Humpback whale (*Megaptera novaeangliae*) song occurrence at American Samoa in long-term passive acoustic recordings, 2008–2009

Lisa M. Munger[a] and Marc O. Lammers
Hawai'i Institute of Marine Biology, University of Hawai'i at Mānoa, Kane'ohe, Hawai'i 96744

Pollyanna Fisher-Pool
Joint Institute for Marine and Atmospheric Research, University of Hawai'i at Mānoa, Honolulu, Hawai'i 96822

Kevin Wong
Coral Reef Ecosystem Division, NOAA Pacific Islands Fisheries Science Center, Kewalo Research Facility, Honolulu, Hawai'i 96814

(Received 17 March 2012; revised 23 July 2012; accepted 31 July 2012)

Humpback whales (*Megaptera novaeangliae*) wintering in American Samoan waters belong to the endangered Oceania subpopulation (IUCN Red List), but survey effort in this region has been relatively limited. Humpback whale seasonal occurrence was assessed using long-term passive acoustic recordings from March 2008 to July 2009 at Tutuila, the most populous island of American Samoa, and October 2008 to September 2009 at the remote Rose Atoll, 240 km to the east. Humpback whale song occurred from mid-July through November at both locations. For days with song, the mean number of recordings per day with song was significantly greater at Tutuila than at Rose Atoll. Song incidence at Rose Atoll peaked at 82% of recordings/day in late September 2008, and at Tutuila 70–100 % of recordings contained song in late August through early September 2009, when recording ceased. Song incidence at Rose Atoll decreased at midday and increased at midnight, whereas there was no significant diurnal pattern at Tutuila. The lower overall incidence of song and its episodic nature at Rose Atoll suggest lower densities of whales traveling through the likely smaller detection area there, whereas greater song incidence and longer peak periods at Tutuila suggest greater whale densities and longer residence times.
 [http://dx.doi.org/10.1121/1.4747014]

PACS number(s): 43.30.Sf, 43.80.Ka [WWA] Pages: 2265–2272

I. INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) that overwinter and breed in waters of the central South Pacific (Oceania) are listed as endangered by the International Union for the Conservation of Nature Red List (Childerhouse *et al.*, 2008). This Oceania subpopulation, which includes whales that overwinter in areas from approximately 145°E (eastern Australia) to 120°W (between French Polynesia and South America) and from the equator to 30°S, was heavily exploited by commercial whaling in the 20th century (Clapham *et al.*, 2009). Although stocks are increasing in some areas, such as eastern Australia (Noad *et al.*, 2006), a recent abundance estimate for the eastern Oceania region (combined for New Caledonia, Tonga, and French Polynesia) remains low, at 3827 animals, with no evidence that post-whaling recovery is taking place (Baker *et al.*, 2006). Based on genetic, photographic, and tag data, humpback whale movement between breeding grounds in Oceania appears to be limited, and these data support a further subdivision of Oceania humpback whales into several smaller breeding stocks (Garrigue *et al.*, 2007; Hauser *et al.*, 2010; Olavarría *et al.*, 2006; Olavarría *et al.*, 2007). Focused humpback whale research efforts in Oceania are ongoing in eastern Australia, New Caledonia, Tonga, the Cook Islands, and French Polynesia (e.g., Garrigue *et al.*, 2007; Olavarría *et al.*, 2007; SPWRC, 2009), whereas efforts are variable and generally less extensive in other island groups.

American Samoa is one of several winter breeding habitats for Oceania humpback whales (NMFS, 2009) for which research effort has been relatively limited until the past decade. Nearshore visual surveys were conducted in 2003–2008 around Tutuila Island, the most populous island in American Samoa, during the peak humpback whale months of September and October. These surveys identified a minimum of 159 individuals, with only three resights between survey years (Robbins *et al.*, 2011; Robbins and Mattila, 2006; NMFS, 2009). Photographic matches indicate some interchange between humpback whales that winter in American Samoa and other wintering areas within the Independent State of Samoa, Tonga, the Cook Islands, and French Polynesia (Garrigue *et al.*, 2007; SPWRC, 2009). Additionally, two whales from American Samoa were recently matched to a summer feeding ground off the Antarctic Peninsula, with one whale making the farthest round-trip

[a]Author to whom correspondence should be addressed. Electronic mail: lmunger@hawaii.edu

mammalian migration documented to date of over 18 800 km (Robbins *et al.*, 2011).

As in other Oceania regions, most survey effort to date in American Samoa has been conducted only during times of known humpback whale occurrence near islands with human populations and infrastructure. As such, these efforts have not been geared toward documenting seasonal patterns in occurrence and habitat use, and a paucity of data exists for remote, uninhabited areas. Therefore, many questions remain regarding habitat use, migratory routes, and the proportion of time spent by Oceania whales in American Samoan waters. Long-term passive acoustic monitoring (PAM) is an effective tool for answering some of these questions. In contrast to visual surveys, PAM is not constrained by weather or daylight, and it can provide months to years of continuous data on sound-producing marine fauna.

Humpback whales are well known for the song that males produce in low-latitude wintering areas where breeding takes place, but song also has been recorded during migration (Clapham and Mattila, 1990; Norris *et al.*, 1999) and on high-latitude feeding grounds (Clark and Clapham, 2004; McSweeney *et al.*, 1989, Vu *et al.*, 2012). Humpback song, therefore, is a reliable indication of whale presence and has been used to investigate seasonal occurrence and provide evidence for wintering grounds in other areas (Lammers *et al.*, 2011). Research on humpback whale song in Oceania to date has been based primarily on short-term hydrophone recordings during the seasonal peak in whale abundance, most often from small boats (e.g., Helweg *et al.*, 1998; SPWRC, 2009) or temporarily moored hydrophone arrays (e.g., Dunlop *et al.*, 2007; Noad and Cato, 2001).

