Whale sound recording technology as a tool for assessing the effects of boat noise in a Brazilian marine park

COURTESY OF RENATA SOUSA-LIMA

Using passive acoustic technology, researchers record the movements of whales, assess the impacts of noise from boat tours, and help refine tourism management

By Renata S. Sousa-Lima and Christopher W. Clark

Editor's Note: You can hear whale song recordings and see a brief video clip showing the movements of two whales before, during, and after exposure to tourism boat noise, both products of this study, on the *Park Science* Web site (http://www.nature.nps.gov/ParkScience/index.cfm?ArticleID=270).

Figure 1. A humpback whale (*Megaptera novaeangliae*) exposes its tail or fluke, a common occurrence while singing, in Abrolhos Marine National Park. Scientists use the unique black-and-white markings of the underside of the fluke to identify individuals. Brazilian Navy facilities are visible on Santa Bárbara Island in the background.

MALE HUMPBACK WHALES (*MEGAPTERA NOVAEANGLIAE*) (fig. 1) produce "songs"—long, patterned sequences of sounds—that are presumed to function as a reproductive display on the breeding grounds (Payne and McVay 1971; Winn and Winn 1978; Tyack 1981). Many preferred breeding areas are conservation hot spots protected by marine parks, and the whale-watching industry has flourished in those sites (Hoyt 2001). Noise generated from whale-watching boat traffic can mask important aspects of whale communication. This raises concerns about the potential influence of noise on reproductive success and population growth. Gray whales may temporarily or permanently abandon critical areas because of excessive exposure to boat noise (Bryant et al. 1984). Therefore, managers in parks created to protect and conserve whales are often faced with the task of managing noise-generating tourism activities, especially in breeding areas.

Because whales are acoustic specialists (Richardson et al. 1995), investigations can rely on listening to understand their social system. Recent advances in passive acoustic technology allow researchers to follow the movements of whales by locating and tracking vocalizing individuals. By continuously sampling and simultaneously following multiple whales, investigators can describe the movements of cohorts of individuals. By comparing whale tracks with the tracks and acoustic characteristics of human activities, investigators can measure whale responses to human-caused disturbance, such as an approaching vessel.

In this study, we used passive acoustic technology to evaluate the effects of boat traffic on the spatial-acoustic behavior of vocally active male humpback whales in the Abrolhos Marine National Park, Brazil (fig. 2); this park is situated in the main humpback whale breeding grounds in the southwestern Atlantic Ocean (Engel 1996). Our specific objectives were (1) to determine the types of singer responses to an approaching boat, and (2) to identify the "distance of disturbance"—the distances to which avoidance (i.e., movement away from boat) and behavioral disruption (i.e., cessation of singing) are observed.

Methods

We deployed an array of four "pop-ups" (fig. 3) programmed to record continuously from 5 July to 4 October 2005 inside the area of the Abrolhos Marine National Park in the northeastern part of the Abrolhos Bank (16°40'–19°30'S). The whale sounds were detected and located in the recordings using the software XBAT (http://www.xbat.org) written in MATLAB (the MathWorks computing language and interactive environment). We assigned each located whale sound to a particular individual singer based on (1) the unique repetition pattern of the sounds within the humpback whale song and (2) the location of the sound in relation to other located singers. We consolidated all located sounds from the same singer within 90 seconds into a single median point location and interpolated the sequences of such locations to yield an acoustic track using a custom programming routine (ISRAT_LT 1.3.2, Urazghildiiev unpublished) also written in MATLAB.

We gave Global Positioning System (GPS) units to tourism boats before they visited the park, and generated boat tracks from the GPS locations in ISRAT_LT 1.3.2. We used tracks of whales and boats to measure speed and boat-whale distances. We analyzed the spatiotemporal patterns of the movements of singers and boats to determine the orientation of each singer's movement in relation to a boat's movement. Possible orientations included away, toward, and neutral movement; neutral movement indicated that the boat track was parallel to the whale track after the closest point of approach between whale and boat.

