The role of seals in the food webs of Cape Cod beaches

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Abstract:

Animal species at the top of food webs potentially play major roles as top down controls in their ecosystems. However, the populations of many top predators were decimated before these roles were understood. Now as these population numbers are rebounding due to protection practices we are beginning to understand the important multifaceted roles they play in their ecosystems. Seals were extirpated from the New England area, and in just the last few decades their population numbers have started to increase. While their ecosystem functions are not yet completely understood, is it speculated that seals contribute to the translocation of marine nutrients to terrestrial environments when they haul-out on beaches to rest, molt, and pup. Stable isotopic analysis, total nitrogen (N) content, total extractable N, and N mineralization rates were utilized to determine the source of N content on Cape Cod, if there are higher N levels on beaches where seals haul-out compared to beaches where seals do not haul-out, and the overall ecosystem effects of seal haul-outs on N cycling to understand the implications the potential translocation of marine nutrients has on the food webs of the beaches in the Cape Cod region. This study demonstrated that seals are aiding in the translocation of marine nutrients to terrestrial coastal ecosystems and that this translocation is stimulating the N cycle leading to potential impacts on plant and animal species found on the beaches where seals consistently haul-out.

Introduction:

Recent studies on trophic subsidies, animal movement and migration, and nutrient translocation have illustrated that top carnivores play important roles in ecosystem function. For example, studies on Pacific salmon populations have illustrated that these carnivores are actually mobile links because of their role in transporting carbon, nitrogen, and phosphorous, elements
essential for the growth and productivity of ecosystems, from the ocean to rivers and riparian ecosystems (Helfield and Naimen 2006). After spending most of their lives feeding and growing in oceanic ecosystems, Pacific salmon return to spawn and die in their natal streams. These returning salmon carry marine derived nutrients in their body tissues that support productivity in streams and terrestrial vegetation mediated through the transfer of nutrients between salmon and various predators (Helfield and Naimen 2006). This example illustrates that carnivores play important roles in ecosystem functions including linking nutrients and energy that stimulate productivity among ecosystems that would otherwise not be connected.

However, these roles were once underappreciated and the populations of many species were decimated before these roles were completely understood. Now as these population numbers are rebounding due to protection practices, humans are beginning to understand the important multifaceted roles that carnivorous species play in their ecosystems. The return of grey wolves in Yellowstone National Park is a well-known example. Humans completely extirpated the wolves by 1926 because they believed that wolves endangered livestock and were responsible for the decimation of game species like elk, deer, and moose (Robbins 2004 and Ripple and Beschta 2012). It was only when people began to realize that the overpopulation of elk caused ecosystem imbalances, such as the overgrazing of woody browse species, and that wolves could control the elk populations that scientists began to reintroduce wolves into the Yellowstone region (Smith et al. 2003). While the direct effects of the reintroduction of grey wolves were expected, there were a lot of unexpected indirect cascade effects such as the increasing of both beaver and bison population numbers (Ripple and Beshta 2012). This demonstrates that the grey wolves were contributing in many different ways to the ecosystem
function of the Yellowstone region and that these contributions are complex in ways that may not be initially visible.

Similarly, the return of seals to New England coastal environments may also restore previously unsuspected ecosystem functions of seals. The grey seal population in the Gulf of Maine was extirpated by humans in the late 19th to mid-20th centuries as a result of state supported bounty hunting (Lelli et al. 2009). Seal populations have increased 100-fold, from a few hundred to a few thousand, from the 1970s to the 2000s because of the passing of the Marine Mammal Protection Act in 1972 that provides seals and other marine mammals protection from harassment, hunting, capture, and killing (Lelli et al. 2009). The repopulation of seals may be restoring old ecosystem functions but since the effects seals have on coastal ecosystems were not known prior to their extirpation, there is still uncertainty of what these functions could be (NOAA 2016).

One of these functions could be the translocation of nutrients from high productivity marine environments to low productivity dune beach terrestrial environments by their movements. Nutrient fluxes between marine systems and terrestrial systems can either increase or decrease primary productivity, causing cascading effects within the ecosystem and impacting both species diversity and abundance (Roman and McCarthy 2010, Lundburg and Moberg 2015). Seals are semiaquatic marine mammals; they forage and hunt in marine systems but haul-out on coastal beaches in the summer to rest and in the winter to rest, molt, and pup (Bowen 1997, Wartzok 1997) This movement between marine and terrestrial systems could be aiding in the translocation of marine nutrients such as carbon and nitrogen to the terrestrial beaches via waste excretions and pupping, and this translocation could be altering the composition and availability
of nutrients and the overall ecosystem functions of the beaches (Kitchell et al. 1979, Kiszka et al. 2015).