This study presents results from the first year-round PAM effort to document humpback whale seasonal occurrence and habitat use within an Oceania wintering and breeding ground. Autonomous acoustic recorders were deployed at a total of five locations in American Samoan waters beginning in 2006 as part of the Pacific Rapid Assessment and Monitoring Program conducted by the National Oceanographic and Atmospheric Administration (NOAA) Pacific Islands Fisheries Science Center. Humpback whale song occurrence was analyzed within two data sets that provided the best temporal coverage at two islands within American Samoan waters: Tutuila, where visual surveys in previous years have been restricted to an approximately two-week period during peak humpback whale occurrence, and Rose Atoll, for which little information on humpback presence exists and no systematic surveys have been conducted to date.

II. MATERIALS AND METHODS

We analyzed long-term recordings that were made in 2008–2009 using Ecological Acoustic Recorders (EARs; Lammers *et al.*, 2008) deployed in shallow (<20 m) water at two locations in American Samoa (Table I; Fig. 1). One EAR was deployed at Tutuila Island within the National Park of American Samoa, where fishing is restricted to subsistence only (National Park Service, 2005). The other was deployed at Rose Atoll, an uninhabited atoll 240 km east of Tutuila, which was designated a Marine National Monument in 2009 and closed to commercial fishing (Federal Register, 2009). Tutuila Island is surrounded by a shallow (<100 m depth) bank of 1 to 9 km in width, whereas Rose Atoll is characterized by a steeply sloping seafloor that reaches depths >200 m within 0.5 km of shore (Fig. 1). Both EARs were programmed to record on a 3.3% duty cycle of 30 s on every 15 min. The Tutuila EAR sampled at 25 kHz, while the Rose EAR sampled at 40 kHz.

For analysis, data sets from both recorders were decimated to a new sample rate of 5 kHz using Matlab R2009a (The Mathworks Inc., www.mathworks.com). Decimated sound files were visually and aurally analyzed using the program *Triton*, a MATLAB-based software package for acoustic data display and analysis (Wiggins, 2003). A long-term spectral average (LTSA) was computed for each entire deployment by averaging power spectral density (Welch, 1967) in 30-s time bins (i.e., the full duration of an individual sound file) and 10-Hz frequency bins. The LTSA spectrogram display was visually inspected to search for potential humpback whale song occurrence. When potential humpback whale song was noted in the LTSA, the analyst examined the corresponding sound files visually and aurally to verify song presence. Consecutive real-time sound files were examined until no additional song was detected within 5 h (20 files) before or 5 h after the period containing song, and searching was then resumed within the LTSA display.

Each file containing song was classified as either "full bandwidth" or "non-full bandwidth," and either "individual"

TABLE I. Location and recording period of EARs and number of files detected with song in each category. Song categories: FBWI = full bandwidth and individual; FBWO = full bandwidth and overlapping; NFBI = non-full bandwidth and individual, NFBO = non-full bandwidth and overlapping. For Rose Atoll, two values are given for earliest song (fifth column) and days with song/days in singing season (sixth column) that include and exclude, respectively, the few isolated detections on 18 June 2008.

						Number of files containing song (% total files with song)			
Site	Coordinates	Depth (m)	Recording period	Earliest, latest song of season	Days with song/days in singing season (%)	FBWI	FBWO	NFBI	NFBO
Rose Atoll	14°32.0′ S 168°9.4′ W	14.9	03/14/08 to 07/16/09	6/18 & 7/22/08, 11/12/08	97/148 (66%) & 96/114 (84%)	362 (18.4%)	22 (1.1%)	1530 (77.9%)	50 (2.5%)
Tutuila	14°16.3′ S 170°43.4′ W	18.6	10/29/08 to 09/08/09	7/18/09, 11/25/08[a]	72/81[a] (89%)	228 (7.7%)	63 (2.1%)	2387 (80.5%)	286 (9.6%)

[a]The "singing season" at Tutuila was composed of partial 2008 and 2009 seasons.

