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Study on diving behavior of sperm whales using suction cup attached TDR tag: an overview

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Studies on diving behavior of marine mammals using data loggers including time depth recorders (TDR) are becoming popular these days. However, cetaceans, which do not come up to the land, have a difficulty in capturing the animal to attach these equipments. This has hindered wide usage of data loggers. Development of the method using suction cup to deploy the tag with data logger directly to swimming animals solved the problem accompanied with capture. We have applied this method to sperm whales off Japan. Sperm whales are thought to have a greatest diving ability among cetaceans but almost nothing is known about their diving behavior. We successfully deployed suction cup attached TDR tags to six whales off the Kumano Coast and the Ogasawara Islands without any intense reactions of the whales. All tags were recovered after they fell off using radio telemetry, and we obtained 1, 9, 13, 14, 17, and 62 hours of diving data. This method proved to be really feasible for studying diving behavior of sperm whales.

Key words: sperm whale, *Physeter macrocephalus*, diving behavior, suction cup attached TDR tag

INTRODUCTION

Recently, many scientists have worked with free ranging cetaceans; whales, dolphins, and porpoises, to study their behavior. However, we can only observe behavior of cetaceans when they stay at near the surface, and we do not know how they behave in the deep water where quite a little part of their life exists. Ecological aspects such as movement, habitat use, or home range of cetaceans have also been studied two-dimensionally, although their habitat is three-dimensional. In order to observe cetaceans' behavior in the water and know their three-dimensional ranging, researchers have to depend on various equipments, including acoustic transponders and data loggers, which are attached to the body of the animals and go down to the depth with them. Acoustic transponder tags are required to monitor the tag's acoustic response to follow the animal's movement, while data loggers, such as time depth recorders (TDRs) record some measurements of behavior and store them in the memory of the logger. The data are retrieved after the logger is recovered (VHF tag) or transmitted via satellite (satellite tag). Although the latter has no need to recover, it can transmit only a limited amount of data and requires additional power, which makes the tag large. On the other hand, the VHF tag has the advantages of recording fine scale and long term data.

Typical method to attach these tags to an animal is capturing the animal, piercing the dorsal fin or dorsal ridge, and attaching the tag with bolts and nuts or wire. The largest problem of this method is that capture of wild cetacean is not easy. It needs a great amount of logistic costs and manpower, and gives considerable stress to the animal. Further, it is practically impossible to capture large whales. To avoid capture procedure, two types of remotely deployment method were developed. One is the penetrating tag having arrow head(s) that penetrates the skin and anchors in the blubber when the tag is shot off by crossbow or air gun and hits the animals' body. This method still hurts the target animal and may change the normal behavior, and thus may not be regarded as an ethical method by other scientists or people concerning animal welfare.

A non-invasive method, using suction cup to deploy the tag, was developed by Jeff Goodyear in 1981. This method have been applied by many scientists and provided many results on diving behavior of various cetacean species including killer whale, *Orcinus orca* (Baird 1994), short-finned pilot whale, *Globicephala macrorhynchus* (M. Amano and R. W. Baird unpublished), long-finned pilot whale, *G. melas* (Baird et al. 2002), false killer whale, *Pseudorca crassidens* (R. W. Baird and A. D. Ligon, unpublished), pantropical spotted dolphin, *Stenella attenuata*, (Baird et al. 2001), bottlenose dolphins, *Tursiops* spp., (Schneider et al. 1998, M. Amano unpublished), Dall's porpoise, *Phocoenoides dalli* (Hanson and Baird 1998), harbor porpoise, *Phocoena phocoena* (M. B. Hanson unpublished), northern bottlenose whale, *Hyperoodon ampullatus* (Hooker and Baird 1999), fin whale, *Balaenoptera physalus* (Panigada et al. 1999), and humpback whale, *Megaptera novaeangliae* (R. W. Baird unpublished). Here, we review this method and the project applying the suction cup attached TDR tag to sperm whales *Physeter mecrocephalus* in Japanese waters.

