Shell of a life: A review of the geographic frequency of amphipods, cnidarians and annelids as loggerhead sea turtle (*Caretta caretta*) epibionts

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Abstract

Loggerhead sea turtles carry diverse communities of organisms including many invertebrate species on their carapace as epibionts. Investigating the frequency of amphipods, cnidarians and annelids from several epibiont studies in different hemispheres reveals geographic information such as migratory behavior about these three groups and their relationships with loggerhead sea turtles. Frequency data from 383 loggerheads in 8 epibiont identification studies was extrapolated and analyzed. A total of 84 invertebrate species were described among these studies. 7% of the total species (6) were cosmopolitan, or found in both hemispheres. The eastern hemisphere displayed the highest overall number of species (49), followed by the western hemisphere with 29 species. The only group found in greater frequency in the western hemisphere was the cnidarians, and this study suggests that cnidarians reside primarily in one hemisphere or the other, therefore sea turtles may lose them from the carapace when migrating. Annelida species were found in low frequencies in both geographic locations but should be expected on loggerhead carapaces in the Mediterranean. Overall, many invertebrates, including ones described in this review, could be deemed novel obligate commensals of loggerheads and their relationship with migrating species provides insight to movement patterns and the life stages of sea turtles.

Introduction

I. Overall Sea Turtle Biology

Sea turtles are marine reptiles under the order Testudines that spend their entire life—with the exception of nesting—in marine or estuarine habitats. A sea turtle's migratory behavior varies between species, but all sea turtles migrate at one point in their life whether that is for food, mating, nesting or just survival (Lutz & Musick, 1996). Newborn sea turtles lack maternal contact after hatching, and their location during their juvenile ages is relatively unknown (Price et al., 2017; Carr, 1952). The migratory behavior of sea turtles is a relatively new area of study with a majority of research occuring in the last few decades, and further research into possible explanations for these "lost years" is necessary.

Sea turtles are found in almost every ocean basin, but they concentrate at tropical beaches for nesting. Loggerhead sea turtles (*Caretta caretta*) are found in every ocean except the Arctic, and they stay relatively close to the equator in the Atlantic, Pacific and Indian Oceans (Abdelrhman et al., 2016). Loggerheads feed primarily on hydroids, bryozoans and sargassum and they have a close association with sargassum in their juvenile years similar to the green sea turtle (*Chelonia mydas*) (Price et al., 2017). Loggerheads nest overnight due to certain thermal requirements when they come onto land which allows for simple observational research often utilized by studies in this review (Lutz & Musick, 1996). *C. caretta* are federally listed as threatened under the Endangered Species Act and internationally listed as vulnerable by the IUCN. Research on their migratory patterns and geographic origins can have lasting impacts on management plans, fishery interactions and research on their commensal relationships.

II. Sea Turtle Epibionts

Epibiosis describes commensal organisms attached to the outside of another organism (Ruckdeschel & Shoop, 2006). The function of epibionts in vertebrates could be camouflage or protection from desiccation depending on the host organism (Majewska et al., 2015). These communities are strongly influenced by morphology and topography of a living substrate allowing for a variety of epibionts specifically on the seven species of sea turtles (Majewska et al., 2017). In sea turtles, epibiosis is used to describe the community of periphytic, microbial and lower invertebrate growth on the carapace. Epibiotic communities must tolerate a wide range of conditions due to the geographical changes taken by sea turtles throughout their lifetime (Caine, 1986). The epibiont community on the carapace serves to describe movement preferences and foraging habitats due to the uniqueness among individual turtles (Voirol, 2018; Robinson et al., 2016; Frick & Pfaller, 2013). Robinson (2017) also suggests that epibionts do not abandon their hosts even if they emerge from the water to nest, but most of this research focuses on lower invertebrates such as worms and crustaceans.

The occurrence of micro-epibionts colonizing turtle carapaces is relatively understudied (Majewska et al., 2015). A bacterial biofilm covers the sea turtle carapace which promotes further microbial attachment (Majewska et al., 2015; Cooksey, 1992; Majewska et al., 2017; Wahl, 1989). Microbes may be found in the surrounding water at the time tissue samples are collected in some diatom-specific studies (Robinson et al., 2016). Turtles will resuspend sand when grazing seagrass which encourages the settlement of sand and microbes on their shells (Rivera et al., 2018). Proper development of diatom communities is ensured by the presence of bacteria (Ashworth & Morris, 2016). Diatom communities may be different depending on the sea turtle species and be drastically different depending on the body part of the same individual

(Majewska et al., 2017). Most microorganism studies associated with sea turtles look at the presence of bacteria (Hernandez-Divers et al., 2009; Orós et al., 2005; Lutz & Musick, 1997). Bacterial infections on the carapace of sea turtles is relatively rare due to the tough integument, but pathogenic microorganisms are usually opportunistic (Orós et al., 2005; Lutz & Musick, 1996). Shell disease is most commonly caused by bacteria, fungi or filamentous algae (Hernandez-Divers et al., 2009). Microbial research is also focused on the gut microbiota of loggerhead sea turtles, specifically characterizing the hologenome, or the community of symbiotic microbes on an organism (Abdelrhman et al., 2016).