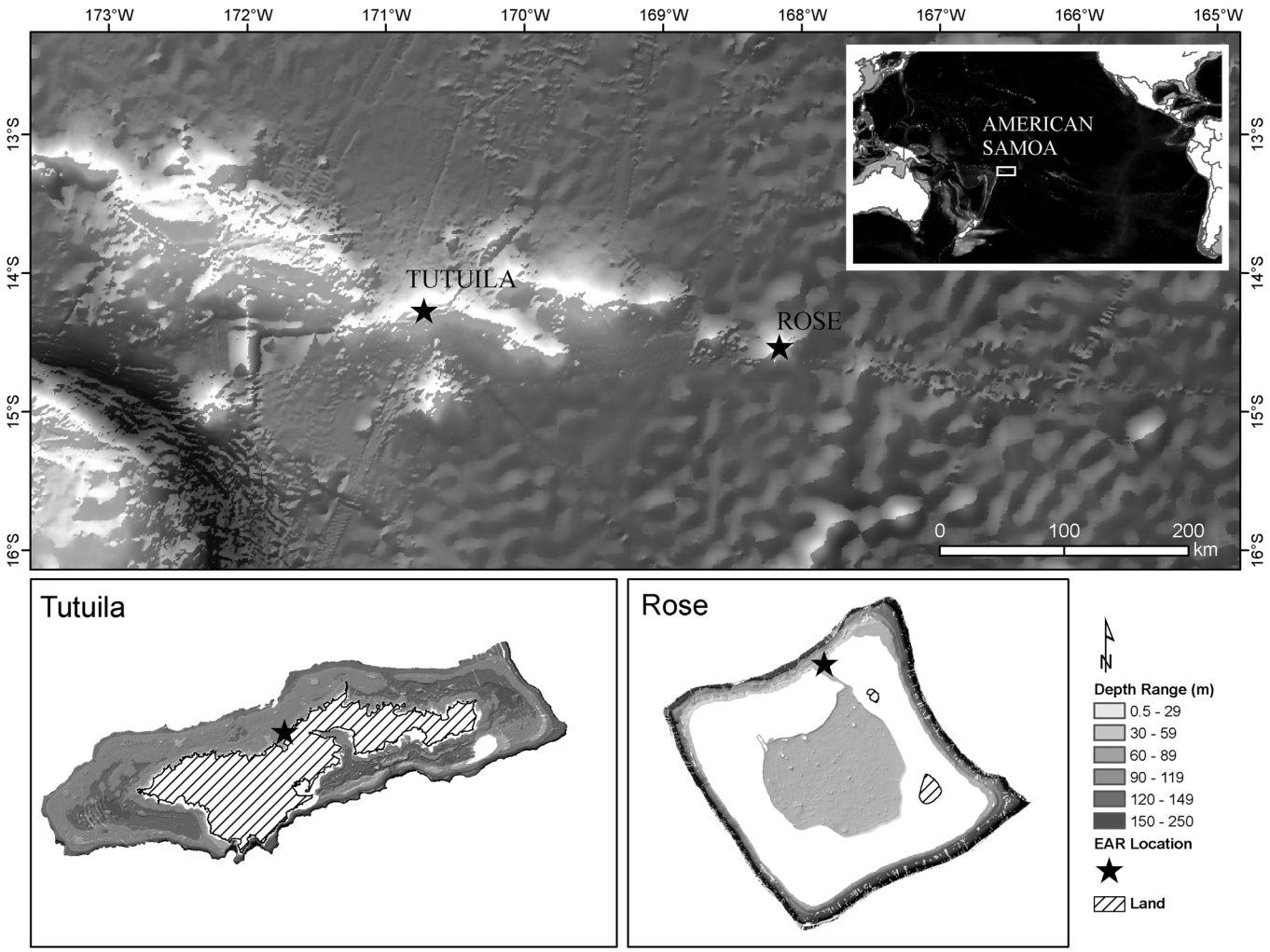

FIG. 1. Map of EAR deployments in American Samoa at Tutuila Island and Rose Atoll.

or "overlapping" (Table I). The first division, full or non-full bandwidth, conveys information related to the distance of the singing whale from the recorder, with the assumption that the closer the singer, the more song harmonics will be apparent in the recording. Files with song were categorized as full bandwidth if harmonics were present in the spectrogram display across more than half the effective bandwidth of 2500 Hz (decimated data), and the converse for non-full bandwidth. Secondly, files with song were divided into "individual" or "overlapping" categories to indicate whether single or multiple singers were detected at a given time. Song was categorized as individual if only one sequence of repeated units was clearly visible, and song was classified as overlapping if at least two of the following criteria were met: overlapping or crossing spectrogram contours, an offset in the intervals between repeated song units, and differences in the audible intensity and other qualities of song units when played back to the analyst. Therefore, four categories were possible: full bandwidth and individual, full bandwidth and overlapping, non-full bandwidth and individual, or non-full bandwidth and overlapping. Within the full bandwidth and overlapping category, at least one of the songs needed to be full bandwidth, and additional overlapping songs may have been either full or non-full bandwidth.

The proportion of days with song during the singing season (from first to last day with song) was calculated for Rose Atoll and Tutuila. Seasonal occurrence and daily incidence of song at Rose Atoll and Tutuila were investigated by plotting the number of recordings that contained song per day. For days with song, the mean number of recordings with song per day was compared between Tutuila and Rose Atoll using a paired Student t-test assuming unequal sample variance (Sokal and Rohlf, 1995). Diurnal patterns in song occurrence were examined at each study site by binning files with song by the hour of the day in which they were recorded; sunrise and sunset times were obtained for EAR deployment locations using the United States Naval Observatory online data service (http://www.usno.navy.mil/USNO/). A chi-square statistic was used to test for a significant difference between the observed number of files with song in each hour and the expected number, which was equal to the total number of detections divided by 24 (hours in a day).

III. RESULTS

The seasonal occurrence of humpback whale song was roughly the same at both locations (Fig. 2). The earliest song of the season was detected on 18 June 2008 at Rose Atoll,

