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Concept Note on the importance of *Sargassum* and the Sargasso Sea for Atlantic Sea Turtles

The Inter-American Convention for the Protection and Conservation of Sea turtles (IAC) and the Sargasso Sea Alliance (SSA) drafted this concept note with the objective to highlight the common objectives of their members and promote the importance of scientific and technical collaboration between the IAC and SSA.

The Importance of *Sargassum* and the Sargasso Sea for Atlantic Sea Turtles

Globally, marine turtles are one of the most threatened groups of animals. The life-history of the marine turtle species in the Atlantic Ocean spans enormous distances and time as turtles hatch and develop into reproductively mature adults over many decades. Despite being the most important stage in development, relatively little empirical research exists on the life-history of neonate turtles in the first several years of their lives in the Atlantic Ocean. Research indicates that within these "lost years" marine turtles remain in the open ocean and rely on *Sargassum* algae as refugia from predators, and sources of food and warmth. To this end, the Sargasso Sea provides ample *Sargassum* habitat for the entire population of Atlantic marine turtles until they reach sufficient size to move to neritic feeding grounds in Bermuda and beyond. Further research and collaboration is necessary to build knowledge about how the Sargasso Sea supports marine turtle populations in the Atlantic.

species distribution | conservation | life-history| areas beyond national jurisdiction

The Sargasso Sea plays a pivotal role in sea turtle development and survival by providing a crucial ecosystem for juvenile sea turtles (Carr 1987, Musick and Limpus 1987). It serves as the center of the dispersal routes for Atlantic turtles hatching on the coasts of North America, Africa, the Mediterranean, and the Caribbean (Musick and Limpus 1997, Witzell 2002, Fuxjager et al. 2011). The Sargasso Sea provides habitat for neonate and juvenile populations for all five species of Atlantic sea turtles. The persistence of *Sargassum* algae may lead to increased juvenile recruitment to the later life stages for each of the five resident sea turtle species and the conservation of these species will require regional and international coordination across the Sargasso Sea region, most of which lies beyond areas of national jurisdiction.

The Sargasso Sea (Figure One) is the only sea in the world not bounded by land. Instead it is confined by the North Atlantic Gyre, bounded by the Gulf Stream to the west, the Canary Current to the east, the North Atlantic Equatorial and Antilles Currents to the south and southwest, and the North Atlantic Current.

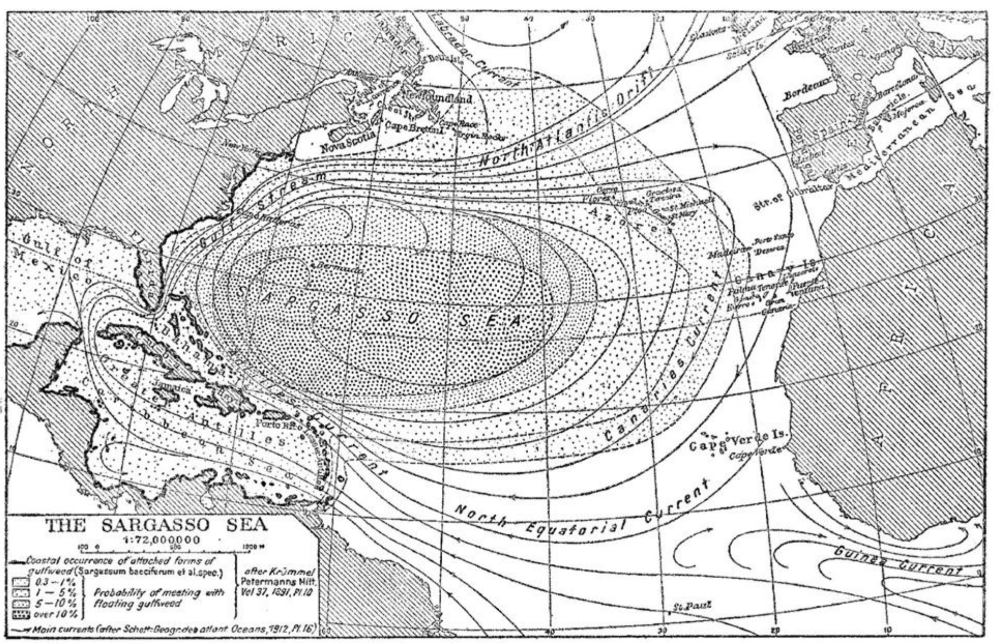

Figure One: Shows the prevailing currents that form the borders of the Sargasso Sea: the Gulf Stream to the west, Canaries Current to the east, the North Equatorial and Antilles Currents to the south and southwest, and the North Atlantic Current (Babcock 1922).

