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Increased use of non-native algae species in the diet of the Green Turtle (*Chelonia mydas*) in a primary pasture ecosystem in Hawaii

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The Green Turtle, Chelonia mydas*, has modified its feeding behavior over the past 36 years to include the increasing abundance of non-native algae growing in the greater Kaneohe Bay area of Oahu, Hawaii. Changes in diet of the Turtles are correlated with an increase in abundance of non-native algae. Turtles are eating 135 species of marine vegetation including the following seven non-native species:* Acanthophora spicifera, Hypnea musciformis, Gracilaria salicornia, Eucheuma denticulatum, Gracilaria tikvahiae, Kappaphycus striatum *and* Kappaphycus alvarezii. *Non-native algae now represent 0.64 proportion of the Turtle diet. The present study for the additional 8 years 2005–2012, shows the utilization of non-native species for food has increased 24% since the last study that included 28 years 1976–2005. Average time for the Turtles to make the shift to non-native species is 10–12 years for the more invasive species and 20–30 years for the slower growing species. During this same time period the numbers of* C. mydas*, body size, and growth rates have also increased, partly due to the increased abundance of the additional non-native food items. This study verifies that the trend of Turtles eating higher amounts of non-native algae in Kaneohe Bay is now stronger than first reported in 2009.*

Keywords: Turtle, feeding, Kaneohe Bay

Introduction

Research regarding the feeding behavior and diet of *Chelonia mydas* (L.) has been conducted since 1976 throughout the Hawaiian Islands, especially on the island of Oahu and specifically in Kaneohe Bay. Russell and Balazs (2009) published results for the first 28 years of data taken from Turtles analyzed from the greater Kaneohe Bay region, which is on the eastern shore of Oahu island, from 1976 to 2005. During this time the Green Turtle population showed remarkable recovery because of a number of efforts conducted by various government and private agencies (Balazs and Chaloupka, 2004a,b). The dietary shifts by *C. mydas* to the increase in seaweed biomass in their feeding pastures may have helped the population rise, as well as their general body size. (Russell and Balazs, 2009).

It is important to understand factors effecting Green Turtle biology to manage their recovery and maintain the ecosystems in which they live (Hirth, 1997). Balazs et al. (1987) gathered data on food sources, pastures, quantities and algae species

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utilized. Although most of the 135 seaweed species utilized by Green Turtles in Kaneohe Bay were native, seven were non-native (Russell and Balazs, 1994). Prior to the 1970s, only one introduced species, *Acanthophora spicifera*, which was introduced by ship (Doty, 1961), was found in the diet of Green Turtles in the Hawaiian Islands; now non-native species comprise the bulk of the Turtle diet (Russell and Balazs, 2009). Their main finding was the discovery of a shift in diet from native species toward non-native species that took 10–12 years to develop in 1985, nearly a decade after the algae were introduced. Red algae species (Rhodophora) comprised most of the native algae diet and the Turtles preferred to eat the newly introduced species, also Rhodophyta, even in locations where the native algae species were abundant.

Only two species of Sea Grass (*Halophila decipiens* and *H. hawaiiana*), which are often growing adjacent to each other, are utilized by Green Turtles in Hawaii, without an apparent preference by the Turtles. Turtles tend to eat more of the abundant Sea Grass species in any particular area (Russell et al., 2003). Animals are also eaten by Green Turtles, but in lesser amounts, which includes Sponges, Cnidaria, Mollusca, Crustacean and others, but the most common animal eaten is the Protein Sponge *Chondrosia chucalla* (Russell et al., 2011). There is no record that non-native species of animals are being utilized by Green Turtles in Hawaii, although this is a clear possibility.

The purpose of this report is to expand upon the first study done by Russell and Balazs (2009) and re-examine their conclusions in light of eight additional years of new data gathered during 2005 to 2012 to see if the trend toward the use of non-native algae was indeed valid and continuing.