DIVING BEHAVIOR OF SPERM WHALES AND UNANSWERED QUESTIONS

The Sperm whale is the largest odontocete species (up to 18 m in adult males and 11 m in females) and occurs in all oceans in the world. Sperm whales generally prefer deep open ocean habitats and they are thought to be one of the deepest mammalian divers. Large whales may dive deeper than 2000 m. Many scientists have been interested in this great diver and investigated their diving behavior with various techniques. Sperm whales entangled with the deep sea cables that set at the deepest depth of 1135 m were the earliest records that suggest their diving depth (Heezen 1957). Active sonars were used in several studies (Lockeyer 1977, Mano 1986, 1990). Lockyer (1977) found that a large whale reached 1100 m, but most of dives were shallower than 400 m using sonar of whaling boat off South Africa. Using similar methods, Mano (1986) found that sperm whales dive down to 600–700 m off Japan. Since these diving patterns were obtained during chasing by whaling boats, the condition must have affected the whales' behavior. A more detailed diving profiles of whales were obtained with the acoustic transponder tag with a penetrating head off Dominica in the Caribbean (Watkins et al. 1993, 2002). One whale made 93 deep dives ranged 420–1330 m with a mean of 990 m during 4.6 days (Watkins et al. 2002).

There are deeper and unreliable records obtained by passive acoustic methods include 1827 m (Rice 1978) and 2250 m (Norris and Harvey 1972). Moreover, a depth of 3195 m was suggested from the distributional depth of sharks found in the stomach contents (Clarke 1976). However, it is still unknown whether sperm whales dive down to as deep as 2000 or 3000 m.

Sperm whales feed on large mesopelagic squids as a primary prey in almost all ocean and their deep dives are supposed to be for foraging (Rice 1989). However, how sperm whales find and catch their prey in the dark deep water remains unknown. They may swim randomly with mouth open and use tactile sense to find prey (Rice 1989). Random swimming may make the stimulated bioluminescent organisms flash around the whale and this light may attract the prey (Fristrup and Harbison 2002). Sit-and-wait strategy was also suggested (Beale 1839). Whale's white lip that may glimmer in the dim light or by bioluminescent mucus from squids were suggested to attract squids (Gaskin 1967). Active search using echolocation is a more accepted hypothesis. However, some scientists believe that echolocation is not efficient to detect squids whose density is close to sea water and insist that whales depend on vision to a higher degree than that we suppose. Sperm whales could see the actively bioluminescent prey and silhouette of prey against a little lighter surface or that among passive bioluminescent organisms (Fristrup and Harbison 2002). Since it should be very difficult to observe sperm whales feeding, direct measurements of some behavioral parameters using data logger are awaited in order to test these hypotheses.

Sperm whales are highly social animals having the largest brain among any organisms. Many odontocetes are known to forage in cooperation with other members of the group. When foraging, sperm whales in a group are reported to swim parallel with each other spreading over 1 km or more (Whitehead 1989). This may suggest some kind of cooperation in searching for the prey. Another interesting behavior is babysitting. Young calves are unable to dive deep and stay at the surface with other members of the group when their mothers dive to forage. These caregiving whales are thought to attend a calf by turns so that themselves can forage (Whitehead 1996). If we can monitor the behavior of more than one whale in a group by attaching the data loggers to them at once, we could know these communal behavior patterns in detail.

Prevailed but unproved hypothesis on diving ability of sperm whales is that this species uses a spermaceti organ, which occupies a most part of the huge head and contains spermaceti wax, for buoyancy control (Clarke 1978). Clarke (1978) suggested that sperm whales cool the spermaceti organ by sea water drawn into right nasal passage, which runs along the bottom of the organ to freeze the wax and increase its density when they dive. When they rise up, they heat the wax by warm blood vessels surrounding the organ and get buoyancy. With this mechanism, the whale is considered to be able to dive without much effort. The opposed view is that the spermaceti organ functions as an acoustic reverberation chamber to emit burst-pulsed sound (Norris and Harvey 1972, Cranford et al. 1996). If we can monitor the movement of tail fluke during the dive by some kind of data logger, we could know whether the whale actively propels to dive or passively sinks by negative buoyancy.

