Exploring the possible effects of Climate Change on Loggerhead (*Caretta caretta*) and Green Sea Turtles (*Chelonia mydas*) in the Eastern Mediterranean

Elyesa Çilingir
S-1725459
Supervised by Prof.dr. J.L. Olsen, CEES-MarBEE
Bachelor Essay 2014
Rijks Universiteit Groningen

Abstract

Climate change comes with projected effects. The main factors that play a role in the Mediterranean are: air/water temperature changes, sea level rise and an increased frequency and severity of storms. Loggerheads and green sea turtles in the Mediterranean are believed to be influenced by the projected effects of climate change. These factors can lead to changing incubation temperatures, leading to a skewed sex ratio. A change in ecological systems and/or habitats, forcing sea turtles to other areas for nesting and/or foraging. Looking at genetics, climate change and its projected effects have never driven sea turtle populations in the Mediterranean to extinction. Nowadays the intentional fishing, bycatch, collision trauma, habitat destruction, competition for nesting beaches with tourism, coastal modification and pollution cause a cumulative effect which makes climate change a serious threat to the loggerheads and green sea turtles of the Eastern Mediterranean. Genetics on the population structure show that both the loggerheads and green sea turtles do not disperse out of the Mediterranean. The presence of suitable habitats along the entire Mediterranean is the only mean that can ensure the sea turtle populations to survive the effects of climate change in the Mediterranean.

Introduction

Climate change

Nowadays climate change is a well discussed issue. With time, its effects are better understood. The global increase in greenhouse emissions is believed to be the main contributor to the greenhouse effect. This global warming will have numerous effects, of which a number have been identified. The sea surface temperatures are increasing worldwide. As a consequence of melting icecaps, the global sea level is predicted to increase. The increase in atmospheric CO_2 causes oceanic acidification. Changes in climate have occurred before. The most recent, drastic climate changes occurred during glacial and inter-glacial periods, not taking the current climatic changes into account. It's the amount and speed in which the climate changes nowadays that makes the climatic changes we experience now different from the historical ones. The anthropogenic contribution to climate change is believed to be the decisive factor. One could argue that all the observed effects are caused by anthropogenic factors. For this thesis I will regard the climate changes as abiotic factors in which the human role is excluded as much as possible.

Local effects of climate change can deviate from global effects. The polar regions for example will endure a relatively higher temperature change than tropical regions. In this case the local focus will be on the Mediterranean.

The Mediterranean harbours an intensively exploited area with high densities of human populations. Because of its semi-enclosed nature, the Mediterranean could be more susceptible to climate changes than any other basin. Because of these unique traits, the Mediterranean could act as a small scale representation for Earth's oceans. The effect of climate change could potentially be easier to distinguish in this 'mini-oceanic' system. At the same time, the high densities of human populations can provide the platform for case studies in case the human and turtle populations will be even more intermingled by the effects of climate change (Steele et al., 2001).

The air temperature along the Mediterranean is to increase in the face of climate change during the next century. As a direct result of this temperature increase the amount of fresh water flow in in-land ecosystems will increase as well. This is mainly due to the melting of snow in the mountainous regions. This increases the frequency and ferocity of precipitation along the Eastern Mediterranean. It could well be that these effects of climate change will have an influence on existing sea currents, thermo regimes and salinity (Onol et al., 2014). It should be noted however that no evidence has been found that an increased in-land fresh water debouch into the sea would affect existing sea currents, thermo regimes and salinity in the Eastern Mediterranean.

During the next century the SST (sea surface temperature) of the Mediterranean will also increase (Carlo & Otero, 2012; The Cyprus Insitute, 2008). This is also suggested to have influence on existing sea current flows and thermo regimes in the Eastern Mediterranean basin. The surface temperature of the Mediterranean will increase by an estimated 2.5-3 °C (Carlo & Otero, 2012)(figure 1).

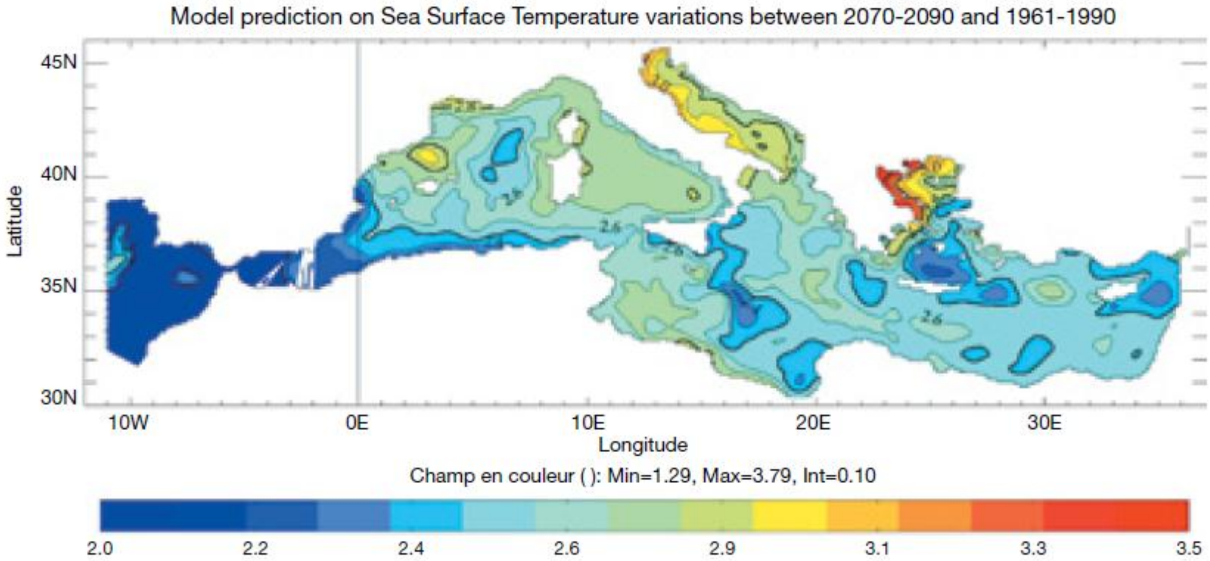

Figure 1 Difference in projected SST (sea surface temperature) between 2070-2090, compared to the SST between 1961-1990. (Source: Carlo & Otero, 2012. Page 5)

SLR (sea level rise) as a consequence of climate change is expected for the Mediterranean. Since the Mediterranean is an enclosed basin, tidal effects are minimal compared to other ocean systems. This mitigated tidal effect also translates in a relatively lower SLR prediction compared to other seas. An sea level increase of 1.3-2.5 cm per decade is predicted to occur in the Mediterranean during the next century as a result of climate change (Carlo & Otero, 2012; The Cyprus Institute, 2008).

