The Impacts of Marine Debris: A Review and Synthesis of Existing Research

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Foreword

In May of 2012, I had the opportunity to travel to Southern Baja, Mexico with a group of fellow graduate students. We spent a few days travelling by boat around Bajai Magdalena, a 170,000 hectare, deep water bay located on the Pacific coast. The bay is incredibly rich in biodiversity. It is critical breeding and calving habitat for eastern Pacific grey whales, and also home to the largest stretches of mangrove forest in the Baja.

We dropped anchor at a small, uninhabited island in a very remote part of this beautiful bay where, much to my shock and dismay, the entire island was completely covered in garbage. Tires, Styrofoam, plastic bottles, shopping bags, fishing nets and other discarded materials stretched across the entire shoreline. We were told by our guide that the material had accumulated on several islands in the bay as a result of tropical storms, and there were simply no resources to deal with it. As a masters candidate at Simon Fraser University's School of Resource and Environmental Management, I had some prior knowledge of the global environmental problem of marine debris. However, I didn't really understand how pervasive and serious this issue was until that day.

A few months later, I was contacted by Living Oceans Society, my previous employer and an organization I truly respect and admire. Thanks in part to a grant from the provincial government, they were building an initiative to deal with the issue of marine debris in the Regional District of Mount Waddington (RDMW). They offered me the opportunity to contribute to the project, and I jumped at the chance to get involved.

The following literature review represents a synthesis of scientific research and reporting that was reviewed between September and December 2012. Given the large and rapidly growing body of research on this crucial subject, additional information will most certainly arise in the future that could supplement this review.

I'd like to thank Living Oceans Society for the opportunity to contribute, and I certainly hope that this review serves to inform project contributors, RDMW residents and the public on the impacts of marine debris.

Sincerely,

Kimberly Irwin
December 29th 2012

"Never underestimate the power of a small group of committed people to change the world. In fact, it is the only thing that ever has." - Margaret Mead

Introduction

Marine debris represents a global environmental crisis that impacts every ocean, coastline and waterway in the world. It can be found in even the most remote areas of the globe, from Antarctica to Tahiti (Barnes, 2002). Dealing with this increasingly serious global environmental problem will require a coordinated effort on a local, national and global scale. In recent years, non-governmental organizations have played an increasingly important role in this effort. Living Oceans Society has undertaken a new initiative to coordinate the efforts of partner organizations and local authorities to remove and safely dispose of marine debris from the intertidal areas of Northern Vancouver Island, in the Regional District of Mount Waddington (RDMW). Three types of marine debris have been identified by residents and local organizations as a major concern, and will be addressed through this initiative:

I. The removal of ghost traps from popular recreational crab fishing areas.

II. The development of responsible methods of derelict vessel disposal.

III. The location, analysis, removal and proper disposal of debris on regional beaches.

This literature review will examine the potential ecological and socioeconomic impact that these types of debris are having on the local marine environment in the RDMW, as well as identify major gaps in research. It will also examine previous attempts by other governmental and non-governmental agencies to coordinate cleanup efforts for these types of debris. This will be done in order to learn from past successes and failures, and examine methods of measuring program success. This review will help to ensure that Living Oceans Society continues its long-standing and strong commitment to ground all of their conservation initiatives in scientific research. Moving forward, it will also be used in part to help inform the public about the impacts of coastal and marine debris.

Background: Marine and Coastal Debris

Marine debris can be defined as "any man-made object discarded, disposed of, or abandoned that enters the coastal or marine environment (National Oceanic and Atmospheric Administration [NOAA], 2012)." An estimated 6.4 million tonnes of debris enter our world's oceans every year (Fisheries and Oceans Canada [DFO], 2012). Due to current patterns in the world's oceans, marine debris can collect in enormous fields of floating garbage, such as the 3-million-tonne Pacific Garbage Patch off the coast of California (NOAA, 2012). This debris also accumulates in lower densities throughout the world, causing serious ecological, aesthetic and human health problems.

The global issue of marine debris is largely thought to be a result of the rise of cheap, durable plastic as an alternative to natural, biodegradable materials. Between 60 and 90% of marine debris is made up of plastic, which can persist for an uncertain amount of time in our marine and coastal ecosystems (Andrady, 2011). Plastics will slowly break apart due to UVB radiation and seawater, forming continuously smaller particles that eventually become synthetic polymers that can remain in the ocean for unknown amounts of time (Andrady, 2011). Other commonly found materials include glass, Styrofoam, metal and rubber. According to a recent report, approximately 80% of marine debris originates from land, while 20% comes from the ocean (Allsop et al., 2009). This report categorizes marine debris in to four main sources: coastal tourism-related litter, sewage-related debris, fishing-related debris and waste from ships and boats. However, poor waste management practices and illegal dumping can also contribute to marine debris accumulation.