SUCTION CUP ATTACHED TDR TAG

The suction cup tag we use is the similar that developed by Robin Baird for his study on killer whales (Fig. 1, Baird 1994). A rubber suction cup for automobile roof rack (about 8 cm in diameter, Canadian Tire) is known to work well for this purpose. The suction cup is attached to the tag body, which was made of pressure resistant synthetic foam, with a plastic tube. A TDR and a VHF transmitter are fixed

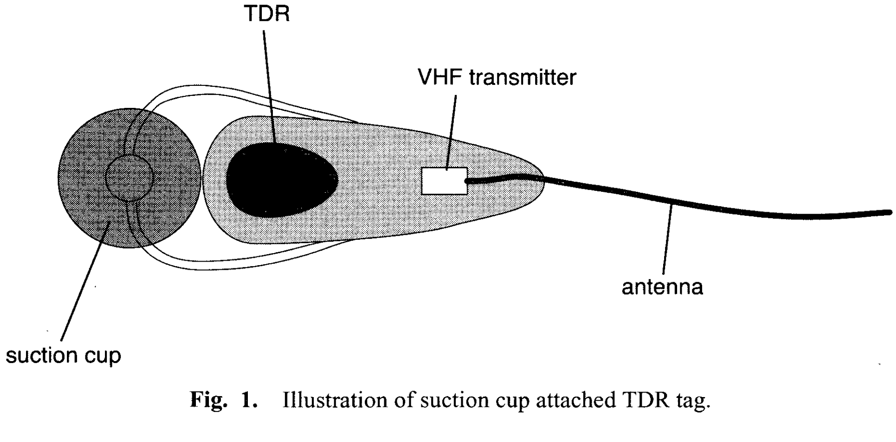

Fig. 1. Illustration of suction cup attached TDR tag.

on it. We use two types of TDR; one is the Mk6 of the Wildlife Computers (Redmond, WA, USA) and the other is W2000L-PDT of the Little Leonard Co. (Tokyo, Japan). Both TDRs can measure the depth, swimming velocity as rotation counts of a turbine, and temperature and store the data in the memory. The VHF transmitter is used for locating the tag to recover.

The tag is remotely deployed using a crossbow to the species that does not come close to the boat or a pole to those bowride or can be easily approached. The tagged animal is usually followed to observe its behavior after the tag deployment and to ensure recovery of the tag falling off during the observation. The tag falls off after a certain time. Some scientists create timed-release mechanisms on the suction cup using magnesium or gelatin, which dissolves in sea water and causes leaking of water into the cup to release. After falling off, the tag floats vertically so that the antenna stands upright. The tag is located following the radio from the VHF transmitter and recovered to download the data and reused.

As mentioned above, the largest merit of the suction cup tag is that the tag can be deployed remotely without capturing animals. Capture is costly and gives stress to the animal, which is hard to evaluate. When the tag is deployed remotely, we can compare the behavior of the target individual continuously before and after the tag deployment to evaluate its effect to the animal. The tag falls off from the animal's body in a relatively short time, usually 10–20 hours depending mainly on the activity of the animal. We can recover the tag and deployed it to the different animal shortly. This can save the cost to prepare a number of expensive tags in each deployment, which is the case when we use unrecoverable tags such as satellite tags. This tag also has a secondary advantage. The tag usually falls off from the body with a small piece of skin adhering to the inside of the cup. We can extract DNA from this skin sample and know sex and other genetic information of the tagged animal.

The suction cup tag also has demerits. The most important is that we have to approach the animal as close as 5–10 meters, in the range of crossbow. It depends on the tolerance of the target animal to the research boat, which varies between species and behavior patterns. The suction cup often bounces off when it does not hit the animal's body at right angle. Shooting the swimming animal from the boat requires much technique and also luck. The attachment by suction cup is not secure, thus deployment longer than a few days cannot be expected and long term movement or migration is not trackable. However, numbers of short period data on different individuals are sometimes more useful than long period data on a small number of individuals. The largest and inevitable risk is the loss of the tag with invaluable data. This possibility is relatively small for the resident species ranging in coastal waters and large for migratory offshore species.