Its namesake is an assemblage of two species of holopelagic brown algae (*Sargassum natans* and *S. fluitans*) that vegetatively reproduce in open water. The adjacent currents of the North Atlantic gyre transport the floating *Sargassum* rafts and their occupants on journeys of either local or oceanic extent or both (Carr, 1982). Due to its ability to form extensive floating mats, *Sargassum* has been referred to as "the golden floating rainforest of the ocean." The abundance of this pelagic drift alga in the Sargasso Sea creates a vital marine ecosystem for a diverse community of species by providing physical habitat, spawning and feeding areas, and migration pathways (Laffoley et al 2011).

A consequence of its geographic position, the Sargasso Sea hosts an incredible diversity of marine life (Hemphill 2005, Laffoley et al. 2011). This includes all wide-ranging nektonic species that transit the North Central Atlantic and any of the planktonic species that exist in the Sargasso Sea or any of the five major currents that surround and contribute to the Sargasso water column. Within this area the most conspicuous species are the two species of *Sargassum* algae, (Class: Phaeophyceae) *S. natans* and *S. fluitans*, that form large assemblages on the ocean surface. These species of holopelagic algae have characteristic pneumatocysts that aid in buoyancy and the rough texture and general hardiness of these algae lend themselves to the ability to withstand strong ocean currents and winds. Both of these species reproduce vegetatively and the Sargasso Sea is the largest unimpeded area for their persistence (Laffoley et al. 2011).

These algae form the structurally complex habitat that precedes the survival of a relatively large diversity of pelagic species (Luckhurst 2007, Laffoley et al 2011). The world's open oceans are generally characterized by relatively low biodiversity, but in this respect the Sargasso Sea provides a noticeable exception. The floating *Sargassum* provides an anchor point for pelagic species and at least ten species are known to be endemic to this ecosystem. These include the Sargassum crab (*Planes minutes*), Sargassum shrimp (*Latreutes fucorum*), Sargassum pipefish (*Syngnathus pelagicus*), Sargassum anemone (*Anemonia sargassensis*), the Sargassum slug (*Scyllea pelagica*), the Sargassum snail (*Litiopa melanostoma*), the amphipods *Sunampithoe pelagica* and *Biancolina brassicacephala*, and the platyhelminth *Hoploplana grubei* (Laffoley et al. 2011). There is also mounting evidence that the Sargasso Sea has an astounding amount of microbial biodiversity that remains mostly unexplored, especially for photosynthetic cyanobacteria (Venter et al. 2004).

In addition to its endemic species, *Sargassum* supports a vast array of invertebrate and fish species that are closely associated with the ecosystem. At least 127 species of fish and 145 described invertebrate species have been associated with the presence of *Sargassum* algae (Laffoley et al. 2011). Most notably, the Sargasso Sea is proposed as the spawning ground of both the American (*Anguilla rostrata*) and European eel (*Anguilla anguilla*) (Schmidt 1923, Kleckner et al. 1983, Friedland et al. 2007) and may also provide pupping grounds for porbeagle sharks (*Lamna nasus*) (Dulvy et al. 2008, Campana et al. 2010), flying fish (Exocoetidae) (Dooley 1972, Sterrer 1992) and a whole suite of economically and ecologically important species. Indeed, within the *Sargassum* mats live juvenile swordfish (*Xiphius gladius*), juvenile and sub- adult jacks (Carangidae), juvenile and sub-adult mahi-mahi (Coryphaenidae), filefish and triggerfish (Balistidae), and driftfish (Stromateidae) (Luckhurst 2007). This rich diversity of pelagic species forms the center of a food web that extends to a number of large predatory species that range throughout the world's oceans and migrate through the Sargasso Sea.

Throughout the world, sea turtles receive varying levels of protection against threats such as poaching, direct take, pollution, coastal development and fisheries by-catch. Sea turtles are protected internationally through a number of conventions including the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC), the Convention on International Trade in Endangered Species (CITES), the convention on migratory species (CMS), and the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (Cartagena Protocol). The IUCN Red List of Threatened Species also classifies each of these species as a member of a threatened (IUCN Red List 2013.2).