Exceptional Sources of Marine Debris

Although marine debris is a persistent and growing problem in British Columbia, it can be acutely exacerbated by extreme weather events and natural disasters. In March of 2011, a magnitude 9.03 earthquake struck Tōhoku, Japan, and generated large tsunamis that swept away 1.5 million tonnes of debris from the surrounding coastal areas (B.C. Ministry of Environment [BC MOE], 2012). While some of this debris will end up in the Pacific Garbage Patch, a significant amount will end up on the shorelines of the Eastern Pacific. The majority of this will likely be made up of plastics, Styrofoam, building materials, rope, fishing nets and buoys (BC MOE, 2012).

The B.C. government has established the Tsunami Debris Management Plan in order to ensure coordination between governmental and non-governmental agencies that will be partaking in any clean-up efforts (BC MOE, 2012). There is currently debris monitoring taking place at three coastal provincial parks. However, large stretches of coastline in remote areas will be difficult to monitor, and these areas have been identified as a major challenge within the management plan (BC MOE, 2012). While the tsunami debris could represent a considerable environmental challenge and place additional strain on coastal infrastructure, it has also served to draw attention and resources to the growing problem of coastal and marine debris in British Columbia.

Background: Regional District of Mount Waddington

The RDMW is located on the Central Coast of British Columbia. It includes the northern portion of Vancouver Island, the adjacent mainland area as well as several islands in Queen Charlotte Strait. The RDMW is home to the municipalities of Port McNeill, Port Hardy, Port Alice and Alert Bay, as well as a number of First Nations villages and other unincorporated areas. It is a region that is highly dependent on the marine environment for its economic well-being. A large proportion of the population is employed in fishing, aquaculture, marine tourism and marine transport (GS Gislason & Associates Ltd, 2011). The marine environment found in this district is rich in biodiversity. It features a wide range of coastal habitat, from estuaries to exposed, rocky shorelines to protected, sandy beaches. Important marine habitats include rocky reefs, kelp forests and eelgrass beds (Jamieson & Davies, 2004). According to a 2002 report by Living Oceans Society, B.C. is home to "6500 known species of invertebrates, approximately 400 hundred species of fishes, 161 species of birds, and at least 29 species of marine mammals living in British Columbia (Ardron et al., 2002, 7)." Given the diverse range of habitats found in the Central Coast marine environment, it is thought that " that most, if not all, of these species can be found in [the Central Coast] (Ardron et al., 2002, 8)."

In consideration of the economic and ecological importance of the coastal and marine environment, marine debris represents an important and pressing issue for RDMW. The following sections will outline the ecological impacts of the three major types of marine debris that have become a major problem in this region: shoreline debris, derelict fishing gear and derelict vessels. It will then examine the socioeconomic impact of marine debris.

Ecological Impacts: Shoreline Debris

Introduction

Debris often accumulates in large quantities on beaches or in intertidal zones, where it can persist for decades, creating a major ecological, economic and aesthetic problem. Shoreline debris can also end up being carried in to the ocean, where it contributes to the global environmental crisis of marine debris. As previously mentioned, a large proportion of this debris is made of durable plastic, including plastic bottles, bags and other packaging (Allsop et al., 2009). The Great Canadian Shoreline Cleanup has also identified cigarette butts and wrappers, beverage cans, glass bottles and building materials as the most prevalent types of marine and freshwater shoreline debris collected in Canada (GCSC, 2011). A recent study of the distribution, composition and density of floating marine debris in coastal British Columbia (excluding the West coast of Vancouver Island) identified Styrofoam, plastic bottles and plastic bags as the most common type of marine debris on the ocean's surface (Williams et al., 2011). Given that 80 percent of marine debris originated on land, cleaning up shoreline debris has the potential to significantly mitigate its devastating effects in the ocean (Allsop et al., 2009).

Wildlife Impacts

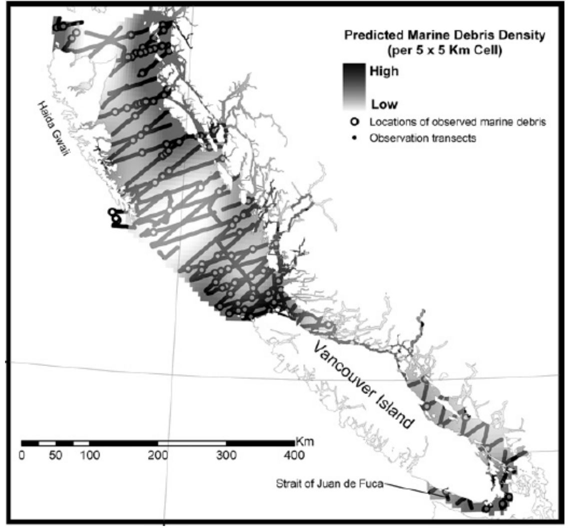
Shoreline and marine debris can have a serious impact on marine wildlife. The UN found that globally, at least 267 different species have experienced entanglement or ingestion of marine debris, including marine mammals, sea turtles, sea birds and fish (Allsop, 2009). While it has been extensively studied, the extent of this problem remains unknown, since most marine animals that die as a result of interaction with marine debris are not recovered.

