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ORIGINAL PAPER

Impact of marine hitchhiker load on host energy intake

Nupur Kale[1] · Lu Quinn[1] · Ahmed Fouad[2] · Graeme C. Hays[3] · Kimberley L. Stokes[1] · Nicole Esteban[1]

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Abstract

Determining the energetic and fitness trade-offs associated with symbiotic relationships (mutualism, commensalism or parasitism) can reveal the implications of symbiosis for species and ecosystem health. To identify hitchhiker impact on sea turtles, this study reviewed global literature and examined the association between remoras (*Echeneis naucrates*) and green turtles (*Chelonia mydas*) at a high-density foraging site in the Red Sea using SCUBA and video ($n=71$ observations) in October 2023. Previous evidence of remora-sea turtle association is limited to qualitative observations from the Atlantic and Pacific Oceans. The results show that depth significantly impacted the number of remoras per turtle ($p<0.05$). Turtle grazing rate was affected by remora load ($p<0.05$), decreasing by ~30% across the load range from a mean of 22.8 bites min^{-1} (0 remoras) to 15.6 bites min^{-1} (3 remoras). There was little evidence of benefit to turtles, with only one observation of a remora cleaning a turtle carapace. The observed reduction in grazing effort suggests potential impacts on green turtle body condition over time, which may affect growth, reproduction, and population health, warranting long-term investigation. These findings present the first quantitative evidence that the remora-sea turtle relationship shifts from commensalism to parasitism as remora load increases, demonstrating the potential costs of hitchhikers for sea turtles.

Keywords Epibionts · Interspecific · Live sharksucker · Marine turtles · Phoresis · Suckerfish

Introduction

Symbiosis plays a fundamental role in ecology, whereby complex energetic and fitness cost-benefit exchanges between individuals can lead to beneficial, neutral, or detrimental outcomes (Douglas 2010). Symbiotic relationships are typically categorised into mutualism (e.g., sea anemones and anemonefish; Kobayashi et al. 2025), commensalism (e.g., Portuguese man-of-war and man-of-war fish; Jenkins 1983) or parasitism (e.g., largespot pompano fish and parasitic isopods; Parker and Booth 2013) and may involve direct or indirect costs and benefits for all species involved. For example, the longfin damselfish *Stegastes diencaeus* has an increased travel time and incidence of attacks from territorial fish to reach cleaning stations for a cleaning symbiosis with gobies (Cheney and Côté 2001). Such host-symbiont interactions are found to influence individual and population health significantly, and ecological communities more broadly (Palmer et al. 2010; Qian and Akçay 2020). At the community level, these interactions can drive species evolution that improves diversity (Forsman et al. 2002; Chomicki et al. 2020) or adversely affects community assemblages (Elma et al. 2023). Therefore, measuring cost-benefit transactions between organisms is important to identify the nature of their association and its impact on species and community dynamics.

Phoresy is a passive association in which one species (phoretic) hitchhikes on a large species (host) to move between resource patches, forming a commensal or mutualistic relationship (Brunnschweiler et al. 2020; Bartlow and Agosta 2021; Seeman and Walter 2023). Some phoretics may also express parasitism by extracting resources from hosts or interfering in their physiological processes such as assimilation or reproduction in transit. For example,

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✉ Nicole Esteban
n.esteban@swansea.ac.uk

[1] Biosciences Department, Swansea University, Singleton Park, Wales SA2 8PP, UK

[2] Red Sea Project, Graz 8010, Austria

[3] Deakin Marine Research and Innovation Centre, School of Life and Environmental Sciences, Deakin University, Geelong, VIC 3280, Australia

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astigmatid mites *Hemisarcoptes cooremani* are known to extract water from their beetle hosts *Chilocorus cacti* (Houck and O'Connor 1995), and an increased load of mites *Macrocheles subbadius* reduced the body and testes condition of flies *Drosophila nigrospiracula* (Polak 1998). Such direct and indirect impacts on host fitness have been examined extensively in terrestrial phoretic arthropods such as mites (Bartlow and Agosta 2021; Sun 2022). However, phoresy in the marine environment remains understudied due to the difficulty of observing this strategy across large spatial scales and other logistical challenges (Bartlow and Agosta 2021).