Atlantic Sea Turtle Biology and Ecology

Five species of sea turtles have been observed in the Sargasso Sea: loggerhead (*Caretta caretta*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), Kemp's ridley (*Lepidochelys kempii*) and hawksbill (*Eretmochelys imbricata*). During their lives these turtle species complete a series of protracted developmental life stages after hatching. These broadly include several transitions between pelagic and neritic habitat during their journey to reproductive maturity. Bolten (2003) outlines three life-history patterns for marine turtles, two of which are represented by the species of Atlantic sea turtle. The pelagic stage remains the least well-known stage of development for all Atlantic sea turtle species and is the only known stage for the leatherback turtle apart from its return to shore to breed (Eckert 2002). The remainder of Atlantic turtle species progress through a life cycle that includes hatching, a frenzied swim to open water, a surface-pelagic juvenile stage, a neritic juvenile stage, followed by alternations of pelagic and neritic adult stages that include nesting behavior and are species dependent (Bolten 2003).

During the surface-pelagic juvenile stage there are a range of accounts of the habitat and behavior of young turtles in the open ocean. Formerly known as the "lost year", this stage has been demonstrated to represent a period of at least 2-10 years when young turtles remain in the open ocean. This stage is now termed the pelagic (Bjorndal et al. 2000), oceanic (Bolten 2003; Mansfield et al. 2009) or epipelagic (Carr 1987, Chaloupka and Limpus 1997, Limpus and Chaloupka 1997, Schmid 1998, Diez and van Dam 2002, Schmid et al. 2003, Seminoff et al. 2003, Casale et al. 2008), or surface-pelagic (Witherington et al 2012) developmental life stage. During this stage, it is widely assumed that young turtles make use of floating rafts of debris, including *Sargassum* algae as habitat. Indeed, behavioral experiments using newly hatched loggerhead and hawksbill turtles showed that individuals were significantly attracted to the cover provided by experimentally controlled floating "algae" and in the ocean, neonate sea turtles are routinely found floating on rafts of *Sargassum* (Carr and Meylan 1980, Mellgren et al. 1994, Mellgren et al. 2003, Smith and Salmon 2009) In this habitat, young turtles are primarily omnivorous and opportunistic feeders that use the structure of algae and other flotsam as habitat (Witherington et al. 2012). The use of these resources in pelagic habitats will provide the highest survivorship during the pelagic and early juvenile stage when predation is highest (Musick and Limpus 1997).

The major shift in life history of Atlantic turtles, apart from the leatherback, is a habitat transition from the surface-pelagic to neritic zone (<200m depth) and the start of a demersal lifestyle. The switch from surface-pelagic to neritic habitat is consistent across all Atlantic turtle species, with the exception of the leatherback which remains a pelagic species throughout its life (Bolten 2003). During this stage, surface-pelagic juvenile turtles move to shallow areas and often establish resident populations of juvenile individuals (Meylan et al. 2011). Accompanying this physical shift of habitat is also a shift in diet. Stable isotope analysis in scutes of juvenile herbivorous green turtles in shallow-water habitats revealed that they spend 3–5 years primarily as carnivores in pelagic habitats before making a rapid ontogenetic shift in diet and habitat to the neritic zone (Reich et al. 2007, McClellan et al. 2010).

The ontogenetic shift from a pelagic to demersal existence is the starkest change during the sea turtle life cycle, apart from hatching. This shift occurs at different times in the development of green turtle, loggerhead, Kemp's ridley and hawksbill turtles but this life history trait is consistent across these species. Additionally, Meylan et al. (2011) provide support for a benthic developmental stage in the Atlantic and Caribbean immediately following the pelagic stage for each of these species. As individuals turn to the neritic juvenile stage they more directly rely on benthic resources and habitat for their development through adolescence.

As they move to the neritic zone individuals broaden their diets to include a larger proportion of plant matter, including sea grasses and algae. Evidence suggests that these habitats are functionally separate from adult foraging grounds, especially for green and hawksbill turtles, which support the inclusion of this stage as part of their development cycle (Meylan et al. 2011). Loggerhead turtles also appear to proceed through a benthic development stage, although the separation of juveniles from adults in these habitats is less pronounced, possibly a consequence of their more relaxed life-history model (Casale et al. 2008). During this time, loggerheads are likely to switch from more immature-dominated to more adult-dominated foraging areas when feeding near shore (Meylan et al 2011).

The onset of puberty for these three species usually precedes a departure from neritic developmental habitat and suggests the possibility that the maturation process might prompt the developmental migration to the adult foraging range which would account for the lack of mature individuals near juvenile-neritic foraging areas in Bermuda (Meylan et al 2011). All species of Atlantic sea turtles nest on the beaches of the Caribbean, Mediterranean, Africa, and the Americas and the life history parameters discussed above, alone provide evidence that Atlantic sea turtles travel large distances and utilize functionally and spatially distinct habitats during their lives.

