

e-mail: klohmann@email.unc.edu

†Department of Biology, University of Central Florida, Orlando, Florida 32816, USA

1. Able, K. P. *J. Avian Biol.* **32**, 174–183 (2000).
2. Gould, J. L. *Curr. Biol.* **8**, R731–R738 (1998).
3. Wiltschko, R. & Wiltschko, W. *Anim. Behav.* **65**, 257–272 (2003).
4. Avens, L. & Lohmann, K. J. *J. Exp. Biol.* (in the press).
5. Lohmann, K. J. & Lohmann, C. M. F. in *Loggerhead Sea Turtles* (eds Bolten, A. B. & Witherington, B. E.) 44–62 (Smithsonian Institution Press, Washington, 2003).
6. Avens, L., Braun-McNeill, J., Epperly, S. & Lohmann, K. J. *Mar. Biol.* **143**, 211–220 (2003).
7. Limpus, C. J. *et al. Wildl. Res.* **19**, 347–358 (1992).
8. Lohmann, K. J., Hester, J. T. & Lohmann, C. M. F. *Ethol. Ecol. Evol.* **11**, 1–23 (1999).
9. Gould, J. L. *Nature* **296**, 205–211 (1982).
10. Lohmann, K. J. & Lohmann, C. M. F. *J. Exp. Biol.* **194**, 23–32 (1994).

Competing financial interests: declared none.

Environment

Whale-call response to masking boat noise

Background noise can interfere with the detection and discrimination of crucial signals among members of a species. Here we investigate the vocal behaviour in the presence and absence of whale-watcher boat traffic of three social groups (pods) of killer whales (*Orcinus orca*) living in the nearshore waters of Washington state. We find longer call durations in the presence of boats for all three pods, but only in recent recordings made following a period of increasing boat traffic. This result indicates that these whales adjust their behaviour to compensate for anthropogenic noise once it reaches a threshold level.

Killer whales are the largest of the dolphin species and are highly social, living in matrilineal pods whose membership is stable over decades¹. The vocal repertoire of whales in our study region shows pod-specific dialects,

and there is a single primary call for each pod that represents up to 52% of the sounds produced by that pod².

We analysed the primary calls from each of the three pods that make up the collection of killer whales known as the southern resident community. Strategies that could be used by the whales to overcome interference from background noise include increasing the frequency, amplitude and duration of their signals. For example, humpback whales lengthen their song duration during playback of low-frequency active sonar³; and an improvement in perception threshold due to increased signal duration (in the context of the time required to integrate the signal) has been demonstrated in many species⁴.

Today's southern resident population of killer whales is exposed to intense whale-watching activity (Fig. 1). This is associated with considerable boat engine noise — there is typically a fleet of 72 commercial vessels and an average of 22 boats following a pod during daylight hours. The number of boats has increased over the past decade and the population has been in decline since 1996 (Fig. 2). Southern resident killer whales may coordinate at least some aspects of cooperative foraging with their repertoire of discrete calls^{5,6}, and theoretical assessments^{6,7} indicate that boat noise could impair communication between killer whales over a range of 1–14 km.

We compared recordings (for methods, see supplementary information) made in the presence or absence of boat noise during three time periods: 1977–81, 1989–92 and 2001–03 (some recordings provided by K. C. Balcomb). We found no significant difference in the duration of primary calls² in the presence or absence of boats for the first two periods, but a significant increase (about 15%) in call duration for all three pods in the presence of boats during the 2001–03 period (J pod: for *t*-test $t = 4.13$, for Mann–Whitney *U*-test $z = 4.09$, $P < 0.0001$, d.f. = 134; K pod: $t = 4.33$, $z = 3.36$, $P < 0.0008$, d.f. = 162; L pod: $t = 3.14$, $z = 2.97$, $P < 0.005$, d.f. = 192; see Fig. 2).