A well-known example of marine phoresy is between remoras (Echeneidae) and megavertebrates such as elasmobranchs and cetaceans (Brunnschweiler 2006; Ten et al. 2022) leading to the common name of sharksuckers for *Echeneis naucrates*. Remoras are teleosts that are free-swimming or attach to large hosts using their modified first dorsal fin as a suction disk, indicating that phoresy is a facultative behaviour (Cressey and Lachner 1970; Astakhov 2020). Through hitchhiking, remoras reduce the energetic costs of locomotion and receive feeding and mating opportunities (Silva-Jr and Sazima 2003; Brunnschweiler and Sazima 2008). In exchange, it is assumed that they clean ectoparasitic copepods, and dead and sloughed tissues from hosts, potentially reducing their disease risk (Strasburg 1959; Cressey and Lachner 1970). The remora-host association is often considered mutualistic; however, the dynamics remain unclear with little quantitative evidence of benefit to the host (Wosnick et al. 2024). Moreover, observations of elasmobranchs and cetaceans attempting to dislodge remoras (e.g. Ritter 2002; Weihs et al. 2007) suggest a complex relationship that may vary with host species and local ecological conditions (Wosnick et al. 2024).

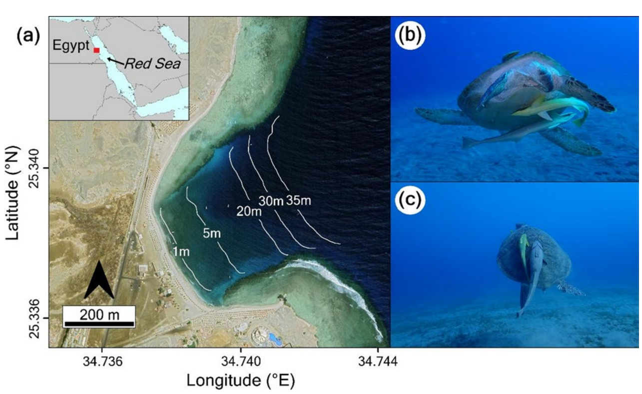


Fig. 1 (**a**) Marsa Abu Dabbab (red square on inset) has multispecific seagrass meadows in the shallow nearshore region and is bound by fringing reefs along the northwest and southeast borders. Remoras (*Echeneis naucrates*) are associated with grazing green turtles (*Chelonia mydas*) and (**b**) swim near or (**c**) attach to the carapace or the plastron depending on green turtle activity, often shifting from the plastron to the carapace as turtles settle on the seabed to graze on seagrass

While the remora-elasmobranch relationship has been frequently investigated, relatively few studies have reported interactions with sea turtles (Fretey 1979; Sazima and Grossman 2006). Historical records indicate that the remora-sea turtle association was exploited in turtle fisheries in Cuba, Colombia, Tanzania, and Madagascar when turtles were ensnared using remora as bait (Holmwood 1884; De Sola 1932; Hughes 1973). Previous studies have documented remora species, specifically *E. naucrates* and *Remora remora*, as epibionts on hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), olive ridley (*Lepidochelys olivacea*), and green turtles (*Chelonia mydas*) in the Atlantic and Pacific Oceans (e.g. Sazima and Grossman 2006; Sosa-Cornejo et al. 2012). Underwater observations describe the remora-sea turtle association as one involving hitchhiking, with remoras feeding on substrate disturbed by the host (Sazima and Grossman 2006).

There is currently a limited understanding of the remora-sea turtle symbiotic relationship, and its associated energetic and fitness costs and benefits have yet to be quantified. In this study, we investigate the association between sharksuckers (*E. naucrates*, hereafter remoras) and green turtles using SCUBA surveys in the Egyptian Red Sea. We examine factors (e.g., size and depth of turtles) that influence the presence and number of remoras carried by turtles, and assess the impact of remoras on grazing. Finally, we conduct a global literature review to examine the association between remoras and sea turtles and consider the implications for turtle populations.

Materials and methods

(a) Characteristics of study site

Marsa Abu Dabbab (25.34°N, 34.74°E) is a shallow bay spanning 0.17 km^2 in the southern Red Sea region of Egypt (Fig. 1a). The bay is characterised by sandy substrate at depths ranging from 0 to 22 m, bound by fringing reefs along its northern and southern margins. Seagrass meadows cover over 60% of the bay, comprising *Halophila stipulacea*, *Halodule uninervis* and *Halophila ovalis*, extending across all depths (Mancini et al. 2015). The meadows support stable populations of megaherbivores, including a high density of green turtles (Fouad et al. 2022) and dugongs (*Dugong dugon;* Shawky et al. 2024) that host remoras (Sazima and Grossman 2006; Ten et al. 2022). Previous studies recorded green turtle densities of up to 674.7 turtles km^{-2} with numbers peaking between October and May i.e., the non-nesting period (Fouad et al. 2022). Despite fluctuations in densities, up to 90% of the individuals are considered year-round residents in the bay (Mancini et al. 2015).

