat, and is therefore intentionally void of any decoration. A 70 ft long underwater viewing tunnel bisects the exhibit. Open Sea holds 800,000 gallons of seawater and reaches 26 feet of depth. It hosts nine *N. cepedianus*; eight males and one female. There are also bat rays, *Myliobatis californica*, leopard sharks, *Triakis semifasciata*, spiny dogfish, *Squalus suckleyi* (Ebert et al., 2010), Pacific salmon *Oncorhynchus*, Pacific mackerel *Scomber*, California anchovies, *Engraulis mordax*, a soupfin shark *Galeorhinus galeus*, and a brown smooth-hound *Mustelus henlei* within the exhibit.

Reproductive behaviors have been observed seasonally among the seven-gill sharks, inter and intra species aggression has occurred occasionally, and shark-diver interactions have been infrequent, though tracked carefully.

In winter 2007, winter 2009, and spring 2011, ethograms were conducted on all *N. cepedianus* to catalogue behaviors and swimming patterns of individual sharks (n=14, 9, and 21).

These ethograms were conducted over a twenty minute time period; position was marked on the exhibit map data sheet every twenty seconds along with direction (clockwise, counterclockwise) and general swimming patterns. Location in the water column was noted and categorized as Zone A, B, or C with A representing the upper third of the water column, B representing mid-water and C representing the lower third or benthos. Also documented was the behavioral choice of *N. cepedianus* to swim over the top of the viewing tunnel arch or to swim under it during each circuit of the swim pattern cycle. Temperature data was gathered from original OCAq aquarist logs from 2007-2011. No raw data exists from fall 2008-summer 2009; instead temperatures for this time period were estimated
by averaging seasonal values from the previous and future years.

![Figure 1. Raw ethogram data from a solitary sampling event](http://archive.rubicon-foundation.org)

**Results**

Temperature within the Open Sea exhibit underwent a 3°F increase between 2007, 57°F, and 2009, 60°F, (Figure 2). In general the water temperature has steadily increased annually with maximums recorded in September and minimums recorded in January (Figure 2). *N. cepedianus* have displayed insignificant changes in their distribution within Zone A; they have shown trends of decreasing their time spent in Zone B and increasing their time in Zone C, an approximate 10% transfer (Figure 3). The swimming behaviors of *N. cepedianus* exhibit a trend towards remaining below the Open Sea tunnel, increasing from 24% in 2007 to 53% and 32% in 2009 and 2011 respectively (standard error= 1.9, 1.1, and 1.5%) (Figure 4).

**Limitations**

This study was limited by several factors, the most notable of which is the inconsistency of the temperature data provided by the aquarists. From January 2007 through summer 2008 temperature data consisted of one to two data points per month, whereas between fall 2009 through winter 2011 temperature data was collected an average of twenty-three times per month. Between fall 2008 through summer 2009 the only available temperature data comprised of a water system connected to the Open Sea and two other exhibits. These data were not used as it did not properly reflect temperatures experienced by organisms within Open Sea and averages are instead displayed in Figure 2.

The ethograms were initially designed to be a detailed mapping of sevengill swimming behavior over a twenty-minute time period. As such the ethograms are better suited to compare changes within a single shark’s behavior rather than accurately representing changes within a population. The small sample size of two to three ethograms per shark per year could be improved by conducting significantly more ethograms. The data could also be more regulated by conducting studies every
season, especially during temperature peaks.

Figure 2. Seasonal temperature averages within the OCAq Open Sea exhibit

Figure 3. Zone distribution of captive *N. cepedianus* within the OCAq Open Sea exhibit during 2007.
2009, and 2011 ethograms.

Figure 4. Percentage of encounters captive *N. cepedianus* spent swimming above or below the OCAq Open Sea exhibit tunnel during 2007, 2009, and 2011 ethograms.

**Discussion**

The Aquarium’s plan to add ocean sunfish into the Open Sea exhibit necessitated a water temperature change to facilitate acclimation of the bony fishes (Figure 2). Ethogram data show a trend in *N. cepedianus* behavior toward spending an increasing amount of time in the benthos of Zone C and making less of an effort to swim above the viewing tunnel since 2007 (Figures 3 and 4). This tendency is thought to primarily correspond with the 2009 temperature increase in Open Sea.

The captive sevengills could be mimicking behaviors of the shortfin Mako, *Isurus oxyrinchus*, which swim towards deeper, colder water when stressed, particularly after being captured and tagged (Holts and Bedfore, 1993; Klimley et al., 2002). It is thought that vertical displacement in juvenile white sharks is triggered by thermal tolerance disruption in eastern Pacific waters, possibly relating to *N. cepedianus* (Weng et al., 2007; Speed et al., 2010). Variable water column distribution is present in sevengill sharks at night when oscillating swimming patterns are utilized for foraging. During the day sevengill sharks remain nearer to the substrate and exhibit long resting periods (Barnett et al., 2010). It is possible that temperature is none or one of several explanations for the swimming changes noted in *N. cepedianus* within the Open Sea exhibit but the continued and potential increased presence of sevengills in the benthic region of Zone C is concerning from a dive safety perspective. Working divers spend the majority of their time in Zone C of the exhibit retrieving/stowing vacuum hoses and clearing the bottom of uneaten food debris from scheduled feedings. Based on the foundation of data evidenced by these ethograms, there is an inevitable increase in shark and diver interactions.
**Future Directions**

Previously, shark diving safety protocol included a classroom session and observation exercise in the observation tunnel during volunteer diver training, a step by step introduction to diving in the Open Sea exhibit, and the use of a safety “stick” diver wherein the stick is used primarily as a visual and physical barrier between the divers and the sharks. This system is widely used in captive shark diving and might be considered the standard of care (Hodges and Frierson, 2008). Previous protocols also included the requirement of the safety “stick” diver to be proficient identifying individual sevengill sharks. Additionally, divers were required to record shark behaviors in a log following the dive for purposes of ongoing monitoring and observing trends in behaviors that effect diver safety.