Epibionts could potentially serve no function, but some studies suggest there are obligate sea turtle epibionts universally present on all sea turtle species such as diatoms and barnacles (Robinson et al., 2016; Frick & Pfaller, 2013). Common epibionts among sea turtles are crustaceans, leeches, mollusks, cnidarians, annelids and amphipods (Lazo-Wasem et al., 2011; Sezgin et al., 2009; Domenech et al., 2014). Caine (1986) suggests the structural assemblage of epibionts is maintained by the loss of scutes, emigration, immigration, stress, predation and the lack of food. Epibiont studies focus primarily on physical assemblages where most epibionts are identified on the posterior third of the sea turtle carapace (Caine, 1986; Frick et al., 1998; Sezgin et al., 2009). Robinson et al. (2016) suggest that loggerheads have the most diverse epibiont communities, and other studies describe loggerhead research as the most extensive documentation of epibiosis in any species (Pfaller et al., 2008, 2010). Analysis of the cirripedia species found on all turtle species, and especially loggerheads, is abundant, but there are no reviews of geographic distribution for amphipods, cnidarians or annelids among sea turtles.

III. Invertebrates overall as epibionts

Sessile epibionts such as algae create a stable environment for smaller invertebrates such as amphipods, annelids, crabs and snails (Pfaller et al., 2008). These smaller invertebrates are almost always found in association with algal mats on loggerhead sea turtles (Fuller et al., 2010). Amphipods can exist as commensals or free-living forms (Domenech et al., 2014). They are more likely to be found at higher frequencies on pelagic turtles, as researchers have observed amphipods to abandon turtle hosts as they approach the shore and they are prone to clinging to floating substrates because they are not efficient swimmers (Pinou et al., 2011; Sezgin et al., 2009). They develop close relationships with barnacles because amphipods scrape the carapace to feed which may encompass barnacle "spat" (Caine, 1986).

Little is known about the distribution of cnidaria as loggerhead epibionts other than they are often found attached to obligate barnacles (Pfaller et al., 2008). Their presence on sea turtles is not surprising, but research on the geographic distribution of cnidarians on sea turtles is not researched extensively. Annelids are frequently found under colonies of tunicates and barnacles in the Atlantic Ocean or within algae mats which makes research on them as epibionts extremely difficult (Pfaller et al., 2008; Kitsos et al., 2005). Many studies have identified invertebrate species such as barnacles and leeches as potential mediums of turtle herpes virus transmission and ectoparasites (Lazo-Wasem et al., 2011; Domenech et al., 2014). Annelids, and more specifically polychaetes, are commonly found on the axial portion of the shell and can be found on the fleshy part of a turtle's body (Kitsos et al., 2005; Domenech et al., 2014). Leeches (e.g., *Ozobranchus margoi*) have been found on the axial portion and ovipositors of sea turtles (Frick et al., 1998).

Epibiont studies are focused primarily in one location; there is a gap in geographic correlations especially within invertebrate research. Kitsos et al. (2005) provide a brief geographic analysis of loggerhead epibionts, but their results were biased towards Mediterranean locations. Caine et al. (1986) found evidence of movement between northern and southern assemblages along the east coast of Florida. Evidence shows that epibiont diversity is geographically influenced, but one study showed significantly less diversity in the Pacific compared to the Atlantic for olive ridley turtles (Lazo-Wasem et al., 2011). Studies in the Gulf of Mexico show a higher percentage of non-obligate species serves to characterize the local benthos which might be attributed to the absence of algae and hydroids on sea turtles in this region (Lazo-Wasem et al., 2011).

IV. Aims and Broader Impacts

Analyzing the presence of epibionts between the two hemispheres will assist in the verification of a turtle's origin because Atlantic- or Mediterranean-specific species can be indicators of migratory patterns. Macro-invertebrates such as amphipods, cnidarians and annelids are bio-indicators for geography and their presence can help with determining the recent migratory behavior of loggerheads. These three groups of organisms lack literature reviews for their existence as epibionts and especially regarding their geographic distribution on loggerheads. The three main goals for this research are 1. To perform a literature search on epibiont identification studies and identify gaps in the research, 2. To collect and compile frequency data for amphipods, cnidarians and annelids into tables separated by geographic location (eastern hemisphere, western hemisphere and cosmopolitan) and 3. To identify possible novel obligate epibionts among loggerhead sea turtles.