We defined treatment periods (pre-exposure, exposure, and post-exposure) for each singer based on the distances between singer and vessel. Pre-exposure was defined as the period before the closest point of approach between whale and boat during which distances were greater than 4.0 kilometers (2.5 mi). The period considered "exposure" occurred while the distances between whale and boat were less than 4.0 kilometers, which is a documented mean for whale-boat distance shown to have caused bowhead and humpback whales to respond to vessels (Richardson et al. 1985; Baker and Herman 1989). Post-exposure was

Figure 2. Investigators used passive acoustic technology to document and analyze the effects of boat traffic on the spatial-acoustic behavior of vocally active male humpback whales in Abrolhos National Marine Park. The polygons in the inset image define the park area.

COURTESY OF RENATA SOUSA-LIMA

Figure 3. "Pop-ups"—marine autonomous recording units developed by the Bioacoustics Research Program at Cornell University—are ready to be deployed at sea.

defined as the period after the closest point of approach between whale and boat during which distances were greater than 4.0 kilometers.

Noise generated from whale-watching boat traffic can mask important aspects of whale communication. This raises concerns about the potential influence of noise on reproductive success and population growth.

Results

We analyzed four tracks of a single tourism boat and 11 acoustically tracked singers. Some singers moved away and stopped singing as the boat approached their location (four out of nine or 44.5%); others moved away but kept singing (five out of nine or 55.5%).

The predominant movement of singers relative to the boat's closest point of approach was "away" (77.8%). Six of the nine singers (66.7%) that moved away from the boat initiated movement before 4.0 kilometers (2.5 mi). The proportions of time devoted to movement away from, toward, and neutral to the boat were similar during pre-exposure. However, an increase in the proportion of time moving away occurred during the exposure, which continued to be disproportional during post-exposure (fig. 4). We identified two types of singer responses to the boat: (1) displacement followed by cessation of vocal activity (44.5%) and (2) displacement and continued vocal activity (55.5%). All located singers in the sampled area were displaced as the boat approached, and the ones that quit singing did not resume singing for at least 20 minutes.

Discussion

All whales moved from their original positions as the boat approached. Direct observations of singers being approached by boats in Abrolhos show that if they stopped singing, they invariably also left the area. Thus, we interpret cessation of singing as displacement.

Bejder et al. (2006) proposed that the individuals that are most sensitive to boat approaches would abandon preferred areas because of increased boat disturbance. Assuming this is true, only the individuals less sensitive to boat disturbances would remain in the area. The effect this selection for boat noise–habituated males could have on the population structure is unknown; it could affect