Studying nutrient cycling of carbon (C) and nitrogen (N) with the aid of stable isotopic analysis can be particularly useful in understanding the transfer of marine derived nutrients within coastal ecosystems via biogenic sources such as animals (Lysak 2013). Stable isotopes can be used to better understand trophic dynamics and in determining source origins of nutrients because of characteristic signatures of plants at the base of the ecosystem food webs and trophic fractionation as food moves up the food web (Peterson and Fry 1987). Trophic fractionation particularly occurs with $^{15}$N, the heavier isotope than that of the common $^{14}$N form. Because of its lighter weight, $^{14}$N is preferentially excreted, leading to an enrichment of $^{15}$N in organisms higher up on the food chain. Organic matter in marine systems typically have higher $\delta$N$^{15}$ values than organic matter in terrestrial systems, and further trophic fractionation through oceanic food webs leads to seals to the top of the food web. Thus higher $\delta$N15 values within sediments and plants on coastal beach systems could indicate an input of marine N from biogenic marine sources (Schoeninger and Deniro 1984).

In this study, I want to determine if seals are aiding in the translocation of marine derived nutrients to coastal terrestrial systems and what the overall long-term ecosystem effects are of this translocation. Comparing N concentrations of sediments and plants found on coastal terrestrial systems where seals consistently haul-out to sediments and plants found on coastal systems where seals are not present as well as $\delta$N$^{15}$ values of both locations will illustrate if seals are translocating marine derived nutrients to coastal terrestrial environments. If translocation via seals is occurring, I would expect there to be higher N levels as well as higher $\delta$N$^{15}$ values in both the sediment and the plant samples on the beaches where seals consistently haul-out. I
further expect that the increased nutrient levels will stimulate nutrient cycling processes, leading to long-term ecosystem changes in the systems where seals consistently haul-out.

**Methods:**

**Field Sites:**

Sediment and plant samples were collected from two coastal dune beach locations, South Cape Beach and Head of Meadow Beach, on Cape Cod, Massachusetts. South Cape Beach acted as the “No Seal” site as seals do not haul-out at this location. Samples were collected from two sites about half a mile apart at Head of Meadow Beach. The first site was a site where seals are not expected to haul-out in significant numbers and was designated as the occasional seal site. The second site was a known summer/fall haul-out site for about 200 seals. Based on my observations of seals on the beach at this site, the haul-out site extended from the low-tide wash zone to the high-tide mark on the beach and was approximately 35 m wide. Samples at both sites were collected in early November.

**Field Sampling:**

To collect sediment and plant samples at both locations, a grid was set up, scaled to each location. At South Cape Beach (no seals) and the haul-out site at Head of Meadow Beach (seal haul-out), this grid was 10 meters by 10 meters. At the occasional seal site at Head of Meadow beach (occasional seal), this grid was 100 meters by 10 meters. The center horizontal line of the grid was placed at the high tide mark at each site. Three vertical transects were run from the center line at zero, five, and ten meters on five meters on either side of the center line with the exception of the seal haul-out location where the transect at the center line was extended 10 meters towards the shoreline to achieve more dense sampling in the haul-out zone. Along each
transect, five centimeter deep sediment core samples were taken at every meter. A total of 33 sediment cores were taken in each grid. At five meters, a transect was run into the dunes and five centimeter deep sediment core samples were taken from the dry beach, foredune, and high dune regions (Figure 1). A dune grass sample was collected from the high dune region at each site and a marine macro algae sample was collected from the center of the grid at each site. Seal scat samples were also obtained from the NOAA Northeast Fisheries Center as well as the Head of Meadow Beach seal haul-out location.