Methods

In order to compile an extensive list of papers focused on sea turtle epibiosis, I used keywords “sea turtle” and “epibiosis” in Scopus and ScienceDirect databases. I sorted 34 papers into a spreadsheet based on the species of sea turtle. After analyzing the scope of research that has been performed on various sea turtles and epibionts, I narrowed my focus to loggerhead sea turtles (15 papers) and specifically their relationship with amphipods, cnidarians and annelids because there was an abundance of papers on these invertebrates. There was an absence of a literature review for each of these invertebrates.

I isolated 12 papers focusing on the two invertebrate phyla and one order to investigate the interaction between these invertebrates and sea turtles. I performed a secondary search through the databases using keywords “amphipod”, “cnidarian”, “annelida” and “loggerhead”. Eleven papers (Lazo-Wasem et al. only considered olive ridley sea turtles) were compiled into a new spreadsheet into separate sheets based on the specific epibiont that was identified in the paper. One source (Casale et al.) was omitted as specific amphipod species were not indicated and another source (Sezgin et al.) was removed because the sample size was 1 turtle. Multiple papers fit into more than one topic, so they were included in more than one sheet. After these sources were established, frequency data was extracted from the tables and placed into the spreadsheet. Each piece of data was recorded next to the species name. This frequency data for each epibiont type (amphipoda, cnidaria and annelida) was placed into new tables based on three locations: Western Hemisphere (Gulf of Mexico and Atlantic Ocean), Eastern Hemisphere (Mediterranean Sea and subseas), and cosmopolitan (both hemispheres) (Appendix Tables 2a-4c). One more source (Robinson et al., 2016) was omitted from the review due to the lack of information contributing to frequency data calculation and loggerhead turtles; there was a final total of eight papers used across all topics (Table 1).

Results

Six sources, Domenech et al. (2014), Kitsos et al. (2005), Frick et al. (1998), Caine (1986), Pfaller et al. (2008) and Badillo (2007) contributed to all three invertebrate data collections. A total of 84 invertebrate species were identified across all eight papers: 24 amphipods, 17 cnidarians, and 43 annelids. Six invertebrates were found in both hemispheres, none of which were cnidarians. Overall, a larger diversity of invertebrates were found in the eastern hemisphere (EH); 55 were found in the EH while only 35 were found in the western hemisphere (WH).

Amphipoda. The most common amphipods across both hemispheres were *Podocerus chelonophilus* and *Caprella andreae* (Table 2a). Both species were found in all 7 papers at frequencies from 4-100%. Another common amphipod, *Elasmopus rapax*, was found at lower frequencies (1-15.2%) in 5 of the 7 papers. A more diverse range of amphipods were found in the EH (16 species of the total 23 between both hemispheres), and 14 out of 16 EH species were found in the Mediterranean Sea (Table 2b). Of the 12 species found only in the EH, *Protohyale grimaldii* had the highest frequency, appearing in 43% of the turtles found in the Zakhama-Sraieb et al. Mediterranean Sea study. In the WH, the amphipod with the highest frequency was *Paracaprella tenuis*, appearing in 92% of loggerheads in the Frick et al. Georgia study (Table 2c). *Caprella equilibra* was found in all of the WH papers. Only 4 of the 23 total species were found in both hemispheres: *P. chelonophilus*, *C. andreae*, *E. rapax*, and *Caprella penantis*. 100% of the turtles in the Frick et al. Georgia study yielded *C. andreae* on their carapaces.

Cnidaria. There were zero cnidaria species found present in both hemispheres. Each individual cnidaria species in the EH was found in one paper; there was no overlap between species across the Mediterranean Sea and subseas. Only 4 cnidarian species were found in the EH (Table 3a). *Obelia geniculata* had the highest frequency appearing in 8% of loggerheads in the Kitsos et al. Aegean Sea study. 13 cnidaria species were found in the WH; three of these species were found in all three papers describing cnidaria in the WH (*Obelia dichotoma*, *Leptogorgia virgulata*, *Tubularia crocea*) (Table 3b). *T. crocea* was found at a frequency of 71% at Canaveral National Seashore, but only around 2% and 6% on the Atlantic Coast and Georgia respectively. *Hydractinia echinata*, a hydroid species, had the highest frequency in the WH; in the Frick et al. Georgia study, they were found on 100% of loggerheads surveyed. Of the 13 cnidaria species found in the WH, 10 of them were found in Georgia which had the largest diversity of cnidaria species across both regions.

