Question 6: How Does Marine Debris Affect Wildlife and the Environment?

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I. Problem statement

Is marine debris just an eyesore or are there effects that will cause harm to the environment, economy, or human beings? In this session we explored and defined the effects of marine debris on the environment and coastal users. These answers inform prevention, outreach, and education efforts and should be tailored to varied audiences from the public to lawmakers.

II. Introduction

Why is this an important issue?

Debris from marine and terrestrial sources, including lost/discarded fishing gear and consumer plastics, litters marine and nearshore habitats across the globe. This debris impacts numerous organisms directly (through entanglement and ingestion) and indirectly by damaging marine habitats (smothering, physical damage to shorelines and sessile flora and fauna). Another possible impact relates to the introduction of invasive species transported by marine debris into Alaska marine ecosystems.

In addition to these "mechanical" impacts, the chemical composition of marine debris poses a threat to wildlife. For instance, high concentrations of hydrophobic organic contaminants have been measured on plastic marine debris collected from the environment, but the toxicological effects and the fate of these contaminants (e.g., phthalates, fire retardants) are poorly understood. Moreover, the role of bioaccumulation through the food web, the potential absorption of other pollutants (e.g., persistent organic pollutants, POPs) by marine debris, and the synergistic interactions of these various compounds are critical and poorly understood aspects. As plastics are mechanically or chemically degraded into smaller and smaller particles, are there additional impacts on lower trophic levels in the food web?

Relevance to/in Alaska

Marine debris is a very important environmental, economic, and possibly human health concern in Alaska for the following reasons:

1. Alaska's vast coastline, ocean currents, and geography make the state a sink for marine debris originating from local fisheries and throughout the North Pacific. Ocean currents transport marine debris originating from distant sources, throughout the North Pacific basin.
2. Alaska is the source of 54% of the seafood landings in the United States, with critical economic value to the state and the nation. Alaska led all states in volume with finfish and shellfish landings of 5.3 billion pounds, a value of $1.5 billion, in 2007 (National Marine Fisheries Service Office of Science and Technology; http://www.st.nmfs.noaa.gov/st1/fus/fus07/).
3. Tourism is critical to the economy in Alaska, with over 1.8 million visitors spending approximately $1.7 billion during the 12 months prior to April 2007 (Alaska Visitor Statistics Program; http://www.commerce.state.ak.us/oed/toubus/research.htm).
4. Local residents of the state rely heavily on marine resources through subsistence harvests and commercial fisheries.
5. Large populations of upper-trophic marine predators (i.e., marine mammals and birds) breed or seasonally migrate to Alaska. Many of these populations are harvested by subsistence hunters.
6. The high volume of shipping through the great circle route (west coast of North America to Asia) and the potential opening of a northern passage route through the Bering Strait to the Atlantic increase the potential debris sources and vessel interactions with debris.

History of the marine debris problem in Alaska

Marine debris has been reported at sea and on beaches throughout the North Pacific since the 1970s (reviewed in Derraik 2002), with the number of published reports and studies increasing in the 1980s and 1990s (e.g., Wong et al. 1974, Day and Shaw 1987). Entanglement and ingestion by wildlife has been reported in a wide range of marine taxa, including fish, birds, turtles, and mammals (reviewed in Laist 1997). While there are few time series of the abundance and types of marine debris over time, longitudinal studies suggest an increasing trend. For instance, deposition rates on beaches on the Pribilof Islands indicate accumulation rates higher than previously reported in other areas of the Bering Sea (see King 2009, this volume)

Time series of biological impacts are also revealing trends of increasing ingestion rates by locally breeding seabirds (from 1969-1977 to 1988-1990; Robards et al. 1995), and a shift from "industrial" to "consumer" plastics in stomach contents (Vlietstra and Parga 2002). Entanglement is another particularly difficult wildlife impact to study. Fowler (1987) found a reduction in juvenile male northern fur seal entanglement by the late 1980s on St. Paul Island, but investigations do not have the power to detect recent changes in the proportion of juvenile males entangled if any have occurred (Williams et al. 2004). Recent research on St. George Island (Zavadil et al. 2006) corroborates previous findings (Delong et al. 1988, Kiyota and Fowler 1994) that the rate of entanglement among female fur seals increases with the arrival of young females from late July through September. Similarly, data for northern fur seal pups during two consecutive years on St. George Island show a mean entanglement rate of 0.06-0.08%, with a potential maximum rate of up to 0.11% in October prior to weaning (Zavadil et al. 2006). These studies indicate that the rate of entanglement among adult females and pups may be higher than previously estimated (e.g., Fowler 2002).