Entanglement

While wildlife can often be entangled in derelict fishing gear, it can also be entangled in material such as ropes, six-pack rings and other land-based materials. Entanglement can cause debilitating lacerations and other injuries to animals, or impair their ability to move properly. It can also lead to starvation, and leave the animal weak and vulnerable to predators (Oehlmann et al. 2009; Laist, 1997). Given that entanglement affects such a large number of taxonomic groups, it has the potential to affect a number of species of marine wildlife in RDMW. Often it is the entanglement of large marine mammals that receives the most attention. A recent spatial analysis of British Columbia's coast identified areas of high interaction between marine mammals and floating debris. It was found that there were several areas of overlap, which indicates that there is a high likelihood of entanglement or ingestion in these areas (Williams et al., 2011). Less studied and publicized are the innumerable, undocumented entanglements of smaller animals. These entanglements have been referred to as 'cryptic', since there is little chance that carcasses from entanglement will be recovered, and discovery is often opportunistic (Laist, 1997).

Figure 1: Williams et al. (2011): Predicted density of marine debris in British Columbia

Ingestion



Wildlife of several taxonomic groups often ingest plastics and other synthetic debris (UNEP, 2011; Laist 1997; Baird & Hooker, 2000). The ingested materials can be large items such as plastic bags, or small, industrial plastic pellets. There is also evidence that microscopic plastic material can be ingested by filter feeders and detritivores (Thompson et al. 2004) Plastic ingestion can be even more difficult to identify than entanglement, since there are rarely any external indicators. Ingestion can cause blockage of the digestive tract, poisonings and toxin absorption, internal wounds, suffocation and general debilitation (Laist, 1997; Gregory, 2009). Marine sea birds are often considered an effective indicator of anthropogenic impact on the marine environment. Blight and Burger (1997) examined the stomachs of sea bird carcasses killed in experimental driftnet fisheries in the Eastern North Pacific. Eight of eleven species of sea birds had ingested plastic particles, including 100 percent of surface feeding birds. While most studies have focused on the ingestion and entanglement of marine mammals and seabirds, few studies have focused on species at lower trophic levels. One 2010 study examined the stomach contents of planktivorous fish found near the North Pacific Central Gyre to quantify the presence of anthropogenic debris (Boerger et al. 2010). A total of 670 fish were caught in eleven trawls, 35% of which were found to have plastic in their digestive tract. An average of 2.1 pieces of plastic per fish were recorded, though one fish was found to have ingested 83 pieces (Boerger et al. 2010). The authors were unable to comment on the ecological impact of this level of ingestion, and identified this as a major gap in research.

Habitat Impacts

Release of Toxins

Alongside direct impacts on marine wildlife, debris can also negatively affect shoreline and marine habitats and disrupt ecosystem functioning. It has been determined that plastics and other debris can transport and release toxins in to the marine environment. This is particularly true of pre-industrial plastic pellets, which are the 'raw material' from which user plastics are made. Mato et al. (2001) have identified two possible mechanisms by which plastic pellets incorporate toxins. Some chemicals, such as PCBs, can be adsorbed from seawater. Others are plastic additives that have been used in the production process. This study collected plastic pellets from four coastal sites in Japan, and examined their concentrations of PCBs, DDE, and nonylphenols. Concentrations of PCB and DDE were found in concentrations 10^5-10^6 higher than the surrounding marine environment (Mato et al., 2001). Microplastics can be digested and absorbed by body tissues, as demonstrated by Browne et al. (2008) in their experiments on mussels, as well as by Thompson et al. (2004) in their experiments on tubeworms and shellfish. A more recent laboratory study found that PCBs could be transferred to the tissues of shearwater chicks via contaminated plastic (Teuten et al. 2009). Due to the potential for bodily absorption, the toxicity of certain chemicals found in plastics could have a wide range of negative health effects on organisms, including humans (Oehlmann *et al*. 2009; Tueten et al. 2009). Furthermore, common items such as paint, hydrocarbons and batteries can all leach toxic materials in to the marine environment.

Biological Invasions

While dispersal of organisms via natural substrate is common, the increase in synthetic marine debris has led to potential acceleration of marine biological invasions (Bax et al., 2003; Barnes, 2002). The most common species found on plastic debris are hard-shelled organisms, including barnacles, tube worms, foraminifera, algae and bivalves (Gregory, 2009). Plastics may also attract other mobile species, often attracted by smaller prey or the provided shelter (Gregory 2009). Bax et al. (2003) list marine debris as one of the main vectors of modern invasive species, alongside aquaculture, ballast water and others. In a survey conducted of islands at all latitudes in the Atlantic Ocean, researchers found that not only is marine debris present at all latitudes, but an exotic species, the barnacle *Elminius modestus*, was found attached to debris in the Northern Atlantic (Barnes & Milner, 2005). Furthermore, observational studies conducted in Europe found dinoflagellates and other harmful algal bloom species attached to marine debris in high concentrations. They concluded that debris represents an important mode of dispersal for these species (Maso et al. 2003).