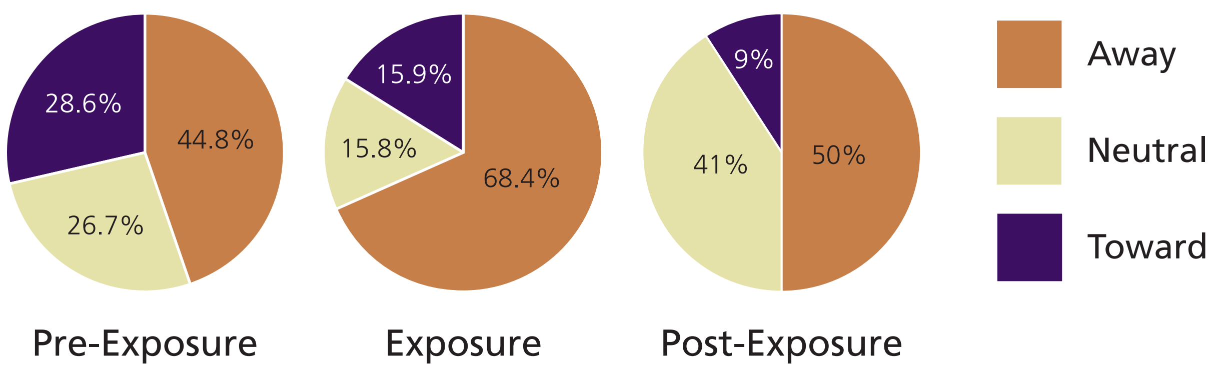

Figure 4. The pie graphs show the proportion of total time that the whales spent moving away from the boat (brown), neutral or not moving (beige), or moving toward the boat (purple) during each treatment period. Pre-exposure was defined as the period before the closest point of approach between whale and boat during which distances were greater than 4.0 kilometers (2.5 mi). The period considered "exposure" occurred while the distances between whale and boat were less than 4.0 kilometers. Post-exposure was defined as the period after the closest point of approach between whale and boat during which distances were greater than 4.0 kilometers.

Our results should aid park managers in directing resources to keep noise disturbance at low levels in the park, perhaps through expansion and enforcement of regulatory measures such as the use of quieter engines, speed regulation, and boat quantity limitation.

female choice and consequently the distribution of breeding success among the males of this population. A primary management concern is that whale habituation to boats could increase the probability of fatal encounters with vessels.

The majority of the singers (77.8%) moved away from the boat at the boat's closest point of approach, suggesting avoidance, although the most compelling evidence that singers avoid boats was the direction of their movement. Almost 70% of singer movement was away from the boat when the singer-boat distance was less than 4.0 kilometers (2.5 mi). Vessel-singer distance also affected swimming direction of humpbacks off Hawai'i (Frankel and Clark 1988) and Alaska (Baker and Herman 1989): Whales moved away from approaching vessels. In our study, during the post-exposure period, singers were still moving away from the boat, which suggests a residual avoidance of the disturbance area.

Baker and Herman (1989) have observed boat avoidance orientation in humpback whales out to 8.0 kilometers (5.0 mi). The majority of singers in our study responded by swimming away from the boat at distances greater than 4.0 kilometers (mean distance of approximately 7.5 kilometers [4.7 mi]). Other studies from boats and land-based platforms found that whales were disturbed at closer ranges (<300 meters [984 ft]) (Watkins 1986; Corkeron 1995; Sousa-Lima et al. 2002; Morete 2007). While this could be a reflection of smaller sampling areas or specific close-range analytical designs, it could also be a bias toward less sensitive whales.

We have shown that the use of an acoustic array provides the acoustic equivalent of a bird's-eye view into cetacean behavior and can be a cost-effective monitoring tool to evaluate marine animal responses to human disturbances. Our results should aid park managers in directing resources to keep noise disturbance at low levels in the park, perhaps through expansion and enforcement of regulatory measures such as the use of quieter engines, speed regulation, and boat quantity limitation.

Park managers can use passive acoustic technology in a variety of wildlife management scenarios. This technology will help document and monitor wildlife distributions and responses to human activities, especially in areas of low visibility, difficult access, at night, or underwater. The U.S. National Park Service has begun to use acoustic monitoring of protected areas (e.g., Glacier Bay National Park), and its use as a diagnostic and regulatory tool for park rangers and managers may increase as its benefits become known.

Acknowledgments

We thank Stephen Morreale, Milo Richmond, and John Hermanson for their suggestions; Lucas Goulart Collares, Bruna Mazoni Guerra, and the *Piloto* crew for field assistance; Eric Shannon, Michelle Mathios, Jessica Musa, Caitlin Armstrong, and Roman Lesko for data processing. The Instituto Baleia Jubarte and its sponsor Petroleo Brasileiro S.A. (Petrobras), Abrolhos tourism operators and boat owners, the Brazilian government (CAPES, BEX 1523-01-5), Cornell Laboratory of Ornithology, and the Canon National Parks Science Scholars Program provided funding and support.

References

Baker, C. S., and L. M. Herman. 1989. Behavioral responses of summering humpback whales to vessel traffic: Experimental and opportunistic observations. Final Report NPS-NR-TRS-89-01. U.S. Department of the Interior, National Park Service, Anchorage, Alaska, USA.

