Research consistent with the IWC Large-scale Whale-watch Experiment (LaWE): assessing effects of human activity on spinner dolphins in resting bays in Hawai‘i and the effectiveness of time-area closures as a proposed mitigation tool

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ABSTRACT

Due to growing concerns about the potential negative impacts of nature-based tourism on Hawaiian spinner dolphins, the U.S. National Oceanic and Atmospheric Administration (NOAA) is developing management plans to reduce the exposure of resting spinner dolphins to human activity in Hawaiian waters. One potential management approach under consideration by NOAA focuses on time-area closures to reduce the number and intensity of interactions between humans and dolphins during critical rest periods in particular bays. To investigate the efficacy of this approach, significant research is required to assess how spinner dolphins respond to time-area closures. The conceptual framework for this study follows a Before-After-Control-Impact (BACI) design where the local abundance, distribution and behaviour of spinner dolphins in five resting bays will be assessed before and after the implementation of time-area closures. Specifically, time-area closures will be introduced in four dolphin resting bays (each with varying levels of human activity) while the fifth bay (control) will remain open. At present, the timing of closures has not been determined, but these would not be implemented until a full year of pre-closure data collection has been completed. The data will be collected during field seasons lasting six months per year over three-four years. We highlight this study as a possible candidate project for inclusion in the IWC Large-scale Whale-watch Experiment (LaWE) initiative as it incorporates many facets that the LaWE initiative strives to achieve.

INTRODUCTION

At present, it is unclear how human interactions may affect Hawaiian spinner dolphins (*Stenella longirostris*). Emergent research is showing that cetacean-based tourism has the potential to cause biologically significant impacts on targeted dolphin communities (Bejder et al. 2006, Lusseau et al. 2006a, Lusseau et al. 2006b). In Hawai‘i, the dolphin-based tourism industry has grown rapidly in recent years (Hu *et al*. 2009). Recent studies (Danil et al. 2005, Courbis 2007, Delfour 2007, Courbis & Timmel 2009) suggest that resting periods for spinner dolphins in Hawai‘i may be interrupted or truncated by exposure to human activity; although, no conclusions regarding possible population-level effects could be made. Limited quantitative data are currently available to assess potentially biological significant impacts of tourism activities on targeted animals in Hawai‘i.

Hawaiian spinner dolphins have predictable, daily movement patterns of foraging offshore at night and returning to inshore sheltered bays to rest during the day (Norris *et al* 1994; Courbis and Timmel 2009). This consistent movement pattern may render them particularly vulnerable to disturbance because of their reliance on a limited area of sheltered waters to rest, socialise and avoid predators. Considering that the impacts of tourism on dolphins have been documented in locations of substantially less tourism pressure, it seems likely that similar impacts are occurring in Hawai‘i. Specific concerns in regards to human-spinner dolphin interactions include: changes to dolphin behavioural budgets, energetic deficits, reduced vigilance for predators, truncated rest periods, alteration of social interactions with conspecifics, inadequate recovery from day-time disturbances with a concomitant reduction in nocturnal foraging efficiency and displacement of dolphins from prime habitat to less optimal habitat with a concomitant increase in predation risk.

Elsewhere, these effects have led to long-term consequences for the viability and fitness of individual dolphins (Bejder et al. 2006, Lusseau et al. 2006a). One potential management approach under consideration by the U.S. National Oceanic and Atmospheric Administration (NOAA) to resolve this issue focuses on time-area closures to reduce the number and intensity of interactions between humans and dolphins during critical rest periods. Research is required to investigate the efficacy of this management approach, to assess how spinner dolphins respond to time-area closures, and to determine how this may affect their local abundance, distribution and behaviour. Reliable estimates of spinner dolphin abundance and use of resting bays on the west coast of the Big Island of Hawaiʻi are fundamental to understand the effects exposure to human activity may be having on the spinner dolphin population.