Lab Analyses:

Plant and sediment samples for all three locations were analyzed for total percent organic matter, total C and N content, and N$^{15}$ stable isotopic composition. A subset of sediment samples was also analyzed for N mineralization rates. Scat samples were analyzed for percent organic matter, total C and N content, and N$^{15}$ stable isotopic composition. Before all analyses were performed, all samples were dried for 48 hours at 50°C. For stable isotopic analysis, scat and plant samples were ground and weighed into tin capsules; 4-5 mg was used for seal scat and 5-6 mg was used for dune grass and marine macro-algae. To get reliable data for the sediment samples, the organic matter was floated out of the sediment with seawater and then filtered onto a GF/F filter where ¾ of each filter was used for stable isotopic analysis. A loss on ignition method was used to determine percent organic matter; samples weighing between 10 and 20 grams were ashed at 450°C in a muffle furnace for 5 hours. Total C and N content of plant and sediment samples were determined through elemental N analysis on 20 to 30 mg of ground sample (SES Particulate Carbon and Nitrogen Protocol 2016). Sediment samples were analyzed for N mineralization rates using colorimetric analysis to determine total extractable ammonium (NH$_4^+$) and nitrate (NO$_3^-$). Analysis was run on samples before and after a two week incubation
at 25°C. Ammonium and Nitrate were extracted from the sediment cores by performing a 1M potassium chloride extraction with 15 grams of sediment from both the fresh subsample and the incubated subsample and measured through colorimetric analysis (SES KCL extraction of soils for N mineralization 2016, Zumdahl 1992, Strickland and Parsons 1972, Solarzano 1969, Wood et al. 1967, and Griess 1879).

Potential Translocation Model:

A model of the potential amount of N seals could be translocating from marine environments to terrestrial environments was calculated using information collected from the seal haul-out site. The total possible N input from seal scat was calculated from the number of seals observed hauled out at the seal haul-out site, the area of the haul-out site, the number of individual seal scat found in that area, and the weight and N content of the seal scat. This was calculated for varying durations of haul-outs, including per haul-out (at low tide), per day (hauling out twice a day at each low tide), and per six months (hauling out twice a day).

Statistical Analysis:

If applicable, data were subjected to tests of standard error of the mean and analysis of variance (ANOVA, P<0.05). The sediment stable isotopic data were subjected to an analysis of covariance (ANCOVA; Low-Tide Wash Zone, P<0.01).

Results:

A potential translocation model and stable isotopic analysis were used to determine the source of organic matter at each site. The potential translocation model demonstrates that seal scat can contribute up to 5815 µgN/m² to terrestrial systems if the seals consistently haul-out for six months (Table 1). Comparison of the δN¹⁵ values and C:N ratios of the sediments to the
potential organic matter sources of N, seal scat, marine algae, and dune grass. Seal scat has an average $\delta N^{15}$ value of 16‰, marine macro-algae has a $\delta N^{15}$ value of 7‰ and dune grass has a $\delta N^{15}$ value of 0.5‰ (Figure 2). At all three sites, the $\delta N^{15}$ values for the sediments from the dune zone fall between 3 and 7‰. For the low tide wash zone, the $\delta N^{15}$ value at the no seal site is about 6‰. The $\delta N^{15}$ values are elevated in the low tide wash zone at the occasional seal (9‰) and the seal haul-out sites (13‰) (Figure 3). C:N ratios of the potential organic matter sources was also calculated. Seal scat has a low C:N ratio of 6.5 compared to the higher values of 32 for marine algae and 58 for dune (Figure 4).

Total percent organic matter, total N content, and total extractable N was also evaluated at each site to determine if there are differences in nutrient content at beaches with and without seals. There is no significant difference in the average total percent organic matter in the sediments at each site (Figure 5). The frequency distribution of the sediment percent organic matter illustrates that the no seal site has the most variable distribution of percent organic matter and the occasional seal site has the least variable distribution (Figure 6). There is also no significant difference in the average percent organic matter found in the vegetation (dune grass and marine algae) at each site, and these values are equal to the expected values of percent organic matter (Figure 7). Overall, total N content is low at each site. The occasional seal site has the lowest total N content, and the no seal and seal haul out site are virtually equal in N content, although there is more variability in total N content a the seal haul-out site (Figure 8). The total extractable N includes total extractable ammonium and nitrate from each location and follows the same pattern as total N content, although the trends are more pronounced. The seal haul-out site has the most extractable N (Figure 9).
To determine the total ecosystem effects on N cycling, the rate of N mineralization was calculated in terms of both gN/m$^2$yr (assuming a 210 day growing season per year) and in gN/g dry sediment/day. The rate of N mineralization is about four times higher at the seal haul-out site than at either the no seal or occasional seal sites (Figure 10, Figure 11).

