Good news for sea turtles

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Following the overexploitation of sea turtle populations, conservation measures are now in place in many areas. However, the overall impact of these measures is often unknown because there are few long time-series showing trends in population sizes. In a recent paper, George Balazs and Milani Chaloupka chart the number of green turtles *Chelonia mydas* nesting in Hawaii over the past 30 years and reveal a remarkably quick increase in the size of this population following the instigation of conservation measures during the 1970s. Importantly, this work shows how even a small population of sea turtles can recover rapidly, suggesting that Allee effects do not impede conservation efforts in operation worldwide.

There is worldwide concern over the status of sea turtle populations, with all species for which there are available data being listed by the International Union for Conservation of Nature and Natural Resources (IUCN) as endangered or critically endangered (http://www.redlist.org/). The plight of sea turtles has been heightened by high-profile reports detailing the decline of some populations [1–3]. For example, strong empirical evidence suggests that leatherback turtles *Dermochelys coriacea* in the eastern Pacific are being driven to extinction through incidental capture by pelagic fisheries [1]. Although the decline of certain populations is real and a cause for great concern, there are turtle conservation success stories [4]. Most recently, a 30-year time-series of population number for green turtles *Chelonia mydas* in Hawaii reveals a remarkable population recovery following the introduction of conservation measures during the 1970s [5]. This new finding provides an important message: conservation measures can lead to rapid population recoveries for sea turtles.

Historical exploitation and population recovery

Around the world, there are many examples of how the exploitation of sea turtles by humans has reduced the size of populations [6,7]. One of the most startling examples is from the Caribbean, where it has been estimated that, before Europeans arrived during the 15th century, there were tens of millions of green turtles, a figure that has subsequently been reduced by 93–97% as a result of harvesting [2]. In many areas, the recent history of turtles has been more favourable, with various local, national and international conservation measures in place. However, because there are very few long-term studies of sea turtle population sizes, it has been difficult to assess how populations have faired following the introduction of conservation measures (Box 1).

Over the past three decades, George Balazs and his team have recorded the number of green turtles nesting in the Hawaiian archipelago. Most turtles nest on French Frigate Shoals, a tiny atoll several hundred kilometres from the populated islands. In a new paper, Balazs and Chaloupka provide encouraging evidence for how this population has increased over a relatively short period [5].

Green turtles in Hawaii have been subject to human exploitation from at least the mid-1800s, but have received protection since 1978 under the US Endangered Species Act. Following their first visit to French Frigate Shoals in 1973, Balazs and his team have returned to the atoll every year to count the tracks of nesting turtles and, hence, have been able to evaluate how the population has responded to the introduction of protection measures. Balazs and Chaloupka highlight how conventional wisdom held that a seriously depleted green turtle population might take >100 years to recover after the cessation of harvesting, with recovery impeded by the low fecundity, late maturation and long generation times that are characteristic of such species [3,8]. However, the longitudinal study revealed an approximately fourfold increase in nesting numbers over the past 30 years. The fact that this corresponds with the introduction of the Endangered Species Act suggests that the recovery is a result of conservation measures rather than simply being part of much longer term (multi-decadal) fluctuations in population size. The population has recovered so well

Box 1. Methodological issues and interannual variability

Assessing the size of marine turtle populations is not straightforward. Whilst they are at sea, individuals are typically dispersed widely and so are difficult to count. The standard method is to make counts on nesting beaches. However, the counts in one year do not equate to the number of mature females in a population, because individuals rarely nest every year, with the typical interval between successive nesting seasons, termed the remigration interval, being two–four years. Feeding conditions, and the attainment of a threshold body condition, might influence the length of the remigration interval, with large-scale climate signals driving synchrony in breeding cycles between individuals [15,22]. This synchrony can cause a high degree of interannual variability in nesting numbers with, at the most extreme, nesting numbers varying by more than an order of magnitude between years [23]. Consequently, several years of monitoring are required to produce an accurate index of a population size.

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that the authors conclude that it might now be approaching the carrying capacity of the foraging grounds. The recovery is probably not due to the immigration of individuals from other populations, because the isolation of Hawaii means that immigration of individuals from other Pacific rookeries is rare, a point confirmed by mtDNA studies by Balazs and his collaborators.

Allee effects and sea turtles

What is particularly striking about this Hawaiian green turtle case-study is both the speed of the population recovery and that such a large population could have quickly resulted from so few individuals. For many species, there is a per capita drop in reproductive output when population density is low, termed the Allee effect, so that recovery of small populations is often difficult [9,10]. Allee effects operate in several ways. For example, at low population densities, male–female encounters might be reduced, whereas, in cooperative breeders, there might be a critical group size below which a group cannot operate effectively [9]. Whether Allee effects operate in sea turtle populations, and at what population density, is unknown but, encouragingly, the Hawaiian green turtle population has staged a strong recovery in spite of low population numbers. For example, annual nesting numbers in Hawaii are approximately two orders of magnitude lower than in the Costa Rican green turtle population, which has shown a similar decadal trend of increasing size (Figure 1). These parallel trends for both small and large populations suggests that populations of sea turtles that have been reduced elsewhere as a result of the activities of humans could recover if conservation measures are implemented.