III. Discussion topics

Major concepts

To organize the information in a coherent fashion, we considered the following five components.

1. Habitats:
   Intertidal (e.g., beaches, mud flats, rocky shorelines).
   Subtidal (e.g., kelp beds, continental shelf, canyons).
   Deepwater (e.g., coral beds, seafloor).
2. Living marine resources (fish, mammals, birds).
3. Commerce (fisheries, tourism, shipping).
4. Traditional/subsistence harvest, livelihoods.
5. Ecosystem (including issues relating to pollutants, toxins, invasive species).

For each component listed above, we addressed four knowledge areas:

a. Currently known—direct (i.e., effects on individuals).

b. Currently known—indirect (i.e., emergent effects on populations and food webs).

c. Theories on impacts (i.e., physical, biological, economic, social).

d. What is unknown (next steps) (i.e., research needs, methods to test theories listed above).

1.a. Habitats, known direct effects.

Current understanding focuses on "high use" habitats, defined herein as those of high subsistence, economic, and recreational value to humans, yet the ecology and potential impacts on many other habitats are not well understood.

We acknowledge that any review of marine debris impacts should recognize these biases and avoid falling into the "out of sight, out of mind" trap. In particular, we identified four poorly known habitats potentially impacted by marine debris:

- Seamounts/offshore banks (important foraging and spawning areas; open or closed to fishing).
- Subtidal (debris resuspension and transport may affect submerged areas adjacent of beaches).
- Canyons (important fish habitat, and onshore-offshore transport; potentially a path and site of aggregation for sunken debris).
- Seafloor (ghost fishing and entanglement on deep-sea corals).

1.b. Habitats, known indirect effects.

- Characterize impacts where debris accumulates (e.g., smothering of the habitat in the high tide zone).
- Investigate whether marine debris can destroy the different habitats, by altering their structure/function permanently, or whether the impacts vanish once the debris is removed.

1.c. Habitats, theories on impacts.

- Impacts of marine debris on intertidal communities: latitudinal differences (i.e., tropical vs. temperate vs. subarctic).
- Return time after disturbance longer in Alaska due to slower regeneration. Debris degradation time shorter/longer in Alaska (e.g., waves, sunlight, temperature).
- Resuspension/transport of debris (e.g., high-energy beaches, winter storms).

1.d. Habitats, unknown.

- Fate of debris on beaches (e.g., deposition, resuspension, loss, degradation).
- Effects of debris on beaches (e.g., plastic pellets/fragments incorporated into sediments, smothering of flora and fauna, physical/chemical changes).
- Role of seasonal changes/events (e.g., temperature/rain variability, movement of debris by winter storms, seasonal ice).

- Can habitat be destroyed by marine debris?
- Invasive species transported by marine debris? (If so, how far, what are the sources?) (e.g., northwestern Hawaiian Islands study involving marine debris and invasives).
- Time series needed to assess status and trends:
  - Baselines: archived samples, "memory" (oral history traditional ecological knowledge, photos).
  - Start new time series: shore zone mapping (Prince William Sound Regional Citizens' Advisory Council photos 2007).
- Evaluate existing resources for marine debris monitoring (e.g., photos, "environmental sensitivity maps").
- Characterize extent of marine debris impact (e.g., depth in sediment, transport inland by wind, wildlife, storms).

2.a. Living marine resources (fish, mammals, birds), known direct effects.

- Mechanical damage/smothering of intertidal and deep-sea organisms (e.g., corals).
- Entanglement pervasive (e.g., mammals, birds).
- Plastic and hook ingestion (e.g., zooplankton, fish, mammals, birds)—secondary marine mammal plastic ingestion (Eriksson and Burton 2003) and anecdotal salmon ingestion.

2.b. Living marine resources (fish, mammals, birds), known indirect effects. Contaminant loads in organisms: When should they reflect ingested debris? Consider other mechanisms for transfer of this pollution (e.g., food webs).

2.c. Living marine resources (fish, mammals, birds), theories on impacts. Entanglement and ingestion cause individual injuries, but it is difficult to estimate mortality at sea. Theories for assessing impacts are thus limited by reliable extrapolation to the entire stocks or populations.

2.d. Living marine resources (fish, mammals, birds), unknown.