The bay provides optimal conditions for studying sea turtle behaviour and the remora-sea turtle association as green turtles foraging in this location are largely undisturbed by observer presence (Mancini et al. 2015). Other factors including good visibility (up to 30 m) and accessible nearshore seagrass meadows facilitate *in situ* observations of turtles at their foraging grounds (Mancini et al. 2015).

(b) **Remora-green turtle encounters**

Data were collected using observations and video recordings during SCUBA dive surveys between 9 and 26 October 2023. Dives were categorised as either morning (0800–1200 h) or afternoon (1200–1600 h). SCUBA divers used a search-like pattern within the bay to maximise the likelihood of green turtle encounters. Upon each encounter, the number of remoras (i.e., remora load) attached to each turtle and their position in the water column or depth (m) were noted. Turtle size, measured as straight carapace length (SCL_{max}), was estimated to the nearest 5 cm using a 120 cm-long measuring stick held along or above the carapace, depending on the observer's location, to minimise disturbance to the turtle (e.g. Donoso and Dutton 2010). We used handheld cameras (Olympus Tough TG-6, Olympus Corporation, Japan and GoPro Hero 10, GoPro Inc., US) to photograph the turtle's left and right facial profiles and carapace and to record their grazing activity for at least 2 min.

Sex and life stage were recorded; turtles with SCL_{max} < 70 cm were classified as immature (70 cm, Howell et al. 2016; 77 cm, Phillott and Rees 2018). To check for repeat observations of the same individual, we used photographs of facial scute patterns of all observed turtles for identification, following the method in Jean et al. (2010). We created a database for the study by assigning identification codes to individuals based on the unique shape and position of their facial scutes.

Grazing rate (or bite rate; bites min^{-1}), a common measure of foraging efficiency in megaherbivores (e.g. Gulick et al. 2022), was used to assess the potential impact of remoras on turtle fitness. We measured grazing rate by counting the number of bites in video recordings and then calculated the rate for each turtle. We noted any instances of remoras cleaning turtle carapaces as an indicator of benefits to host health. We used focal sampling to develop an ethogram of remora behaviours during their interactions with green turtles and reviewed all video observations included in this study.

(c) **Statistical analysis**

All analyses were performed in R v4.2.3 (R Core Team 2024). We employed stepwise multiple linear and logistic regressions to investigate the relationship between remoras and green turtles. Explanatory variables were selected based on statistical significance, using a *p*-value threshold of $\alpha = 0.05$. Linear regression model residuals were checked for normality using Shapiro-Wilk tests. Where residuals violated assumptions of normality, the logarithmic of the response variable was used. Values are reported as mean ± SD, range.

i) Remora load

We explored the relationships between (a) remora presence/absence and turtle size using logistic regression (binomial distribution) and (b) mean remora load per individual and depth underwater using linear regression.

We examined if the observed distribution of remoras across turtles differed from that expected assuming that remoras randomly associated with turtles. We had 71 observations of turtles and a total of 80 remoras spotted. So we randomly selected 71 numbers from a distribution of integers from 0 to 4, that summed to 80, to simulate the expected number of remoras for each turtle. We repeated this simulation 20 times and in each case we compared the modelled number of remoras per individual versus the observations using a Chi-squared goodness-of-fit test.

ii) Impact of remoras on green turtle fitness

Turtle grazing rates were compared between morning and afternoon observations using a Welch Two Sample t-test. A stepwise multiple regression was conducted to examine the relationship between mean grazing rate per individual (bites min^{-1}) and turtle size, mean remora load per individual and depth, with grazing rate as the response variable.

(d) **Global review of remora-sea turtle associations**

We searched for peer-reviewed literature on remora-sea turtle associations on Web of Science and Google Scholar between 26 and 28 September 2024 using a combination of keywords: ("remora" AND (("sea" OR "marine") AND "turtle") AND ("interaction" OR "association")) considering studies published between 1960 and 2024. We examined studies for information on remora-sea turtle associations. We then used the snowball method to identify additional literature by scanning reference lists of shortlisted papers