Physical Impacts

Marine debris can also have physical impacts on beaches and benthic habitats. While a good portion of marine debris floats, fouling organisms can weigh it down, causing it to rest on the seabed. This can lead to reduced light and smothering of coral or rocky reef ecosystems (Goldberg, 1994; Chiappone et al. 2005). This type of habitat damage can also impact species that rely on these ecosystems for their own survival. While much of this damage can be attributed to fishing gear, land-based plastics can have a similar effect. This physical impact is not limited to shallow, coastal waters, but has been shown to impact deeper benthic habitats as well. A trawl survey conducted off the coast of California found that 14% of the Southern California Bight was found to have significant anthropogenic debris on the seafloor. This number increased to up to 32% in areas close to urban centers (Moore & Allen, 2000). Given the logistic difficulty of retrieving deep water debris, it is likely to persist in these habitats for longer than coastal debris.

This section has demonstrated the serious consequences for marine ecology that can result from shoreline debris, and the resulting marine debris. The following section will look at the impacts of one specific type of marine debris, derelict fishing gear.

Ecological Impacts: Derelict Fishing Gear

Introduction

Derelict fishing gear refers to equipment used in fish harvesting operations that has been lost or abandoned in marine or aquatic ecosystems. Its continued accumulation is a global environmental issue that has increased significantly in the last 50 years (Macfadyen et al., 2009). This is not only due to an increase in global fishing pressure, but also due to the use of more non-biodegradable, durable materials to produce fishing gear. Fishing gear can be lost or abandoned for several reasons that vary across time and spatial scales. Gear can be lost due to storms and extreme weather conditions, misplaced by fishermen or intentionally discarded due to economic or operational pressures (Macfadyen et al, 2009; Donohue et al., 2000). Derelict gear has accumulated across the globe in coastal areas, gyres and open water, where it has been shown to have serious ecological and socioeconomic effects. It can be found floating at the surface, on the seafloor or submerged at all depths of the water column.

Derelict fishing gear and its effects have only become a global issue of concern in the last few decades. This means that there are still many uncertainties regarding the global extent of the problem and its diverse range of impacts. However, improvements in monitoring technology and mounting public concern have led to an increase in research on this topic. It has been determined that derelict fishing gear is not only an issue due to 'ghost fishing', but can also have major effects on benthic and intertidal habitat, cause entanglement or ingestion by threatened species, and contribute to the continuing global problem of marine debris (Macfadyen et al., 2009) The following section will outline the ecological effects of derelict fishing gear as they affect the coastal and marine habitat in RDMW.

Wildlife Impacts

Ghost Fishing

Ghost fishing occurs when "derelict fishing gear, either lost or abandoned, continues to function in the water; continuing to induce mortality of aquatic organisms without human control (Matsuoka et al., 2005, 691)." While not all derelict fishing gear has the ability to ghost fish, abandoned traps, pots and gillnets commonly trap and kill fish, mammals and invertebrates for long periods of time after being lost (Matsuoka et al., 2005, 692). It is thought to be less of an issue with other types of fishing gear, such as seines and trawl nets (FAO, 2012)

Ghost Fishing: Traps

Derelict traps and pots have been shown to ghost fish long after they have been lost or abandoned. Traps are often lost after their surface buoy is dislodged. Once the trap is lost, it will continue to trap crabs, prawns and other invertebrates in the short term using the existing bait. As these animals are caught and die, they re-bait the trap, attracting more animals (Breen, 1987). Modern traps and pots are required by law to use regulated escape cords, which hold the trap shut or seal an opening (DFO, 2011). This cord is made of small diameter, biodegradable fiber which will eventually degrade away and unseal the trap in order to provide trapped crabs and other species a chance to escape (DFO, 2011). While these cords have been shown to reduce mortality in derelict traps, studies have shown that they can still take up to 130 days to degrade (Antonelis et al., 2011).

Several studies have been done in British Columbia and Washington which have attempted to quantify the impact of ghost fishing from derelict traps. One of the first studies conducted on the subject examined the rate of trap loss, as well as the catch rate of derelict traps in Departure Bay, British Columbia. Researchers put in place 10 simulated lost traps in the Bay, and conducted dive surveys of the traps over a one year period. It was found that each trap studied had a catch rate of 16.9 crabs per year, 52% of which died during the study period (Breen, 1987). However, this study was done prior to the widespread use of escape cord.

Another study was conducted in Washington State that recreated Breen's 1987 study, but it examined the impact of ghost fishing crab traps that were fitted with escape cords (Antonelis et al., 2011). 12 traps (6 commercial, 6 recreational) were set in Dungeness Bay and Port Susan, WA in the summer of 2008. Escape cords were found to degrade between 100 and 148 days, though the traps continued to ghost fish for the entire year-long study. Over the course of the study, 1077 crabs were caught, indicating an overall catch rate of 0.135 crabs per trap per day. Of these 1077 crabs caught, 46% (500 crabs) died during the study. Based on an extrapolation of the results to all of Washington State, the researchers estimated a total annual mortality of 178,874 Dungeness Crabs as a result of ghost fishing.