The results of this study have prompted some changes in the safety protocol for diving with captive sharks at the OCAq. Prior to diving, dive teams observe the sharks from the tunnel of Open Sea to get a general sense of the behavior of the sharks and practice identifying individual sevengills. It is expected that during this session lead divers will discuss swimming patterns and identification features unique to specific *N. cepedianus* and that all team members will become proficient in identifying the individual animals. A volunteer diver developed a web-based online identification examination using flashcard photos that display a physical profile of each Sevengill, and point out color, freckle/spot patterns, scars, and other identifying marks. During the exam, the flashcards are displayed and the user is prompted to select the correct shark from a randomly generated list of possible sharks. Volunteer divers are now required to go to the website and complete the flashcard examination and print their results, which is filed on the diver’s record. Divers are encouraged to use the tool until mastery (100% recognition) is achieved. The protocol of logging shark behaviors post dive has also been improved, with the use of a standardized form and ranking system. All divers are now encouraged to become familiar with these tools and use them, rather than restricting it to the lead divers. It is the belief of the DSO that volunteers should be as aware as possible of any potential risk and that by better understanding the behavioral ecology within Open Sea, a stronger and safer dive program within the OCAq will result. The primary focus has been to develop a culture of safety among the divers through participation and full involvement in all aspects of the dive, including making observations, planning, briefings, and post dive discussions and assessments of shark behavior.

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Burrow and Current Production by the Mantis Shrimp, *Squilla empusa*

Kristina S. Mead\(^1,2\)* and Halle Minshall\(^1,3\)

\(^1\)Denison University, Granville, OH 43023, USA
\(^2\)771B Loma Verde Ave., Palo Alto, CA 94303, USA
\(^3\)21700 South Woodland Rd., Shaker Heights, OH 44122, USA

* corresponding author

**Abstract**

The mantis shrimp *Squilla empusa* forms extended burrows in the silty mud. We investigated burrowing in *S. empusa in situ* using SCUBA, and animals were collected for further laboratory studies. Burrowing in the field was studied primarily by making repeated daily visits to individually marked burrows and recording changes in the number, diameter, and structure of burrow openings. Burrows varied considerably in their length, width, number of openings, and the amount and timing of reconstruction, with some changes occurring on a daily basis. We analyzed burrowing activity by releasing captive animals back into their native habitat and filming the resulting burrow excavation. Animals were also filmed moving sediment in the laboratory. Both in the laboratory and in the field, *S. empusa* employ two methods of moving sediment: pleopod fanning, which directs stirred-up sediment posteriorly, and carrying sediment forward in a “basket” made of their maxillipeds. The pleopod fanning motion is also instrumental in generating large currents within the burrow once the construction is complete. These currents were studied in detail using field particle image velocimetry. The resulting current profiles make it possible to distinguish between burrows with one opening and burrows with multiple openings.

Keywords: fanning, maxilliped, particle image velocimetry, pleopod, sediment

**Introduction**

The mantis shrimp *Squilla empusa* form extended burrows in silty substrates along the Atlantic Coast south from Cape Cod to the Gulf of Mexico (Pollock, 1998). The animals rely on these burrows for protection from predators, as a base for their own hunting, and for reproduction. This temperate species is known to have vertical burrows in the winter, and U-shaped burrows in the summer (Myer, 1979). However, mantis shrimp lore has long held that burrows are costly to create and stridently defended, and that no changes are made to the burrow over long periods of time except for the yearly changes noted by Myers (1979). However, recent studies of *S. empusa* burrows in Great Harbor have shown that these animals engage in frequent burrow remodeling, altering the number or type of opening between successive dives on the same day. To better understand this behavior, field and laboratory studies were undertaken to understand the extent of burrow remodeling, and to investigate the burrowing process. Early studies of animals in the laboratory revealed that *S. empusa* fan their pleopods vigorously, presumably to facilitate ventilation. Field observations indicated that this activity created currents vigorous enough to stir up sediment into a visible plume. These currents, not yet described in the literature, became the focus of this project.
Methods

Burrow identification and measurement
Two to five hundred foot transects were laid out in Great Harbor, near Woods Hole, MA each summer for a total of twelve transects over a four year period. During this period, a total of 94 burrows were marked with survey flags or with numbered floating whiffle balls. Sixteen burrows were measured once each in 2009, 32 burrows were measured and monitored over 26 dives over a six week period in 2010, 35 burrows were measured and monitored 21 times in 16 days in 2011, and 11 burrows were measured 3 times each over seven weeks in 2012. Squid bait was used to lure the mantis shrimp out of its burrow and ascertain the size and sex (when possible) of the inhabitant. Fluorescein dye was injected into burrows to determine which openings belonged to a particular burrow. The number of openings, opening diameter, distance between openings, and distance between burrows was measured. Burrow diameter was measured to the nearest mm, and distance between openings and between burrows was measured to the nearest cm.

Observation of burrowing activity in the laboratory and in the field
Nine wild caught S. empusa that were returned to Great Harbor burrowed in the substrate immediately following release. The burrowing activity was filmed using a 30 Hz JVC Pixsio video camera. Burrowing was also investigated in the laboratory, using a Fastec Imaging Troubleshooter operating at 125 Hz. Because filming using the natural sediment led to murky water and poor filming, aquarium gravel and sand were used to facilitate analysis of burrowing movements in the laboratory, although S empusa were not able to form complete burrows with the artificial sediment. Both field and laboratory videos were digitized using Image J software, freely available from NIH.

Current measurement using dye and field particle image velocimetry
Currents produced by animals in their burrows were measured by slowly injecting fluorescein dye and filming the motion of any dye that emerged from a burrow opening using a 30 Hz JVC Pixsio video camera. Forty burrows were characterized in this manner. The movement of the dye front was analyzed using Image J. To measure velocity in greater detail, divers used a 250 mW 532 nm laser-generated light sheet and a 30 Hz video camera as per Dabiri et al. (2010) to obtain videos of particulate matter moving within the plane of the lightsheet. These videos were processed using DaVis software. This analysis generated finely scaled current profiles perpendicular to the openings of four burrows.