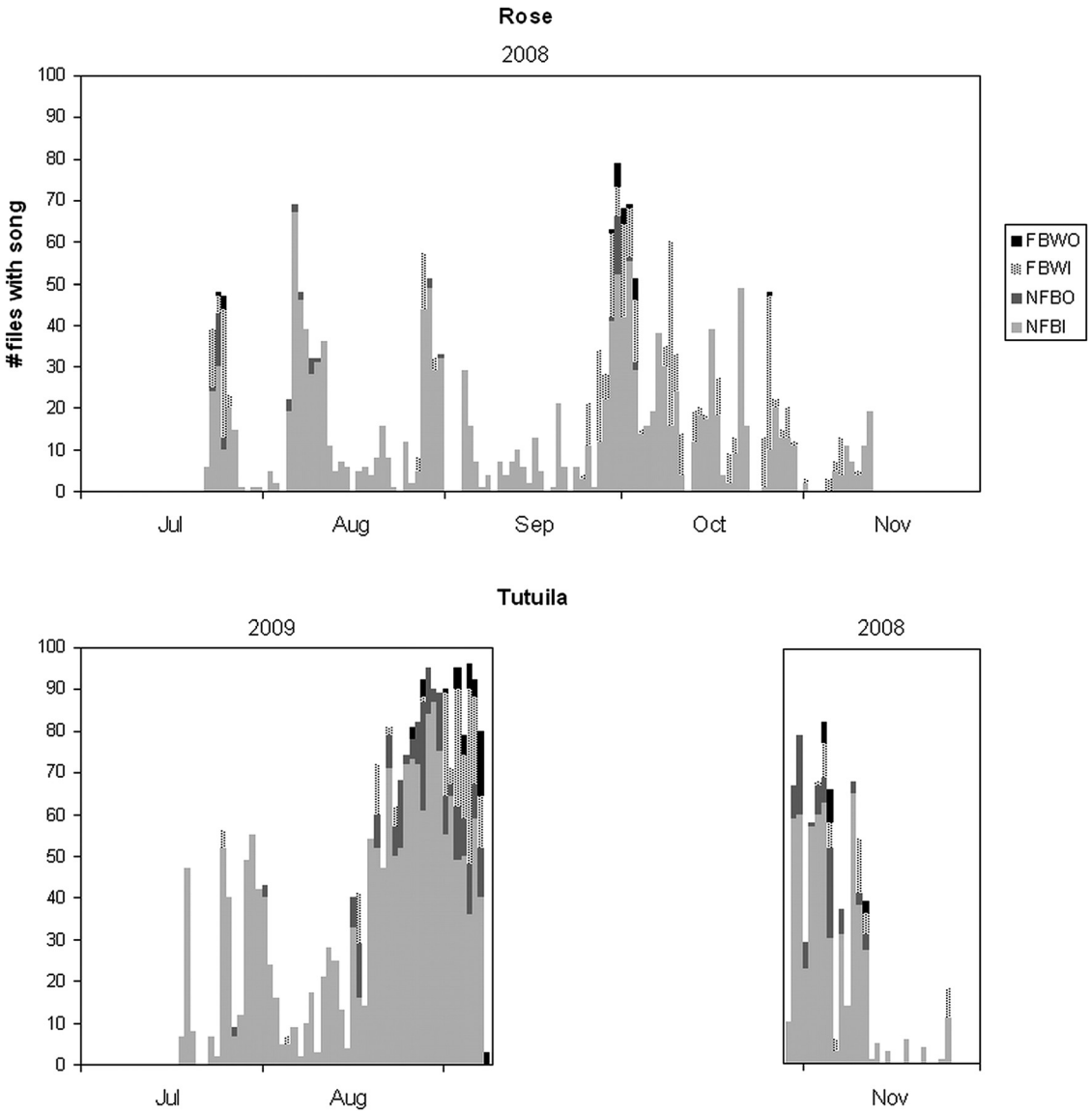

FIG. 2. Number of files with song per day at Rose Atoll and Tutuila Island. For figure clarity, only the portion of recording containing humpback whale song is shown; no song was detected during recording in December through May. Note that recording years at Tutuila (bottom) are shown in reverse order to align seasons with recording from Rose Atoll (top). Song categories: FBWI = full bandwidth and individual; FBWO = full bandwidth and overlapping; NFBI = non-full bandwidth and individual, NFBO = non-full bandwidth and overlapping.

but song was not subsequently detected there again until 22 July (Table I). The earliest humpback whale song of the season at Tutuila was detected on 18 July 2009 (Table I; note that the Tutuila EAR began recording in mid-singing season 2008 and ceased in mid-season 2009). The latest seasonal detection of song was 12 November 2008 at Rose Atoll and approximately two weeks later, on 25 November 2008, at Tutuila. The percentage of days with song during the singing season was 84% at Rose Atoll (excluding the single day with song in June) and 89% at Tutuila (Table I). The peak in monthly song incidence was in October at Rose Atoll, and was undetermined at Tutuila because the EAR there ceased to record during the first week of September 2009. However, song was detected in 90% of recordings at Tutuila during the first week of September 2009 and in over 60% of recordings during the last two days in October 2008.

Humpback whale song was more prevalent at Tutuila than at Rose Atoll (Fig. 2). The mean number of recordings

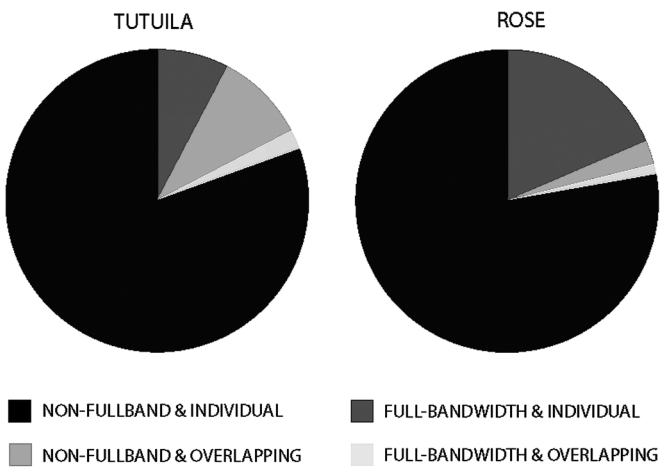

FIG. 3. Proportion of recordings with song in each category.

with song per day (on days with song) was significantly greater at Tutuila than at Rose Atoll (Student t-test assuming unequal variance; $\bar{x}_{\text{Tutuila}} = 41$, $\bar{x}_{\text{Rose}} = 20$, df = 107, $p < 0.05$). In addition, periods with song were longer in duration at Tutuila than at Rose Atoll. Song was present in the majority of recordings (>50%) at Tutuila over a 19-day period, from 19 August to 7 September 2009, and, in late August through early September, song consistently occurred in 70–100% of recordings per day (Fig. 2). Song was more episodic at Rose Atoll, where song bouts lasted a few days to a week and up to 30% or more of recordings contained song on peak days, followed by periods of one to several days with low (<10%) or no song incidence (Fig. 2). The peak in daily song incidence at Rose Atoll was on 30 September, when song was present in 82% of the recordings that day and present in the majority of recordings (>50%) in the surrounding five-day period from 29 September to 3 October (Fig. 2).