TAGGING ATTEMPT

The tag deployments to sperm whales were carried out in two fields; off the Kumano Coast, Wakayama Prefecture and off the Chichijima Island of the Ogasawara (Bonin) Islands. Sperm whales migrate off the Kumano Coast in summer. These whales are not resident in the area and occasionally disappear for a few days to weeks (Takahashi 2001). Whales are usually found out of the steep continental slope where deeper than 1000 m. Contrary, sperm whales off the Chichijima Island occurs year round and most of them may be resident. Their main habitat is also located in waters deeper than 1000 m with intricate topography. In the both fields, photo-identification study has been carried out and more than 200 whales have been catalogued so far.

Two whales were successfully tagged off Kumano Coast in June 2000 and May 2002, and four off the Chichijima Island in October 2001 and 2002, and we obtained diving profiles of 1 to 62 hours.

Sperm whales were relatively easy to approach. However, a fast approaching speed tended to cause avoidance behavior, which made it hard to get into the shooting range of the crossbow. Approaching very slowly or stop-and-waiting for the whale coming close was more efficient. The best attachment position is around the lateral side just below and anterior to the dorsal fin, where rises up high from the surface when the whale is at the surface and it allows longer period to find the direction of the whale by the VHF radio. Although the surface of the sperm whale posterior to the head is irregularly wrinkled, it does not seem to hinder the suction cup attachment. Because of the large body size and slow movement, deployment to sperm whales is not very difficult.

Although all whales showed a reaction when the tag hit the body from twitching the body to spy hopping, they are neither intense nor violent. Behavior of the whales did not change before and after the tag deployment and was not different from that of other whales in the group. Therefore, influence of the tag deployment is thought to be negligible.

The tag remained attached to the whales for 1, 9, 13, 14, 17, and 62 hours. The 62 hours attachment of a Kumano Coast whale is the extraordinarily long record for the suction cup tag. It made difficult to recover the tag. We were not able to find the tag by thorough survey from the boat and land, and finally located it from the air at 80 miles away from where we tagged. On the other hand, tags were able to be detected from the boat and recovered without much effort in Ogasawara waters, though we left the whales with tag at the sunset and started searching for the detached tag next morning.

CONCLUSIONS

Almost nothing is known about underwater behavior of sperm whales and there are untested hypotheses about it. Since we cannot dive with whales to observe their behavior, data loggers, which are attached to the animal's body and record its behavioral parameters, show us indirectly their behavior in the water. The problem of attachment to the species whose capture is impossible has been resolved by using suction cup to attach the data logger. Successful deployments in the current project indicates that the remotely-deployed suction cup tag is a simple but very useful tool in investigating sperm whale's behavior in the great depth where is completely out of our sight.