Results

Burrow opening measurements
Over the course of each summer, burrows changed seasonally, daily and even on hourly timeframes. At the start of the summer (typically the first couple of weeks in June), almost all burrows had a single opening, which was often plugged during daytime dives. By the end of June, about 80% of the burrow openings were cleared (unplugged), and about 75% of these burrows were U-shaped, with two openings. Over the course of the 2009-2012 summers, 94 burrows were measured (Figure 1).

Burrow openings ranged from 10-75 mm in diameter. Overall, 47% percent of S. empusa burrows had two openings, and 36% had one opening, although the relative percentages changed dramatically as the summer progressed. When burrows had multiple openings, the mean ± sd between openings was 59 ± 29 cm (n = 44), and the mean distance between burrows was 2.13 ± 0.95 m (n = 94). Thus, dynamic changes include removing a plug (n = 92) and excavating a second opening (n = 42), often within 24 hours of a previous examination of the same burrow. In addition, the repeated measurements of the same burrows undertaken in 2011 showed that the diameter of burrow openings
usually changed on a daily basis, as the inhabitants increased or decreased the opening by a few mm to cm or sealed off an opening completely. Within a given pair of dives, some animals enlarged burrow openings while others narrowed them; we saw several examples of changes in the opposite direction within the same burrow. Burrow openings that were enlarged showed a 16% mean increase in burrow opening diameter in the three hours between morning and afternoon dives (n = 16), and a 57.2% mean increase over a 24-hour period (n = 11). Burrow openings that were filled in showed a 20.1% mean decrease in burrow opening diameter between morning and afternoon dives (n = 17), and a 22.1% mean decrease over a 24-hour period (n = 13). Less commonly observed were large mounds and cones built around one opening, often constructed within three hours (n = 2). Two mid-October dives indicated that the burrows had single openings that were partially obstructed, with a thin crust extending from the periphery and covering up to 70% of the surface area of the opening (n = 18).

**Burrowing activity**

Burrowing activity observed when nine previously captured animals were returned to the field indicated that *S. empusa* can form small but functional burrows in the field within 30-45 minutes. Continued analysis of burrowing in the field and in the lab has shown that *S. empusa* employ two different methods for moving sediment. The animals typically start by vigorously fanning their pleopods, which suspends and pushes sediment behind their telson. The posterior end of the growing depression ultimately becomes the primary burrow opening. Most individuals are able to create a depression big enough to fit their body within 1-2 minutes, but this method of moving sediment is not sustainable. After several bouts of this exercise, the animals turn around and engage in a new method of substrate removal using their maxillipeds to carry lumps of sediment forward and out of the burrow. This second burrowing method only moves about one fifth as much sediment per unit time as pleopod fanning, but animals can maintain this excavation approach for much longer. *S. empusa* continue burrow construction with their maxillipeds until their body can be completely enclosed by the growing burrow. This quick burrowing method is facilitated by the dorsoventral flattening of the body, which enables tight turns. Preliminary scanning electron microscopy studies suggest extremely
setose pleopods and maxillipeds, which may help them to move and/or carry large amounts of sediment.

**Burrow currents**

The pleopod fanning motion that is used to move sediment is also used to create substantial currents in the burrow. Since the pleopods move fluid posteriorly, the direction of the fluid flow through the burrow depends on the location of the mantis shrimp relative to the burrow opening of interest. Animals typically make currents that bring water into the burrow opening when they are positioned head-up by the burrow opening. In contrast, when the animal is upside-down near an opening, the current sends water out of that burrow opening. The latter position is believed to be defensive.

Fluorescein dye and PIV data indicate that the animals can produce currents of up to 6 cm/s. The PIV measurements also made it possible to resolve the time course of fluid ejection from the burrow. Often, the current started with a large, fast, constantly flowing expulsion of fluid, followed by a slower, oscillatory period. The mean current out of the burrow during this period was 2.7 ± 0.3 cm/s.

In the two hours of PIV video, the mantis shrimp were shown creating these currents 35% ± 14% of the time. However, there is a great deal of individual variation in the relative amount of time individuals spend generating incurrents (from 5% to 24%) and excurrents (7% to 41%).

Lastly, PIV profiles make it possible to distinguish between burrows with one opening and burrows with two openings. The former typically had water flowing into one side of a burrow opening and out the same opening, while the latter experienced flow into one end of the burrow and out the other end of the burrow.

**Discussion**

Mantis shrimp burrowing activity, at least in *S. empusa*, appears to be more dynamic than previously thought. Most burrows acquire a seasonal second opening, and the diameters of the burrow openings change on a daily basis. The actual burrow excavation mechanisms that give rise to these changes, pleopod fanning and the use of maxilliped baskets to carry sediment, are fast and efficient. The fact that *S. empusa* can build new burrows quickly may explain their lower level of aggression relative to other mantis shrimp species (Caldwell and Dingle, 1976). The constant remodeling could have important effects on other inhabitants of the substrate. These effects could include damage to their shelters, changes in ventilation and oxygenation and other biogeochemical aspects of the sediment, and exposure to predation.

Pleopod fanning seems at first like an inefficient and inaccurate means of moving sediment. However, recent studies show that pleopod movements provide jet propulsion-like motion during mantis shrimp escape responses (Campos et al., 2012). These observations suggest that the water currents produced by pleopod fanning that move sediment during burrowing could be more directed and thus more efficient than previously considered. A less vigorous version of pleopod fanning creates strong currents within the burrows. Putative functions for these currents include both ventilation and transport of chemical signals. These possibilities will be the subjects of future investigations.

*S. empusa* burrows are similar to *S. mantis* burrows in that they both typically have two openings with one usually larger than the other. However, the openings are closer together in *S. empusa* than in *S. mantis* (Atkinson, 1997). The methods of moving sediment also appear to differ between the two species. *S. mantis* appear to use more head and maxilliped probing and less pleopod fanning to make
the initial depression. During later stages, larger animals back out to deposit the sediment held by maxillipeds or push it beneath their body rather than somersaulting and exiting forward like S. empusa. Furthermore, S. mantis appear to spend more time grooming with its first maxillipeds. In S. empusa, the first maxillipeds are most often used to tamp down and consolidate the bolus of sediment held within the basket formed by maxillipeds 2-5. Perhaps as a consequence of these differences, S. mantis takes several hours to burrow down 20 cm, while S. empusa can dig this deep in less than an hour.