Annelida. A total of 42 annelida species were identified as epibionts on loggerhead sea turtles across five papers. Only 2 species were found in both hemispheres: *Serpula vermicularis* and *Ozobranchus margoi* (Table 4a). *S. vermicularis* had a higher frequency (16%) in the EH (Aegean Sea) than the WH (Georgia) where the frequency was 10%. *S. vermicularis* was identified in five of the six papers including annelida data. 31 species were identified only in the EH (Table 4b). 29 of these organisms were found in Kitsos et al. (2005); this paper had the highest abundance and diversity of annelids. *Hydroides elegans* and *Hydroides norvegica* had the highest frequencies (13.5%). *Pomatoceros triqueter* was the only species found in the EH in all Mediterranean Sea and subseas. No single species was found in all three papers located in the WH (Table 4c). 8 of the 9 species were found in the Frick et al. Georgia paper. *Nereis falsa* had the highest frequency in the WH at 69% in Canaveral National Seashore. The frequency of *N. falsa* in Georgia was only 5%.

Discussion

The eight studies examined in this review utilized similar methods for collecting and recording epibionts. Five studies collected samples using sharp tools (razors, scalpels, tweezers, etc.) to remove epibiots from nesting females (Fuller et al., 2010; Caine, 1986; Pfaller et al., 2008; Frick et al., 1998; Badillo, 2007). The other three studies used similar extracting methods on stranded, usually dead, turtles which may have led to the appearance of strange epibionts or the lack of common species (Zakhama-Sraieb et al., 2010; Domenech et al., 2014; Kitsos et al., 2005). Although the studies used different specific methods, each study found organisms from at least one of the invertebrate groups in question and discussed carapace properties. Fuller et al. (2010), indicated the number of loggerheads that hosted epibionts in the Mediterranean; only 52% of the turtles they surveyed had epibionts. Another Mediterranean study, Zakhama-Sraieb et al. (2010) found that 100% of their individuals hosted epibionts, but the sample size in this study was relatively smaller (7 compared to 43 or more in other studies). Another common trait among most studies is the presence of invertebrate epibionts on the posterior third of the carapace (Fuller et al., 2010; Zakhama-Sraieb et al. 2010; Caine, 1986; Frick et al., 1998). Fuller et al. (2010) found one amphipod in particular, *P. chelonophilus*, to be associated with large cracks or lesions in the carapace; research from Moore (1995) suggests the potential for a parasitic relationship between this amphipod and host turtles. Leeches are also found in the axial region of the carapace which are often associated with ovipositors in nesting females (Frick et al., 1998).

Invertebrates exist attached to algal mats, barnacles or tunicates creating smaller sub-ecosystems on the turtle carapace. Organisms from the two phyla Cnidaria and Annelida as well as the Order Amphipoda are almost strictly associated with algal mats on loggerhead carapaces (Fuller et al., 2010; Zakhama-Sraieb et al., 2010; Pfaller et al., 2008; Badillo, 2007). Badillo (2007) even suggests that the presence of *Polysiphonia* algae directly determines the presence of *P. chelonophilus* and *H. grimaldii*. Sessile epibionts such as the obligate commensal barnacles create microhabitats for worms and amphipods (Pfaller et al., 2008). The presence of many barnacles is a bioindicator that smaller, motile invertebrates live among this sub-niche.

Every source included in this review identified at least one species from each invertebrate group: amphipod, cnidarian and annelid. Kitsos et al. (2005) showed approximately 90% of invertebrate epibionts found on Mediterranean loggerheads were cosmopolitan or Atlanto-Mediterranean species. In this review, only about 24% of the invertebrate species found on Mediterranean turtles were considered cosmopolitan. Comparatively, around 17% of the species identified in the western hemisphere were considered cosmopolitan. Kitsos et al. identified all three invertebrate groups in the Aegean Sea, and about 73% of the EH species were found in the Aegean Sea. This suggests that there is a higher concentration of epibiont species in the Aegean Sea, but more specifically, annelids are often found in low frequencies. Since the Aegean Sea is a smaller subsea in the Mediterranean, it is possible that worm species are more highly concentrated because there is a slight separation from the larger body of water. Another potential reason for a larger distribution of organisms compared to older studies is more detailed identification of species as a result of decades of new research (Kitsos et al., 2005; Caine, 1986; Gramentz, 1988 & Frick et al., 1998).

Fewer species of cnidaria were identified in the EH than the WH. In all four EH papers that found cnidaria, only one or two species were recorded per study, but a total of four different species were identified (Fuller et al., 2010; Domenech et al., 2014; Badillo, 2007; Kitsos et al., 2005). Frequency percentages for cnidaria in the EH range from 3 to 10.2%, so they were found in very few individual turtles. In the WH, the frequencies ranged from 1.5 to 100%. One of the most shocking findings from this review was the 100% frequency of *Hydractinia echinata*, or snail fur, found in Frick et al. which had a sample size of 65 turtles. No other study found this species or even mentioned the presence of hydroids. This review does not suggest that any one cnidarian should be considered an obligate of loggerheads because they are found so infrequently, but their presence on sea turtle carapaces is ecologically interesting.

