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Hematological differences between stingrays at tourist and non-visited sites suggest physiological costs of wildlife tourism

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ABSTRACT

Wildlife tourism alters the environmental conditions in which the focal animal lives, and it is therefore necessary to assess the ability of the animal to adjust to and persist in these novel conditions if the industry is to be sustainable. Here, we report on the physiological responses of southern stingrays (*Dasyatis americana*) which are the focus of intense marine provisioning-tourism in the Cayman Islands. Using stingrays from non-tourist sites about Grand Cayman as a basis for comparison, we show in this natural experiment that tourist-exposed stingrays exhibit hematological changes indicative of physiological costs of wildlife tourism. The novel conditions with which the stingrays must interact include non-natural food, higher injury rates (from boats, conspecifics and predators), and higher parasite loads (from crowding conditions). As a result of this year-round environment, stingrays display sub-optimal health: lower hematocrit, total serum protein concentrations, and oxidative stress (i.e., lower total antioxidant capacity combined with higher total oxidative status). Moreover, they show evidence of attenuation of the defense system: for tourist stingrays only, animals possessing both injuries and high parasite loads also exhibit lowest leukocrit, serum proteins and antioxidant potential, as well as differing proportions of differential leukocytes indicative of suppression (lymphocytes and heterophils) and down-regulation (eosinophils), thus suggesting that the physiological changes of tourist stingrays are in partial response to these stressors. While survival- and reproduction- quantification was not possible in this long-lived marine species, the physiological measures -situated within ecological context, indicate that the long-term health and survival of tourist stingrays have a significant probability of being affected. Consequently, management of the tourism attraction is essential. The indicators chosen in this study reflect general health indices and defense capabilities used across taxa, and represent a tradeoff between ease of collection/analysis and interpretation so that managers can continue the research for monitoring purposes.

1. Introduction

Animals which are the focus of nature-based tourism are exposed to changes in their environment that may influence their survival and reproduction. Their response to these changes depends on whether they perceive humans and their associated activities as a disturbance, predatory threat (Frid and Dill, 2002), refuge, or new food source. Responses within the range of the animal's normal behavioural and physiological repertoire may pose minimal costs (e.g., brown bear, *Ursus arctos*, wildlife viewing; Rode et al., 2006), and in some cases animals can alter their life-history traits to take advantage of the novel conditions created by tourists (Alaskan grizzly bear, *U. arctos*, wildlife viewing; Nevin and Gilbert, 2005). If, however, the new environment causes animals to shift their energetic balance at the cost of maintaining homeostasis, there may be negative impacts on the animal's reproductive effort, survival, and health (e.g., yellow-eyed penguin, *Megadyptes antipodes*, viewing; Ellenberg et al., 2007), particularly for animals exposed to persistent conditions of tourism activities.

Several significant challenges arise when determining the impacts of tourism on marine animals, particularly those that spend their entire life cycle confined to marine waters (unlike seals or penguins). First, marine organisms that do not depend on some above-water-surface resource are often difficult to access and/or observe. The measurement of reproductive success is not always feasible due to the existence of communal nursing grounds or the complete absence of parental care. Similar to terrestrial organisms that are the focus of wildlife tourism, many marine species are long-lived so that tourism effects may be manifested only in

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the long-term, and have large home ranges and migrate over long distances making monitoring and population estimates difficult. Finally, the lack of control populations or baseline estimates for comparison hampers the effectiveness of long-established conservation indicators.

As a result, most studies on the impacts of marine wildlife tourism focus on behavioural changes of the focal species, rather than assessing traditional indicators in conservation biology and wildlife management (animal abundance, food habits, home range size, reproductive success and survival rates; although see Bejder et al., 2006a for an exception). There are difficulties, however, in using deviations in animals' behavioural repertoires to establish cause and effect and/or to demonstrate net cost (Orams, 2004). For instance, many tourism-impact studies rely on wildlife avoidance movements to ascertain energetic costs (Williams et al., 2006), or to establish effective buffer zone distances around viewed animals (Davis et al., 1997). However, sites where avoidance responsiveness is high are not necessarily sensitive areas in need of greater protection; animals in good energetic condition may adopt risk-averse behaviours and initiate avoidance early, whereas animals in poorer condition remain if the cost of escaping is too high (Gill et al., 2001). Alternatively, short-term behavioural responses are insufficient indicators of impacts of anthropogenic disturbance, as moderated responses may not be attributable to habituation but rather due to the absence of sensitive individuals which have already left (Bejder et al., 2006b; Ellenberg et al., 2006).