In conclusion, S. empusa may be unusual in the rapidity with which they first construct and later remodel their burrows. Their building efficiency may affect both their own behavior by minimizing the pressure for aggressive defense of their burrows. The frequent construction may also affect the surrounding sediment and other animals living in the sediment.

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Experimental Marine Ecology Along the Open Coastline of the Western Antarctic Peninsula

Kathryn M. Schoenrock1*, Charles D. Amsler1, James B. McClintock1, and Bill J. Baker2

1University of Alabama at Birmingham, 1300 University Blvd. CH 464, Birmingham, AL 35294, USA
ksrock@uab.edu
2University of South Florida, Department of Chemistry, 4202 E. Fowler Ave. NES 107, Tampa, FL 33620, USA
*corresponding author

Abstract

Although every region where science diving occurs has unique challenges, one of the most formidable diving regions is Antarctica, from McMurdo Sound to the western Antarctic Peninsula. Along the open coastline of the western Antarctic Peninsula challenges differ from areas of Antarctica with year round ice cover. They can range from encounters with megafauna to the extreme environmental characteristics of the continent. Common science diving protocols and techniques need to be adapted in order to deal with these challenges and perform ecological field experiments. This presentation discusses these protocols and techniques in reference to the work done by the University of Alabama at Birmingham and the University of South Florida. The ecological work is multi-disciplinary and includes chemical ecology, drug discovery, algal physiology, and climate change.

Keywords: western Antarctic Peninsula, dry suit, climate change, marine ecology, SCUBA

Antarctica

The Antarctic marine ecosystem is a combination of unique biology and extreme environmental factors. The separation of Antarctica from surrounding land masses and formation of the Southern Ocean, including creation of the Antarctic Circumpolar Current (ACC), effectively isolated the continent from other marine habitats in the late Cretaceous. Isolation of the biological community from previously sympatric communities led to high incidences of endemism and losses of many marine phyla (Dell, 1972). Yet, Southern Ocean deep water upwelling provides waters with high nutrient content sustaining many biologically rich marine communities. These include pelagic seas which host abundances of krill, a keystone species in the Antarctic food web (May et al., 1979), subtidal benthic communities like those in the Ross Sea, which are largely dominated by invertebrates (Dayton, 1994), and benthic communities dominated by macroalgal canopies along the western Antarctic Peninsula (Wiencke and Amsler, 2012). Antarctica is designated as an area most likely to be impacted by global climate change, especially the Antarctic Peninsula (Clark et al., 2007). Examining these unique ecosystems provides an opportunity to study ecological processes (Amsler et al., 2001) and their response to a rapidly changing environment.

Fifty nations actively work in Antarctica in ordinance with the Antarctic Treaty. Most stations dot the coastlines (Figure 1), and are facilitated by vessels which some also use for research. Diving programs vary between country and station, and generally are tailored to the highest degree of safety for the type of science and specific environmental conditions to which the divers are exposed. The three Antarctic dive platforms outlined in the Office of Polar Programs’ diving manual include
McMurdo Station, Palmer Station, and Research Vessels along the peninsula. This paper will discuss the work and conditions at USAP Palmer Station along the western Antarctic Peninsula.

Figure 1. Map of Antarctic Continent with stations (image from http://www.scar.org/information/).

http://archive.rubicon-foundation.org
Diving along the western Antarctic Peninsula

Conditions along the Antarctic Peninsula are tumultuous and can change rapidly. The western Antarctic Peninsula has varied sea ice cover, reaching maximum mean density in mid-August and minimum mean density in mid-March (Stammerjohn et al., 2008). Open coastline conditions allow the use of Zodiacs as a diving platform and as transportation to and from dive sites. However, these coastlines are steep and are subject to surge, pack ice, wind, swell, dim light conditions, and are accessible to top predators (Figure 2).

These conditions require live tending and at least two dive tenders on board the Zodiacs at all times. Lines are rigged to the Zodiacs for gear retrieval and a diver recall horn is always on board in the event that the weather changes or a leopard seal is observed in the vicinity (Figure 3).

Figure 2. Leopard seal (photo credit Bill Baker).

Figure 3. Dive boat setup with tenders (photo credit Deneb Karentz).
Visibility along the peninsula can range from 30m in the late Austral winter through early summer to 1-5m in the summer and early fall because of phytoplankton blooms and glacial flour. Water temperatures are low, with maximum fluctuations between -1.5ºC and 2ºC during the Summer. Weather and leopard seals are a primary concern in safety, as well as the type of science planned for the dive. Therefore extensive measures are taken when surveying a dive site. After a site is deemed safe a ten minute or longer leopard seal survey is done within a 1km radius of the dive site.

The remoteness of the study area increases the danger of diving. In the case of a dive accident, protocol for treatment first includes retrieval of the diver(s). Since divers are not tethered, there is no anchor or descent line, and underwater breathing is self-contained, this would become difficult if the diver was non-responsive. When a diver(s) are retrieved from an accident site, his or her condition is assessed (ABCs), oxygen therapy and/or treatment for hypothermia is initiated, and the dive group immediately returns to the station. Although the doctor on station is briefed in diving medicine, that is not his or her professional specialty and there is no chamber access. Therefore any extended treatment, specifically recompression, requires immediate transport to BAS Rothera Station or Argentine base Jubany (Figure 1) via vessel or Twin Otter, or immediate transport by vessel to recompression in South America. The OPP DSO is immediately contacted and accident management is carried out using dive logs and diver, dive buddy, and dive tender debriefs.

Dry suits are used by most divers in this area and cold water gear includes two regulators (the primary is equipped with a Zeagle isolator valve in case of free flows), a standard weight harness with easily dumped weight pockets, a vest BC, and back-lit dive computer (Figure 4).