Materials and methods

The materials and methods used in this study are the same as described in detail in Russell and Balazs (2009) available at www.pacificscience.org/publications. A total of 194 additional samples were taken from Turtles sampled in the same Kaneohe Bay region as the previous report. Only a brief description of the methods is given here, because the same methods were used for this eight year extension (2005–2012) as were used for the original study (1976–2005). We allowed the one year overlap to include some new data gathered for that year. Green Turtles feed by nipping off small pieces of algae with their beaks, pressing this on the roof of their mouth and swallowing. The food items are packed into a pouch located at the base of the esophagus (Balazs et al., 1998). Samples (50 ml) of these algae are taken from this esophageal pouch or forestomach, placed in 10% formalin/seawater and later analyzed (Russell and Balazs, 2000). As the living Turtles are protected from harm by law, it is standard practice that only the dead "stranded" Turtles were necropsied according to (Work, 2000) and forestomach samples taken. No living Turtles were harmed. The entire sample was suspended and poured into a 2 × 14 cm Petri plate etched with a 2 × 2 cm grid and this represented the sample area from which percent cover (a general estimate of amount) was estimated; biomass was not calculated. This estimated the volume of the species, because the sample has uniformly distributed depth over the surface of the plate (Russell and Balazs, 2009). Contents were examined microscopically until only trace species were found. A trace species was one that occupied less than 1% of the sample area and most of these trace species were microscopic thallus fragments of large algae or microscopic species. For example, *Lyngya majuscula* (filmentous Cyanophyta) is almost always microscopic and contributes very little to the diet when compared to macroscopic forms. For statistical purposes trace amounts were given a value of 0.1% to show that they are present and do represent some small fraction of the sample. Statistical analysis was done using SPSS 15.0 (SPSS Inc., Chicago) and Minitab 16 (Minitab Inc., State College).

Results and discussion

A total of 135 species were being eaten by Green Turtles in Kaneohe Bay. This included 130 species that were reported by Russell and Balazs (2009), plus 5 additional species added from the second investigation (*Galaxaura filamentosa, Padina sanctae-crucis, Trichogloea subnuda, Neomeris annulata* and *Caulerpa verticillata)*. All five species, except *G. filamentosa*, were found in only one sample and in trace amounts (Table 1). A total of 72 species of algae, including two Sea Grasses were in the latest 194 samples, with the

Table 1. The number of samples in which each algae species was found in 194 Green Turtle samples, percent of the number of samples represents only the number of samples that species was found out of the total 194 samples, average amounts (% cover with SD) is the amount of that species present as a % of cover and is an indication of possible biomass and the proportion is the combination of % of samples and the % amount. The remaining 33 species, not shown in the table, were found in only one sample, were less than 1% average amount and had <0.01 frequency out of a total of 72 species that were found in Turtle samples between (2005–2012). They were generally microscopic species and contributing an insignificant amount to the Turtle diet.

Species	No. of Samples	% No. Smp	Avg % Amt	Proportion
**Acanthopnhora spicifera*	137	71.00%	33.7 ± 5.0	0.26
**Gracilaria salicornia*	130	67	54.0 ± 9.4	0.38
Laurencia nidifica	41	7.2	7.5 ± 2.3	0.02
Codium arabicum	39	20.1	16.4 ± 3.6	0.03
Amansia glomerata	37	19.1	39.2 ± 7.1	0.08
**Hypnea musciformis*	37	19	15.5 ± 5.9	0.03
Codium edule	34	17.5	23.2 ± 6.8	0.04
Pterocladiella capillacea	34	17.5	20.3 ± 3.5	0.04
Lyngbya majuscula	22	11.3	2.2 ± 1.0	<0.01
Dictyosphaeria verslysii	16	8.3	18.6 ± 5.2	0.02
Halophila decipiens	14	7.2	40.2 ± 8.1	0.03
Spyridia filamentosa	14	7.2	0.6 ± 0.3	<0.01
Halophila hawaiiana	13	6.7	47.0 ± 8.5	0.03
***Cladophora* sp.	11	5.7	0.1 ± 0.1**	<0.01
Microdictyon umbellicatum	11	5.7	0.6 ± 0.3	<0.01
Turbinaria ornata	11	5.7	6.6 ± 4.0	<0.01
Sphacelaria sp.	10	5.2	<0.1 ± 0.1	<0.01
Halimeda discodea	9	4.6	11.0 ± 0.1	<0.01
Sargassum sp.	9	4.6	<0.1 ± 0.1	<0.01
Gelidium crinale	8	4	14.7 ± 5.3	<0.01
Dictyosphaeria cavernosa	7	3.6	0.2 ± 0.1	<0.01
Dictyota acuteloba	7	3.6	0.5 ± 0.3	<0.01
Dictyota friagilis	7	3.6	1.6 ± 1.3	<0.01
Hypnea cervicornis	7	3.6	8.2 ± 3.8	<0.01
Sargassum echinocarpum	7	3.6	0.4 ± 0.3	<0.01
Galaxaura filamentosa	6	3.1	48.0 ± 7.2	<0.01
Cladophora sericea	5	2.5	20.1 ± 8.4	<0.01
Laurencia sp.	5	2.5	0.1 ± 0.1	<0.01
Polysiphonia howei	5	2.5	0.1 ± 0.1	<0.01
Champia parvula	3	1.6	0.1 ± 0.1	<0.01
**Eucheuma denticulatum*	3	1.6	41.3 ± 7.4	<0.01
**Kappaphycus alvarezii*	3	1.6	17.0 ± 5.0	<0.01
Bornetella sphaerica	2	1	0.1 ± 0.1	<0.01
Cladophoropsis luxuriens	2	1	0.1 ± 0.1	<0.01
Coelothrix irregularis	2	1	1.8 ± 0.1	<0.01
Dictyota divaricata	2	1	<0.1 ± 0.1	<0.01
Dictyota sp.	2	1	0.1 ± 0.1	<0.01
**Gracilaria tikvahiae*	2	1	68.0 ± 10.8	<0.01
Lobophora variegata	2	1	<0.1 ± 0.1	<0.01
Valonia aegagropila	2	1	<0.1 ± 0.1	<0.01