To fully determine the impacts of tourism, it is imperative to quantify the organism's ability to persist in face of novel selection processes in altered environments (Reznick and Ghalambor, 2001; Stockwell et al., 2003). However, in the absence of the ability to actually determine persistence (i.e., survival and reproduction), a promising alternative or complement to behavioural methods is the use of physiological indicators, the changes in which may be indicative of altered survival and reproductive capabilities. For instance, physiological trade-offs arise when animals have limited resources to allocate between competing life-history traits (Stearns, 1992). Therefore, changes in animals' physiological state may indicate that some important change in their environment has occurred, as well as signify resultant or potential costs. When used in conjunction with other fitness measures, physiological tools can enable the development of effective countermeasures (Hofer and East, 1998; Wikelski and Cooke, 2006) to the effects of wildlife tourism. Indeed, in the absence of population, reproductive and survival estimates, physiological methods are also often the only tools available to assay the perception by an animal of its environment (Wingfield et al., 1997). Moreover, recent advances towards an integrated ecosystem approach to conservation and management have included organismal physiological adaptation as an important link in understanding the relationship between individual- and population-level plasticity (Stevenson et al., 2005); and marine resource management and conservation initiatives are calling upon 'conservation physiology' (Wikelski and Cooke, 2006) to improve fisheries, top pelagic predator conservation (Block, 2005; Young et al., 2006), and in determining the effects of climate-change induced marine acidification (Widdicombe and Spicer, 2008).

Wildlife-tourism impacts on animal physiological defenses have been receiving attention, with recent advances being made. Studies have demonstrated that Galapagos marine iguanas, *Amblyrhynchus cristatus* (Romero and Wikelski, 2002), and adult Magellanic penguins, *Spheniscus magellanicus* (Fowler, 1999), seemed to habituate to tourist disturbances as measured by the stress hormone corticosterone. The chicks of the hoatzin, *Opisthocomus hoatzin*, however, had lower body mass and higher mortality (Müllner et al., 2004), and yellow-eyed penguins (*M. antipodes*; Ellenberg et al., 2007) had higher chick mortality and lower fledgling weight as a result of tourist visitation, using the same hormone as a titer for disturbance. Incubating Royal penguins, *Eudyptes schlegeli*, displayed higher heart rates in the presence of tourists, more so than in the presence of predators (Holmes et al., 2005), and common wall lizards, *Podarcis muralis*, in tourist areas exhibited lower body condition, a higher infection to ticks, lower cell-mediated immune response, and consequently reduced reproductive output (Amo et al., 2006). The ability of physiological measures to reflect health state and predict survival and reproduction of animals exposed to wildlife tourism is therefore immensely effective, and these physiological markers prove reliable tools for evaluating environmental changes including those imposed by tourism. Although conservation physiological approaches have been applied in terrestrial wildlife-tourism settings, we know of no studies to date which have examined animal physiological responses to wildlife tourism confined to the marine environment.

Here, we investigate the physiological responses of the southern stingray (*Dasyatis americana*), the focus of intense tourism activity in Grand Cayman. 'Stingray City Sandbar' (SCS) is an internationally-known tourist attraction approximately 7740 m^2 in area and located in a shallow sound along the island's north coast that began operating in 1984. Year-round, up to 2500 tourists from 40 tour boats can be simultaneously present at any one time at the sandbar feeding, touching, and holding stingrays as part of their marine tourism experience (Shackley, 1998). An estimate of 150 stingrays of both sexes simultaneously aggregate (southern stingrays are normally solitary foragers) at SCS to feed on squid, a non-natural food item, provided by tourists. Corcoran (2006) found that the Grand Cayman tourist stingrays have altered their behaviours in response to the provisioned food including a reduced activity space, strong and persistent site fidelity, and a shift to diurnal behaviors in comparison to stingrays from non-tourist sites. A comparison in serum fatty acid profiles between tourist and non-tourist stingrays suggested that squid is the major food item in the diet of the SCS animals (Semeniuk et al., 2007). Semeniuk and Rothley (2008) have found that as a result of this feeding regime, SCS has now become a permanent habitat for a large population of stingrays which are more likely to have lower body condition (measured as residuals of length–weight relationship), be injured by boats and predators, be susceptible to ecto-dermal parasites, and be engaged in intense interference competition (in the form of conspecific bite marks).

Although behavioural changes have been noted in the SCS stingrays, it is inconclusive whether they represent long term costs to the animal. Our decision to use physiological indicators was motivated by several factors: comparisons of population size with control populations could not be performed due to the very low recapture probabilities of solitary, control stingrays; reproductive effort (fecundity and pup survival) was not measurable as stingrays give live birth in communal pupping areas around the island; and the southern stingray has an estimated longevity of 26 years (Henningsen, 2002), and therefore mortality was not readily observable. Accordingly, physiological indicators were chosen to reflect the capability of stingrays to persist in response to their altered behaviours, non-natural diet, and grouping costs that result from interactions with tourists. Our hypothesis is that group-living stingrays at the tourist site will exhibit differences in their hematological parameters that are indicative of increased physiological costs, in comparison to solitary stingrays from non-tourist sites. The indicators measured include general-health and defense-system parameters: hematocrit (Hct), leukocrit (Lct), total serum protein concentration (Tsp), differential white blood cell counts, and antioxidant capacity (TAC) and oxidative status (TOS). We therefore predict that tourist-exposed stingrays will show evidence of reduced general health (lowered Hct and Tsp), immunosuppres-