Ecological experiments

Diving facilitates ecosystem studies otherwise impossible along the western Antarctic Peninsula. Field experiments, specialized collections, photography, and exploratory dives are just an example of this dive work. Specific areas of research are detailed below with brief descriptions of corresponding dive activities.

Chemical Ecology
The study of chemical ecology examines how biologically produced chemicals (primary and secondary metabolites) are involved in ecosystem interactions including those between organisms, and those between organisms and their environment. In Antarctica, studies to date have described the role of chemical defenses in trophic interactions (Amsler et al., 2001), defense against predation in common invertebrate and algal species (Amsler, 2001; Mahon et al., 2002; Mahon et al., 2003; Amsler et al., 2005), biofouling (Amsler et al., 2000), and community-wide interactions involving biological chemistry (or secondary metabolites). The interaction between the large mesograzer cohort and the chemically defended macroalgal canopy has been described as a mutualism, where the mesograzers gain refuge from predation within the chemically defended macroalgae and benefit macroalgae by grazing down potentially harmful epiphytic algae (Amsler et al., 2009; Zamzow et al., 2010; Aumack et al., 2011). Other current studies include examination of the role reactive oxygen species have in anti-predator defenses (McDowell, personal communication) and of how cell wall constituents of coralline algae may affect invertebrate recruitment to Antarctic reefs (Schoenrock, in progress). These projects require a variety of diving skill sets, including underwater identification and collection for extraction and manipulation in lab, night diving, and deployment of substrates to weight down long-term field experiments. This sort of technical diving is done with extreme care and consideration of the environmental conditions (Figure 5).

Figure 5. Dive tenders lowering concrete substrates to divers off Zodiacs at Norsel Point, Amsler Island 2010 (photo credit Maggie Amsler).

**Drug Discovery**

It is commonly predicted that incidences of chemical defenses in organisms will decrease from low to high latitudes globally (Bakus and Green 1974). Antarctica is the exception to this rule; many marine organisms, both invertebrates and algae, have been found to elaborate secondary metabolites within their tissues (Amsler et al., 2000). Whether this has evolved as a defensive mechanism or is product of the evolutionary isolation of the continent remains in question. Still, drug discovery capitalizes on natural biological products, and compounds from many marine organisms common to the western Antarctic Peninsula are medically interesting. Collections for these studies require dives of up to 150 feet for specific organisms and can be long (up to 40 minutes). Dives are always planned within no decompression limits.

**Algal Physiology**

The study of algal physiology is broad, spanning from the various forms of metabolism within the algae to plant (thallus) morphology. Experiments examining the various physiological aspects of
algae along the western Antarctic Peninsula include an examination of phlorotannin production of dominant macroalgae (Fairhead et al., 2005) and an investigation into the impact of filamentous algal endophytes on growth, reproduction, and survival of various endemic and cosmopolitan algae (Schoenrock, in progress). Field work for these experiments includes field collections from multiple depths, use of a pulse amplitude modulated fluorometer (Walz, Germany) to analyze photosynthetic characteristics of individuals, community sampling using quadrats, and deployment of substrates for transplant experiments.

**Climate Change**

The western Antarctic Peninsula has been cited as an area of the world that is very susceptible to global climate change. In 2012, a study at Palmer Station investigated the response of two calcified marine invertebrates, and both calcified and non-calcified crustose algal species, to current and predicted levels of water temperature and acidity. Diving collections provided organisms of the appropriate size and species for an in-lab experiment.

**Conclusion**

Although broad in spectrum, all of the research conducted along the western Antarctic Peninsula provides information on marine benthic community interactions and individual species distributions as well as how they persist in this particularly harsh environment. Although science diving in the Antarctic can present physical and environmental challenges to research, the ability to safely and thoroughly conduct studies in this area provides an ecological baseline for future research. Further, new methods for conducting *in situ* experiments in this environment are always being sought and this paper will hopefully inspire discussion and new projects.

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Closed-Circuit Diving Techniques for Wild Sea Otter Capture

Joseph A. Tomoleoni¹*, Benjamin P. Weitzman¹,³, Colleen Young², Michael Harris², Brian E. Hatfield¹, Michael Kenner³

¹ United States Geological Survey, Biological Resources Division, Western Ecological Research Center, 100 Shaffer Rd, COH Bldg., Santa Cruz, CA 95060
jtomo@usgs.gov

² California Department of Fish & Game, Office of Spill Prevention and Response, Marine Wildlife Veterinary Care and Research Center, 1451 Shaffer Rd, Santa Cruz, CA 95060

³ University of California Santa Cruz, Ecology & Evolutionary Biology, 100 Shaffer Rd, COH Bldg., Santa Cruz, CA 95060

* corresponding Author

Abstract

Sea otters (Enhydra lutris) are both a keystone and sentinel species in temperate coastal ecosystems of western North America, and provide researchers with a “window” into the health of the nearshore environment. In order to accurately monitor these populations, it is necessary for researchers to capture wild sea otters to collect morphometric data, tissue samples, and to attach or implant markers for long-term tracking studies. As a result, a collaboration of the US Geological Survey, California Department of Fish & Game, and University of California, Santa Cruz, has developed an innovative approach to capturing wild sea otters using divers. The techniques have evolved over several decades and currently utilize state-of-the-art equipment including closed-circuit oxygen rebreathers, highly modified diver propulsion vehicles, and custom designed “Wilson Traps” to catch sea otters. Stress or chance of injury to the animal is minimized using the current design. The design is ideal for re-capture of sea otters in order to retrieve archival instruments (i.e. implanted time-depth recorders) and conduct longitudinal studies related to health and disease or pathogen exposure. The described diving techniques have greatly advanced the field of sea otter research, providing greater understanding of sea otters and the capability to closely monitor this federally protected species throughout its range.