Overall the salinity in the Mediterranean is expected to increase further. Higher temperatures lead to a higher evaporation rate. This makes the entire Mediterranean, but especially the Eastern basin, more saline. The effect of increased salinity, higher density water, and increase in SST, lower density water, is not fully understood. The assumption that these effects of higher- and lower density waters will cancel each other is not solid. These effects play a role to a certain extend but the exact interaction between the two phenomena is difficult to predict. The increase in salinity is bound to have an effect on existing dynamics in the oceanic systems of the Mediterranean (Carlo & Otero, 2012; The Cyprus Institute, 2008). The prediction of the effect of increased salinity is more complicated compared to the increase of temperature and SLR. This makes it hard to predict what the effects will be.

Since turtles are able to cope with saline environments and predictions concerning salinity increase are difficult, the increase in salinity will not be discussed further.

The effect of OA (oceanic acidification) in the Mediterranean is poorly understood. At the same time, there is no indication that OA has a direct influence on turtles. The acidification is bound to have some effect on ecological systems on which turtles ultimately depend. Since these effects are neither understood or proven and there is no known direct effect on turtles, OA will not be discussed further.

The SST will increase the most in the Adriatic and Aegean (Carlo & Otero, 2012)(figure 1). These water masses are relatively shallow. This makes the Adriatic and the Aegean more prone to heating up. The SST in the Eastern Mediterranean basin will be higher than the Western Mediterranean basin (Carlo & Otero, 2012)(figure 1).

SLRs in the Eastern Mediterranean depend mostly on the width of the continental shelfs. The beaches that are located on a wide continental shelf (Libya, South/South-East Turkey, Cyprus) have a gradual slope. The sea level on these beaches will therefor rise gradually. Whereas beaches on a narrow continental shelf (Western Greece) will have a steep slope (Clusa et al., 2013). The SLR on these beaches will be higher as compared to the beaches on a wide continental shelf.

The frequency and ferocity of precipitation is believed to increase during the next century for the Eastern Mediterranean. This means that storms occur more often en will be more fierce (Onol et al., 2013). As a result, coastal zones with high density of human populations are at risk. There is however the curious case of the Nile delta where it was found that a combination of natural and manmade structures formed an unintended barrier. Reducing the expected impact of inundations (Hassaan & Abdrabo, 2013).

Sea turtles

There are seven species of sea turtles and they inhabit all of the world's oceans and seas, apart from the polar regions. At the moment, only the olive ridley and the leatherback are considered vulnerable according the IUCN status. Both the loggerhead and green sea turtle are endangered and the kemps ridley and the hawksbill are critically endangered. There is no sufficient data for the flatback, although it has been categorized as vulnerable in the past. This shows that all species of sea turtles are under pressure (IUCN Red List).

The main cause for decreasing turtle numbers is of anthropogenic nature. Intentional fishing, by-catch and collision trauma are a few of these causes. But also habitat destruction, competition for nesting sites with tourism, coastal modification and pollution are main contributors to declining turtle numbers (Gilman et al., 2010; Casale, 2011; Turkozan et al., 2013). This anthropogenic pressure dates back a long time in history. It should be noted that harvesting activities probably went back as far as Imperial Roman times, which means that sea turtle populations have been under constant anthropogenic pressure. Due to a high demand of luxury products based on sea turtles, both the loggerhead and green sea turtle populations in the Mediterranean were subjected to harvesting activities. The first documented harvests are from early 20th century. Unfortunately, exact numbers are missing. It is however assumed that the harvesting activities decimated the populations. The introduction of protective legislation and restrictions in wildlife trade during the 70´s and 80´s caused a decline in the exploitation of sea turtles in the Mediterranean. The drop in wildlife stock and decline in luxury food consumption (turtle soup) also played a role in the decline of exploitation. Especially the North African coastline is subjected to poor legislation monitoring. Some amount of exploitation of turtle populations could therefor still be present at local communities in these regions. The general assumption is that even though little to no data is available regarding the exploitation of turtle populations in the Mediterranean, these populations suffered severe declines in numbers (Council of Europe, 1990).

The loggerhead, *Caretta caretta* and the green sea turtle, *Chylonia mydas* are the two residential species of sea turtles in the Mediterranean (Broderick et al., 2002). The leatherback *Demochelys coriacea* only ventures into the Mediterranean basin for foraging and is the only sea turtle species that regularly visits the Black Sea (U.S. Fish and Wildlife

Service & National Marine Fisheries Service, 2007). The focus here will be on the green sea turtle and loggerhead populations.

It should be noted that not all aspects of sea turtle dynamics is fully understood, especially in the Eastern Mediterranean basin. But over the course of time, some fundamental research has been done. Unfortunately some regions lack proper scientific research, causing a lot of missing data. Most research efforts are concentrated along the northern and north-eastern coastline (Greece, Turkey and Cyprus) of the Eastern Mediterranean basin. These regions also harbour the bulk of the Mediterranean loggerhead and green sea turtle populations. The loggerheads are the most researched marine turtles of the Mediterranean.

Sea turtles play an important, ecological role in marine and terrestrial ecosystems. They provide a substrate for, for example, sessile species to sustain/increase their genetic diversity. The turtles also play a role in keeping species domination shifts to a minimum. Nutrient availability in marine and marine-to-terrestrial cycles is also influenced by sea turtles. Green sea turtles are key-grazers in the subtropical Caribbean. They increase the productivity of seagrass by grazing off the older parts of the leaves. These clipped leaves are taken away by currents (Bjorndal 1980; Thayer, 1984), decreasing the deposit of organic matter in seagrass patches. This gives a lower nitrogen concentration to be taken up by the seagrass (Thayer, 1984; Jackson, 1997). Since the availability of nitrogen decreases, the plant species, nutrient cycling, animal densities and predator-prey relations within the seagrass area are affected (Thayer, 1984; Jackson, 1997). The impact of grazing by green sea turtles on seagrass beds, and with it on multiple ecological interactions, proves not to be negligible. The decline of seagrass in Florida Bay and the Gulf of Mexico has a strong correlation with the ecological extinction of green sea turtles (Jackson, 2001).