All comparisons of call rate were non-significant (and data were not available for an assessment of call amplitude). Functional differences between the repetition rate of calls and their duration may explain the lack of correlation for repetition rate, although we have no direct evidence for this. The average number of vessels attending the whales increased roughly fivefold from 1990 to 2000, suggesting that there is a threshold level of disturbance beyond which 'anti-masking' behaviour, such as increased signal duration, begins.

Structural changes have been found previously in the songs of birds and humpback whales in environments altered by humans^{3,8}, but our findings show a response that seems to be initiated to counteract anthropogenic noise only once it reaches a critical level.

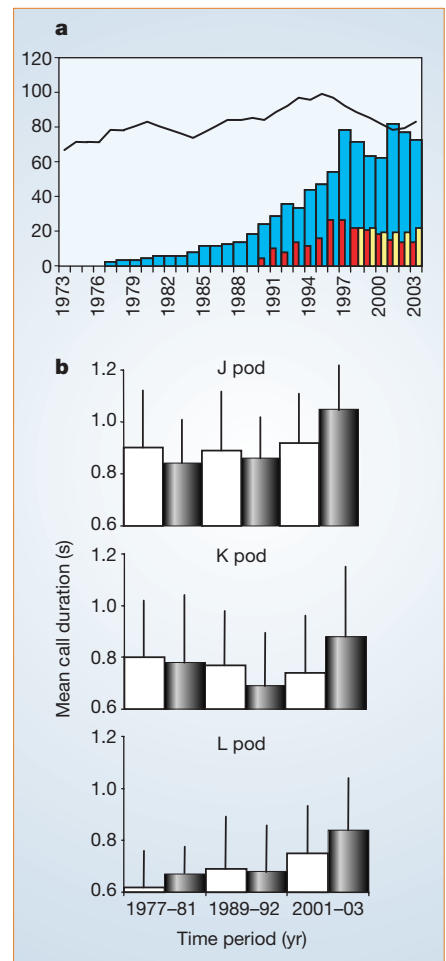


Figure 2 Effect of whale-watcher boat noise on calls made by killer whales. a, Boat and whale numbers are shown for the period between 1973 and 2003. Solid line, size of whale population; blue bars, number of active commercial boats per year; red bars, average number of boats following whales, measured from shore base (Lime Kiln Lighthouse, San Juan Island, Washington state; data for 1990–2003 only); yellow bars, average number of vessels following whales, measured using boat-based observations (1998–2003 only). b, Call duration in seconds for the three pods (termed J, K and L) recorded in the presence (black) and absence (white) of boats for each time period (error bars show 1 s.d.).

Andrew D. Foote*, Richard W. Osborne†, A. Rus Hoelzel*

*School of Biological and Biomedical Sciences, University of Durham, Durham DH1 3LE, UK e-mail: a.r.hoelzel@dur.ac.uk

†The Whale Museum, PO Box 945, Friday Harbor, Washington 98250, USA

1. Bigg, M. A. *et al. IWC Special Issue* **12**, 383–405 (1990).
2. Hoelzel, A. R. & Osborne, R. W. in *Behavioural Biology of Killer Whales* (eds Kirkeveld, B. & Lockard, J. S.) 373–403 (Liss, New York, 1986).
3. Miller, P. J. O. *et al. Nature* **405**, 903 (2000).
4. Heil, P. & Neubauer, H. *Proc. Natl. Acad. Sci. USA* **100**, 6151–6156 (2003).
5. Hoelzel, A. R. *Anim. Behav.* **45**, 581–591 (1993).
6. Bain, D. E. & Dahlheim, M. E. in *Marine Mammals and the Exxon Valdez* (ed. Loughlin, T. R.) 243–256 (Academic Press, San Diego, 1994).
7. Erbe, C. *Mar. Mamm. Sci.* **18**, 394–418 (2002).
8. Slabbekoorn, H. & Peet, M. *Nature* **424**, 267 (2003).

Supplementary information accompanies this communication on Nature's website.

Competing financial interests: declared none.



Figure 1 Killer whales from the southern resident community in Washington state, pictured with onlookers.