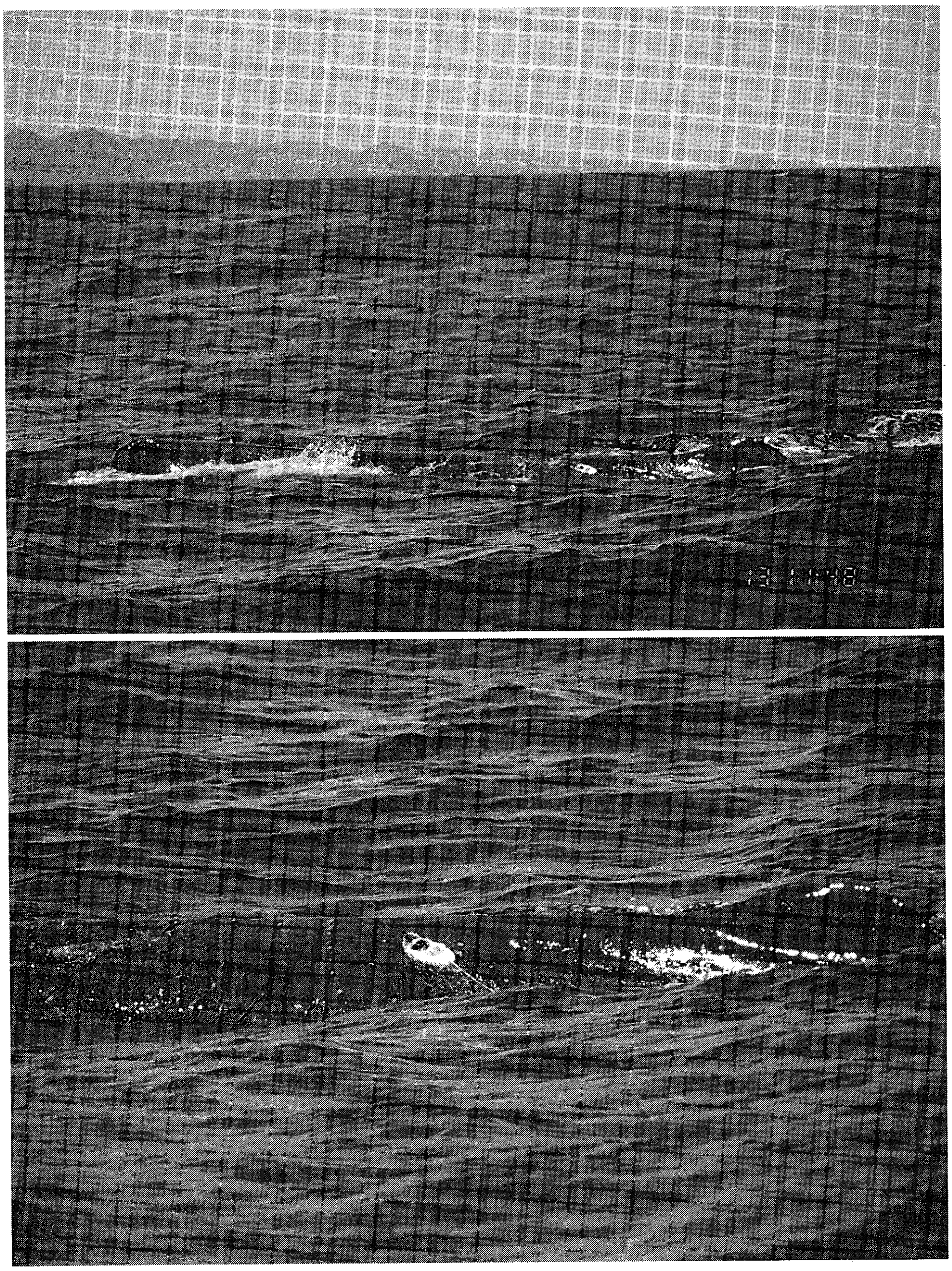

Fig. 2. A sperm whale with suction cup attached tag off the Chichijima Island, Ogasawara, October 2001 (photo by K. Mori).

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LITERATURE CITED

Baird, R. W. 1994. Foraging behaviour and ecology of transient killer whales (*Orcinus orca*). Ph. D. Thesis, Simon Fraser University, Burnaby, British Columbia, Canada.

Baird, R. W., Ligon, A. D., Hooker, S. K., and Gorgone, A. M. 2001. Subsurface and nighttime behaviour of pantropical spotted dolphins in Hawai'i. Can. J. Zool. 79: 988–996.

Baird, R. W., Borsani, J. F., Hanson, M. B. and Tyack, P. L. 2002. Diving and night-time behaviour of long-finned pilot whales in the Ligurian Sea. Mar. Ecol. Prog. Ser. 237: 301–305.

Beale, T. 1839. The natural history of the sperm whale. John Van Voorst, London.

Clarke, M. R. 1976. Observation on sperm whale diving. J. Mar. Biol. Ass. U.K. 56: 809–810.