The decline in commercially interesting fish for Caribbean fisheries has been correlated with the decline of green sea turtle populations. The seagrass beds decline in overall condition. Since these seagrass beds are important nursing grounds for all sorts of species, the commercially interesting reef fish populations, together with other populations of fish species, decreased. This decrease had a direct effect on the availability of protein-rich food for the local people (McClenachan et al., 2006).

It should be noted that there also is a correlation between the decline in seagrass meadows and overgrazing by green sea turtles. In some areas in the Bahamas the recent rebound of green sea turtles increased the grazing pressure on the already depleted seagrass meadows. It seems that in these areas the carrying capacity of sea grass beds is exceeded (Fourqurean et al., 2010).

Since green sea turtles are not that well-studied in the Eastern Mediterranean, little is known about their role in marine ecosystems. It could well be that the portrayed ecological role greens play in the subtropical Caribbean also applies for the Eastern Mediterranean sea grass beds and fish species that use these seagrass beds as nursing grounds. Loggerheads are reported to occasionally graze on Mediterranean seagrass beds, though seagrass is not their primary diet component (Margaritoulis & Demetropoulos, 2001).

Loggerheads in the Eastern Mediterranean are classified as predators (Margaritoulis & Demetropoulos, 2001). They prey on all sorts of marine life, as long as it fits through their beaks. Benthic crustaceans are their primary targets. It is suggested that the pulverizing of crustacean shells by loggerheads is influencing, increasing, the solubility of calcium (Bjorndal & Jackson, 2003). Whether this has major effects on the Eastern Mediterranen ecosystems is not known at the moment.

The presence of sea turtles in a marine ecosystem can be vital in mitigating shifts in species domination. The global increase of jellyfish numbers is a result of collapsed fish stocks. This increase in jellyfish numbers has a negative effect on the growth of the current fish populations (Purcell et al., 2001). Since the Mediterranean is a highly fished area, the increase in jellyfish is becoming a problem. Jellyfish are an important part of sea turtle diet (Spotila, 2004). The leatherback, an occasional visitor to the Mediterranean, is the only species which primarily preys on jellyfish. Both the loggerhead and the green sea turtle also depend on jellyfish, being on a lesser degree (Lynam et al., 2006). The sea turtles of the Mediterranean can therefor play a vital role in mitigating the growth of jellyfish populations.

Whether the loggerheads and green sea turtles (can) play a significant role in jellyfish population control in the Eastern Mediterranean remains to be proven/discussed.

The sex of turtle embryos is determined by temperature (Spotila, 2004). For example: at 28°C, all hatchlings from a green sea turtle become males, while at 31°C, all hatchlings become female. At the pivotal temperature of 29°C, the hatchlings develop into males and females. The ratio depends on the temperature distribution within the nest. The developing embryos also produce heat. The general pattern in sea turtle nests is that females are in the warmer middle of the nest, while the males are on the cooler edges (Spotila, 2004).

The sex determining mechanism in turtle embryos is prone to environmental influences. A few days of rain during the sex determining phase can lower the temperature in a nest. Embryos that would have developed into females, now turn into males because of the temperature drop (Spotila, 2004; Rafferty & Reina, 2014). The predicted higher frequency and increased ferocity of storms will not only drop nest temperatures, inundations/sea swells as a consqequence of storms also pose a serious risk to nests. The nests could be flooded by storms, suffocating the eggs/hatchlings.

It has been noted that a high nest temperature gives smaller sized hatchlings with reduced locomotion compared to nests with low temperatures (Rafferty & Reina, 2014). The nest depth can also be a measure for turtles to maintain a nesting temperature. It turns out that the nest depth may not mitigate sex ratio skews (Refsnider et al., 2013). Shading of nests seems to work in some areas. By applying shade, the nest temperature drops, reducing the amount of females in a nest.

The predicted temperature changes in the Eastern Mediterranean could cause difficulties for sea turtles to find an adequate nesting site on the beach. The higher the temperature, the faster an embryo develops. Nesting in a shaded area or closer to the beach perimeters could increase the incubation period by weeks, making the clutch more vulnerable to predation (Spotila, 2004).

SLR during the next century will force sea turtles to rearrange their nesting sites. The beaches that are located on a wide continental shelf (South/South-East Turkey, Cyprus) will have a gradual increase of sea level. This will probably enable turtles to slowly adjust to the rising sea level, by nesting on higher grounds on the same beach. For areas with a narrow continental shelf (West Greece) the turtles will probably lose entire nesting beaches to the rising sea level. The chance of new beaches emerging due to SLR are slim, since most beaches are surrounded by cliffs (Katselidis et al., 2014). The most probable expectation will be that the populations in an area with a narrow continental shelf will have a harder time adapting to the changes than those populations associated with a wide continental shelf. Moving up a beach slope generally means moving closer to trees, bushes and/or rocks. These obstacles could provide shading and whether this will enhance or inhibit the embryonic development remains to be seen. Loggerheads in the Mediterranean move at a constant speed during long-distance migration legs. Whether they head into or swim with a current, the travel speed stays constant. During foraging activities in the pelagic however, the turtle movement seems to coincide with the sea currents. It should be noted that this research was only done for loggerheads, migrating from the Western- to the Eastern Mediterranean basin (Bentivegna et al., 2007). Since the size and weight of both loggerheads and green sea turtles is similar (Spotila, 2004), it is highly reasonable to assume that green sea turtles apply the same migratory patterns described for loggerheads.

The increase in SST and SLR, and the increased severity and frequency of storms could be factors that force the populations in the Eastern Mediterranean to alternative nesting sites. The current major nesting sites along the Eastern Mediterranean are protected wildlife areas. Since there is a chance these areas will not be suitable during the next century, alternative areas that could be new nesting sites need to be identified and protected accordingly. Precise predictions of the effects of climate change are not yet possible. However, the models used to predict these effects become more reliable. Any proposed changes in Mediterranean sea currents due to climate change, should not pose an immediate threat to the sea turtles. I already showed that sea turtles in the Mediterranean are active migrators and do not depend on sea currents for their mobility.

The data gathered for turtle movement patterns are mainly done by satellite tracking, tagging is the alternative method (Bentivegna et al., 2007). Fundamental movement patterns for green sea turtles are also known by the use of the GPS data (Turkecan et al., 2011). Movement patterns depend on the gender mostly. Female loggerheads show more willingness for migration than males. Males usually show a tendency to be residential to a specific area, especially foraging grounds.

