RESEARCH SUMMARY

ROLE OF SEA TURTLES IN TERRESTRIAL FOOD WEBS

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Nutrient and energy transfers between ecosystems are essential for maintaining food web structures and community dynamics (Polis *et al*., 1997). Mobile organisms transfer nutrients and energy between habitats, functioning as subsidies that enhance ecosystem productivity (Likens & Bormann, 1977; Vander Zanden *et al*., 2012). For example, seabird guano is a significant source of nitrogen and phosphorus compounds that enriches mangrove vegetation and supports invertebrate food webs (Appoo *et al*., 2024). Similarly, carrion and macrophytes provide energy to consumers, reducing predation and grazing pressures respectively on resident species (Bouchard & Bjorndal, 2000; Spiller *et al*., 2010) and influencing population dynamics across ecosystems. Therefore, it is important to identify ecosystem subsidies and their role in sustaining complex food webs.

Sea turtles play multiple ecological roles, such as ecosystem modifiers, e.g., green turtles regulate seagrass productivity (Lal *et al*., 2011; Christianen *et al*., 2014), and prey for marine apex predators, e.g., for tiger sharks (Hammerschlag *et al*., 2015). Despite spending limited time on land, they also transport nutrients between marine and terrestrial ecosystems. For example, live hatchlings carry nutrients and energy back to the sea while dead turtles wash ashore supplying energy as carrion. Nest contents such as hatched eggshells, chorioallantoic fluid from hatched eggs, undeveloped eggs, and dead hatchlings can provide an average of 688 g of organic matter, 18,724 kJ of energy, 151 g of lipids, 72 g of nitrogen and 6.5 g of phosphorus (Bouchard & Bjorndal, 2000) to the beach environment, nourishing nutrient-poor coastal habitats. These deposited nutrients are then utilised by dune vegetation and meiofaunal communities, improving beach productivity and underscoring the importance of sea turtles in non-marine habitats (Madden *et al*., 2008; Vander Zanden *et al*., 2012; Le Gouvello *et al*., 2017).

During the nesting season, sea turtles create a nutrient pulse, serving as a critical food source for terrestrial species. Nutrients remaining in the nest are consumed by detritivores and decomposers such as nematodes, flies etc. (Bouchard & Bjorndal, 2000; Tsiafouli *et al*., 2020), while eggs and hatchlings are predated upon or scavenged by mammals or birds, including jaguars, rats and seabirds (Caut *et al*., 2008; Fonseca *et al*., 2020; Stokes *et al*., 2024). Through the nutrient influx, sea turtles link food webs across marine and terrestrial habitats. The recent studies summarised below have further demonstrated the ecological importance of sea turtles in maintaining terrestrial food webs.

Sea turtle eggs and hatchlings provide nutrition to coastal species during incubation or after emergence. Avenant *et al*. (2023) investigated the contributions of loggerhead turtle (*Caretta caretta*) eggs and hatchlings to the golden ghost crab (*Ocypode convexa*) diet at Ningaloo World Heritage Area, Australia. Golden ghost crabs predominantly scavenge on beach detritus, carrion, seagrass, and algal wrack with occasional consumption of turtle eggs and hatchlings (Rae *et al*., 2019; Avenant *et al*., 2023). This study employed multiple dietary techniques including stable isotope analysis (SIA), gut content analysis (GCA), DNA analysis, and feeding trials to assess ghost crab diets. Due to the different temporal scales captured by these techniques, GCA did not detect sea turtles in the crab diet; however, SIA and DNA analysis identified their presence through nitrogen and carbon isotopic signatures and reptile DNA respectively. Feeding trials demonstrated that ghost crabs preferentially consumed eggs and hatchlings over algal wrack, though not over fish carrion. This suggests that eggs and hatchlings may provide highly nutritious protein for ghost crabs during the nesting season. Avenant *et al*. (2023) effectively identified the inputs of sea turtles into coastal food web systems using complementary techniques.

In addition to coastal species, sea turtles can contribute to the diet of terrestrial predators like dingoes. Behrendorff *et al*. (2023) examined predator-prey interactions between dingoes and green (*Chelonia mydas*) and loggerhead turtles, revealing that dingo packs rely heavily on eggs as a nutrition source during the sea turtle nesting season. Turtle nests on K'gari (formerly known as Fraser Island), Australia, were monitored for predation over two nesting periods and then compared across survey zones, years and dingo packs. The findings showed that dingoes predated on 84-94% of sea turtle nests, indicating that these nests potentially sustain the dingo population in northern K'gari during the turtle nesting season. Excessive dingo predation could cause a collapse of the turtle rookery so a nest translocation and *in situ* protection program was initiated to regulate the predation rate. However, given the cultural significance of dingoes to the traditional owners, the Butchulla community, and their protected status under Queensland law, restricting access to turtle nests may impact their populations. Therefore, conservation managers and policymakers must consider innovative approaches to ensure the survival of both sea turtle nests and dingoes. Behrendorff *et al*. (2023) highlighted that sea turtle nest consumption by protected or culturally important species can create a conservation challenge.

Several turtle rookeries globally focus conservation efforts on reducing predation impacts on their populations, which can inadvertently disrupt local seasonal food webs and affect other species. Lin *et al*. (2023) investigated the effect of green turtle nest protection on insular reptile and amphibian populations. On Orchid Island, Taiwan, predatory snakes such as the kukri snake and stink ratsnake predated turtle eggs until this resource was cut off after the initiation of a nest protection program. Lin *et al*. (2023) used 23-year population monitoring data on these predatory snakes and their alternative amphibian prey to assess the impact of removing turtle nests as a nutritional source. Additionally, they conducted feeding experiments and mark-recapture programs to estimate the daily turtle egg biomass consumed by snakes. Their results showed that in the absence of turtle eggs snake species predated on lizard eggs causing a sharp decline in lizard populations. Snakes consumed more eggs to maintain their daily mass intake, depleting recruits to lizard populations. Moreover, the change in prey availability prompted snakes to alter their habitats, moving closer to forests and concrete walls for easier access to lizard nests. Comparative analyses of lizard populations across different islands confirmed the removal of sea turtle resources as the primary cause of their decline. These findings highlight the role of sea turtles in supporting island food webs and the need to consider ecosystem-level consequences before implementing conservation strategies (Lin *et al*., 2023).

Collectively, these studies expand our understanding of the ecological role of sea turtles, revealing their functions in other ecosystems. Avenant *et al*. (2023) and Behrendorff *et al*. (2023) focus on their contributions as important prey for coastal species, while Lin *et al*. (2023) underscores their role in regulating terrestrial food webs by alleviating predatory pressure on other taxa. Furthermore, these studies address a key research priority identified by Hamann *et al*. (2010) and Rees *et al*. (2016) by assessing the role of sea turtles as nutrient transporters and prey. Further studies on the presence of sea turtles in the diets of other predators, particularly from coastal and terrestrial habitats, at different rookeries will be essential for determining the potential integration of sea turtles into non-marine food webs. Their value to terrestrial food webs should also be considered when developing or selecting conservation strategies, such as moving eggs to a hatchery, which may remove or centralise nutrients on a nesting beach.

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