- Use existing samples and monitoring programs (e.g., diet and stomach content analysis from fish, seabirds, and marine mammals from research, recreational, commercial, or subsistence harvests).
- Entanglement/ingestion data from various sources (e.g., fish, plankton, sportfishing: salmon, halibut, and herring).
- Need to develop reliable and accurate bio-indicators. Consider previous heavy metal study organisms, and species involved in trophic transfer in the food web and subsistence/commercial harvests.

- Explore correlation studies between ingested plastics and pollutant loads.
- Develop controlled studies with animals: plastic ingestion, pollutant absorption. (Note: fish may be suitable model organisms.)
- Evaluate links to human health through commercial/subsistence harvests/uses.

3.a. Commerce (fisheries, tourism, shipping), known direct effects.

- Ghost fishing/bycatch (undetectable, may affect species targeted by Endangered Species Act).
- Gear/vessel damage.
- Damage to "high-value" tourism resources and habitat.

3.b. Commerce (fisheries, tourism, shipping), known indirect effects.

- Economic loss to entire fishing-based economy.
- Recycling marine debris to create "new" fishing gear.
- Incentive for tourism and fishing industry to recycle (avoid landfills).

3.c. Commerce (fisheries, tourism, shipping), theories on impacts.

- Cost/benefit analysis of "green" practices (e.g., Puget Sound commission study on fish loss due to ghost fishing).
- Consider established modeling frameworks:
  - Contingent valuation analysis.
  - Benefit transfer analysis.

3.d. Commerce (fisheries, tourism, shipping), unknown.

Research needs will focus on obtaining the required cost/benefit data for the modeling discussed above.

4.a. Traditional/subsistence harvest; livelihoods, known direct effects.

We considered these "indirect" impacts on the harvested populations.

4.b. Traditional/subsistence harvest; livelihoods, known indirect effects.

- Fur seals/sea lions (e.g., entanglement).
- Ghost fishing reducing resource availability.
- Eggs, seabirds, sea ducks, mammals, fish, and invertebrates may constitute an indirect impact due to public health concerns from contaminants associated with debris breakdown.
- The indirect effects mentioned above can also affect other terrestrial organisms consuming contaminated marine organisms. For instance, black-tailed deer in Kodiak consume kelp.

- Invasive species introductions mediated by marine debris may modify the habitat and compete with native species.

4.c. Traditional/subsistence harvest; livelihoods, theories on impacts.

- Bio-accumulation in harvested organisms.
- Food web magnification, especially of upper-trophic organisms.
- Trophic level and longevity of the resources (e.g., mammals, birds, rockfish).

4.d. Traditional/subsistence harvest; livelihoods, unknown.

- Evaluate pollutants in resources used by subsistence harvests (beware of indirect effects).
- Model pathways of bio-accumulation and food web magnification.
- Review traditional ecological knowledge (TEK) with elders and communities to evaluate resource use, reliance on different resources, and potential direct and indirect impacts.

5.a.b. Ecosystem (pollutants, toxins, invasive species), known direct and indirect effects.

We considered direct/indirect effects together because the ecosystem inherently involves direct/indirect processes.

- Alaska beaches are a sink of marine debris transported from the North Pacific.
- Evidence of invasive species arriving in Alaska is lacking, yet potential links with marine debris transporting invaders or modifying the habitat are unknown.
- Changes in physical/chemical conditions when large marine debris is deposited on beaches (e.g., sediments going anaerobic).

5.c. Ecosystem (pollutants, toxins, invasive species), theories on impacts.

- Loss or reduction of ecosystem function from marine debris.
- "Alternate states" hypothesis may lead to persistent ecological effects from marine debris.
- Climate change, may alter marine debris sources/magnitude/effects:
  - Currents influence source/amount/location of debris deposition.
  - Alaska more benign to invasive species under a warming scenario.
  - Increased shipping through Bering Sea after arctic ice loss.
- Role of high-energy beaches (e.g., resuspension, faster mechanical degradation).

5.d. Ecosystem (pollutants, toxins, invasive species), unknown.

- Characterize how currents and wind transport/concentrate debris and relate marine debris deposition on beaches to currents (e.g., subsurface debris accumulations/transport, "small-scale" eddies).
- Investigate how much debris originates from the ocean versus the rivers/erosion of coastal landfills.
- Evaluate physical/chemical conditions on beaches with marine debris deposition.
- Compare Alaska patterns with other ocean basins/U.S. regions/North Pacific.
- Do chemicals leach out of marine debris (e.g., into water, sediment, organisms)?
- Consider other "non-fishing" debris, including terrestrial sources (e.g., toxic/treated wood, consumer plastics).