The Northwest Straits Marine Conservation Initiative recently collected data on crab trap ghost fishing during a 2011 program to identify and remove derelict fishing gear (NWSI, 2011). The team used a sidescan sonar survey to locate derelict crab pots in shallow areas of Semiahmoo Bay, BC. The team found a density of between 390-586 traps per square kilometer. Of the 1,829 trap targets found in the Canadian portion of the bay, 787 (43%) had the potential to be actively fishing. The rest were buried or highly degraded. Over the course of four days, two divers removed 214 pots, and dislodged but left behind four. Of the 214 pots encountered, 21 were identified as actively fishing. Of these 21 pots, 12 were not equipped with an escape cord, 6 had an escape cord that was still intact, and three were held shut by anemones. A total of 64 Dungeness and 31 red rock crabs were recovered from the traps.

Little research has been conducted in to the catch of non-target species from derelict traps. The 2011 NWSI report indicated that staghorn sculpins, starry flounder, sunflower stars, sea cucumbers, graceful crabs and mottled sea stars were all found in derelict traps during the removal process (NWSI, 2011). Stevens et al. (1999) examined the incidence of non-target species caught in ghost traps in Alaska. During the survey and removal of 147 traps, researchers found 189 sunflower stars and 16 giant Pacific octopuses, along with 29 other plant and animal species.

Ghost Fishing: Derelict Nets

While incidences of derelict traps and pots are likely more numerous, derelict nets have the potential to affect a larger number of species and have a more diverse and serious impact on coastal habitat. While all types of fishing nets have the potential to be lost at sea, recent studies have shown that gillnets represent the vast majority of those recovered in Pacific waters (Brown et al., 2005). Other nets with the potential to ghost fish include trammel nets, purse seines, aquaculture nets, bottom trawls as well as various types of fishing lines (Brown et al., 2005). While several researchers have found that the potential for ghost fishing declines substantially over time as nets degrade, there is also evidence that they can continue to impact coastal ecology for over 20 years (Erzini et al. 1997; Tschernij and Larsson, 2003; McFayden et al. 2009). The ability and efficacy at which nets are able to continue ghost fishing is largely dependent on benthic topography. Three-dimensional and complex benthic substrate, such as rocky reefs, hold nets open and allow them to occupy more of the water column than a flat-bottomed substrate (Matsuoka et al., 2009).

A recent study conducted in Puget Sound surveyed and recovered 876 nets, the vast majority of which were gillnets (Good et al., 2010). Of these nets, 25% were found to be over five years old, a testament to the use of long-lasting, synthetic materials used to construct modern fishing gear. Within these 876 derelict nets, 32,846 animals were found. All together, this constituted 106 different species of fauna. This included 1036 fishes (93% of which were dead), 509 marine birds and 23 marine mammals. It was noted that this represents just a small fraction of the mortality that these nets have likely caused, since only organisms that haven't decomposed can be counted. A similar study also conducted in Puget Sound used data collected from diver surveys in order to estimate the daily catch rates of four derelict gillnets (Gilardi, 2010). Using a Poisson regression model, mean incident catch rates per day were calculated. They were found to be 2.119, 0.196 and 0.275 for invertebrates, seabirds, and fish respectively. Using data on the average decomposition time (16.8 days on average), researchers developed a model to predict the number of organisms of a particular species that had been entangled during a certain period of time by a particular net.

A recent recovery initiative conducted by NWSI removed and surveyed a large purse seine net off of Pender Island, B.C. (NWSI, 2011) The net covered over 25,000 square meters of rocky reef benthic habitat, and was thought to have been abandoned over 20 years prior. It was found to contain 1,799 animals, both dead and alive. However, again this was thought to be a drastic underestimation of mortality, since dead animals are likely eaten by other species within two weeks of their death.

Marine Mammal Interactions

One of the most troubling problems caused by derelict gear is entanglement and ingestion by marine mammals, many of which are threatened or endangered species. While marine mammals can also interact with other types of marine debris, studies have demonstrated that fishing gear is the most common material in these situations (Raum Suryan et al., 2009; Stewart & Yochem, 1987). These animals are often attracted by previously trapped prey species, and can quickly become entangled. Entanglement in fishing gear can lead to drowning, exhaustion, lacerations and other serious wounds and death in marine mammals. However, little is known about the extent of this problem, since the vast majority of carcasses are unlikely to be recovered (Laist, 1997). However, it has been estimated that 43% of marine mammal species are impacted by debris ingestion and entanglement (US Marine Mammal Commission, 2001).

A meta-analysis of marine mammal entanglements on the West Coast of the United States found records of 204 marine mammal entanglements from 2001-2005, encompassing nine species (Moore et al., 2009). However, researchers stated that "the entanglements recorded represent an unknown proportion of entangled animals that die and sea; thus, it is difficult to establish what impact entanglements are having on any of the species' populations (Moore et al., 2009, 1050)." It has also been noted that it is difficult to determine whether gear was active at the time of entanglement and was lost as a result, or was derelict prior to entanglement (Moore et al., 2009; Laist, 1997). Raum-Suryan et al. (2009) conducted a long-term observational study of Steller Sea Lions in Southern Alaska and Northern British Columbia in order to estimate entanglement rates. They found 386 incidences of entanglement in or ingestion of marine debris, which represents an entanglement and ingestion rate of 0.26% of the population. Over half of observations involved fishing gear, including fishing lines, hooks, ropes and salmon 'flashers'. This entanglement and ingestion rate was similar to an older study that was conducted on sea lions, elephant seals and harbor seals in California (Stewart & Yochem, 1987), which found an entanglement rate of 0.07-0.22%.