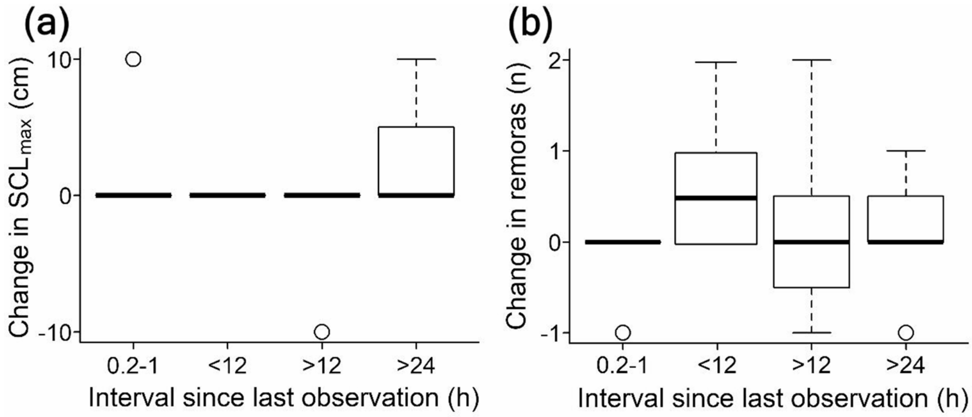


Fig. 2 Repeated observations of turtles were confirmed using photo-identification (Jean et al. 2010), with 14 individuals recorded up to 6-times across intervals spanning 10 min (0.2 h) to 1–11 days (>24 h). Comparison between observations showed that (**a**) the maximum difference in estimated turtle size was ±10 cm reflecting the error associated with visual *in situ* size estimation and (**b**) remora load per individual remained constant for 50% of the observed turtles, with the change in load ranging from −1 to +2 remoras (see Table S1)

(Greenhalgh and Peacock 2005) and conducted a forward search by checking articles that cited the shortlisted papers. From each study, we extracted information on observed remora and sea turtle species, site, ocean basin, and the number of observations.

Results

We recorded 71 observations of green turtles and 37 video observations of grazing activity during 29 SCUBA dives at depths between 1.5 and 16.4 m in Marsa Abu Dabbab. Up to 4 remoras were attached to the carapace and/or plastron of green turtles in 58% of observations with a mean of 1.13 (±1.13) remoras per individual. Remoras were observed attached to turtles across their size range (50–120 cm). Most turtles (88%) were mature (SCL_{max}: X±SD=81.19±14.86 cm, 55–115 cm; n=71). In 100% of observations, neither green turtles nor remoras showed signs of disturbance due to observer presence, such as changes in behaviour or ceasing activity.

(a) Observations of the same individuals

There were repeat observations of 14 green turtles, with their estimated body size (SCL_{max}; Fig. 2a) and remora load (Fig. 2b) varying by ±10 cm and from −1 to +2 remoras between consecutive observations for 28.5% and 50% of the turtles (Table S1). The time interval between observations ranged from 10 min to 11 days.

(b) Remora load

Smaller turtles were less likely to have remora than larger turtles (Logistic regression, $\chi^2=13.18$, df=69, $p<0.05$, $n=71$; Fig. 3a, Table S2), and mean remora load per turtle increased with mean depth (Linear regression, $F_{1,38}=9.58$, $R^2=0.20$, $p=0.004$, $n=40$; Fig. 3b).

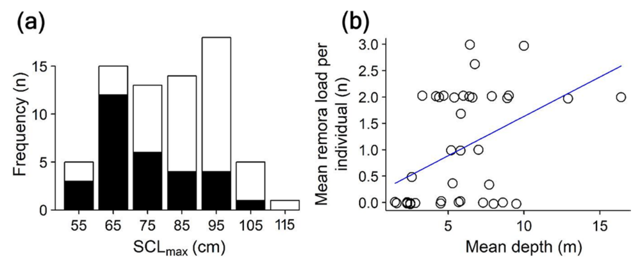


Fig. 3 **(a)** Remoras (*Echeneis naucrates*) were observed hitchhiking on foraging immature and mature green turtles (*Chelonia mydas*) in Marsa Abu Dabbab, Egyptian Red Sea. Black and white bars represent turtle observations where remoras were absent and present respectively. Turtle size (SCL_{max}) axis labels indicate the mid-point of each category. Size was estimated using a measuring stick with 10 cm increments. **(b)** Mean remora load per green turtle in Marsa Abu Dabbab ranged from 0–3. Remora load per individual increased significantly with depth (remora load=0.14+0.15*depth; $R^2=0.20$, $p=0.004$). Blue line represents the line of best fit

One simulation is shown for the distribution of remoras per individual assuming that remoras randomly associated with turtles (Fig. 4). In 20 out of 20 simulations, the modelled distribution differed from the observed number (Chi-squared, $\chi^2>9.50$, df=4, $p<0.05$). In short, the number of times we observed 2 remoras per individual was much higher than expected by chance.