Interesting points

1. Alaska is unique and different from other regions of the United States and the world. Regional/international comparisons may help us understand how Alaska residents, wildlife, fisheries, and ecosystems will be affected by marine debris.
2. Due to the large coastline, the low population density of the state, and the input of marine debris from the North Pacific, fishing-related and other marine sources of debris comprise the vast majority of marine debris found in Alaska.
3. Wind circulation patterns transport airborne pollutants north, making Alaska a global sink for these pollutants. It is critical to consider the ability of plastic debris to absorb and concentrate these pollutants as well.
4. Large subsistence user community in the state extracts resources directly from the marine environment. Rural residents may be particularly susceptible to toxic effects of marine debris and direct losses of wildlife populations and ecosystem functions.

IV. Critical elements

Marine debris is not just an eyesore—the available time series of debris deposition, collection, removal, and the incidence of impacts on wildlife (e.g., entanglement, ingestion) indicate the incidence and magnitude of these effects are increasing over time. Yet, while there is mounting quantitative evidence that individual organisms are impacted by marine debris, it is inherently difficult to evaluate potential effects at the population level (primarily due to mortality at sea) and to extrapolate these impacts to the entire ecosystem. Identifying the synergies and pathways involved in these indirect effects, and quantifying the magnitude and spatial/temporal variability of these factors, are critical information gaps and research needs.

Quantifying societal and economic effects on commercial fisheries, tourism, recreational fisheries, and subsistence harvests will also require considering direct/indirect effects and a variety of modeling approaches. These approaches will require data on the resources used by different groups, and the associated costs/benefits of ongoing and future losses due to marine debris.

V. Data gaps

Short term—key components that need to be addressed before moving forward:

- Fate of debris on beaches (e.g., deposition, resuspension, loss, degradation).
- Develop time series needed to assess status and trends of marine debris in Alaska.
- Baselines: archived samples, "memory" (oral history, traditional ecological knowledge, photos).
- Start new time series: shore zone mapping (e.g., Prince William Sound Citizens' Advisory Council photos 2007).
- Evaluate existing resources for marine debris monitoring (e.g., photos, "environmental sensitivity maps").
- Characterize extent of marine debris impact (e.g., depth in sediment, transport inland by wind/ocean, wildlife, storms).
- Use existing stomach collections and diet monitoring programs from commercial, subsistence, and recreational harvesting to evaluate direct and indirect plastic ingestion.
- Use existing stomach collections and diet monitoring programs from commercial, subsistence, and recreational harvesting to evaluate correlations between pollutant loads and direct and indirect plastic ingestion.
- Assess entanglement data from various sources (e.g., marine mammals, seabirds, fish, plankton, sportfishing—salmon, halibut, herring, subsistence harvest).
- Review traditional ecological knowledge (TEK) with elders and communities to evaluate resource use, reliance on different resources, and potential direct and indirect impacts.
- Evaluate pollutants in resources used by subsistence harvests (beware of indirect effects).
- Expand scope of marine debris research by considering other "non-fishing" debris, including terrestrial sources (e.g., toxic/treated wood,

consumer plastics, and terrestrial inputs via rivers).

Long term—components that need to be addressed to obtain full understanding of marine debris impacts:

- Effects of debris on beaches (e.g., plastic pellets/fragments incorporated into sediments, smothering of flora and fauna, physical/chemical changes).
- Investigate whether marine debris changes the physical/chemical conditions on beaches. Do chemicals leach out of marine debris? (e.g., into water, sediment, organisms).
- Role of seasonal changes/events/climate change (e.g., temperature/rain variability, movement of debris by winter storms, seasonal ice).
- Invasive species transported by marine debris, now and in the future? (If so, how far, what are the sources?)
- Need to develop reliable and accurate bio-indicators. Consider previous heavy metal study organisms, and species involved in trophic transfer in the food web and subsistence/commercial harvests.
- Develop controlled animal studies (e.g., plastic ingestion, pollutant absorption) using bio-indicators.
- Evaluate links to human health through commercial, recreational, and subsistence harvests/uses.
- Model pathways of bio-accumulation and food web magnification.
- Compare Alaska patterns with those from other U.S. regions/North Pacific areas/ocean basins.
- Evaluate conceptual models of marine debris impacts and collect long-term data to assess whether marine debris can destroy Alaska habitats and impact its marine ecosystems.

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