Keywords: animal health, diving, nearshore ecology, oxygen rebreathers, sea otter

Introduction

Sea otters (Enhydra lutris) are an important predator in nearshore ecosystems of the North Pacific. Unlike all other marine mammals, sea otters do not have a thick insulating layer of blubber, and instead, possess the thickest fur of any animal (Kenyon, 1969). This unique fur coat allows otters to survive in cold Pacific waters, an environment well outside their zone of thermal neutrality (Morrison et al., 1974). This fur coat made sea otters a prized commodity in the 1700’s to Russian fur traders. The sea otter hunt continued until the passage of the International Fur Seal Treaty in 1911. By the early 1900’s only 13 remnant sea otter colonies existed in the Pacific. A mere 30-50 otters survived in California, where current numbers have rebounded to approximately 2,800 individuals, and they remain listed as a federally threatened species. Historically, sea otters populated the entire west coast of North America, from Baja California all the way around the Pacific Rim to Russia and Japan. Today, three subspecies exist in fragmented populations. Enhydra lutris nereis occurs only in Central California, while E. l. kenyoni is found in Alaskan waters, British Columbia, and Washington, and E. l. lutris in Russian waters.
As a keystone species in kelp forest and other nearshore communities, the presence or absence of otters can greatly affect the dynamics of an entire ecosystem (Estes and Palmisano, 1974). They are also considered a sentinel species, making them critical indicators of the health of our coastal environments and resources (Jessup et al., 2004).

In order to monitor the health and status of sea otter populations, and by extension, the health of nearshore ecosystems, researchers must be able to effectively and efficiently capture sea otters. Catching these animals not only allows scientists to assess health and individual body condition, but information on diet and feeding habits, exposure to disease, toxins, or other stressors, can be gained from sampling tissues, whiskers, and blood. Additionally, captured otters can be implanted with archival instruments like time-depth recorders (TDRs) or VHF radio transmitters allowing for long-term monitoring and tracking studies that provide scientists with a wealth of behavioral and biogeographic data.

History

A variety of sea otter capture methods have been utilized over the past several decades. Dip netting of otters from a fast boat has been effective at catching rehab animals, juveniles in open water, or distressed animals such as those in the 1989 Exxon-Valdez oil spill in Prince William Sound, Alaska. Tangle nets, which are similar to gill nets, are very effective at catching a large number of otters, but are indiscriminate, risk injury or drowning to the animals, and also tend to catch non-target species such as seals, sea lions, small cetaceans, or marine birds. In most circumstances, these two methods have been replaced by the capture of individual animals using diver-operated traps.

The capture of sea otters using divers was pioneered by biologists from the California Department of Fish & Game (CDFG) and was later adopted by the U.S. Fish & Wildlife Service and U.S. Geological Survey. The basic concept utilized an aluminum framed basket lined with netting to entrap an otter when a purse line was pulled. CDFG biologists Ken Wilson and Jack Ames developed the design for this trap, which today is known as the Wilson trap (Ames et al., 1986). In the early days, the trap was attached to the end of a long pole (typically a broomstick) and manually pushed through the water by a pair of divers. These divers utilized conventional SCUBA to swim this awkward trap through the dense kelp forest and occasionally had to “walk” the trap across the bottom. Once an otter was located, the two divers would simultaneously steer and push the trap up under the resting otter. This method proved to be effective (80-90 otters were caught this way) but inefficient as it required a tremendous amount of effort (Sanders and Wendell, 1991). The divers or their bubbles were easily spotted or smelled by the otters, resulting in many failed capture attempts.

A number of great improvements were made to the original design, the first of which was to replace the broomstick with a diver propulsion vehicle (scooter) to push the trap and pull the diver through the water. Not only did the scooter technique make moving the trap much easier, but it allowed for both divers to carry a trap and scooter, potentially doubling the catch on every dive. The use of scooters also allowed divers to travel faster and cover much greater distances, which meant that dives could be started further away, reducing the chances of the boat spooking the otters. Scooters were a great improvement over the push pole technique; however, the exhaust bubbles from using conventional SCUBA still regularly alerted otters to the presences of divers below them. In 1988, sea otter capture divers sought to solve the bubble problem by using closed-circuit oxygen rebreathers. The effectiveness and efficiency of otter captures increased dramatically when rebreathers were used in combination with the scooters and Wilson traps.

The diving techniques for capturing sea otters are constantly evolving and being honed. In recent years, divers have further increased their success by wearing a handheld marine radio in a custom built pocket on their hood. The radio is packed in a vacuum-sealed bag to keep it dry. The addition of
a radio allows the diver to receive directions and critical information from a boat driver or shore spotter when the diver is at the surface. The divers can only receive transmissions and not respond, but there is little need for a response. The addition of the “radio heads” allows the boat/spotter crew to keep the diver abreast of changes in the status of the target animals and give them new headings or course changes. This information is often critical to a successful capture dive.

The most recent equipment addition is the use of radio telemetry to locate divers. Though telemetry has been used to locate otters for decades, we have only recently realized that this could be a useful tool for signaling that a capture diver is at the surface. In poor sea conditions (large swell, intense sun glare), or dense *Nereocystis luetkeana* kelp beds, it becomes very difficult for the boat crew to spot a diver’s head at the surface. When the diver is at the surface, they are waiting for course correction information and target status information from the boat crew. By wearing a small radio transmitter on the hood or mask strap, a boat equipped with a radio receiver and antenna will immediately be alerted that a diver is at the surface. The crew can then give information to the diver even if they can’t see him/her. Wearing a radio transmitter isn’t always necessary, but it can be extremely helpful in less than ideal weather conditions. Capture divers have also recently started using custom made hoods that are solid black, feature a sewn neoprene radio pocket over the ear, and have a fluorescent yellow panel on the back of the head. Since divers are almost always facing the otter, the yellow panel on the back of the head faces the boat, which greatly improves the boat crew’s ability to spot a diver at the surface and provide directions.

**Methods**

**The Dive Team**

In California there are a total of six sea otter captures divers: three from the U.S. Geological Survey, two from the California Department of Fish & Game, and one from the University of California Santa Cruz. In Alaska, the U.S. Geological Survey has a total of three sea otter capture divers. Great efforts have been made to standardize training and equipment configurations in order to operate as a cohesive unit. Only divers that had a great deal of experience on open-circuit SCUBA, and demonstrated exceptional skill in the water, were selected to receive training as a sea otter capture diver. All divers received advanced rebreather training in the classroom, pool, and ocean, and exceeded the training requirements set forth by their respective institutions and AAUS.