Clarke, M. R. 1978. Buoyancy control as a function of the spermaceti organ in the sperm whale. J. Mar. Biol. Ass. U.K. 58: 27–71.

Cranford, T. W., Amundin, M. and Norris, K. S. 1996. Functional morphology and homology in the odontocete nasal complex: implications for sound generation. J. Morphol. 228: 223–285.

Fristrup, K. M. and Harbison, G. R. 2002. How do sperm whales catch squids? Mar. Mamm. Sci. 18: 42–54.

Gaskin, D. E. 1967. Luminescence in a squid *Moroteuthis* sp. (probably *ingens* Smith) and a possible feeding mechanism in the sperm whale *Physeter catodon* L. Tuatara 15: 86–88.

Hanson, M. B. and Baird, R. W. 1998. Dall's porpoise reactions to tagging attempts using a remotely-deployed suction cup tag. Mar. Tech. Soc. J. 32: 18–23.

Heezen, B. C. 1957. Whales entangled in deep sea cables. Deep-Sea Res. 4: 105–115.

Hooker, S. K. and Baird, R. W. 1999. Deep-diving behaviour of the northern bottlenose whale, *Hyperoodon ampulatus* (Cetacea: Ziphiidae). Proc. Royal Soc. London, Ser. B. 266: 671–676.

Lockyer, C. 1977. Observations on diving behavior of the sperm whale *Physeter catodon*. *In* A voyage of discovery (M. Angel ed.), pp. 591–601, Pergamon Press, Oxford and New York.

Mano, S. 1986. The behavior of sperm whales in schools observed from an operating whaler. Bull. Fac. Fish. Nagasaki University 60: 1–31.

Mano, S. 1990. Analysis of diving behaviour of sperm whale *Physeter catodon*. Nippon Suisan Gakkaishi 56: 179–187.

Norris, K. S. and Harvey, G. W. 1972. A theory for the function of the spermaceti organ of the sperm whale (*Physeter catodon* L.). NASA Special Publications 262: 397–417.

Panigada, S., Zanardelli, M., Canese, S. and Jahoda, M. 1999. How deep can baleen whales dive? Mar. Ecol. Prog. Ser. 187: 309–311.

Rice, D. W. 1978. Sperm whales. *In* Marine mammals of eastern North Pacific and Arctic waters (D. Haley ed.), pp. 82–87, Pacific Search Press, Seattle.

Rice, D. W. 1989. Sperm whale *Physeter macrocephalus* Linnaeus, 1758. *In* Handbook of marine mammals vol. 4, river dolphins and the larger toothed whales (S. H. Ridgway and R. Harrison eds.), pp. 177–233, Academic Press, San Diego.

Schneider, K., Baird, R. W., Dawson, S., Visser, I. and Childerhouse, S. 1998. Reactions of bottlenose dolphins to tagging attempts using a remotely-deployed suction cup tag. Mar. Mamm. Sci. 14: 316–324.

Takahashi, I. 2001. Relationship between occurrence of sperm whale and oceanographic conditions in Kumano Sea, Japan. Master thesis, Mie University. 44pp.

Watkins, W. A., Daher, M. A., Fristrup, K. M., Howald, T. J. and Notarbartolo de Sciara, G. 1993. Sperm whales tagged with transponders and tracked underwater by sonar. Mar. Mamm. Sci. 9: 55–67.

Watkins, W. A., Daher, M. A., DiMarzio, N. A., Samuels, A., Wartzok, D., Fristrup, K. M., Howey, P., W. and Maiefski, R. R. 2002. Sperm whale dives tracked by radio tag telemetry. Mar. Mamm. Sci. 18: 55–68.

Whitehead H. 1989. Formations of foraging sperm whales, *Physeter macrocephalus*, off the Galapagos Islands. Can. J. Zool. 67: 2131–2139.

Whitehead H. 1996. Babysitting, dive synchrony, and indications of alloparental care in sperm whales. Behav. Ecol. Sociobiol. 38: 237–244.