Currently, little is known about the abundance and stock structure of spinner dolphins that inhabit the Hawaiian Islands. The most recent estimate of spinner dolphins (3,351 individuals) comes from a (2002) ship line-transect survey carried out within the U.S. Exclusive Economic Zone (EEZ) waters surrounding the Hawaiian Islands (Barlow 2006). Unfortunately, this survey was unlikely to capture the abundance of spinner dolphins that rest in near shore waters during the day. The most closely studied population of spinner dolphins, for which published data exists, is located around the Big Island of Hawaiʻi (Norris et al. 1994). Although Norris *et al.* (1994) described this population as open, with individual animals regularly transiting in and out of different areas, some spinner dolphins were found to consistently use particular areas around the island for resting (Norris et al. 1994).

The overall conceptual framework for this study is based on a Before-After-Control-Impact (BACI) design (Underwood 1991), where the local abundance, distribution and behaviour of spinner dolphins in five resting bays will be assessed prior to and after the implementation of proposed time-area closures. Specifically, time-area closures for human activity will be introduced in four resting bays off the Big Island of Hawaiʻi while the fifth bay, off Molokaʻi Island (control), will remain open. The study will combine boat-based and land-based visual observations with passive acoustic monitoring to quantify the effects of human interactions on spinner dolphins in the Pacific Islands Region. The field seasons for this study will be six months per year over a three-four year period. Long term studies such as this are essential in helping to determine the impact of human interactions on cetacean populations (Bejder et al. 2006, Lusseau et al. 2006b). It is envisioned that time-area closures will be introduced after year 2 of this study when the initial results are available for comparison. This provides an excellent opportunity to assess the utility of time-area closures as management tools. This research will be fully integrated with continuing efforts to study spinner dolphins through strong collaborations with the NOAA Pacific Islands Fisheries Science Centre and with the Pacific Islands Photo Identification Network.

APPROACHES, METHODS AND TECHNIQUES

1. Mark recapture analyses based on photo-identification data will be carried out to evaluate abundance and distribution of spinner dolphins in resting bays before and after time-area closure implementations.
Boat based photo-identification surveys will be conducted in each of the four resting bays off the west coast of The Big Island of Hawaiʻi and another control area survey off the island of Molokaʻi to evaluate abundance of spinner dolphins before and after the implementation of time-area closures.

There are a number of capture-recapture methods that are well established for estimating the abundance of wildlife populations (Durban *et al*. 2005). For cetaceans, mark-recapture methods applied to photographic identification using natural markings of individuals can be used to estimate trends in abundance (Wilson et al. 1999, Durban et al. 2005, Friday et al. 2008, Verborgh et al. 2009). It is important to ensure that the assumptions of the mark-recapture model match the characteristics of the sample data in order to provide reliable population estimation (Pollock *et al.* 1990, Durban *et al.* 2005). For example, capture probability heterogeneity is likely to exist in some degree in capture-recapture studies due to animal differences and cannot be completely eliminated (Pollock *et al.* 1990). Capture probability heterogeneity introduces a negative bias into the analysis by underestimating the population by re-sighting the same animals repeatedly. However, such capture probability heterogeneity can be reduced by associating it with some measurable characteristic that can be obtained in the field (e.g. age, sex) (Pollock *et al.* 1990) and stratifying the analysis by that characteristic. Heterogeneity of capture probabilities can also be introduced into the sampling regime as a result of heterogeneous sampling intensities, thus it is important that the sampling regime is maintained with equal intensity throughout the study period.

Two types of population models are generally considered for capture-recapture sampling designs: closed and open population models. Closed population models assume no migration in or out of the population due to immigration, births, emigration or deaths between sampling periods. Closed population models are generally used for short study periods (Pollock *et al.* 1990). During long study periods it is not always possible to assume that the population being studied is closed to immigration and emigration. However, open models allow estimations of recruitment, survival rates and population but the capture probabilities are assumed to be equal (Pollock *et al.* 1990, Pledger *et al*. 2003).

In this study, we will use the (robust) capture-recapture sampling design to reduce population parameter bias when estimating the abundance of spinner dolphins in the five resting bays. The robust capture-recapture design has been shown to allow considerable flexibility in estimating population parameters for long-term studies by combining closed and open population models (Pollock *et al.* 1990). The robust design consists of primary sampling periods between which the population is assumed to be open, and secondary sampling periods within the primary sampling periods between which the population is assumed to be closed (Pollock *et al.* 1990). The robust design can be used to estimate unbiased population parameters while temporary emigration is in operation (Kendall *et al.* 1997, Kendall & Nichols 2002). Temporary emigration is the result of an identified animal moving outside the study area and being unavailable for capture (Kendall & Bjorkland 2001).