**Discussion:**

I hypothesized that if seals are translocating marine nutrients to terrestrial environments that there would be elevated $\delta N^{15}$ values in the sediment samples from beaches where seals are present. It was further hypothesized that this translocation would lead to higher total N content on the beaches with seals and that the increased nutrient levels would stimulate N cycling.

A potential translocation model demonstrates that seal scat can contribute a significant amount of N onto terrestrial systems when compared to the existing standing stocks of N at each site (Table 1 and Figure 8). This input of N could have a big impact on the coastal ecosystem because sediment found on beaches are typically low in organic matter. Thus a high input of N into a nutrient limited environment could have the potential to have a big impact on ecosystem processes by stimulating the N cycle and potentially adding to the total biomass of that environment.

At the no seal site, the $\delta N^{15}$ values from sediment match the average $\delta N^{15}$ values of the organic matter, indicating that a combination of dune grass and marine algae are contributing to the organic matter N. This is also true for the dune zone sediment at the occasional seal and seal haul-out sites (Figure 2, Figure 3). The low tide wash zones of both the occasional seal and seal haul-out sites had elevated $\delta N^{15}$ values that more closely match the $\delta N^{15}$ values of the seal scat than marine algae (Figure 4). An analysis of covariance (ANCOVA) for the low-tide wash zone
between seal abundance (no, occasional, and haul-out) and δN15 values indicates that there is a significant difference between seal abundance and δN15 values (p <0.01). This indicates that the source for some of the N found at the occasional seal site and the seal haul-out site is the seal scat and that seals are translocating nutrients from marine systems to terrestrial systems. Seal scat has a low C:N ratio compared marine algae and dune grass (Figure 4), suggesting that seal scat decomposes fairly quickly in comparison (Chapin et al. 2012).

Total percent organic matter was also evaluated at each site to determine if there are differences in nutrient content at beaches with and without seals. There is no significant difference in the average total percent organic matter found in the sediments at each site (Figure 5). An analysis of variance (ANOVA) further indicates that there is no difference in the total percent organic matter between sites (p <0.05). The frequency distribution of the sediment percent organic matter illustrates that the no seal site has the most variable distribution of percent organic matter and the occasional seal site having the least amount of variation (Figure 6). This could be attributable to the fact that this is a highly physically disturbed area with winds and tides washing any organic matter away; the physical landscape is constantly changing. In addition, seal scat waste is high in organic matter, has a low C:N ratio, and decomposes fairly quickly. The seal scat could be decomposing before it has a long lasting impact on the on the C content of the beach system. There is also no significant difference in the average percent organic matter found in the vegetation (dune grass and marine algae wash-up) at each site, and these values are equal to the expected values of percent organic matter (Figure 7). C content between each site is not expected to change, but the addition of N to the sites where seals haul out might stimulate total biomass, which was not measured in this study.
Total N content and total extractable N was calculated for each site to also determine differences in nutrient content. Overall N content is low at each site, which is as expected as the sediments are low in percent organic matter. The occasional seal site has the lowest N content, and the “no seal” and “seal haul out” site are virtually equal in N content, although there is more variability in total N content at the seal haul-out site (Figure 8). An ANOVA further indicates that there is no statistical differences in the total N content between all three sites (p<0.05). These trends are unexpected in that with an increasing number of seals there should be increasing N content. These unexpected trends could also be a result of the high physical disturbance of the beaches and quickly decomposing seal scat. The total extractable N from each location follows the same pattern as total N content, although the trends are more pronounced. The seal haul-out site has the most extractable N, although it is not significantly different than the other two sites (Figure 9). Total extractable N is the amount of ammonium and nitrate that can be extracted by a particular solution from the sediment. Extractable N pools in soils and sediments are controlled by organic matter inputs, among other processes (Ros et al. 2009). At the seal haul-out site, there is an increased addition of N from seal scat. This increases the extractable N content of the sediments, explaining why there is only a slight difference in total N content between each site, but a more pronounced difference in total extractable N between each site.