The destruction of suitable marine habitats is another factor influencing the survival of sea turtle populations in the future (Council of Europe, 1990). It could well be that the change in nesting sites and foraging grounds due to climate change can drastically change turtle movement patterns within the Mediterranean. Since sea turtles are migrators, the presence of foraging grounds and nesting sites along the Mediterranean should be sufficient to sustain the population. Given that there will be no negative, anthropogenic effects on individuals on these new migration routes.

Three principle, benthic foraging grounds for loggerheads and green turtles have been identified in the eastern Mediterannean: The Nile delta (Laurent et al. 1996), the Bay of Iskenderun (Turkey)(Oruc, 2001) and Lakinos bay (Greece)(Margaritoulis 1992) The Adriatic Sea coast, especially the Gulf of Gabes is a major foraging ground for loggerheads only (Margaritoulis, 1988; Argano et al., 1992; Laurent & Lescure, 1994; Lazar et al., 2000).

The feeding grounds for turtles will probably undergo changes as a result of SLR. A rise of 1.3 to 2.5 cm per decade is predicted for the Mediterranean (Carlo & Otero, 2012). In the next century this would mean an increase of 13 to 25 cm. This will narrow beaches, but the chance of entire nesting beaches being completely submersed in the next century seems unlikely (Katselidis et al., 2014). The effect on foraging grounds is impossible to be known. It seems probable that there will occur some shifts of foraging grounds. In some regions, the diet could be altered as a result of residing sea grass beds.

These foraging grounds are thought to be close to some of the main nesting sites. There are male individuals, mainly green sea turtles but loggerheads as well, who travel long distances for foraging (Casale et al., 2013). Large patches of seagrass can be found of the coast of Libya and Tunisia. These regions also form an overwintering area for both the loggerheads and green sea turtles (figure 2) (Margaritoulis et al., 2001). Some loggerheads venture into the Western Mediterranean basin, whereas green sea turtles are rarely seen in the western basin (Margaritoulis et al., 2001). The latter is probably related to temperature, since the Western Mediterranean has a cooler surface temperature.

Individuals from the Atlantic populations of loggerheads and green sea turtles are known to disperse into the Mediterranean, whereas there is no known case of dispersal from the Mediterranean populations into the Atlantic. The Mediterranean meta population for loggerheads can roughly be divided into two sections, the Western Mediterranean and Eastern Mediterranean populations.

The Eastern Mediterranean loggerhead population is to be considered residential, meaning that females from these populations are philopatric in nesting activities and only migrate to the Western Mediterranean basin for foraging (Margaritoulis & Demetropoulos, 2001).

The Western Mediterranean loggerhead populations show more genetic relatedness to Atlantic loggerhead populations (Margaritoulis et al., 2001; Council of Europe, 1990; Clusa et al., 2013). In this case, it is assumed that loggerhead individuals form the Western Mediterranean do disperse back into the Atlantic, being on a lesser degree than the influx from the Atlantic to the Mediterranean. It is therefore assumed that the strait of Gibraltar acts as a ‘turtle filter’, with influx from Atlantic populations but little to no efflux from Mediterranean populations (Margaritoulis et al., 2001).

The green sea turtle is found almost exclusively in the Eastern Mediterranean basin. Sightings of individuals in the Western Mediterranean basin are not known, this could be explained by the lower surface temperatures in the Western basin. Little to nothing is known about movement patterns of loggerheads and green sea turtles that nest on the minor nesting sites. The general consensus is that these minor nesting sites are visited at random by individuals.

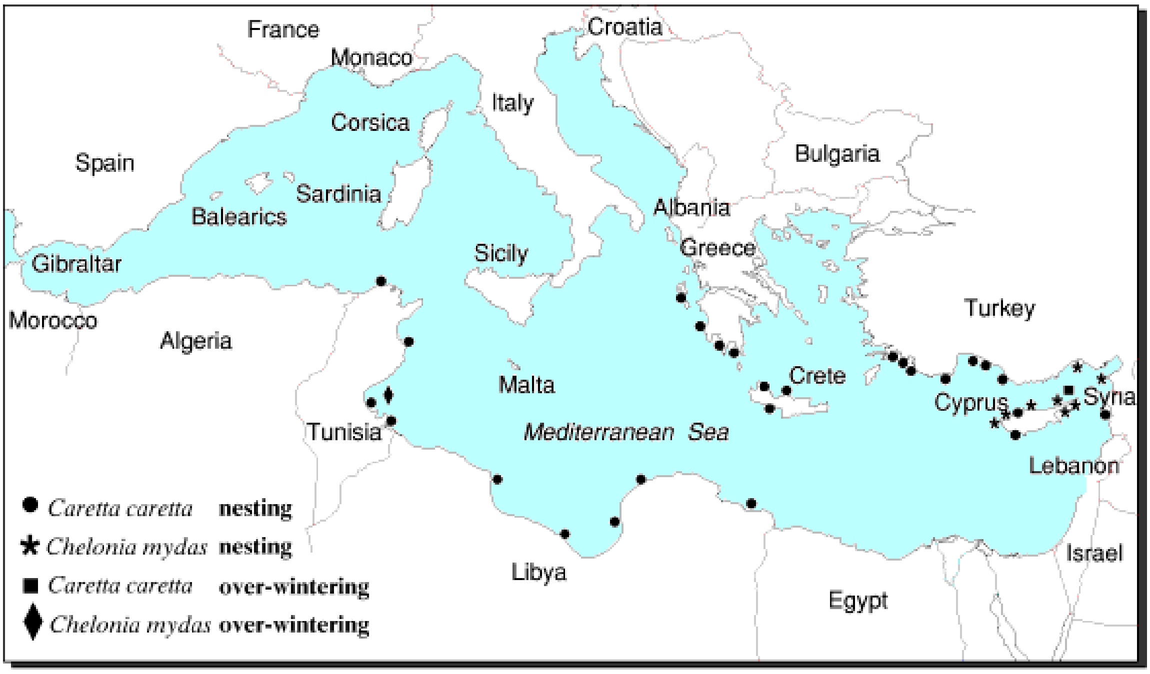

Figure 2 Showing the key breeding sites and over wintering areas for loggerheads and green sea turtles. Note that the Eastern basin, especially the coasts of Cyprus, Turkey and to a lesser extend Greece, harbour the bulk of the nesting sites. The major nesting sites for both loggerheads and green sea turtles are also located in these areas. (Source: http://www.euroturtle.org/distrib.htm)