The four bays on the Big Island of Hawai‘i will be surveyed on a monthly basis (primary sampling period), in between which the spinner dolphin population will be assumed to be open. Boat-based photo-identification surveys will be conducted in each bay and will take place over consecutive days (secondary sampling period), in between which the population of spinner dolphins will be assumed to be closed. Two of the four bays will each be surveyed on four consecutive days, while the remaining two bays will be surveyed on two consecutive days resulting in 12 days of photo-identification each month. Past research has shown that individual spinner dolphins move along the west coast of the Big Island of Hawai‘i (Norris et al. 1994, Ostman-Lind et al. 2004). This sampling regime, and the use of the robust capture-recapture population model will help to reduce the bias of spinner dolphin capture probability heterogeneity and allow spinner dolphin population and meta-population dynamics to be inferred (Kendall & Bjorkland 2001). Boat based photo-identification surveys will be carried out at the control bay on the island of Moloka‘i during a two-three week period sampling during each field season. This sampling regime on the five spinner dolphin resting bays will be carried out before and after time-area closures have been implemented.

2. Land-based theodolite tracking and boat-based group focal follows

Where possible, the movements and behaviour of spinner dolphins and boats will be studied from local cliff tops overlooking spinner dolphin resting bays using a digital theodolite. Theodolite tracking is a standard technique for studying the distribution and movement patterns of cetaceans in coastal waters (e.g. Johnston 2002). Digital theodolites convert angles of declination and azimuth to xy-coordinates using standard trigonometric functions. Theodolite studies have been used extensively to study spinner dolphins in Hawai‘i, and these previous studies may provide useful comparisons.

Specifically, we will use theodolite data to derive time series of information on activity state, path sinuosity, speed, and synchronicity of schools. The first three time series will be used as the observed processes in a state space model relating behaviour to a physiologically relevant energy level state. This state can be used in other state space model relating physiology to vital rates. The time series of synchronicity measures will be used to estimate the degree of influence of conspecifics on the behaviour performed by individual animals. We now have a mechanistic model that can explain how the activity of schools emerge from the motivation of individuals in dolphin populations (Lusseau & Conradt 2009). Therefore, we will be able to relate population-level information to the physiological influences of disturbances at individual-level using information on the population’s composition that will be collected using photo-identification. This can be used to inform variation in physiological status of different groups of individuals within the school (e.g. nursing mothers, calves, adult, etc.). The model will be extended to account for the influence of conspecifics on the emergence of behaviour at the individual-level from an individual’s motivational space. The state-space model will therefore use behavioural information collected at the population-level to inform the time series of resulting energetic-level variation of individuals from different energetic status/motivational space categories (mothers, adult males, calves, etc.). First the model will include the estimation of the correlation in activity states within and between individual categories, informed from the observed synchronicity data (Hastie *et al*. 2003). Secondly, the motivational space will vary between those categories as well. For example, we will express the motivation of mothers to allocate energy away from the calf.

3. Acoustic observations of spinner dolphins in resting bays on the Big Island of Hawai‘i before and after time-area closures.

The use of passive acoustics for monitoring the presence and behaviour of cetaceans is growing. Passive techniques provide opportunities to extend monitoring effort over longer time frames and longer distances at greatly reduced cost. These techniques also have drawbacks, often related to species identification issues and limited information on how frequently animals use sound under different environmental conditions and varying behavioural states.

Passive acoustics have been used to study spinner dolphins since the 1980s, and recent studies have provided insight into the acoustic behaviour of spinners in the near shore waters of Hawaiʻi (e.g. Lammers 2004). As such, we are well positioned to include passive acoustic monitoring of spinner dolphins in resting bays as one component of this integrated project.

The type of sensors to be deployed is an important consideration, and we are in the final stages of evaluating two types of recorders for the project. Both have varying capability to record whistles, burst pulses and echolocation clicks produced by spinner dolphins (see Lammers & Au 2003), and the remaining factors for this decision are related to storage, battery life, and duty cycle capabilities.