Approximately 80% of song recordings at each site were classified as non-full bandwidth and individual (Table I; Fig. 3). At Rose Atoll, most of the remaining recordings were full bandwidth and individual, and only a small percentage of song (<4%) was classified as overlapping (full or non-full bandwidth). At Tutuila, the remaining recordings were more evenly divided into the full bandwidth and individual and non-full bandwidth and overlapping categories, and, similar

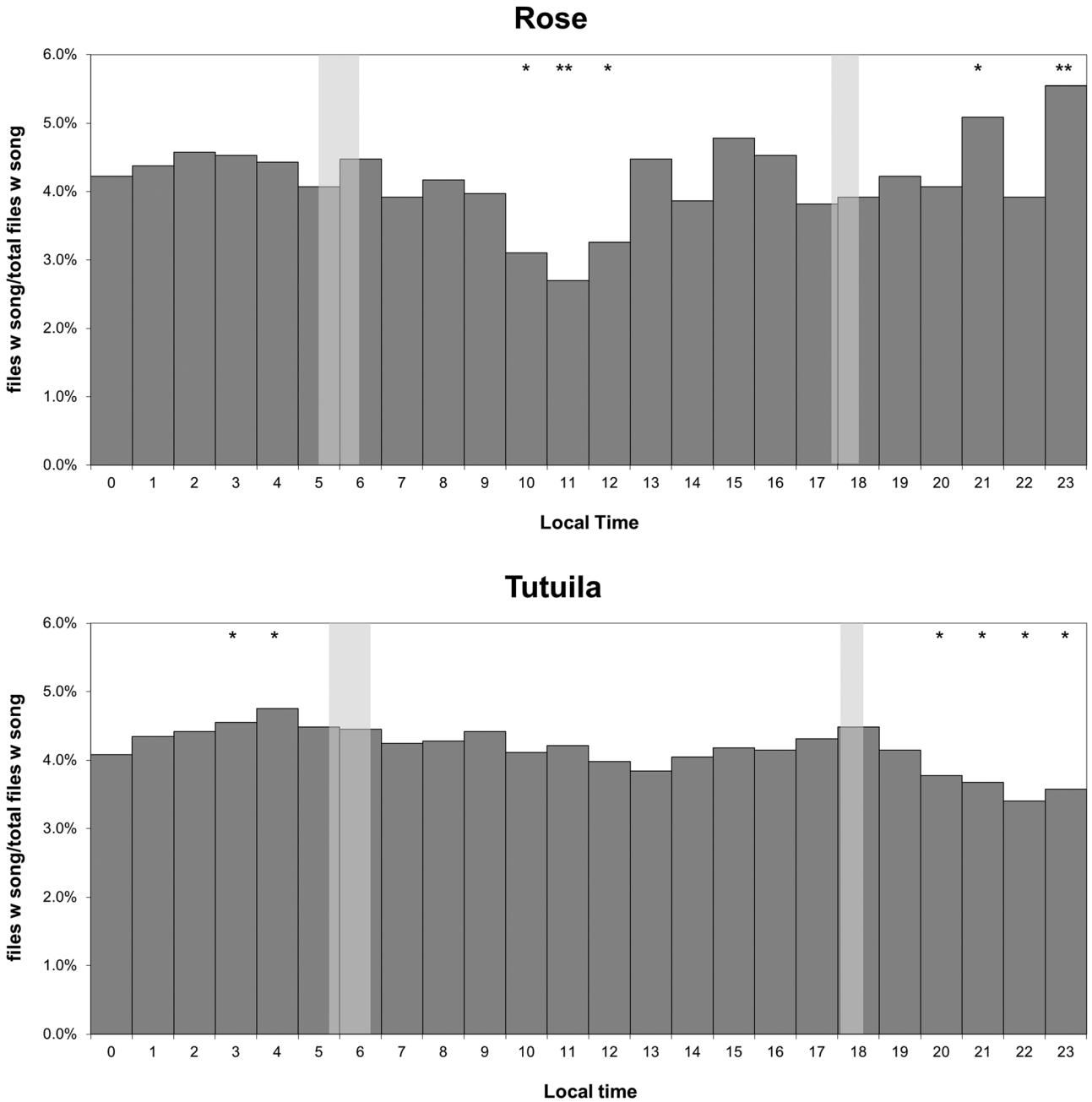

FIG. 4. Song incidence by hour of day, displayed as percentage of total files with song for comparison. Asterisks indicate the magnitude of the difference in standard deviations (* = difference > 1 SD, ** = difference >2 SD) between observed and expected number of files with song (not between observed and expected percentage). Shaded bars denote variation in sunrise and sunset times for months containing humpback song.

to results from Rose Atoll, only a small percentage of recordings (~2%) were full bandwidth and overlapping (Table I; Fig. 3).

At Rose Atoll, song incidence varied significantly by hour of day, with lower than average occurrence at midday and greater than average occurrence at midnight [Fig. 4(a); Chi-square value = 39.78, critical value = 35.17 at $p = 0.05$, df = 23, $n = 1964$]. However, at Tutuila no significant diurnal pattern in song was observed [Fig. 4(b); Chi-square value = 17.59, critical value = 35.17 at $p = 0.05$, df = 23, $n = 2964$].