Both the loggerheads and green sea turtle populations show a significant amount of genetic variation between nesting populations, indicating that females are philopatric (Yilmaz et al., 2011; Bagda et al., 2012). This lowers the gene flow between populations in the Easter Mediterranean drastically. It should be noted that in the case of the green sea turtles, mtDNA analysis did not lead to preferable conservation implications. The variation in mtDNA in green sea turtles in the Eastern Mediterranean obscured genetic structuring on mtDNA basis (Bagda et al., 2012). Microsatellite analysis for both green sea turtles and loggerheads proved that there are significant differences in genetics between different nesting populations. At the same time it shows that each green sea turtle nesting site should be considered as a management unit, whereas for loggerheads five management units were described (Yilmaz et al., 2011; Bagda et al., 2012). These five loggerhead management units harboured the highest allelic diversity and can provide a solid basis, through conservation management, for genetic diversity along the smaller and genetically less diverse nesting sites (Yilmaz et al., 2011). For the green sea turtles no population was found that could provide the entire Mediterranean population of greens with genetic diversity.

We can roughly conclude then that the loggerhead populations of the Eastern Mediterranean are of a lower conservation interest then the green sea turtle populations. The absence of data from other regions (Libya, Egypt, Israel, and Lebanon) gives a huge gap and restricts the knowledge of population dynamics in the Eastern Mediterranean. However, since the populations in Turkey and Northern Cyprus showed extremely low amounts of gene flow, the same could be suggested for the populations in Libya, Egypt, Israel and Lebanon.

How did loggerheads and green sea turtles end up in the Mediterranean? It appears that turtles colonized the Mediterranean during the Pleistocene era. Modern sea turtles came apparent in the fossil record around 145 mya. For the colonisation of the Mediterranean we have to wind back time to the Pleistocene era. During this era, 2.5 mya to 12 kya, multiple glacial-interglacial cycles occurred. Due to these cycles the species distribution along the Mediterranean was highly dynamic. Looking at other marine species, it seems that refugia in the Mediterranean enabled the survival of thermophilic species during glacial periods (Clusa et al., 2013). The same principle enabled loggerheads and green sea turtles to survive the lower temperatures during the glacial periods in the Mediterranean (Clusa et al., 2013; Yilmaz et al., 2011; Bagda et al., 2012).

Looking at the genetic structure of loggerheads, haplotypes, the sampled populations in Libya and eastern Turkey showed the highest number of unique haplotypes. Samples from

Western Greece showed a lower diversity in haplotypes. This suggests a gradient of haplotype diversity decreasing from east to west in the Mediterranean. To further prove this trend, the suggested gradient is found in sampled populations on the southern coast of Turkey, showing a decreasing amount of unique haplotypes from east to west (Yilmaz et al., 2011).

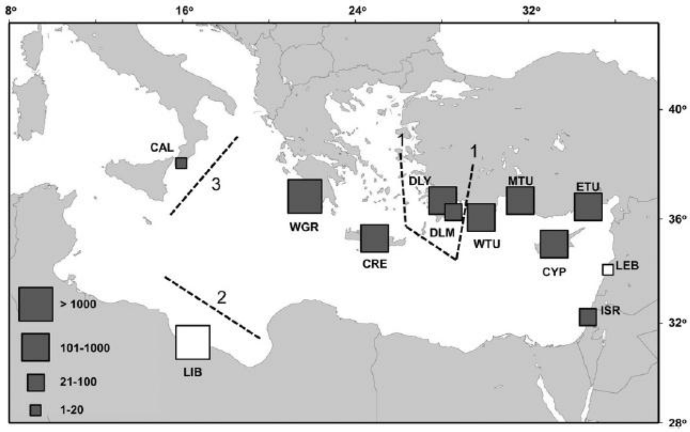

Figure 3 The sampled nesting sites for genetics in the Eastern Mediterranean basin. Grey squares are monitoring numbers, white squares are estimates. Dotted lines represent borders between populations based on genetics. The lowest number corresponds with the strongest barrier. (Source: Clusa et al., 2013. Figure 1)

The wider continental shelf in Eastern Turkey and Libya is the main reason for higher genetic variation, compared to Western Greece with a much narrower continental shelf. It is suggested that neritic habitats on wide continental shelves are less prone to temperature changes and could therefor present more stable habitats for turtles to exploit (Clusa et al., 2013). Combined with the strong correlation between nDNA diversity, width of the continental shelf and sea surface temperature, the highest genetic diversity was found in Libya. Eastern Turkey showed the highest amount of unique haplotypes after the samples from Libya (figure 3). This suggests that these areas not only acted as refugia during glacial periods, but were the first to be colonized. Libya was probably colonized first, followed by the Turkish and Greek coast. The Greek and Turkish coastlines experienced local extinctions multiple times as these regions became more and less favourable during the glacial and interglacial periods, while the coast off Libya formed more stable refugia. This process would explain the differences in haplotype diversity between the loggerhead subpopulations. (Clusa et al., 2013).

A different haplotype was found in Calabria, Italy. This haplotype shows a stronger correlation with Atlantic populations than the haplotypes encountered in the Eastern Mediterranean basin. This leads to a strong suggestion that there was also a colonisation event during the Holocene era. During this era, the Western Mediterranean basin warmed up, enabling the recolonisation by Atlantic populations, since the thermo barrier during glacial periods caused populations in the Eastern Mediterranean to further differentiate from the Atlantic populations (Clusa et al., 2013).

The Pleistocene colonization event is suggested to have taken place 200 kya to 20 kya. The Holocene colonization took place between 5 kya to 50 kya. It should be noted that the haplotypes found in the Western Mediterranean basin could be the result of gene flow from the Atlantic populations, rendering the Holocene colonization obsolete (Clusa et al., 2013).