In general, we will deploy bottom-mounted recorders in two of the resting bays that will also be subject to photo-ID and theodolite studies described above. Initially the acoustic survey periods will be continuous (no duty cycle) and will coincide with daily visual observations in order to link acoustic detections with the distribution and behaviour of dolphins. These initial deployments will provide baseline data to refine the sampling protocol such that longer deployments that rely on duty-cycling the instrument will be optimized. This will allow for efficient and rigorous sampling of the acoustic environment over longer periods while conserving storage space and battery life.

INTEGRATIVE ANALYTICAL TECHNIQUES

Our multi-faceted approach will allow for predictive habitat modelling and individual-based modelling (IBM) of spinner dolphin behaviours, along with deriving estimates of local abundance and site fidelity of groups and individuals using the visual and acoustic techniques described above. Individual based modelling is becoming an important tool in ecology that captures the heterogeneity in the life history of individuals (Grimm & Railsback 2005). Recently, research has started to use IBMs to understand consequences of the interactions of non-linear influences on individuals to that of population dynamics. For example, Lusseau *et al*. (2006b) have integrated current information on impacts of cetacean-watching on individuals or groups of cetaceans in a population dynamics model. In a similar fashion, IBM can be applied to explore how often spinner dolphins are exposed to human activities in relation to life parameters known to be affected by interactions. Photo-identification data will be used to develop initial discovery curves to assess local abundance of individuals in the study area, and the final year these individual encounter data will be incorporated into a robust population mark-recapture analysis framework for abundance estimation for each bay. Furthermore, we hope to use photo-identification data to provide initial demographic parameters for the local population of spinner dolphins. Long-term acoustic monitoring will provide an excellent time series to assess when changes in dolphin residency occur, and the extent to which signal prediction by dolphins is altered by the closure. Acoustic data will be analysed using Cornell's eXtensible Bioacoustic Tool (XBAT – see http://xbat.org).

Based on spinner dolphin sighting records, predictive modelling techniques can be used to predict habitat preference of dolphins throughout Hawai'ian waters (even for habitats that haven't been surveyed for dolphins) – based on using both physiographic variables (*e.g*, depth, slope, bottom-type, distance from the coast, distance to feeding areas and wind shade) and remotely-sensed variables (*e.g*, sea surface temperature, chlorophyll-a concentration, wind-shade) (Redfern et al. 2006, Johnston et al. 2007, Thorne et al. 2007, Redfern et al. 2008). This allows for predictions to be made on: a) the quality of a given area for spinner dolphins; and, in turn, b) the distance, quality, and availability of alternative sites for spinner dolphins. Thus, by identifying key habitats for spinner dolphins through predictive modelling and quantifying disturbance levels within these areas, it is possible to predict the consequences of high human disturbance and dolphin displacement to less disturbed locations.

INTEGRATION WITH THE IWC LaWE INITIATIVE

This research project, which aims to assess the effects of human activity on spinner dolphins in resting bays in Hawaiʻi and the effectiveness of time-area closures as a proposed mitigation tool, will implement and augment many key aspects of the LaWE initiative. Specifically, the LaWE initiative aims to understand possible effects of whale-watching (and dolphin-based tourism) on the demographic parameters of cetacean populations. Objectives of the LaWE initiative include: a) to determine how exposure to cetaceanwatch activities affects the ecology, behaviour and/or physiology of cetaceans; and b) to determine the effectiveness of mitigation measures employed to reduce the effects of whalewatching. The LaWE initiative proposes to implement a world-wide nested block study design to account for environmental and biological variability. The Hawaiian spinner dolphin project will also implement a nested research design with data available from before and after time-area closure implementation, coupled with replicates of exposure and control sites. As such, this study will help account for inherent variability in the natural system when evaluating impacts of human activity on spinner dolphins and the effectiveness of management intervention. Despite differences in scale, both the LaWE and the Hawaiian spinner dolphin project aims are similar and complementary research designs, and thus we suggest that the Hawai‘i spinner dolphin research initiative become an integral part of the LaWE initiative.

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