(c) Impact of remoras on green turtle fitness

The mean green turtle grazing rate was 21 bites min^{-1} (±6, 10–34 bites min^{-1}, n=37 videos) recorded over a mean observation duration of 3.8 min (±1.4, 2–7.8 min, n=37). The number of observations per individual varied from 1 to 6 (2.5, n=15 individuals). For each individual,

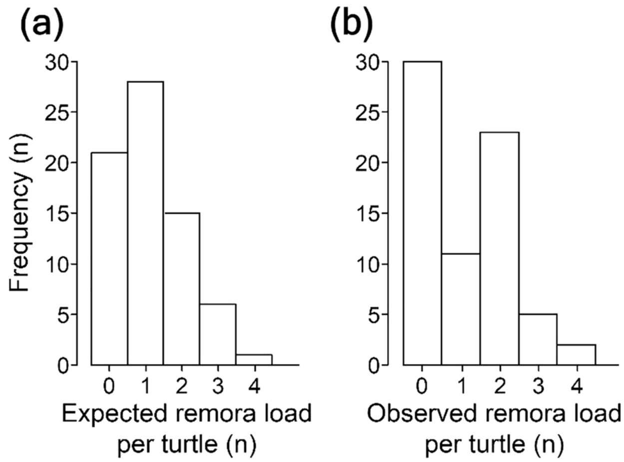


Fig. 4 Frequency distribution of (**a**) expected vs. (**b**) observed remora load per turtle. Solitary remoras were rare compared to pairs of remoras, which were observed more frequently than expected by chance

Table 1 Ethogram of green turtle-associated remora behaviours in Marsa Abu Dabbab, Egyptian Red Sea (n=25 turtles, 45 remoras, 94 min of video observations)

Behaviour	Description	Count (n)
Detach and reattach	Remoras detach and reattach on the same host but at a different position	36
Disturbance to host	Remora behaviour disturbs or interferes with host behaviour	5
Remain attached	Remoras remain attached to the host throughout observation period	4
Feed	Remoras feed on organisms on host carapace or from disturbed substrate	2
Switch hosts	Remora switches hosts	1
Attempt hitchhiking	Remora attempts attaching on turtle	1
Cleaning	Remora cleans host by feeding on organism attached to the carapace	1
Free swimming	Remora detaches and swims away from host	1

the mean measured size, depth, remora load and grazing rate was calculated. Mean grazing rate per individual was then entered into a stepwise multiple regression against turtle size, depth and remora load. Both turtle size and remora load per individual significantly impacted grazing rate, explaining 35% and 24% of the variation in grazing rate respectively (grazing rate = 7.14 + 0.21*SCL_{max} – 3.19*remora load; multiple stepwise regression, turtle size: $F_{1,13}$ = 11.39, p = 0.01; remora load: $F_{1,13}$ = 7.01, p = 0.02, n = 15; Fig. 5), i.e. grazing rate increased with turtle size and decreased with remora load per individual. Grazing rate did not differ between morning (X ± SD = 20 ± 6 bites min^{-1}, n = 12) and afternoon (22 ± 8 bites min^{-1}, n = 9) observations (T-test, t = −0.41, df = 4, p = 0.71), and was not affected by depth (Linear regression, $F_{1,11}$ = 0.03, p = 0.87).

We recorded one observation (out of n = 37 video observations) of a remora cleaning a turtle carapace (SCL_{max}: 105 cm) at 6 m depth.

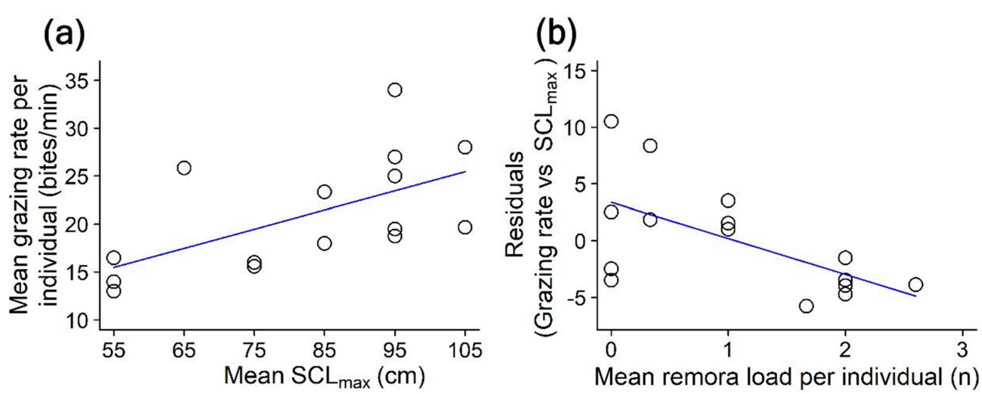
(d) **Remora and green turtle behaviour**