It is assumed that green sea turtles show the same colonization pattern of the Mediterranean as loggerheads. Not much is known about the colonization of the Mediterranean by green sea turtles. Some suggest that Mediterranean green sea turtles show no dispersal out of the Mediterranean, based on mtDNA analysis, and form a subpopulation (Bowen et al., 1992; Margaritoulis & Demetropoulis, 2001; Bagda et al., 2012). If this Mediterranean isolation for greens is to be factual, the colonization of the

Mediterranean by green sea turtles took place during the Holocene era (Bowen et al., 1992; Bagda et al., 2012). Others claim that Atlantic and Mediterranean green sea turtles do exhibit genetic interchange (Roberts et al., 2004; Mrosovsky, 2006). This gene flow between the Mediterranean and Atlantic greens is suggested to be male mediated by mtDNA and nDNA analysis (Roberts et al., 2004). Since both sides seem to provide adequate data and no official (IUCN) notification has yet been made, and the articles that suggest the Holocene colonization of greens are still cited at recently published articles, I consider the Mediterranean green sea turtles as a residential population that colonized the Mediterranean during the Holocene.

Loggerheads and green sea turtles in the Eastern Mediterranean could face a range shift as a consequence of climate change. As discussed before, the SSTs are assumed to increase during the next century. The most probable range shift would be northward. This would mean that the loggerhead and green sea turtle populations would move into the Aegean and Adriatic. However, these seas are predicted to show the most temperature increase. It would therefore be unlikely for sea turtles to move into these regions. The changes in the ecosystems in the Aegean and Adriatic are expected to be the most severe as a consequence of the changing temperature regime (Carlo & Otero, 2012). It turns out that the Eastern Mediterranean basin shows a relatively uniform distributed SST increase between 2.2 and 2.4°C. The Western Mediterranean basin shows a uniform distributed increase of 2.0°C (figure 1) (Carlo & Otero, 2012; Onol et al., 2013). If the change in temperature in the Mediterranean is tolerable by sea turtles and the ecosystems shift accordingly, we could well see a range shift of loggerheads and green sea turtles into the Western Mediterranean.

Since detailed knowledge of the effects of climate change are deficient, it could be that the added effect of climate change, on top of the anthropogenic causes, will lead to the inevitable extinction of sea turtles. The growing relevance of climate change in our modern day society also applies to turtle populations. The anthropogenic factors I discussed earlier, influence sea turtle abundance along the Mediterranean. These human pressures pose the biggest threat to marine turtles, compared to climate change. When combining the threats of both climate change and human impact, we have a cumulative effect. When sea turtles of the Mediterranean will try to cope with climate change, their response is restricted due to the anthropogenic pressures. The other way round; When the turtle populations of the Mediterranean are given the time to recuperate from human pressures due to legislations, climate change can severely restrict the available space. Compared to the anthropogenic factors, climate change has not yet been proven to be responsible for declining turtle numbers. The cumulative effects of anthropogenic factors and climate change however, could topple turtle populations into extinction.

Discussion

Will the sea turtle population of the Eastern Mediterranean be able to overcome the effects of climate change? To be able to answer this main question, first, we will have to go back in time. As mentioned before, sea turtles have been around for hundreds of millions of years. During this period they have seen their fair share of climatic events. A recent study revealed that diversity among marine reptiles depended heavily on SLR/decline during the Triassic. SLR led to increased concentrations of nutrients, since terrestrial sediments became flooded. As a response, the primary production in these areas increased resulting in an increased amount of benthic invertebrate prey. In contrast, the decline of sea level eliminated existing habitats. This forced populations to become denser and deplete local resources worldwide. This process lead to the extinction of numerous taxa (Kelley et al., 2014). The population dynamics of sea turtles during the latest glacial periods showed a similar trend worldwide. During glacial periods, sea turtles were forced into refugia. During inter glacial periods, new areas became suitable for sea turtles. Some areas were colonized during inter glacial periods, abandoned during glacial periods and recolonized at the following inter glacial (Moll, 1983; Clusa et al., 2013; Yilmaz et al., 2011; Bagda et al., 2012). These colonization events show that sea turtles can adapt to climate changes. It should be noted that these climate changes all occurred at a steady pace. This enabled the populations to adapt adequately.

At the present, the main impact on turtle populations is anthropogenic (Gilman et al., 2010; Casale, 2011; Turkozan et al., 2013). The same anthropogenic factors limit the ability of sea turtles to shift their habitat range accordingly as a response to climate change. The coastline of the Eastern Mediterranean basin harbours a high density of human populations (Turkozan et al., 2013). The competition for space on beaches between turtles and humans already has a negative effect on sea turtle populations (Gilman et al., 2010; Casale, 2011; Turkozan et al., 2013). This pressure is only going to be increased in the course of climate changes. The chance of populations being driven into ecological traps is reasonable (Pike, 2013). The cumulative effect of climate change and anthropogenic pressure on the loggerhead and green sea turtle populations in the Eastern Mediterranean will most probably be, as mentioned before, devastating.

The increase in nest temperature can be battled by shading nests. This conservation strategy is applied in Australia. At nesting sites that were mainly female biased (high temperature nests), shading of nests reduced the bias towards females (Wood et al., 2014). Artificial beach nourishment, maintaining beach slope and covering of nests with sand, however reduces nesting success for loggerheads and green sea turtles (Brock et al., 2009).

There is no data available at the moment considering the success of relocated turtle nests in Florida. These turtles were trans located to another beach during the BP oil rig disaster in the Mexican Gulf. The turtles were transported during incubation to the Atlantic coast of Florida, in the hope that the hatchlings would return to these beaches rather than the polluted ones in the Gulf of Mexico. The effect of human intermingling in these processes is not yet fully understood. But if this relocation project in Florida generates the intended result the conservation management of sea turtles worldwide will be spared another complexity. The famous head-start project (rearing turtles to a certain point and releasing them back in the wild) for Kemp's Ridleys in the Mexican Gulf is an example of an ineffective conservation effort. This project resulted in 15 recorded nesting individuals over a period of 15 years. The costs involved are calculated at approximately $200.000 for a single individual. The conservation of habitats and nesting sites for turtles could therefor safe the taxpayer more money than, for example, a head-start project (Spotila, 2004). Conservation efforts like head-start projects, artificial beach nourishment and relocation give us an indication of how complex the managing of threatened turtle populations can be. At the same time, the effect of these measures could all be negative to the turtles, since artificial beach nourishment leads to a decrease in hatchling success for both loggerheads and green sea turtles (Brock et al., 2009).

Conclusion

To summarize, loggerheads and green sea turtles in the Mediterranean have been able to adapt to climate changes during the Pleistocene era. This is a proof that climate change in itself poses little to no threat to sea turtle populations in the Mediterranean. Although the current rate of climatic changes is said to be among the fastest climatic changes ever experienced. The anthropogenic pressure on the Mediterranean populations combined with climate change, is an cumulative effect.