**Equipment**

Capturing sea otters is a clandestine operation. If an otter is alerted to the presence of a diver, they will quickly depart, often disturbing other otters in the vicinity and making their capture impossible. Therefore, sea otter capture divers have abandoned the use of traditional SCUBA equipment in favor of closed-circuit oxygen rebreathers. The “bubble-less” nature of closed-circuit rebreathers allows the divers to position themselves directly underneath otters without being detected, even getting within inches of them if desired. The ability to remain undetected while swimming below the otters allows the dive team to carefully assess the group and selectively capture individual target otters if necessary. Since sea otters rest at the surface, typical dive profiles for capture dives are very shallow (<7m, and typically in the 2-3m range). Sea otter capture divers have no need for any complicated gas mixing, so the team uses simple 100% oxygen rebreathers, which minimizes nitrogen-related risks. Utilizing pure oxygen does bring up other potential problems (mainly oxygen toxicity), but keeping careful track of depth and total oxygen time helps avoid these issues. Embolism is always a concern when breathing compressed gasses, but capture divers are careful to exhale during ascents to minimize such risks. Sanders and Wendell (1991) outlined the risks and precautions associated with using closed-circuit oxygen rebreathers.
Unlike most recreational oxygen rebreathers, the military grade units used by sea otter capture divers are fully closed circuit rebreathers and do not release gas on ascent. In 2009 most of the capture team replaced their older Draeger LAR V or COBRA rebreathers with the Aqualung FROGS (Full Range Oxygen Gas System) rebreather. This compact oxygen rebreather is only available to the government or military and has been in use by the French Navy since 2002. The FROGS rebreather features multiple water traps, diver adjustable breathing resistance, a bypass system that allows the diver to breathe even with a second stage failure or flooded unit, easy maintenance, and tool-free assembly and disassembly. The FROGS unit is also very sleek, streamline, and one of the most compact rebreather units on the market. This unit was originally designed to be chest mounted, but when mated with the Aqualung Combat Swimmer Assault Vest (CSAV) or backplate buoyancy compensator, can be worn on the back. The CSAV functions as a buoyancy compensator and has its own gas supply (two 1.5 ft³ cylinders) if desired, as well as fully ditch-able weight integration.

A few researchers are still diving Carleton COBRAs (Closed Circuit Oxygen Breathing Apparatus), an older but reliable closed circuit oxygen rebreather. The COBRA rebreather was based on an even older design, the CCR-25, originally manufactured by Biomarine Inc. This is a back mounted unit and even today is considered to be one of the easiest breathing and most comfortable oxygen rebreathers that our dive team has used.

Each member of the dive team uses either Oceanic Mako or Tekna scooters that have been modified for otter captures. The nose cone of the scooter has been fitted with a custom machined metal post where the Wilson trap can be attached to the scooter. Since the original design of the scooter was intended simply to pull a diver through the water and not to push and steer a heavy trap, there was some skepticism as to how well the scooter would perform this advanced duty. We were surprised to learn that the Makos and Teknas performed well, even at factory settings. Adding a trap to the front greatly reduced speed and maneuverability, but the scooters still handled the additional load. In recent years, we have made more custom modifications to these scooters including: high power motors, clutch upgrades, and battery upgrades to provide the divers with more speed and power. We also use prop guards on the scooter shroud to keep the propeller free from entanglement when navigating a dense kelp forest.

Every diver on the capture team now wears custom DUI Combat Diver drysuits, which are modified CLX suits only made available to the military and government. The combat diver suit features multiple cordura and kevlar overlays that make the suit extremely robust and durable. The added durability is a necessity for capture work as divers often get off on wash rocks or beaches and sometimes need to hike to scout for animals to avoid spooking them. Some divers have moved the suit inflation valve from the chest to the upper thigh. This location is beneficial when wearing a chest mount rebreather, but also allows the diver to wear a small inflation cylinder on the thigh, solving cylinder attachment and hose routing problems. The drysuits, as well as the rebreathers, scooters, and traps, are all black with no bright colors or reflective material. This helps the divers go undetected both underwater and at the surface. Pockets and accessories are customized for each individual diver, though several have a bellows pocket on the right thigh, and an inflation bottle pocket on the left thigh. U.S. Geological Survey divers are using Aqualung D.S.I.S. (Drysuit Inflation System) cylinders that provide 5ft³ of gas for offsetting drysuit squeeze, or as a redundant source of providing positive buoyancy.

Sea otter capture divers use a gauge console that is trap-mounted so that it is in the direct line of site when the diver is navigating to the target otter. The console consists of a compass and depth gauge, which are monitored continuously to ensure that proper headings and depth restrictions are maintained. Many divers also wear dive computers, some of which (Suunto Vyper 2 or Vytec) are capable of logging total O₂ saturation for continuous diving. The previously mentioned “radio head”
Hoods worn by capture divers are additionally customized by including a single fluorescent yellow panel on the back of the otherwise black hood, which helps the boat crew spot a diver at the surface. For safety purposes, divers carry surface signaling devices, whistles or air horns, and a cutting tool.

Capture diving is done from a variety of vessels, but the boats are carefully selected and modified for stealth and functionality. The vessels are usually fiberglass boats in the 16-20ft range but frequently inflatables and RIBs are used as well. Regardless of the boat type, it must have a low profile, preferably be a muted color (i.e. navy gray), reflective surfaces must be taped over, and the motor should be a four-stroke outboard (lower smell and noise signature than two stroke motors). Virtually silent electric trolling motors can even be used when extreme stealth is required. Each of these requirements aid in the ability to covertly move into a position to begin the dive.