Remoras were often observed in dimorphic pairs (grey and yellow individuals; Fig. 1b, c), occasionally accompanied by smaller individuals. Detaching temporarily to change positions on the carapace or from carapace to plastron of the same host was the dominant behaviour across observations. They were sometimes observed changing hosts (e.g., from dugong to green turtle; Video S1, or from turtle to turtle; Fig. S1) or shifting to a free-swimming state. Free-swimming remoras were also seen attempting attachment to turtles. Turtles sometimes reacted to remora movements by brushing them off using front flippers or interrupting grazing when remoras attached/detached (Table 1, Video S2, S3).

(e) **Global remora-sea turtle encounters**

Remora-sea turtle associations have been reported in 13 studies in the Pacific and Atlantic Oceans since 1979 and included both *R. remora* (n=11) and/or *E. naucrates*

Fig. 5 (**a**) Mean grazing effort increased with green turtle body size (SCL_{max}) and (**b**) decreased with remora load per individual, resulting in 30% reduction in grazing rate as remora load increased from 0 to 3 remoras (p<0.05). Lines of best fit shown in blue



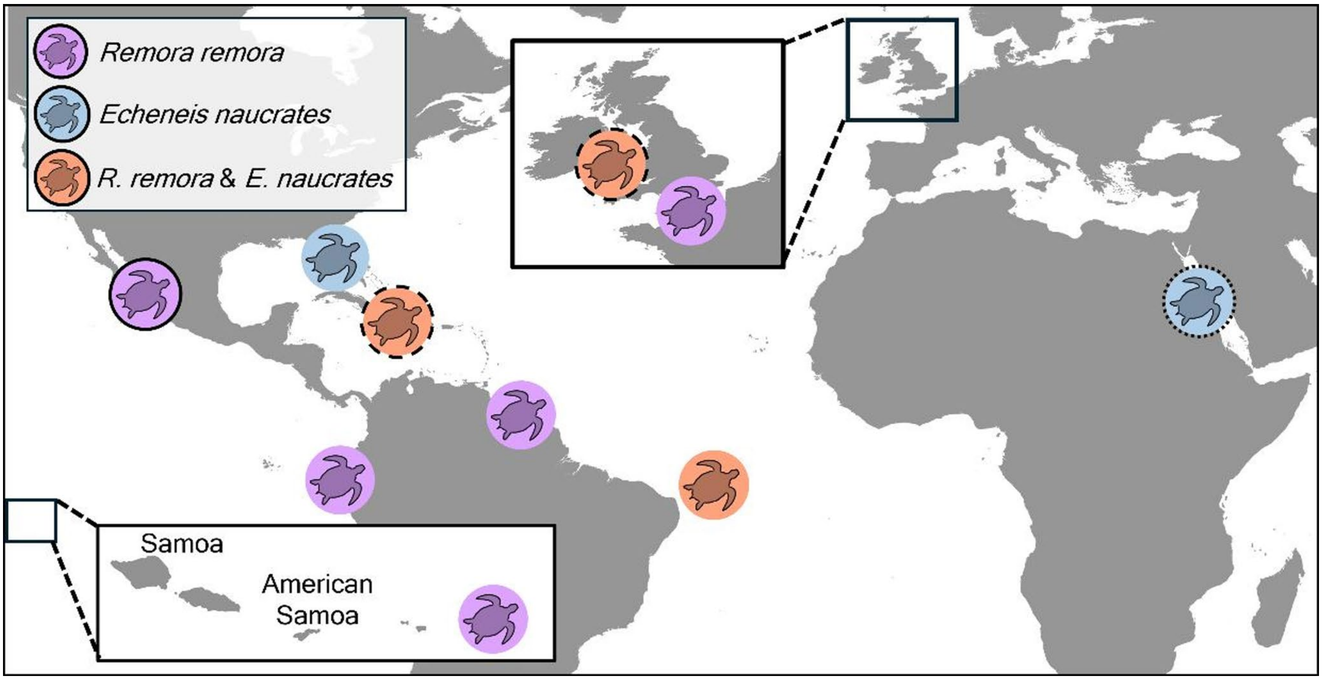


Fig. 6 Two species of remora have been observed to associate with sea turtles, previously in studies in the Atlantic and Pacific Oceans. The present study is the first report from the Indian Ocean region (dotted circle). Open, dashed and closed circles represent one, two or three studies respectively (see Table S3)

($n=5$) (Table S3). Remoras have been associated with five of the seven sea turtle species excluding flatback (*Natator depressus*) and Kemp's ridley (*Lepidochelys kempii*) turtles (Fig. 6). Observed remora-sea turtle interactions were mainly during nesting (53%), swimming (41%) or net capture (6%). Records included remora and sea turtle morphometrics ($n=7$), attachment positions ($n=1$), remora-sea turtle body size ratio ($n=1$) and behavioural descriptions of remoras ($n=1$).