These pressures have been lightened in certain areas (wildlife legislation, protected habitats, and lowered numbers of intentional and unintentional catches). Needless to say, the coastal zones of the Mediterranean are densely populated. Leaving no room for turtles to look for alternative nesting sites. Since turtles are migratory species and travel great distances for foraging or breeding, the change in nesting sites and/or breeding grounds will not pose the biggest impact. The presence of foraging grounds and nesting sites in the Mediterranean is crucial and should be sufficient to maintain the populations. The regeneration of foraging grounds (mainly sea grass beds) can be impaired, since negative anthropogenic factors are the main influence on seagrass beds in the Mediterranean. The Mediterranean populations, especially the Eastern Mediterranean populations, are residential. These populations do not show a tendency to leave the Mediterranean basin. Green sea turtles do not even venture into the Western Mediterranean basin. The question remains whether these populations would leave the Mediterranean basin in cases of threatening climatic changes. There is no evidence or trend found that sea turtles would leave the Mediterranean basin in case of catastrophic climate changes. Therefore I conclude that climate change poses a real threat to the loggerheads and green sea turtles of the Eastern Mediterranean basin.

References

Airi, V., Gizzi, F., Falini, G., Levy, O., Dubinsky, Z., Goffredo, S. 2014. Reproductive Efficiency of a Mediterranean Endemic Zooxanthellate Coral Decreases with Increasing Temperature along a Wide Latitudinal Gradient. PLOS ONE 9(3): e91792.

Argano, R., Basso, R., Cocco, M., Gerosa, G. 1992. New data on loggerhead (*Caretta caretta*) movements within Mediterranean. Boll. Mus. Ist. biol. Univ. Genova 56-57: 137-164.

Bagda, E., Bardakci, F., Turkozan, O. 2012. Lower genetic structuring in mitochondrial DNA than nuclear DNA among the nesting colonies of green turtles (*Chelonia mydas*) in the Mediterranean. Biochemical Systematics and Ecology 43: 192-199.

Bentivegna, F., Valentino, F., Falco, P., Zambianchi, E., Hochscheid, S. 2007. The relationship between loggerhead (*Caretta caretta*) turtle movement patterns and Mediterranean currents. Marine Biology 151(5): 1605-1614.

Bjorndal, K.A. 1980. Nutrition and grazing behavior of the green turtle *Chelonia mydas*. Marine Biology 56: 147-154.

Bjorndal, K. A., Jackson, J.B.C. 2003. Roles of sea turtles in marine ecosystems: Reconstructing the past. In Lutz, P.L., Musick, J.A. and Wyneken, J. (Eds.) The Biology of Sea Turtles Volume II. CRC Press, Boca Raton, Florida (USA). Pp. 259-273.

Bouchard, S.S. and Bjorndal, K.A. 2000. Sea turtles as biological transporters of nutrients and energy from marine to terrestrial ecosystems. Ecology 81: 2305-2313.

Bowen, B.W., Meylan, A.B., Ross, J.P., Limpus, C.J., Balazs, G.H., Avise, J.C. 1992. Global Population Structure and Natural History of the Green Turtle (*Chelonia Mydas*) in Terms of Matriarchal Phylogeny. Evolution 46(4): 865-881.

Bowen, B.W., Wallace, B. 2009. How Sea Turtles Have Weathered Past Climate Changes. SWOT report 5: 13-15.

Brock, K.A., Reece, J.S., Ehrhart, L.M. 2009. The Effects of Artificial Beach Nourishment on Marine Turtles: Differences between Loggerhead and Green Turtles. Restoration Ecology 17(2): 297-307.

Broderick, A.C., Glen, F., Godley, B.J., Hays, G.C. 2002. Estimating the number of green and loggerhead turtles nesting annually in the Mediterranean. Oryx 36(3): 227-235.

Carlo, G., Otero, M. 2012. A changing Mediterranean coastal marine environment under predicted climate-change scenarios, A manager's guide to understanding and addressing climate change impacts in marine protected areas. IUCN and MedPan brochure.

Casale, P. 2011. Sea turtle by-catch in the Mediterranean. Fish and Fisheries 12: 299-316.

Casale, P., Freggi, D., Cinà, v., Rocco, M. 2013. Spatio-temporal distribution and migration of adult male loggerhead sea turtles (*Caretta caretta*) in the Mediterranean Sea: further evidence of the importance of neritic habitats off North Africa. Marine Biology 160: 703-718.

Council of Europe. 1990. Marine Turtles in the Mediterranean: distribution, population status, conservation; Turtle Exploitation. Nature and Environment 48: 82-86. ISBN 9287118647.

Clusa, M., Carreras, C., Pascual, M., Demetropoulos, A., Margaritoulis, D., Rees, A.F., Hamza, A.A., Khalil, M., Aureggi, M., Levy, Y., Türkozan, O., Marco, A., Aguilar, A., Cardona, L. 2013. Mitochondrial DNA reveals Pleistocenic colonisation of the Mediterranean by loggerhead turtles (*Caretta caretta*). Journal of Experimental Marine Biology and Ecology 439: 15-24.

Cyprus Institute, The. 2008. Climate change and impacts in the Eastern Mediterranean and the Middle East; A regional climate assessment by the Cyprus Institute.

Fourqurean, J.W., Manuel, S., Coates, K.A., Kenworthy, W.J., Smith, S.R. 2010. Effects of excluding sea turtle herbivores from a seagrass bed: Overgrazing may have led to loss of seagrass meadows in Bermuda. Marine Ecology Progress Series 419: 223–232.

Gilman, E., Gearhart, J., Price, B., Eckert, S., Milliken, H., Wang, J., Swimmer, Y., Shiode, D., Abe, O., Peckham, S.H., Chaloupka, M., Hall, M., Mangel, J., Alfaro-Shigueto, J., Dalzell, P., Ishizaki, A. 2010. Mitigating sea turtle by-catch in coastal passive net fisheries. Fish and Fisheries 11: 57-88.

Hannan, L.B., Roth, J.D., Ehrhart, L.M., and Weishampel, J.F. 2007. Dune vegetation fertilization by nesting sea turtles. Ecology 88(4): 1053-1058.