Interactions with derelict fishing gear and other marine debris is difficult to study given its cryptic nature. The impact of fishing gear and other debris on marine mammals in British Columbia remains a serious gap in research that has been identified by marine mammal researchers (Williams et al., 2009).

Habitat Impacts

Habitat Impacts: Traps

Derelict traps and pots have been shown to damage benthic habitats. Sandy and muddy bottoms are less impacted by incidences of traps than complex habitat such as rocky, coral and sponge reefs and vegetated bottoms such as eelgrass and kelp beds (Barnette, 2001). While individual traps may not have a large impact individually, cumulatively they could seriously damage benthic habitat (Macfadyen et al., 2009). Traps have the potential to damage coral and sponges, smother marine flora and scour sediments (Macfadyen et al., 2009). This damage to live substrate can in turn reduce food and shelter for other organisms (Barnette, 2001). While little research has been done on quantifying this impact, one recent study conducted by NWSI attempted to do so in the Salish Sea. Researchers removed a derelict crab pot which was located within an eelgrass bed. At the time of removal, there was no eelgrass in the crab pot's footprint, and a fifteen square foot area behind the pot had been scoured away due to changed currents, creating a one foot deep hole. However, upon site re-examination four months later, there was a 30% recovery of eelgrass, and the hole had been filled in (June & Antonelis, 2009).

While very little research has been done in temperate waters, there are several studies that have examined the impact that derelict traps have on marine habitat in tropical waters, and found significant damage to sessile invertebrates such as coral and sponges (Lewis, 2009; Chiappone, 2005). A study conducted in waters off Puerto Rico observed significant damage to corals, gorgonians and sponges as a result of derelict traps. The study found 70 cm^2 of damage under every 1 m^2 of trap (Appledoorn, 2000). A recent study conducted by NOAA in the US Virgin Islands noted the change in community structure that resulted from the presence of derelict traps. Communities of diverse 'fouling' organisms commonly develop in and around derelict traps, since they provide substrate for these organisms to do so (Clark et al., 2012). The habitat impact of traps in temperate ecosystems appears to be a major gap in the current body of research.

Habitat Impacts: Nets

Due to their large size, derelict nets can impact a much larger area of benthic habitat than traps. Derelict nets can cause damage in numerous different types of benthic habitat, but it has been noted that reef habitat is particularly susceptible due to its topographic complexity and fragility (Brainard et al., 2000). Nets can entrap sediments which suffocate sessile benthic invertebrate communities, and obstruct or inhibit access to fish and other marine species that live within the reef habitat. Nets can also cause breakage or damage to corals and other fragile species from scouring during net movement that can result from currents or storms (Brainard et al., 2000). A recent diver survey of four derelict nets in Puget Sound found that immediately after net removal, there was significant qualitative damage to the benthic habitat. It was noted that upon removal there was a "lack of attached kelp, sessile animals and the presence of essentially bare rock, gravel and sand under where the derelict net had been located (June & Antonelis, 2009, 2)." Furthermore, almost no habitat recovery had occurred six months after removal, and species abundance remained low compared to control sites. Surveys conducted one year after net removals indicated that some habitat recovery had occurred at all sites and species abundance had increased from when the nets were first removed.

Given the importance of commercial and recreational fishing in the RDMW, derelict fishing gear poses a potential risk to many of the region's species, particularly its diverse populations of marine mammals. The following section will examine the ecological impacts of derelict vessels, one of the largest and most problematic forms of marine debris.

Derelict Vessels

Introduction

The presence of derelict, abandoned or grounded vessels along British Columbia's coastlines has become an increasingly serious ecological, aesthetic and economic issue. These derelict vessels can be sunk, semi-submerged in the intertidal zone, grounded on beaches, or anchored or moored afloat. The reasons behind vessel abandonment are diverse, and can include storm or other environmental damage, economic and financial issues, accidental groundings and the high costs associated with proper disposal (Bright, 2011; Ferris, 2012). While there is no data available on the exact number of derelict vessels present along B.C.'s coastlines, many local politicians have raised concern in the media and through other outlets regarding this growing problem (Mickleburgh, 2012).

In British Columbia, it has been referred to as an issue of 'underlapping jurisdiction', since the federal government can only intervene if it is a threat to spawning grounds or navigation, and the provincial government can only act if the vessel is on crown-owned foreshore lands (Mickleburgh, 2012). In June of 2011, a private member's bill was introduced in the Canadian parliament by Jean Crowder, MP for Nanaimo-Cowichan. The bill would have amended the 2001 Canada Shipping Act to make the Canadian Coast Guard responsible for removal and disposal of derelict vessels (Crowder, 2011). As of December 2012, the bill had not been voted on. However, these vessels remain a jurisdictional 'grey area'. Therefore, derelict vessels are often left in place for long periods of time, creating long-term environmental and aesthetic issues and acting as a safety and navigational hazard.