Caine (1986) claims that *P. chelonophilus* has never been reported in habitats other than the sea turtle carapace. This species was first identified in 1888 by Chevreux and de Guerne in the Mediterranean, but several studies have identified them in other geographic areas such as the coast of Ecuador, the Mediterranean, the Gulf of Mexico and the Atlantic coast of Florida (Baldinger, 2000; Zakhama-Sraieb et al., 2010; Domenech et al., 2014; Kitsos et al., 2005; Badillo, 2007; Frick et al., 1998 & Caine, 1986). This amphipod is found both on the carapace and the base of the tail or legs (Zakhama-Sraieb et al., 2010). *P. chelonophilus* is described as an obligate epibiont which is supported in this review, and it was found at higher frequencies in the Atlantic compared to the Mediterranean (Domenech et al., 2014; Frick & Pfaller, 2013). This review confirms the obligate characteristic of *P. chelonophilus* because it was found in 6 of the 8 studies at frequencies from 5.4 to 60.1%.

H. grimaldii and *C. andreae* were the most abundant amphipods according to Zakhama-Sraieb et al. (2010) and this is paralleled by the results of this study. At least for *H. grimaldii*, this is likely due to Zakhama-Sraieb et al. having a comparably small sample size. In this study, there were 1-3 species per host, but other studies did not verify if epibionts were present on every individual (Zakhama-Sraieb et al., 2010). *C. andreae* and *H. grimaldii* are deemed as “facultative chelonophilic” species, or ones who live on the carapace at opportunistic times, which is also supported by the findings in this review; seven sources described *C. andreae* in their identifications and five described *H. grimaldii*. The latter chelonophilic species was only found in the eastern hemisphere, but one study, Domenech et al. (2014) identifies them as part of a subset that should be expected on loggerheads regardless of geographic origin which is not supported by the findings of this review. *C. andreae* was identified with a 100% frequency in Georgia which was not surprising, as it emphasizes the facultative role described in epibiont research studies. *Jassa* amphipods are another group that were previously described as cosmopolitan, but the studies in this review did not support this statement (Domenech et al., 2014). *Jassa* species were only identified to the genus level and only in two studies, both from the EH.

Annelids accounted for 51% of the total invertebrates in this review. 79% of annelida species were found in the EH and, of this region, 91% were found strictly in the Aegean Sea. Frequencies in the EH ranged from 2.7 to 13.5%, but there were a total of 32 species found in this region. The concentration of annelida in the Aegean Sea suggests that worms should be expected on Mediterranean loggerheads even though the individual frequencies were relatively low. *O. margoi*, often referred to as the turtle leech, is another recorded obligate species on loggerheads which was only found in four studies (Domenech et al., 2014). The turtle leech can be found on soft body parts such as under the tail and legs, but in this review, all specimens were derived from the carapace (Domenech et al., 2014). The turtle leech is often associated with fibropapillomatosis, but there was no report of this species and their parasitic relationship with sea turtles in these 8 studies.

There are limitations to the nature of this review and the available data in these papers. Several papers identified individuals only to the genus level meaning there may have been a greater number of specific species for *Podoceridae*, *Stenothoe* and *Jassa* amphipods, *Obelia* cnidarians and *Hydroides*, *Prionospio*, *Spionidae*, *Naididae*, *Tubificidae* and *Errantia* annelids. Every source except for Fuller et al. described at least one cosmopolitan species which supports the transatlantic migration patterns of loggerhead sea turtles (Baldinger, 2000). Zakhama-Sraieb et al. had a sample size of 7 turtles which is small compared to the other studies (7 compared to 43 or more in all other papers), so their frequencies were higher due to the lower total number of loggerheads. The nature of epibiont identification studies prevents the reader from acknowledging how many species came from a single turtle. For example, there is no way to determine from the results of these papers if every species identified came from a few turtles or at least one epibiont was found on every turtle.