Hassaan, M.A., Abdrabo, M.A. 2013. Vulnerability of the Nile Delta coastal areas to inundation by sea level rise. Environmental Monitoring and Assessment 185(8): 6607-6616.

IUCN Red List. 2014. The IUCN Red List of Threatened Species 2014.1, ISSN 2307-8235. http://www.iucnredlist.org/ Consulted on: 13-06-2014.

Jackson, J.B.C. 2001.What was natural in the coastal oceans? Proceedings of the National Academy of Sciences of the United States of America 98 (10): 5411-5418.

Jackson, J.B.C. 1997. Reefs since Columbus. Coral Reefs 16: S23-S32.

Katselidis, K.A. , Schofield, G., Stamou, G., Dimopoulos, P., Pantis, J.D. 2014. Employing sea-level rise scenarios to strategically select sea turtle nesting habitat important for long-term management at a temperate breeding area. Journal of Experimental Marine Biology and Ecology 450: 47-54.

Kelley, N.P., Motani, R., Jiang, D., Rieppel, O., Schmitz, L. 2014. Selective extinction of Triassic marine reptiles during long-term sea-level changes illuminated by seawater strontium isotopes. Palaeogeography, Palaeoclimatology, Palaeoecology 400: 9-16.

Laurent L., and J. Lescure. 1994. L'hivernage des tortues caouannes *Caretta caretta* (L.) dans le sud Tunisien. Revue d' Ecologie (Terre et Vie) 49: 63-85.

Laurent, L., Abd El-Mawla, E.M., Bradai, M.N., Demirayak, F., Oruç, A. 1996. Reducing sea turtle mortality induced by Mediterranean fisheries: trawling activity in Egypt, Tunisia and Turkey. WWF International Mediterranean Programme, Rome, Italy, 32 pp.

Lazar B., Margaritoulis, D., Tvrtkovicã. N. 2000. Migrations of the loggerhead sea turtle (Caretta caretta) into the Adriatic Sea. Proceedings of the Eighteenth Annual Symposium on Sea Turtle Conservation and Biology :101-102.

Lynam, C.P., Gibbons, M.J., Axelsen, B.E., Sparks, C.A.J., Coetzee, J., Heywood, B.G., Brierley, A.S. 2006. Jellyfish overtake fish in a heavily fished ecosystem. Current Biology 16(13): R492-R493.

Margaritoulis D. 1988. Post-nesting movements of loggerhead sea turtles tagged in Greece. Rapp. Comm. int. Mer Médit. 31(2): 284.

Margaritoulis D., N. Kousias, G. Nicolopoulou, and K. Teneketzis. 1992. Incidental catch of sea turtles in Greece: the case of Lakonikos Bay. in Proceedings of the Eleventh Annual Workshop on Sea Turtle Biology and Conservation: 168-170.

Margaritoulis, D., Demetropoulos, A. 2001. Proceedings, First Mediterranean Conference on Marine Turtles. CMS Report.

McClenachan, L., Jackson, J.B.C., and Newman, M.J.H. 2006. Conservation implications of historic sea turtle nesting beach loss. Frontiers in Ecology and the Environment 4(6): 290-296.

Moll, D. 1983. A Proposed Origin of Nesting Location Divergence and a Shared Feeding Range in Brazilian Green Turtle Populations. Copeia (1): 121-125.

Mrosovsky, N. 2006. Does the Mediterranean Green Turtle Exist? Marine Turtle Newsletter 111:1-2

Onol, B., Bozkurt, D., Turuncuoglu, U.U., Sen, O.L., Dalfes, H.N. 2014. Evaluation of the twenty-first century RCM simulations driven by multiple GCMs over the Eastern Mediterranean-Black Sea region. Climate Dynamics 42(7-8): 1949-1965.

Pike, D.A. 2013. Forecasting range expansion into ecological traps: climate-mediated shifts in sea turtle nesting beaches and human development. Global Change Biology 19: 3082-3092.

Purcell, J.E. and Arai, M.N. 2001. Interactions of pelagic cnidarians and ctenophores with fish: A review. Hydrobiologia 451: 27-44.

Rafferty, A.R., Reina, R.D. 2014. The influence of temperature on embryonic developmental arrest in Marine and freshwater turtles. Journal of Experimental Marine Biology and Ecology 450: 91-97.

Refsnider, J.M., Bodensteiner, B.L., Reneker, J.L., Janzen, F.J. 2013. Nest depth may not compensate for sex ratio skews caused by climate change in turtles. Animal Conservation 16: 481-490.

Roberts, M.A., Schwartsz, T.S., Karl, S.A. 2004. Global population genetic structure and male-mediated gene flow in the green sea turtle (*Chelonia mydas*): Analysis of microsatellite loci. Genetics 166:1857-1970.

Spotila, J.R. 2004. Sea Turtles: a complete guide to their biology, behaviour, and conservation. ISBN 0801880076.

Steele J.H., Thorpe, S.A., Turekian K.K. 2001. Ocean Currents. Mediterranean Sea Circulation. 283-298. ISBN 0080964869.

Thayer, G.W., Bjorndal K.A., Ogden, J.C.,Williams, S.L., Zieman, J.C. 1984. Role of larger herbivores in seagrass communities: Functional ecology of seagrass ecosystems: A perspective on plant-animal interactions. Estuaries 7(4): 351-376.

Turkecan, O., Yerli, S.V. 2011. Satellite Tracking of Adult Green Sea Turtle from Turkey: A Long Distance Diary. Marine Turtle Newsletter 131: 38-41.

Türkozan, O., Özdilek, Ş.Y., Ergene, S., Uçar, A.H., Sönmez, B., Yılmaz, C., Kaçar, Y., Aymak, C. 2013. Strandings of loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtles along the eastern Mediterranean coast of Turkey. 23: 11-15.

U.S. Fish and Wildlife Service, National Marine Fisheries Service. 2007. Leatherback Sea Turtle (*Dermochelys coriacea*), 5-year review: Summary and Evaluation.

Wood, A., Booth D.T., Limpus, C.J. 2014. Sun exposure, nest temperature and loggerhead turtle hatchlings: Implications for beach shading management strategies at sea turtle rookeries. Journal of Experimental Marine Biology and Ecology 451: 105-114.

Yilmaz, C., Turkozan, O., Bardakci, F. 2011. Genetic structure of loggerhead turtle (*Caretta caretta*) populations in Turkey. Biochemical Systematics and Ecology 39: 266-276.