Discussion

This study presents the first quantitative assessment of remora impact on green turtles, providing insights into the behavioural costs of hitchhikers. Past studies on remora-sea turtle associations have primarily focussed on recording remora presence on turtles (e.g. Sosa-Cornejo et al. 2012; Van Houtan et al. 2016), with qualitative descriptions of hitchhiker behaviour (Sazima and Grossman 2006). Remora interactions with cetaceans and elasmobranchs sometimes include hosts displaying antagonistic behaviours towards their hitchhikers (Ritter 2002; Brunnschweiler 2006; Weihs et al. 2007), suggesting that the symbiotic association may change depending on host characteristics or environmental factors. Observations of large remoras feeding on parasitic copepods (Strasburg 1959; Gayford 2024) suggest that hosts can benefit from associations with remoras, although the extent of this remains unknown. Although traditionally classified as mutualism or commensalism, our findings show that the remora-host relationship can shift towards parasitism.

Symbiotic interactions are typically evaluated based on net fitness consequences for the species involved (Gayford 2024). Our results demonstrate that hosting 1–3 remoras had a reductive effect on green turtle grazing effort, and would therefore be expected to impact fitness. Remora hosts sometimes incur significant health costs, including physical damage from the adhesive disk or injuries caused by small remoras forcing themselves into body cavities, for example through mobulid gill slits (Silva-Jr et al. 2005; Becerril-García et al. 2020). Hosts also alter their behaviour in response to irritation from remora attachment and detachment (e.g. Ritter 2002; Brunnschweiler 2006; Silva-Jr and Sazima 2006; this study). In our study, remora-sea turtle associations were observed during periods of foraging activity, and it is possible that mutualistic interactions are more prevalent at other times of day that were not observed, such as during periods of inactivity or rest. Even if carapace cleaning occurs more frequently at other times of day, fitness costs through reduced grazing effort may still outweigh potential benefits. Whilst there are few documented examples of negative impacts of phoresy in the marine environment, impacts on migration and reproduction have been reported in terrestrial systems, for example a load of >6 parasitic mites *Acarophenax lacunatus* affected the mobility and flight of grain borer beetles *Rhyzopertha dominica* (Rocha et al. 2009). Regular monitoring of individuals with varying remora loads would be required to assess long-term fitness costs from impacted foraging behaviour in green turtles.

Green turtle grazing rates were 30% lower with high remora loads of 2–4 remoras compared with no remoras in Marsa Abu Dabbab, which is likely to compromise body condition over time. Body condition serves as an indicator of an animal's fitness and energy budget, including its ability to acquire, store and allocate energy to vital processes such as growth and reproduction (Stubbs et al. 2020). For immature turtles, low energy intake can delay growth, while in mature turtles, reduced energy reserves may impact functions such as reproduction, affecting population size. These energy deficits may also affect their ability to migrate, with negative implications for phoresy. Remoras have been observed on green turtles afflicted with fibropapillomatosis (Overing 1996), suggesting that hitchhiking may continue irrespective of host body condition.

Theoretical and empirical evidence supports our result that green turtle grazing rate increases with body size, showing a weak relationship as expected for marine ectotherms (Rall et al. 2012; Nunes et al. 2021). The bite rate recorded in Marsa Abu Dabbab was comparable to rates reported in the US Virgin Islands (USVI; mean = 20.7 bites min^{-1}) for individuals ranging between 36.3 and 120 cm (straight carapace length, SCL_{n-t}; Gulick et al. 2022). However, grazing effort was not affected by body size at some other sites (Gulick et al. 2022), and this difference could be attributed to local conditions such as predator pressure, habitat productivity or population structure. Monitoring of green turtle grazing effort across years where possible could provide insights into additional drivers such as changes in foraging habitat and levels of tourism (e.g., Ayad 2021).