This is the first review considering geographic comparisons for amphipods, cnidarians and annelids. Epibionts are used as biological markers to distinguish Atlantic and Mediterranean loggerhead sea turtles (Kitsos et al., 2005). Extending the knowledge of the presence and absence of various invertebrate species provides evidence for the primary habitat or origin of loggerheads. Lazo-Wasem et al. (2011) suggests that there is less epibiont diversity in the Pacific compared to the Atlantic Ocean. This can neither be supported nor rejected by this review, as an extensive literature search revealed zero epibiont identification studies for loggerheads in the Pacific. This indicates an area of necessary further research, as the Pacific Ocean remains in the loggerhead geographic distribution. Research on the presence of epibionts in the Pacific can provide even more knowledge on the migratory behavior of these organisms and provide insight to migration of other vertebrate basibionts such as whales and crocodiles. The sea turtle carapace, and especially those of loggerheads which host the most diverse communities, create new ecological niches for a variety of small invertebrates (Fuller et al., 2010). This review confirms the consistent research on *P. chelonophilus* and *C. andreae* as obligate epibionts on loggerheads but also it is the first to suggest that annelids should be expected on loggerheads in the Mediterranean Sea. Overall, this research showed lower percentages of cosmopolitan species than individual studies. The confirmation of obligate loggerhead epibionts prompts further research on sea turtles carapaces as sub-habitats for invertebrates and their purpose as commensals.

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Appendix

Figure 1. Geography of primary literature. Studies included in this review were focused either in the Eastern or Western hemisphere. Studies are numbered as such: 1) Fuller et al., 2010, 2) Zakhama-Sraieb et al., 2010, 3) Domenech et al., 2014, 4) Kitsos et al., 2005, 5) Badillo, 2007, 6) Frick et al., 1998, 7) Caine, 1986, 8) Pfaller et al., 2008.

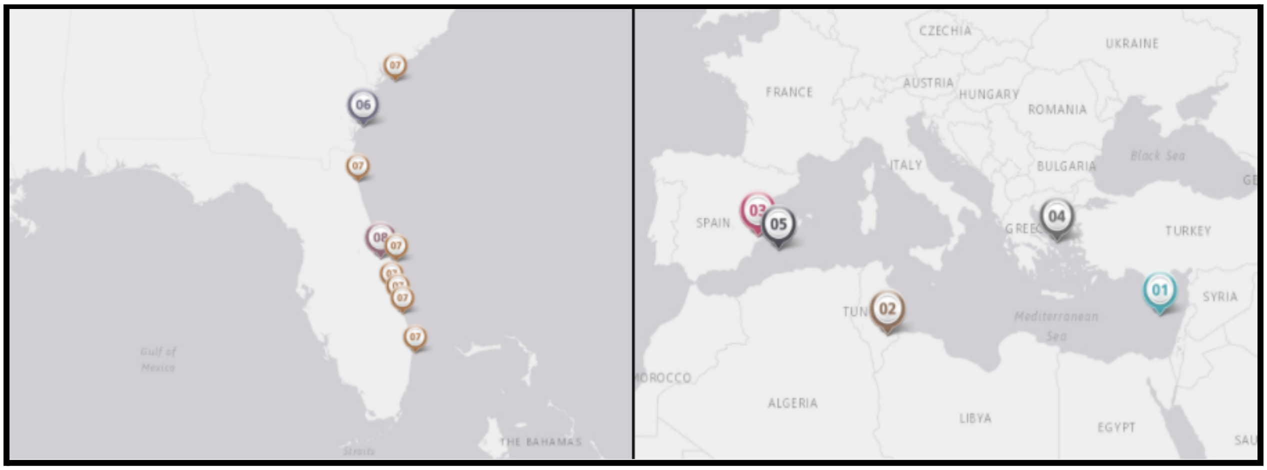

Table 1. Source Data. Location and total number of loggerhead sea turtles were reported from eight primary research studies identifying epibionts from loggerhead sea turtles.

Title	Author(s)	Year Published	Location/Body of Water	Total Number of Loggerheads
Motile homes: a comparison of the spatial distribution of epibiont communities on Mediterranean sea turtles	Fuller et al.	2010	Mediterranean Sea	100
Amphipod epibionts of the sea turtles *Caretta caretta* and *Chelonia mydas* from the Gulf of Gabe`s (central Mediterranean)	Zakhama-Sraieb et al.	2010	Mediterranean Sea	7
Epibiont communities of loggerhead marine turtles (*Caretta caretta*) in the western Mediterranean	Domenech et al.	2014	Mediterranean Sea	104
Composition of the organismic assemblage associated with *Caretta caretta*	Kitsos et al.	2005	Aegean Sea	37
Epizoítos y parásitos de la tortuga boba (*Caretta caretta*) en el Mediterráneo Occidental	Badillo	2007	Balearic Sea	104
Epibionts associated with nesting loggerhead sea turtles (*Caretta caretta*) in Georgia, USA	Frick et al.	1998	Georgia, US, Gulf of Mexico, Atlantic Ocean	65
Carapace epibionts of nesting loggerhead sea turtles: Atlantic coast of U.S.A	Caine	1986	Atlantic Coast of USA, Gulf of Mexico, Atlantic Ocean	138
Carapace epibionts of loggerhead turtles (*Caretta caretta*) nesting at Canaveral National Seashore, Florida	Pfaller et al.	2008	Canaveral National Seashore, FL	52

Table 2a. Cosmopolitan amphipod abundance on loggerhead sea turtles. Four amphipods were found in both hemispheres. Studies included frequency calculations in their results. I compiled the frequency percentage data in this table based on location.