**Sea Otter Capture Techniques**

In order to catch a sea otter, researchers must first formulate a plan and locate target animals. In areas where otters are very skittish, we often employ the use of shore spotters, who can locate animals from great distances away by reaching an elevated observation point and utilizing high powered spotting scopes that are capable of magnifying 80x. The approximate location of the target otters are relayed to a boat crew. With the targets’ location known, the boat is kept a good distance away (often 1 km or more) until the divers can visually locate the target animals using binoculars. Once a visual is obtained, the boat silently and slowly closes the distance to the otters. The targets are always approached from downwind, and whenever possible, an approach is made that places the shoreline, rocks, or some natural feature behind the boat, making the outline of the boat less likely to stand out than if the otters were approached from offshore with a clean horizon. The minimum acceptable distance to the otters depends on their level or alertness. In Monterey, California, where otters are conditioned to constant boat activity, the boat might be able to get within 300m of the target animals. However, in remote locations like Big Sur, California, or certain areas of Alaska, 500 or 600m might be the minimum distance before the otters spook. In extreme cases, a minimum distance of 800m to 1km might be required.

Once an appropriate distance is reached, the motor is shut down and the boat is secured if possible. If the boat is in a kelp bed, tying the bow line to kelp is the preferred method for securing the boat since it is silent and can be undone quickly by the boat tender. When no surface kelp is present, the anchor may be deployed, which is more likely to spook the otters and may also result in the boating taking longer to get to the divers if a problem were to occur. In some cases, such as in the narrow fjords of Alaska, the bottom is too deep to anchor and the team must make live boat drops over open water. This is a situation where a very skilled boat operator is critical to the success of the mission.

With the boat secured, the targets are observed using binoculars. The team attempts to assess the activity level of the group, and the relative positions of target and non-target animals within the group. It is important that the target and surrounding otters be resting, with their heads above the surface, so they are unlikely to hear or see approaching divers. The dive is declared a “go” once it is decided that the targets are resting or in a state of inactivity. At this point, a buddy team of two divers gear up and “go on oxygen.” This involves donning the rebreather, fully purging the breathing loop of CO₂, and beginning to breathe oxygen. The buddy team always consists of a “lead diver,” that navigates to the target otter(s), and a “follow/trailing diver.” Both divers in the buddy team are equipped with Wilson traps so that a double capture can be made if the opportunity presents itself. The lead diver takes a compass bearing from the boat to the target otter and quietly enters the water. The dive team meets beneath the boat and begins to move in the direction of the target by swimming the proper heading. Ideally, the trailing diver falls into formation alongside, and slightly behind the lead diver, which allows the lead diver to see their buddy in their peripheral vision while maintaining focus on the trap mounted compass. In poor visibility, the two divers will be nearly shoulder to
shoulder. The underwater kelp forest represents a maze of tangled obstacles which means course deviations and corrections are constantly being made as needed. The depth of the dive depends on thickness of the kelp canopy. As a rule, because the dives are on 100% oxygen, divers never descend below 7m (20ft). In practice, the dive depth usually ranges between 2-3m. Throughout the dive, the lead diver will periodically surface to confirm that they are on the correct course. While at the surface, the diver can receive instructions (via the radio in their hood) on the status of the target(s) and course correction information from the boat crew. The number of “head checks” will vary based on the distance to the otters and the activity level of the target animals. During surface checks, the trailing diver follows the lead diver towards the surface, but hangs just below the surface. Head checks are a critical time when the otters might spot the diver, so one head at the surface is stealthier than two. The lead diver spends only enough time at the surface to get information from the boat crew, or to visually locate the targets.

Depending on visibility, the final head check may be made anywhere from 10 to 30m away from the targets. After the final head check, the dive team begins to make preparations for a capture by “shaking out” any trapped bubbles, securing loose gear, adjusting the speed on their scooters, and spreading out to increase the chances of spotting the otters from below. Once the otters are located, the divers move into position below them, identify which ones they are targeting, orient their traps and scooters vertically, and then ascend quickly, while exhaling, using the scooters to power upwards in the water column. Synchrony between the two divers is critical for timing a double capture. During the ascent, the divers are exhaling the entire way. The depth from which the final ascent starts varies depending on the speed needed to break through the kelp canopy. When otters rest in open water, the ascent might start with the trap rim only 1 of 2ft below the otter. The rim of the trap breaks the surface and envelopes the otter. The immediate flight response of a sea otter is to dive, which actually aides in getting the otter deep into the net of the Wilson trap. A drawstring cord is quickly cinched and tied off to a cleat on the trap. With the otter(s) secured, divers attain positive buoyancy by inflating their drysuits and/or buoyancy compensators. The trap is easily held at the surface with the otter inside. In cases where a particularly large or strong animal wants to dive, the divers can combat this by activating the scooter and keeping the otter at the surface. If the trap and otter is still too heavy, there is a buoyancy balloon with a CO₂ canister mounted on either the trap or the scooter that can be activated to provide additional buoyant force. A hand signal is given to the boat crew to pick up the divers and captured otters.

The otters are transferred from the Wilson traps to specially designed sea otter transport boxes on the capture boat, and then either brought ashore to a mobile veterinary lab or to a large vessel that serves as a mobile vet lab. Under the direction of the chief veterinarian, anesthesia and the sampling and instrumenting process can then begin.

**Discussion**

The California Department of Fish & Game, U.S. Geological Survey, and U.S. Fish & Wildlife Service have been using divers to catch otters for nearly 30 years. Over this time period, the equipment and techniques have continually evolved to take advantage of new technology that has greatly improved our effectiveness and efficiency. The techniques described here allow researchers to selectively target individual animals while also minimizing the risk of injury to both the sea otters and the divers. The selective nature of this capture technique is most beneficial when trying to re-capture an animal in order to retrieve previously implanted instruments. Time-depth recorders could hold a full year’s worth of dive data, but is only useful if that specific animal can be recaptured and the TDR retrieved. Selective recapture also allows us to replace VHF transmitters once their batteries die, so that a study animal can continue to be monitored. Though the methods described here are highly
specialized for sea otter capture, portions of these diving techniques might be adopted for the covert capture of other marine animals (i.e. marine birds) that remain at the surface for a significant amount of time.

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