The rate of N mineralization is about four times higher and significantly different at the seal haul-out site than at either the no seal or occasional seal sites (Figure 10, Figure 11). Seal scat has a very low C:N ratio compared to the marine algae and dune grass. This plays a role in N mineralization rates in that seal scat is highly decomposable and is derived from animal prey and thus has a high protein content. The higher N content found in the seal scat may also be facilitating the decomposition of other organic matter sources that have higher C content, thus
freeing up nutrients into forms that can potentially be used by plants growing on the beach/dune area (Chapin et al. 2012).

**Conclusions:**

There is evidence from stable isotopic data that seals are vectors for the translocation of nutrients from the marine environments to the terrestrial beaches on which they are hauling out. There is also evidence through N mineralization rates that the N cycle is stimulated by the additional input of N from seal scat into the terrestrial systems. However, data on the percent organic matter in both plants and sediments and total N content in the sediments at each site indicate that the ecosystem effects of this increased N input are not yet impacting the total ecosystem. It would be interesting to investigate if there is a greater ecosystem impact at locations where greater densities of seals haul-out in both the summer and the winter. In the Cape Cod region, on the islands of Muskeget and Monomoy thousands of seals haul out over mile long stretches of beach in the summer and haul-out up into the dunes in the winter to pup. Both waste excretions and the placenta from the birth of pups lead to high inputs of N which will stimulate the N cycle. High N mineralization rates could lead to increased plant growth in the dune area thus impacting other species in the rest of the food web who rely on those plants as a food source. It would be interesting to conduct the same study and analyses at these types of locations to further understand the impacts the translocation of marine nutrients, via the seals, are having on terrestrial coastal systems.
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Figures and Tables:

Figure 1.

A) Arial photograph of a seal haul-out zone on Monomoy Island.

B) Illustration of field sampling procedure. A grid system was set up at each field site: South Cape Beach, Head of Meadow, and Head of Meadow, Seal Haul-Out site. The center of the grid was placed at the high tide line, and sediment samples, illustrated by the red circles, were taken at one meter intervals on either side of the center line. Samples were also taken from the dry beach/dune zone. At the seal haul-out site, an additional five samples, spaced every meter apart in the low tide wash zone, were taken from the center vertical line to achieve denser sampling in the seal haul-out zone.
Table 1.

A) Base Information for Potential Translocation Model

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<table>
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<tbody>
<tr>
<td>Number of Seals</td>
<td>45</td>
</tr>
<tr>
<td>Area of Haul Out (m²)</td>
<td>832</td>
</tr>
<tr>
<td>Number of Scat</td>
<td>42</td>
</tr>
<tr>
<td>Weight of Scat (g)</td>
<td>667.19</td>
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<tr>
<td>Average N Content (µg N/g scat)</td>
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B) Potential Translocation Estimate

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<th>Duration of Consistent Haul-Out</th>
<th>N input (µg N/m²)</th>
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</thead>
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<td>Low-Tide</td>
<td>22.6</td>
</tr>
<tr>
<td>Day</td>
<td>45.3</td>
</tr>
<tr>
<td>6 Months</td>
<td>5814.8</td>
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Table 1: A) Base information collected at seal haul-out site. B) Potential translocation estimate model of the total potential N input from seal scat.
Figure 2: $\delta N^{15}$ values per type of sample collected: marine algae, dune grass, and seal scat. The average $\delta N^{15}$ value for each sample type is represented in red.
Figure 3: $\delta N^{15}$ values of sediments collected from the dune zone and low-tide wash zone of each site.
Figure 4: C:N ratios of each potential organic matter source: seal scat, marine algae, and dune grass.
Figure 5: Average percent organic matter found in the sediments at each site. Error bars were calculated as standard error of the mean.
Figure 6: Frequency distribution of the percent organic matter of the sediments collected from each site.
Figure 7: Average percent organic matter found in plants (dune grass and marine algae). Error bars were calculated as standard error of the mean.
Figure 8: Average nitrogen content (µgN/g dry sediment) in the sediments sampled at each site. Error bars were calculated as standard error of the mean.
Figure 9: Total extractable nitrogen content (ugN/g dry sediment) in the sediments sampled at each site. Error bars were calculated as standard error of the mean.
Figure 10. Nitrogen mineralization rates (gN/m$^2$yr) at each site.
Figure 11: Nitrogen mineralization rates (gN/g sediment/day) at each site.