Species	**Location**	**% Frequency**
Elasmopus rapax	**Atlantic Coast of USA[7]**	**15.2**
	Mediterranean Sea[2]	14.3
	Georgia[6]	4.6
	Aegean Sea[4]	2.7
	Mediterranean Sea[3]	1
	Balearic Sea[5]	1
Podocerus chelonophilus	**Atlantic Coast of USA[7]**	**60.1**
	Georgia[6]	26.2
	Mediterranean Sea[2]	14.3
	Balearic Sea[5]	8.7
	Mediterranean Sea[3]	8.0
	Aegean Sea[4]	5.4
Caprella andreae	**Georgia[6]**	**100**
	Atlantic Coast of USA[7]	96.4
	Canaveral National Seashore FL[8]	90.4
	Mediterranean Sea[2]	85.7
	Balearic Sea[5]	47.5
	Mediterranean Sea[3]	41.0
	Aegean Sea[4]	13.5
Caprella penantis	**Canaveral National Seashore FL[8]**	**32.7**
	Georgia[6]	29.2
	Aegean Sea[4]	8.1

[2]Zakhama-Sraieb et al., 2010
[3]Domenech et al., 2014
[4]Kitsos et al., 2005
[5]Badillo, 2007
[6]Frick et al., 1998
[7]Caine, 1986
[8]Pfaller et al., 2008

Table 2b. Amphipod abundance on loggerheads in the eastern hemisphere. Five studies focused in the Mediterranean and Aegean Seas identified amphipods in their epibiont analysis of loggerhead sea turtles. Studies included frequency calculations in their results. I compiled the frequency percentage data in this table based on location.

	% Frequency		
Species Name	**Mediterranean Sea[1,2,3]**	**Aegean Sea[4]**	**Balearic Sea[5]**
Caprella fretensis	12[1]	—	
Hyale nilssoni	2[1]	—	
Hyale grimaldii	36[3]	2.7	37.3
Hyale schmidti	3[1]	—	
Hyale sp. *	—	—	16.9
Podoceridae sp.*	1[1]	—	
Corophium acherusicum	14.3[2]	8.1	
Protohyale grimaldii	42.9[2]	—	
Erichthonius punctatus	14.3[2]	—	
Stenothoe sp.*	14.3[2]	—	
Apocorophium acutum	—	8.1	
Jassa sp.*	2[3]	—	3.4
Caprella scaura	11.5[2]	—	

[1]Fuller et al., 2010
[2]Zakhama-Sraieb et al., 2010
[3]Domenech et al., 2014
[4]Kitsos et al., 2005
[5]Badillo, 2007
*These species were identified only to the genus level.

Table 2c. Amphipod abundance on loggerheads in the western hemisphere. Three studies focused in the Gulf of Mexico or the Atlantic Ocean identified amphipods in their epibiont analysis of loggerhead sea turtles. Studies included frequency calculations in their results. I compiled the frequency percentage data in this table based on location.

	% Frequency		
Species Name	**Georgia**[6]	**Atlantic Coast**[7]	**Canaveral National Seashore FL**[8]
Stenothoe minuta	4.6	14.5	—
Paracaprella tenuis	92.3	2.2	—
Ampithoe ramondi	3.1	21.7	—
Erichthonius brasiliensis	1.5	16.7	—
Podocerus brasiliensis	—	3.6	—
Dulichiella appendiculata	36.9	—	—
Caprella equilibra	67.7	0.7	9.6

[6]Frick et al., 1998
[7]Caine, 1986
[8]Pfaller et al., 2008

Table 3a. Frequency of cnidarians on loggerhead sea turtles in the eastern hemisphere. Four sources focused in the Mediterranean, Aegean and Balearic Seas identified cnidarians in their epibiont analysis of loggerheads. Studies included frequency calculations in their results. I compiled the frequency percentage data in this table based on location.

Species Name	% Frequency		
	Mediterranean[1,2]	**Aegean Sea[3]**	**Balearic Sea[5]**
Laomedea flexuosa	3[1]	—	—
Obelia geniculata	—	8.1	—
Aiptasiogeton pellucidus	—	5.4	—
*Obelia spp.**	6[2]	—	10.2

[1]Fuller et al., 2010
[2]Domenech et al., 2014
[3]Kitsos et al., 2005
[5]Badillo, 2007
*These species were identified only to the genus level.