We found that the mean remora load per individual increased by 20% across the depth range (2–16 m) at Marsa Abu Dabbab. This observed range partially overlaps with previously recorded depths of 8–23 m for *E. naucrates* (e.g. Overing 1996; Astakhov 2020). In contrast, *R. remora* remains attached to its hosts across a far wider depth range (range: 0–1460 m; Becerril-García et al. 2020; Fontes et al. 2023; Castellano-González et al. 2025). Information on *E. naucrates* ecology or their physiological tolerance limits at different depths remains unknown, with this knowledge gap restricting our understanding of their response to vertical spaces occupied by their hosts. Further research is necessary to ascertain if *E. naucrates* occurs at depths beyond 23 m across global sites and to examine other biotic and abiotic factors, including temperature and symbiont abundance, that may influence the number of remoras attached to a host.

Repeated observations of turtles provided insight into temporal variations in remora load, indicating a dynamic remora-sea turtle relationship characterised by host-switching behaviour or facultative attachment patterns (Williams Jr et al. 2003). Paired remoras were observed more frequently than solitary individuals on green turtles in Marsa Abu Dabbab, strongly suggesting preferential attachment to turtles already carrying conspecifics. Such attachment patterns are commonly reported at sites where host species aggregate for breeding or foraging (Strasburg 1964; Wingert et al. 2021), increasing opportunities for mate selection and reproductive success. For example, *R. remora* pairs were more frequently recorded than groups of three or more individuals on sicklefin devil rays (*Mobula tarapacana*; Castellano-González et al. 2025); remora load on a single dolphin was zero or two remoras over two years (Silva-Jr and Sazima 2003); and *Remora australis* pairs remained attached to the same dolphins across multiple observations over 87 and 74 days (Silva-Jr and Sazima 2003). Furthermore, observations of active host-switching behaviour, specifically targeting hosts carrying conspecifics, support social factors influencing host selection mechanisms (Nakajima et al. 1987). Thus, hitchhiker attachment likely depends on factors such as the presence of conspecifics and resource availability, with individuals modifying their strategies for more favourable opportunities.

Our findings contribute to epibiont research by recording the remora-sea turtle association for the first time in the Indian Ocean and examining potential effects of remora hitchhiking. Previous studies of this association were limited to the Atlantic and Pacific Oceans, focussing mainly on the frequency of remoras, morphometric data and behavioural observations (e.g. Fretey 1979; Sazima and Grossman 2006; Ramos-Rivera et al. 2021). While sea turtle epibionts such as barnacles and amphipods have been extensively studied as indicators of sea turtle habitat-use patterns and distribution (Pfaller et al. 2014; Nolte et al. 2020; Robinson and Pfaller 2022), there is limited research documenting the costs and benefits of epibiosis on hosts such as reduced swimming efficiency or increased disease potential (see Frick and Pfaller 2013). Further assessments of the impact of epibionts on host turtle physiology and behaviour will be important to characterise specific host-hitchhiker relationships.

An unavoidable methodological limitation of our study was the use of a meter stick for visual assessment of approximate turtle size measurements, which resulted in variation within a range of ± 10 cm for repeatedly observed individuals. This variation was consistent with expected ranges for underwater visual estimation techniques, previously validated using mock turtle carapaces (size range: 40–70 cm; Houghton et al. 2003). All repeat measurements of the turtles in our study were collected by the same researcher, ensuring minimal observer bias.

Our study reveals a complex symbiotic relationship between remoras and sea turtles that may shift along the commensalism-parasitism spectrum depending on factors such as remora load. While remoras did not directly harm turtles in Marsa Abu Dabbab, our findings indicate that they negatively influence turtle foraging efficiency and are therefore expected to affect body condition. Our single observation of a remora cleaning a turtle carapace further suggests a skewed symbiotic relationship favouring the remoras. Whether these impacts extend to other sea turtle species and marine megavertebrates requires further investigation to quantify hitchhiker impacts on host behaviour such as feeding, reproduction and overall body condition across different marine environments. Given the role of marine megavertebrates in ecosystem functioning (Wabnitz et al. 2010; Desbiens et al. 2021; Kiszka et al. 2022), quantifying the energetic and fitness costs of symbiosis can provide crucial insights into ecological processes that affect individual and population health, locally and on broader scales.

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Author contributions **N.K.**: data curation, formal analysis, investigation, methodology, visualization, writing – original draft, writing – review & editing. **L.Q.**: investigation, writing – review & editing. **A.F.**: writing – review & editing. **G.C.H.**: formal analysis, funding acquisition, methodology, resources, supervision, validation, writing – review & editing. **K.L.S.**: formal analysis, supervision, validation, writing – review & editing. **N.E.**: conceptualization, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, validation, writing – review & editing.

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Declarations

Competing interests No conflicts of interest or competing interests to declare.

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