IV. DISCUSSION

This study presents results of year-round acoustic monitoring for humpback whale presence at two locations in American Samoa, a breeding ground for endangered Oceania humpback whales. The recordings at each location overlapped in time but were not synchronous, capturing a single entire singing season at Rose Atoll in 2008, and partial singing seasons at Tutuila in 2008 and 2009. Continual singing occurred over similar time frames at both sites, with the onset in mid-July and cessation in late November, and no song was detected during recording effort in December through May. The earliest detection of song was on a single day in mid-June at Rose Atoll, but no further song was detected until approximately a month later. The earliest sighting of the year reported at Tutuila was also in June; the latest reported sighting was in December (Craig, 2009; Kaufman, 1983), a month after the latest detection of song in November (this study). The differences in seasonality between this and previous studies may reflect some interannual variation in migration timing; it is also possible that male humpback whales cease singing before commencing migration, or that the late visual observations in December are non-singing whales (i.e., females or juveniles). Although the present study represents only approximately one year of recording effort, the seasonal occurrence of song at American Samoa is congruent with occurrence determined visually during recent surveys in French Polynesia and the Cook Islands, where whales are observed from mid- to late-July to November (with one or two outlier sightings in early July and mid-December; SPWRC, 2009).

Humpback whale song was prevalent in recordings at Tutuila by late August, when nearly 100% of recordings per day consistently contained song (Fig. 2). Most of the song recorded prior to this time was categorized as non-full bandwidth, suggesting that singers were relatively distant from the recorder, perhaps beyond the edge of the shelf. By early September, nearly half of the recordings with song were categorized as full bandwidth (individual or overlapping), indicating that whales were closer to the EAR. Unfortunately, the Tutuila EAR ceased recording at the beginning of the second week in September, before the presumed peak in whale density at Tutuila (Robbins and Mattila, 2006). However, the high song incidence during the first week of September 2009 and decreasing song incidence in late October through November the previous year support a probable peak in humpback whale occurrence in the September time frame. In addition, the peak in humpback song incidence at Rose Atoll in late September and early October corresponds with the peak in humpback whale encounter rates from visual surveys conducted during the same time of year at Tutuila (Robbins and Mattila, 2006).

Humpback whale song was detected at Rose Atoll throughout the entirety of the wintering season, although it was less prevalent in recordings at Rose Atoll than it was at Tutuila. The relatively lower occurrence of song at Rose Atoll is probably due to a combination of whale behavior, habitat preference, and acoustic characteristics of the different environments. The episodic pattern of song occurrence at Rose Atoll suggests that whales were not remaining within detection range of the EAR for extended periods of time. Despite the fact that they did not stay for long durations, whales frequently came close to the EAR at Rose Atoll, as indicated by the high percentage (18%) of "full bandwidth and individual" song recordings (Table I; Fig. 3). The lower overall prevalence of song at Rose Atoll may reflect that whale density in the vicinity of the recorder was lower at Rose Atoll than at Tutuila, perhaps due to the lack of preferred, shallow (<200 m) shelf habitat (e.g., Johnston *et al.*, 2007). The low song prevalence and episodic peaks in song at Rose Atoll also may be related to the smaller detection area there relative to Tutuila, because of the steeply sloping seafloor and acoustic shadow effect of the atoll as whales move around it and propagation to the EAR is blocked. It is unlikely that there was any overlap in the recording range of the two EARs, as they were deployed 240 km apart on opposite sides of Tutuila Island (Fig. 1).

The incidence of song in American Samoan waters was comparable to the incidence of song near O'ahu, one of the main Hawaiian islands, which comprise a well-known wintering area for North Pacific humpback whales (Lammers *et al.*, 2011). The proportions of days with song within the singing season at Rose Atoll (excluding the single day in June) and Tutuila were 84 and 89%, respectively (Table I); these percentages are comparable to the proportion of days with song reported for west O'ahu (85%; Lammers *et al.*, 2011). In addition, although the Tutuila EAR ceased recording before the presumed peak in humpback whale abundance, the proportion of recordings with song in August at Tutuila (44%; Fig. 2) approaches the proportion of recordings with song during the peak month of April at O'ahu (53%; Lammers *et al.*, 2011). Although the two regions showed similar proportions of days with song, the number of humpback whales estimated to winter in the main Hawaiian Islands is more than 10 000 animals (Calambokidis *et al.*, 2008), which is more than twice as many whales as are estimated to winter throughout the entire eastern Oceania region (3,827; Baker *et al.*, 2006). Humpback whales in American Samoa compose an unknown (and likely small) fraction of the Oceania subpopulation; the minimum population size in American Samoa is small, at 159 individuals (Robbins *et al.*, 2011; Robbins and Mattila, 2006). Therefore, the high prevalence of song near Tutuila probably reflects high local densities of humpback whales around this island rather than high abundance in American Samoan waters overall.

Diurnal patterns in song incidence were not consistent between sites. At Rose Atoll, song incidence decreased

significantly at midday and increased at midnight, whereas no significant diurnal pattern was detected at Tutuila (Fig. 4). Evidence for diurnal patterns in humpback whale song is inconsistent across other wintering grounds in the tropical Pacific as well. Humpback whale song incidence (inferred from sound pressure levels) off Maui in the main Hawaiian Islands was reported to be greater at night (Au *et al.*, 2000), whereas humpback whale acoustic activity (the proportion of randomly sampled recording periods with song) in New Caledonia during the study years 1996–2005 did not vary by time of day (SPWRC, 2009). One possible explanation for this inconsistency is that daily movement patterns, habitat use, and behavior of whales differ depending on the island. Near Rose Atoll, whales may have been traveling more frequently, as suggested by the episodic song occurrence, and perhaps moved offshore or to the opposite side of the atoll during the day and closer to the recorder at night. The high incidence of song at Tutuila and lack of a diurnal pattern is consistent with data from visual surveys, during which whales were encountered more frequently on the northeast side of the island (near the EAR location) and did not show any consistent directional travel (Robbins and Mattila, 2006).