Table 3b. Percent frequency of cnidarians on loggerhead sea turtles in the western hemisphere. Three sources in the Gulf of Mexico or the Atlantic Ocean identified cnidarians in their epibiont analysis. Studies included frequency calculations in their results. I compiled the frequency percentage data in this table based on location.

	% Frequency		
Species Name	**Atlantic Coast of US[7]**	**Georgia[6]**	**Canaveral National Seashore, FL[8]**
Obelia dichotoma	12	29.2	19.2
Leptogorgia virgulata	2.2	4.6	13.5
Ricordea florida	—	—	5.7
Tubularia crocea	6.5	20	71.2
Anemonia sargassiensis	2.2	7.7	—
Anemone sp.*	2.9	—	—
Porites porites	2.2	—	—
Halocordyle disticha	—	13.8	—
Hydractinia echinata	—	100	—
Aiptasia pallida	—	3.1	—
Bunodosoma cavernata	—	1.5	—
Calliactis tricolor	—	26.1	—
Haliplanella luciae	—	3.1	—

[6]Frick et al., 1998

[7]Caine, 1986

[8]Pfaller et al., 2008

*These species were identified only to the genus level.

Table 4a. Cosmopolitan annelida abundance. Two annelid species were found in both hemispheres on loggerhead sea turtles among five studies. Studies included frequency calculations in their results. I compiled the frequency percentage data in this table based on location.

Species Name	**Location**	**% Frequency**
Serpula vermicularis	**Aegean Sea[4]**	**16.2**
	Georgia[6]	10.8
	Atlantic Coast of US[7]	7.2
	Mediterranean[3]	1.0
	Balearic Sea[5]	1.0
Ozobranchus margoi	**Georgia[6]**	**8.92**
	Mediterranean[3]	6.0
	Aegean Sea[4]	5.4
	Balearic Sea[5]	1.9

[3]Domenech et al., 2014
[4]Kitsos et al., 2005
[5]Badillo, 2007
[6]Frick et al., 1998
[7]Caine, 1986

Table 4b. Percent frequency of annelida in the eastern hemisphere. Three studies in the Eastern Hemisphere identified unique annelids in their epibiont analyses on loggerhead sea turtles. Studies included frequency calculations in their results. I compiled the frequency percentage data in this table based on location.

	% Frequency		
Species Name	**Aegean Sea[4]**	**Mediterranean Sea[3]**	**Balearic Sea[5]**
*Aciculata spp. **	—	—	2.9
Ceratonereis costae	2.7	—	
Cirriformia tentaculata	2.7	—	
Demonax langerhansi	2.7	—	
Eunice torquata	2.7	—	
Hesiospina similis	2.7	—	
Hydroides dianthus	2.7	—	
Hydroides elegans	13.5	—	
Hydroides nigra	5.4	—	
Hydroides norvegica	13.5	—	
Hydroides stoichadon	5.4	—	
*Hydroides spp. **	—	5	5.8
Neanthes caudata	2.7	—	
Neanthes succinea	2.7	—	
Nereis zonata	2.7	—	
Phyllodoce mucosa	2.7	—	
Platynereis dumerilii	2.7	—	
Pomatoceros triqueter	5.4	5	5.8
Prionospio multibranchiata	2.7	—	
*Prionospio sp. **	2.7	—	
Schistomeringos rudolphi	2.7	—	
Serpula concharum	10.8	—	
Spio decoratus	2.7	—	
*Spionidae sp. **	2.7	—	
Syllis prolifera	2.7	—	

Syllis variegata	2.7	—	
Terebella lapidaria	2.7	—	
Therlepus setosus	2.7	—	
Enchytraeidae sp.	2.7	—	
Naididae sp.*	2.7	—	
Tubificidae sp.*	5.4	—	
Errantia sp.*	—	2	

[3] Domenech et al., 2014
[4]Kitsos et al., 2005
[5]Badillo, 2007

Table 4c. Percent frequency of annelids in the western hemisphere. Three studies identified annelids in their epibiont analysis. Studies included frequency calculations in their results. I compiled the frequency percentage data in this table based on location.

	% Frequency		
Species Name	**Georgia[6]**	**Canaveral National Seashore, FL[8]**	**Atlantic Coast of USA[7]**
Nereis falsa	4.6	69.2	—
Podarke obscura	7.7	40.4	—
Polychaete sp.*	—	—	23.2
Filograna vulgaris	1.5	—	10.1
Sabellaria vulgaris	4.6	—	12.3
Dorvillea sociabilis	18.5	—	—
Procerea fasciata	1.5	—	—
Sabellaria floridensis	3.1	—	—
Syllis spongicola	3.1	—	—

[6]Frick et al., 1998
[8]Pfaller et al., 2008
[7]Caine, 1986
*These species were identified only to the genus level.