Ecological Effects

The cumulative ecological effects of derelict vessels remains uncertain and localized impacts will vary based on the time frame, the type and condition of the vessel, as well as the environmental and climactic conditions of its location. While a few studies have been conducted on these impacts, many research gaps remain. The majority of research done on derelict vessels has been conducted by NOAA, with very little scientific research conducted in Canada and none conducted in British Columbia.

Release of Chemicals

One of the major concerns is the leaching of toxins and chemicals from the vessel in to the surrounding marine environment. These can include gasoline, diesel, chemicals from paints and resins or from onboard cargo, battery acids, rust and several different heavy metals that are released as the boat breaks down over time. The release of fuel is of particular concern, since even small spills can have a localized impact. Furthermore, unlike large-scale spills, small spills often go unreported and are never cleaned up. O'Hara et al. (2009, 61) stated that "smaller-scale oily discharges probably have a greater ecological impact per volume spilled because they occur more frequently and in more places." Fuels are toxic to marine life, and can lead to long-term habitat damage. It has been demonstrated that these small-scale spills can have a negative cumulative impact on seabird populations (Wiese & Anderson, 2004). Antifouling paints are used on boats to prevent barnacles, algae and other sessile species from attaching themselves to submerged areas (Parks et al., 2010). These paints can leach very persistent biocides in to the surrounding environment, where they build up in benthic sediments. A recent study of paint fragments in coastal waters surrounding marinas found very high concentrations of copper and zinc, consistent with biocides found in the fragments (Parks et al., 2010). Another similar study examined benthic sediments surrounding boatyards, and compared it to sediment from areas away from boat storage facilities. Again, the sediment was found to have significantly higher copper and zinc levels, along with other heavy metals, representing 1% of sediment by weight (Singh & Turner, 2009). Researchers have identified derelict and abandoned vessels as a major factor in this type of pollution (Singh & Turner, 2009).

Physical Damage

Derelict vessels can also lead to localized physical damage from abrasion and crushing of intertidal and benthic habitat, particularly in sensitive habitats such as reef, eelgrass or kelp beds (Lord-Boring et al., 2004). This can occur during grounding, if a vessel partially sinks, or if it moves around significantly while anchored. This physical damage is exacerbated during storms or other extreme weather events. Furthermore, over time the derelict vessels will break apart, creating more widespread and diffuse marine debris.

Despite increasing reports in the media and attention from politicians, there remains little scientific research on the ecological impacts of derelict vessels. This is particularly true in temperate waters, since most existing research focuses on coral reef impacts. However, derelict vessels do pose a threat to wildlife and habitat in coastal areas.

Socioeconomic Impacts of Marine Debris

Along with the serious ecological impact discussed above, marine and coastal debris can have serious social and economic implications as well. The social and economic costs of marine debris are not borne evenly on all stakeholders, but instead disproportionately impact small coastal communities where there are few resources afforded to deal with the issue. The following section will outline some of these costs and impacts, particularly those caused by shoreline debris, derelict fishing gear and derelict vessels. While it will focus on the tangible economic impacts of marine debris, there are likely indirect and non-market costs that, despite being difficult to quantify, represent a large proportion of the socioeconomic impact.

Aesthetic Impact

One of the major impacts that debris can have is to degrade the aesthetic value of marine and coastal areas. This is particularly true of shoreline debris, which can be found in even the most remote coastal areas. Given that marine recreation and tourism generate an estimated $75 million Canadian dollars in revenue for RDMW, the aesthetic quality of these areas is very economically important (GS Gislason & Associates Ltd, 2011). Studies conducted on tourists' perception of marine debris indicated that there is a consistent, highly negative view of such debris, particularly in situations where the item is deemed a health risk (Tudor & Williams, 2003). Other previous valuation studies have demonstrated that tourists and local residents alike place a high value on beach quality (Penn et al. 2012; Smith, 1997). Alongside economic concerns, the aesthetic quality of the coast can be intangible and deeply personal. As stated by Gregory (2010, p. 2014), there are "strongly emotive issues associated with both local beach users and tourist perceptions [of marine debris]." The negative aesthetic impact can be exacerbated if these vessels are used as dumping grounds or become a target for vandals. There have also been several complaints by coastal communities in British Columbia that derelict vessels have turned in to 'floating shantytowns' when people move in to these abandoned vessels (Hopper, 2012).