There are probably several processes contributing to the observed population recovery of green turtles in Hawaii. Importantly, conservation efforts have protected both adult and juvenile turtles, because the archipelago is a foraging area for juveniles and adults as well as a nesting area. For species such as the leatherback turtle *Dermochelys coriacea*, which moves widely and is not in residence within any single country during its juvenile and adult stages, conservation measures must operate at an international level [11,12], which is far more challenging. For green turtles, preventing the harvest of juveniles will have produced an immediate increase in recruitment to the adult population, resulting in an initial rise in nesting numbers following conservation measures. Protection of adults, their eggs and their nesting habitat will have increased the production of hatchlings, ultimately leading to more nesters when these hatchlings attain maturity, which takes ~25 years for this population [13]. Furthermore density-dependent factors might be operating, with growth rates of individual green turtles being faster when population density is low [14], encouraging the recovery of once exploited stocks.

Conservation success stories

The quick recovery of the green turtle population in Hawaii is another remarkable success story to add to turtle conservation efforts worldwide, which have seen many populations, such as green turtles in Tortuguero (Caribbean), the Great Barrier Reef (western Pacific) and Ascension Island (Atlantic) (Figure 2) increasing or maintaining stable numbers over recent decades [15–17]. Furthermore, major nesting grounds continue to be discovered, with, for example, a recent report of >1000 leatherback turtles nesting in the Nicobar Islands (Indian Ocean) [18] which is a sizeable population given that the entire adult population of leatherbacks in the Pacific was thought to number only a few thousand [19]. In conservation biology, bad news (e.g. populations being decimated or driven to

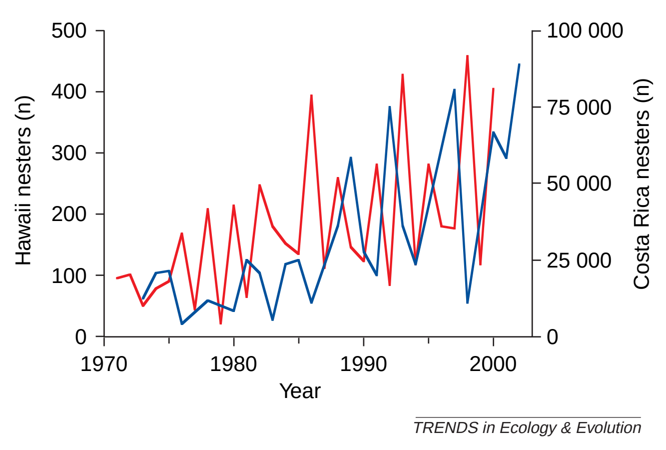

Figure 1. The numbers of green turtles nesting at French Frigate Shoals, Hawaii (blue line) and Tortuguero on the Caribbean coast of Costa Rica (red line) (redrawn, with permission, from [5] and [15,24], respectively). The upward trend in nesting numbers in Hawaii broadly matches that seen at the much larger rookery in Costa Rica. For consideration of the issue of interannual variability in nesting numbers, see Box 1.

Figure 2. A green turtle returns to the sea after nesting on Ascension Island (January 2004). The profusion of tracks reflects that this population, similar to others, is doing well following conservation efforts [17]. Reproduced with permission from Graeme C. Hays.

extinction) is often given priority in the highest ranking scientific journals [1,20,21], the bad-news-sells maxim. However, although turtles have been subjected to considerable human exploitation, the underlying story is certainly not all bleak for these creatures: we can be encouraged that conservation programmes can be successful.

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Stochastic population theory faces reality in the laboratory

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Understanding the factors that affect most severely the extinction risk of populations is crucial for maintaining biodiversity. An important general pattern derived from stochastic population theory is that time to extinction should decrease with increasing environmental stochasticity. Drake and Lodge recently provided one of the first pieces of experimental support for this simple prediction by artificially manipulating the dynamics of populations of *Daphnia*. A future challenge will be to include both demographic stochasticity and environmental stochasticity in such studies.

The extinction of populations and species is the key process determining biological diversity. Until recently, however, ecologists have failed to develop general predictions of the conditions under which extinction is most likely to occur. Even for well studied taxa, such as birds and mammals, with a history of long-term data collection, our understanding of extinction as a process is still poor [1]. However, there is an urgent need for ecologists to make general recommendations (e.g. about critical lower population sizes to secure population viability) that can help reduce the current biodiversity loss. Stochastic population theory has the potential to form the basis for the development of such general guidelines because of its focus on the dynamics of small populations.

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