The Sargasso Sea and Atlantic Sea Turtles

Of all the marine vertebrate species that depend on the *Sargassum*, sea turtles are the most threatened and least understood residents of this ecosystem. There is a considerably amount of evidence, both circumstantial and direct, that the sea turtle species of the Atlantic Ocean, especially green , hawksbill, and loggerhead fully utilize the habitat provided by *Sargassum* during their pelagic life stage. The Sargasso Sea is used primarily by the leatherback as it travels from warm to cold latitudes during its seasonal migration, as this species does not rely on *Sargassum* to the same extent as other species in the Sargasso Sea (James et al. 2005, Fossette et al. 2010).

Kemp's ridley is not a common turtle in the Atlantic Ocean or in the Sargasso Sea. It is primarily restricted to the Gulf of Mexico and the majority of the population of this Critically Endangered species nests at only three sites on the Yucatan peninsula of Mexico (IUCN Red List, 2013). However, in 2006 and 2007 two individuals stranded in Bermuda (50.4 cm and

15.0 cm SCL (respectively) and only one other individual had been recorded in Bermuda in 1949 (Mark Outerbridge personal communication, Mowbray & Caldwell 1958). Pelagic juvenile Kemp's ridley have been observed using *Sargassum* as habitat in the Gulf of Mexico, but this behavior has not been observed in the Sargasso Sea (Manzella et al. 1991, Witherington et al. 2012). However unlikely, it is possible that pelagic juvenile Kemp's ridley turtles ride ocean currents to the Sargasso Sea, perhaps along *Sargassum* mats. The fact that this species has been stranded in Bermuda indicates that there are occasional individuals that find their way into the Sargasso Sea and once they alight from strong currents, the *Sargassum* ecosystem likely provides suitable habitat for this species.

The majority of evidence for the Sargasso Sea as habitat for the pelagic juvenile stage of sea turtle development comes from studies of the green, hawksbill, and loggerhead species. The Sargasso Sea presents two key habitats for marine turtles. First, the extensive *Sargassum* of the region provides the structural complexity and support for the community of species that utilize this pelagic ecosystem, including neonate and juvenile surface-pelagic turtles. Secondly, the island of Bermuda provides an adjacent neritic habitat that has demonstrated value as habitat for juvenile sea turtles that have completed their surface-pelagic life stage, especially the green turtle. Both of these habitats are fully utilized and important in the development of these turtle species from neonates to reproductive adults.

Sargassum

As soon as hatchlings reach the ocean and begin their frenzied swim to sea, there is experimental evidence that at least the three most common species (green, hawksbill, and loggerhead) actively seek out floating objects in the ocean, including *Sargassum* (Mellgren et al. 1994, Mellgren et al. 2003, Smith and Salmon 2009). *Sargassum* has been well documented as refuge, foraging, thermal, and early developmental habitat for neonate and juvenile surface-pelagic sea turtles (Carr and Meylan 1980, Carr 1987, Schwartz 1988, Manzella and Williams 1991, Bass et al 2006, Mansfield et al. 2014). The association with these drifting algae species is hypothesized to account for the extensive dispersal of young turtles around the Sargasso Sea which provides favorable conditions for survival and growth (Carr and Meylan 1980, Bjordal et al. 2000, Fuxjager et al, 2011, Mansfield et al. 2014).

Additionally, neonate turtles are often found in *Sargassum* that has washed ashore and gut content analysis confirms that their concurrence with *Sargassum* is not by chance, but that individuals have been associated with the algae for some time (Carr and Meylan 1980). Carr (1980) also provides significant support for the idea that neonate and juvenile turtles that have not yet completed their pelagic stage are dependent on *Sargassum* in the open ocean. However, he notes that as *Sargassum* is not present throughout the global range of these species, it is not a requirement of turtle biology, but can lead to increased recruitment of surface-pelagic juveniles to their juvenile neritic life stage. However, most evidence of surface-pelagic juvenile turtle association with *Sargassum* has been anecdotal and opportunistic, often relying on stranded individuals or chance observations (Carr 1987, Carr and Meylan 1980, Schwartz 1988, Manzella and Williams 1991).