*Indicates a non-native species.

**Many data entries have a high deviation due to the very few times these species appeared in samples and low contribution to amount.

majority (61 species = 85%) representing less than 1% of the estimated amount being eaten (Table 1). The very small sample sizes and low occurrence of trace species accounts for the large deviations found in Table 1 for these species. Only 11 species (15%) made up the bulk of the Green Turtle's diet and of these, 3 were non-native species (Table 1). The non-native species comprised 64% of the food in Kaneohe Bay, which was 24% higher than what was reported in the earlier study (Russell and Balazs, 2009). Non-native species have become more important in the Green Turtle diet during the past eight years.

The main non-native species being utilized by Green Turtles remained the same, with *A. spicifera*, found in 71.0% of the samples, being the most important, followed by *Gracilaria salicornia* (67.0% samples) and then *Hypnea musciformis* (19.0% samples). In the earlier 1976–2005 study, *H. musciformis* was greater than *G. salicornia*, so these two species switched positions and now, eight years later, *H. musciformis* represents a much lower amount compared to *G. salicornia*. This may be due to natural fluctuations in populations due to unknown variables. Other non-native species reported in the 1976–2005 study were *Eucheuma denticulatum* (41.3% amount), *Kappaphycus alvarezii* (17.0% amount) and *Gracilaria tikvahiae* (68.0% amount), all still being eaten by the Turtles, and only *K. striatum* was not found in the samples from 2005–2012. The high average percentage shown for *E. denticulatum* and *G. tikvahiae* indicated that when these species were discovered by the Turtles, they were preferred and filled their stomachs (Table 1). Some samples contained large masses of only one non-native species (100% amount) with no native algae present. These three species are concentrated in specific isolated locations in Kaneohe Bay, rather than being more widely distributed like *A. spicifera* and *G. salicornia*.

Although there were many more species of native species in the diet they comprised only 36% amount of the Turtle's diet. The most important native species, given here as percent of the number of total samples, were *Amansia glomerata* (8%), *Codium edule* (4%), *Pterocladiella capillacea* (4%), *Codium arabicum* (3%), *Halophila decipiens* (3%), *Halophila hawaiiana* (3%), *Laurencia nidifica* (2%) and *Dictyosphaeria verslysii* (2%). This is almost identical to the first study (Russell and Balazs, 2009). Non-native species continue to be increasingly more important to the Turtle diet than native species, especially when considering the small number of non-native algae species and the large number and variety of native species that are available in Kaneohe Bay. The transition from native species becoming less than 50% of the Turtle diet and non-native food species becoming more than 50% began between 1980 and 1990 and the results of this present study clearly indicates that non-native species are continuing to gain importance as primary food items for Turtles in Kaneohe Bay.

Conclusions

The appropriate protection of feeding pastures of *C. mydas* is essential for the continuing recovery of Green Turtles and their effect in maintaining reef resilience in the Hawaiian islands (Wabnitz et al., 2010). Establishment of several non-native species in Turtle feeding pastures is contributing to greater food availability for an increasing population and these non-native species are of primary importance in their diet. Proper conservation and protection efforts regarding all of the algae species found in the Turtle feeding pastures is important regardless of their origins. Future understanding of this will be enhanced by continuous sampling and monitoring of food sources, along with ecological modeling analysis.

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