Continued, long-term passive acoustic monitoring of humpback whales within American Samoa and other Oceania island groups would provide information that would be challenging or impossible to obtain through real-time platform-based surveys, including habitat use at remote locations, and diurnal and seasonal behavioral patterns. In addition, ongoing geographic comparisons of song among Oceania island groups may provide insight into population structure and patterns in song evolution and transmission (e.g., Helweg *et al.*, 1998; Garland *et al.*, 2011), as well as long-term population trends (e.g., Lammers *et al.*, 2011). Long-term acoustic monitoring is an effective technique that would enhance monitoring programs for endangered Oceania humpback whales.

ACKNOWLEDGMENTS

The authors would like to thank the officers and crew of the NOAA Ship *Hi'ialakai* and staff at the Coral Reef Ecosystem Division (CRED) of the NOAA Pacific Islands Fisheries Science Center who assisted with instrumentation, manuscript editing and graphics, and other aspects of this project. We are especially grateful to R. Brainard at CRED for his role in supporting the passive acoustics program. We thank P. Brown and P. Craig of the U. S. National Park Service for their assistance in deploying and recovering the EAR on Tutuila, and D. Mattila of the NOAA Hawaiian Islands Humpback Whale National Marine Sanctuary for providing helpful information and literature. This work was supported by the NOAA Coral Reef Conservation Program. This publication is HIMB contribution #1464.

Au, W. W. L., Mobley, J., Burgess, W. C., Lammers, M. O., and Nachtigall, P. E. (**2000**). "Seasonal and diurnal trends of chorusing humpback whales wintering in waters off western Maui," Marine Mammal Sci. **16**, 530–544.

Baker, C. S., Garrigue, C., Constantine, R., Madon, B., Poole, M., Hauser, N., Clapham, P., Donoghue, M., Russell, K., O'Callahan, T., Paton, D., and Mattila, D. (**2006**). "Abundance of humpback whales in Oceania (South Pacific), 1999 to 2004," South Pacific Whale Research Consortium report SC/A06/HW51 to the Inter-Sessional Workshop for the Comprehensive Assessment of Southern Hemisphere Humpback Whales, Hobart, Tasmania, 3–7 April 2006.

Calambokidis, J., Falcone, E. A., Quinn, T. J., Burdin, A. M., Clapham, P. J., Ford, J. K. B., Gabriele, C. M., LeDuc, R., Mattila, D., Rojas-Bracho, L., Straley, J. M., Taylor, B. L., Urban, J., Weller, D., Witteveen, B. H., Yamaguchi, M., Bendlin, A., Camacho, D., Flynn, K., Havron, A., Huggins, J., and Maloney, N. (**2008**). "SPLASH: Structure of Populations, Levels of Abundance and Status of Humpback Whales in the North Pacific," *final report for Contract No. AB133F-03-RP-00078*, Cascadia Research, Olympia, WA, pp. 1–57.

Childerhouse, S., Jackson, J., Baker, C. S., Gales, N., Clapham, P. J., and Brownell, R. L., Jr. (**2008**). "*Megaptera novaeangliae* (Oceania subpopulation)," *IUCN Red List of Threatened Species*, IUCN 2011.

Clapham, P. J., and Mattila, D. K. (**1990**). "Humpback whale songs as indicators of migration routes," Marine Mammal Sci. **6**, 155–160.

Clapham, P., Mikhalev, Y., Franklin, W., Paton, D., Baker, C. S., and Brownell, R. L., Jr. (**2009**). "Catches of Humpback Whales, *Megaptera novaeangliae*, by the Soviet Union and other nations in the Southern Ocean, 1947–1973," Marine Fish. Rev. **71**, 39–43.

Clark, C. W., and Clapham, P. J. (**2004**). "Acoustic monitoring on a humpback whale (*Megaptera novaeangliae*) feeding ground shows continual singing into late spring," Proc. R. Soc. London, Ser. B **271**, 1051–1057.

Craig, P. (**2009**) "Natural History Guide to American Samoa," available at www.nps.gov/npsa (date last viewed 3/20/2012), support from *National Park of American Samoa, Department of Marine and Wildlife Resources*, American Samoa Community College, and others.

Dunlop, R. A., Noad, M. J., Cato, D. H., and Stokes, D. (**2007**). "The social vocalization repertoire of east Australian migrating humpback whales (*Megaptera novaeangliae*)," J. Acoust. Soc. Am. **122**, 2893–2905.

Federal Register (**2009**). Presidential Proclamation 8337 of January 6, **2009**, Establishment of the Rose Atoll Marine National Monument, Presidential Documents **74**(7), pp. 1577–1581.

Garland, E. C., Goldizen, A. W., Rekdahl, M. L., Constantine, R., Garrigue, C., Hauser, N. D., Poole, M. M., Robbins, J., and Noad, M. J. (**2011**). "Dynamic horizontal cultural transmission of Humpback Whale song at the Ocean Basin Scale," Current Biol. **21**, 687–691.

Garrigue, C., Baker, C. S., Constantine, R., Poole, M., Hauser, N., Clapham, P., Donoghue, M., Russell, K., Paton, D., Mattila, D. K., and Robbins, J. (**2007**). "Interchange of humpback whales in Oceania (South Pacific), 1999 to 2004," *revised SC/A06/HW55, March 2007*, International Whaling Commission Report No. SC/59/SH14.

Hauser, N., Zerbini, A. N., Geyer, Y., Heide-Jorgensen, M.-P., and Clapham, P. (**2010**). "Movements of satellite-monitored humpback whales, *Megaptera novaeangliae*, from the Cook Islands," Marine Mammal Sci. **26**, 679–685.