However, an association with *Sargassum* has been measured *in situ* by Witherington et al. (2012) who found that neonate and pelagic juvenile green, hawksbill, loggerhead and Kemp's ridley turtles all had a strong spatial and trophic association with *Sargassum* algae. These findings provide experimental support to the long-held assumption of the affinity of surface-pelagic young turtles for *Sargassum* algae mats during their development. The support provided by *Sargassum* in the development of juvenile-pelagic turtles is further supported by the fact that North Atlantic populations of loggerheads make the switch from juvenile pelagic habitat to demersal habitat at a smaller size and (and younger age) than do western South Pacific populations. (Musick and Limpus 1997)

In the first long-term satellite tracking of neonate loggerhead turtles, Mansfield et al (2014) found that turtles rarely travel in continental shelf waters, travel quickly when in prevailing currents, and preferentially select surface-pelagic habitats that are likely to provide a thermal refuge that support growth, foraging and survival. This direct experimental evidence lends credence to the assumption that surface-pelagic stage turtles may remain with *Sargassum* as it leaves ocean currents and becomes established in the Sargasso Sea.

Apart from leatherback turtles, juveniles in the Atlantic that reach the appropriate developmental stage leave the pelagic environment and recruit to neritic foraging grounds to complete their adolescent stage (Musick and Limpus, 1997; Meylan and Redlow, 2006, Meylan et al. 2011). Indeed, Meylan et al. (2011) report that pelagic-juvenile green turtles that approach the size at which they make the switch from pelagic to neritic are populous in the environment surrounding Bermuda, although they admit that the evidence for the occurrence of ambient surface-pelagic hawksbills surrounding Bermuda is stronger. Within the Sargasso Sea, Bermuda is an important location for this life history change.

Bermuda

Bermuda has long been associated with sea turtles and there is mounting evidence of how critical these islands are for the juvenile development of Atlantic turtle species. Bermuda is important for juvenile-pelagic turtles that reside in the Sargasso Sea. This is supported by the fact that green turtle hatchlings are known from *Sargassum* drift lines that exist up current from Bermuda (Meylan et al 2011) and the majority of the loggerheads that stranded in Bermuda between 1983 and 2007 were young, pelagic-phase individuals, 75% of which measured <42 cm SCL, the minimum size at which loggerheads have been reported to recruit to neritic waters (Bjorndal et al. 2000).

Following their juvenile surface-pelagic life stage, a large number of green and hawksbill turtles graduate from *Sargassum* habitat to use Bermuda's extensive reefs and seagrass beds as a developmental neritic habitat during their adolescence (Meylan et al 2011). Additional data collected on the demography of sea turtle populations in Bermuda finds that individual green turtles are overwhelmingly juvenile and exhibit high site fidelity (Meylan et al. 2011).

The general absence of sexually mature turtles in Bermudan waters indicates that Bermuda is not the final, adult habitat for the majority of turtle species (Meylan et al. 2011, Dow et al. 2007). Adult green and loggerhead turtles infrequently nest in Bermuda and the remaining species of Atlantic sea turtles use Bermuda as a foraging ground (Dow et al. 2007). Therefore, each of the species that complete their juvenile-neritic developmental stage in Bermuda must make a significant migration to graduate into the next stage of their life cycle. (Meylan et al 2011).

Future Research and Collaboration

The Sargasso Sea provides a rich habitat that all species of Atlantic sea turtles have been found to utilize as habitat or refuge (Carr and Meylan 1980, Carr 1987, Shaver 1991). Research clearly indicates the important role that *Sargassum* plays throughout a sea turtle's life, especially during the critical neonate and surface-pelagic juvenile stage. The Sargasso Sea provides the largest area on earth for this type of habitat and sea turtle populations rely on the abundance of this ecosystem and the adjacent neritic habitat of Bermuda for their survival in the North Atlantic.

However, despite the importance of the pelagic-juvenile stage in sea turtle development, there remains relatively little empirical information regarding the ecology of Atlantic sea turtle species and their interactions with the *Sargassum* community. This is overwhelmingly due to the fact that neonate turtles are small and their *Sargassum* habitat is constantly moving and shifting in space and time over a large area. The logistics of measuring individual movements and life-history patterns for these species *in situ* presents an incredibly complicated and expensive logistical hurdle for researchers. Still, advances in remote sensing, satellite telemetry, stable isotope analysis, and laparoscopy are beginning to illuminate the incredible life history during the "lost years" of sea turtle development.

The distribution of turtles at each life stage throughout the Caribbean, Atlantic, and Sargasso Sea highlights the necessity for regional and international coordination for the conservation of these threatened species. It is clear that the majority of sea turtle development during the "lost years" occurs in areas beyond national jurisdiction, especially within the Sargasso Sea. The importance of managing marine turtle populations within an internationally cooperative framework, such as the Inter-American Convention for the Protection and Conservation of Sea Turtles and the Sargasso Sea Alliance is necessary to assure the effective conservation of Atlantic marine turtle populations.

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