Bejder, L., A. Samuels, H. Whitehead, N. Gales, J. Mann, R. Connor, M. Heithaus, J. Watson-Capps, C. Flaherty, and M. Krutzen. 2006. Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance. Conservation Biology 20:1791–1798.

Bryant, P. J., C. M. Lafferty, and S. K. Lafferty. 1984. Reoccupation of Laguna Guerrero Negro, Baja California, Mexico, by gray whales. Pages 375–387 *in* M. L. Jones, S. L. Swartz, and S. Leartherwood, editors. The gray whale, *Eschrichtius robustus*. Academic Press, Orlando, Florida, USA.

Corkeron, P. J. 1995. Humpback whales (*Megaptera novaeangliae*) in Hervey Bay, Queensland: Behavior and responses to whale-watching vessels. Canadian Journal of Zoology 73:1290–1299.

Engel, M. H. 1996. Comportamento reprodutivo da baleia jubarte (*Megaptera novaeangliae*) em Abrolhos. Anais de Etologia 14:275–284.

Frankel, A. S., and C. W. Clark. 1988. Results of low-frequency playback of M-sequence noise to humpback whales, *Megaptera novaeangliae*, in Hawai'i. Canadian Journal of Zoology 76:521–535.

Hoyt, E. 2001. Whale watching 2001: Worldwide tourism numbers, expenditures and expanding socioeconomic benefits. International Fund for Animal Welfare, Yarmouth Port, Massachusetts, USA.

Morete, M. E. 2007. Caracterização temporal da estructura de grupos e do comportamento de baleias jubarte (*Megaptera novaeangliae*) na área de reprodução dos Abrolhos (Bahia, Brasil). Dissertation. Instituto de Biociências da Universidade Federal de São Paulo, Brazil.

Payne, R. S., and S. McVay. 1971. Songs of humpback whales. Science 173(3997):585–597.

Richardson, W. J., M. A. Fraker, B. Wursig, and R. S. Wells. 1985. Behaviour of bowhead whales *Balaena mysticetus* summering in the Beaufort Sea: Reactions to industrial activities. Biological Conservation 32:195–230.

Sousa-Lima, R. S., M. E. Morete, R. C. Fortes, A. C. Freitas, and M. H. Engel. 2002. Impact of boats on the vocal behavior of humpback whales off Brazil. The Journal of the Acoustical Society of America 112(5):2430–2431.

Tyack, P. 1981. Interactions between singing Hawaiian humpback whales and conspecifics nearby. Behavioral Ecology and Sociobiology 8:105–116.

Watkins, W. A. 1986. Whale reactions to human activities in Cape Cod waters. Marine Mammal Science 2(4):251–262.

Winn, H. E., and L. K. Winn. 1978. The song of the humpback whale, *Megaptera novaeangliae*, in the West Indies. Marine Biology 47:97–114.

About the authors

Renata S. Sousa-Lima *was a 2003 Canon Scholar from the Department of Natural Resources and Bioacoustics Research Program, Cornell University, and an associate researcher of the Instituto Baleia Jubarte (Humpback Whale Institute), Brazil. She completed her dissertation, "Acoustic ecology of humpback whales (*Megaptera novaeangliae*) in the Abrolhos Marine National Park, Brazil," in 2007. Dr. Sousa-Lima currently is an FAPEMIG (Fundação de Amparo à Pesquisa do Estado de Minas Gerais) postdoctoral fellow at the Universidade Federal de Minas Gerais, Brazil, and can be reached at renata.sousalima@icb.ufmg.br or RSL32@cornell.edu.*

Christopher W. Clark *is the I. P. Johnson Director of the Bioacoustics Research Program, Cornell Laboratory of Ornithology, and a senior scientist of the Department of Neurobiology and Behavior, Cornell University.*