Helweg, D. A., Cato, D. H., Jenkins, P. F., Garrigue, C., and McCauley, R. D. (**1998**). "Geographic variation in South Pacific humpback whale songs," Behaviour **135**, 1–27.

Johnston, D. W., Chapla, M. E., Williams, L. E., and Mattila, D. K. (**2007**). "Identification of humpback whale Megaptera novaeangliae wintering habitat in the Northwestern Hawaiian Islands using spatial habitat modeling," Endang. Species Res. **3**, 249–257.

Kaufman, G. (**1983**). "Ecology of humpback whales in American Samoa," abstract in 5th Biennial Conference of the Society for Marine Mammalogy, Biology of Marine Mammals, Boston, Massachusetts.

Lammers, M. O., Brainard, R. E., Au, W. W. L., Mooney, T. A., and Wong, K. B. (**2008**). "An ecological acoustic recorder (EAR) for long-term monitoring of biological and anthropogenic sounds on coral reefs and other marine habitats," J. Acoust. Soc. Am. **123**, 1720–1728.

Lammers, M. O., Fisher-Pool, P. I., Au, W. W. L., Meyer, C. G., Wong, K. B., and Brainard, R. E. (**2011**). "Humpback whale *Megaptera novaeangliae* song reveals wintering activity in the Northwestern Hawaiian Islands," Marine Ecol. Prog. Ser. **423**, 261–268.

McSweeney, D. J., Chu, K. C., Dolphin, W. F., and Guinee, L. N. (**1989**). "North Pacific Humpback Whale songs—A comparison of Southeast Alaskan Feeding Ground Songs with Hawaiian Wintering Ground Songs," Marine Mammal Sci. **5**, 139–148.

National Park Service. (**2005**). National Park of American Samoa Enabling Legislation as of 12 April 2005, U.S. Department of the Interior.

NMFS (National Marine Fisheries Service). (**2009**). "Humpback Whale (*Megaptera novaeangliae*) IUCN Oceania subpopulation—American

Samoa Stock," Stock Assessment Report, National Oceanic and Atmospheric Administration, Department of Commerce, pp. 281–284.
Noad, M. J., and Cato, D. H. (**2001**). "A combined acoustic and visual survey of humpback whales off southeast Queensland," Memoirs of the Queensland Museum **47**, 507–523.
Noad, M. J., Paton, D., and Cato, D. H. (**2006**). "Absolute and relative abundance estimates of Australian east coast humpback whales (*Megaptera novaeangliae*)," paper No. SC/A06/HW27, International Whaling Commission Comprehensive Assessment of Southern Hemisphere Humpback whales, Hobart, Australia, pp. 1–15.
Norris, T. F., McDonald, M., and Barlow, J. (**1999**). "Acoustic detections of singing humpback whales (*Megaptera novaeangliae*) in the eastern North Pacific during their northbound migration," J. Acoust. Soc. Am. **106**, 506–514.
Olavarría, C., Anderson, M., Paton, D., Burns, D., Brasseur, M., Garrigue, C., Hauser, N., Poole, M., Caballero, S., Flórez-González, L., and Baker, C. S. (**2006**). "Eastern Australia humpback whale genetic diversity and their relationship with Breeding Stocks D, E, F and G," Report No. SC/58/SH25, International Whaling Commission.
Olavarría, C., Baker, C. S., Garrigue, C., Poole, M., Hauser, N., Caballero, S., Flórez-González, L., Brasseur, M., Bannister, J., Capella, J., Clapham, P., Dodemont, R., Donoghue, M., Jenner, C., Jenner, M. N., Moro, D., Oremus, M., Paton, D., Rosenbaum, H., and Russell, K. (**2007**). "Population structure of South Pacific humpback whales and the origin of the eastern Polynesian breeding grounds," Marine Ecol. Prog. Ser. **330**, 257–268.
Robbins, J., Dalla Rosa, L., Allen, J. M., Mattila, D. K., Secchi, E. R., Friedlaender, A. S., Stevick, P. T., Nowacek, D. P., and Steel, D. (**2011**). "Return movement of a humpback whale between the Antarctic Peninsula and American Samoa: a seasonal migration record," Endang. Species Res. **13**, 117–121.
Robbins, J., and Mattila, D. K. (**2006**). "Summary of humpback whale research at American Samoa, 2003-2005," Report No. SC/58/SH5, International Whaling Commission.
Sokal, R. R., and Rohlf, F.J. (**1995**). *Biometry: The Principles and Practice of Statistics in Biological Research*, 2nd ed (W. H. Freeman, New York), pp. 698–703, 729–730.
SPWRC (South Pacific Whale Research Consortium) (**2009**). Report of the Annual Meeting of the South Pacific Whale Research Consortium, 9–12 February, Auckland, New Zealand, SC/61/SH15, presented to the Scientific Committee of the International Whaling Commission, Madeira, Spain, 31 May–12 June 2009.
Vu, E. T., Risch, D., Clark, C. W., Gaylord, S., Hatch, L. T., Thompson, M. A., Wiley, D. N., and Van Parijs, S. M. (**2012**). "Humpback whale song occurs extensively on feeding grounds in the western North Atlantic Ocean," Aquat. Biol. **14**, 175–183.
Welch, P. D. (**1967**). "The use of fast Fourier transform for the estimation of power spectra: A method based on time averaging over short, modified periodograms," IEEE Trans. Audio Electroacoust. **AU-15**, 70–73.
Wiggins, S. (**2003**). "Autonomous acoustic recording packages (ARPs) for long-term monitoring of whale sounds," Marine Technol. Soc. **37**, 13–22.