Industry Impacts

Marine and shoreline debris can have a major impact on marine industries, which are often the major source of livelihood in coastal communities. As mentioned above, marine debris of all kinds can negatively impact marine tourism by reducing the aesthetic value of an area. A study conducted in New Jersey found that as a result of beach debris, losses to the tourism industry in the state were between $728 million and 3.07 billion dollars over two summer seasons (Ofiara and Brown, 1999). Derelict fishing gear also has the potential to impact the commercial fishing industry. One of these impacts is the loss in revenue that can result from ghost fishing mortality. This was demonstrated by Antonelis et al. (2011), who found that derelict traps in the Salish Sea result in the annual loss of $744,296 in value of Dungeness crab, an amount equivalent to 4.5% of recent harvests. A 2007 NWSI study found that derelict gill nets have killed $1.06 million USD per year worth of commercially valuable fish species in Puget Sound, Washington. There is also an economic cost to lost and damaged gear due to entanglement in derelict gear and other marine debris (Macfayden et al., 2009). A survey of commercial fishermen in the Eastern United States conducted by Wallace (1990) found that 45% of them had dealt with their fishing gear entangled by debris. Shellfish aquaculture, an important industry in Mount Waddington, could also be adversely affected by marine debris. While little primary research has been conducted in to this connection, it has been noted by the US Environmental Protection Agency that plastics contain toxic substances that can bio-accumulate in shellfish species (US Environmental Protection Agency [EPA], 2012). A recent study conducted by APEC found that Canada experienced 16.6 million dollars in damages as a result of fisheries losses due to marine debris (McIlgorm et al., 2006).

Human Health Impacts

Marine debris is not only economically problematic, but can also pose a serious safety and health risk. This is particularly true of derelict vessels, which have been identified as a major safety and navigational hazard in coastal areas. The risk of property damage or human harm can be severely exacerbated by storms and flood conditions. This was demonstrated in June of 2012, when an environmental emergency was declared by British Columbia's Minister of Environment due to seven derelict vessels on the Fraser River. These boats posed "significant risks to river traffic, houseboat residents, and critical downstream infrastructure" as well as "an environmental risk due to the potential presence of hazardous materials, physical damage to downstream habitat and risk of secondary spills (BC MOE, 2012)." Coastal and shoreline debris can pose health and safety risks to beachgoers. Sharp material can be buried in the sand, and result in lacerations or other injuries. There is also the potential that certain debris can release contaminants and toxins in to the marine environment, making swimming or wading potentially harmful (US EPA, 2012). Finally, derelict fishing gear can pose a safety hazard for boaters, swimmers and divers who can easily become entangled in nets and other materials (US EPA, 2012).

Cleanup Costs

Alongside the costs of damage caused by marine debris are the costs of clean up and mitigation. Unfortunately, the costs of many marine debris cleanup initiatives remain prohibitively high, particularly in situations where specialized equipment and trained experts are required. The costs of shoreline cleanups range substantially depending on the location and composition of debris. However, they are often conducted by volunteers with little specialized equipment. Larger and potentially hazardous debris, including derelict vessels, can be much more costly to remove. Washington State's Department of Natural Resources allocates $750,000 USD per year on derelict vessel removal, but by its own account this is an inadequate amount to properly deal with the growing problem (Ferris, 2012). A derelict gear removal project conducted from 2004-2007 in Puget Sound, Washington found that the cost of net survey and removal was approximately $4960 USD per acre of net removed, and the removal of derelict pots and traps costs approximately $193 USD per pot/trap (NWSI, 2007). It has been found that marine debris cleanup costs can range from US$100-25,000 per tonne, with an average of US$1500 per tonne (McIlgorm et al., 2008).

Alongside ecological impacts, there are also important social and economic consequences that result from the growing problem of marine debris. This is particularly true in small and remote coastal communities which lack the resources to deal with marine debris adequately. The following section will briefly examine some of the initiatives that have been undertaken by other organizations to deal with marine debris.

A Review of Other Marine Debris Initiatives

Shoreline Debris Initiatives

In British Columbia, coastal cleanup initiatives have been a collaborative effort between non-profit organizations, often with support from the provincial and federal government. Volunteer-based shoreline cleanups are often the least expensive form of marine debris initiative, yet can have a significant cumulative impact (McIlgorm et al., 2008). One of the most well known of these initiatives is the Great Canadian Shoreline Cleanup, a conservation initiative that is currently a collaboration between the Vancouver Aquarium and World Wildlife Federation. First established as a local beach cleanup project in 1994, it now coordinates approximately 56,000 volunteers across the country (GCSC, 2011). Under this program, volunteer cleanup site coordinators not only manage a team of volunteers, but are responsible for data collection regarding the weight and composition of debris found in their cleanup site. While this program has been widely successful at mobilizing volunteers in urban and suburban areas, there are few cleanup sites in remote coastal areas. In 2011, there were just two small GCSC cleanup sites in RDMW, indicating that there was little involvement in this area (GCSC, 2012). Another national organization that has had a large impact on coastal debris is Pitch-In Canada, an organization that was established in 1967, and also coordinates volunteer-based land and coastal cleanups (Pitch-In Canada, 2012). Given the size of these organizations, they largely focus on mobilizing volunteers in individual communities across the country, and are primarily responsible for promotion, marketing and data compilation and analysis. However, as mentioned above, these national organizations largely conduct cleanups in areas surrounding population centres. Regional Initiatives, such as the Vancouver Island chapter of Surfrider Foundation's Combing the Coast program, can be more effective at conducting volunteer-based cleanups in more remote areas. Focusing on Southern Vancouver Island, Surfrider conducts monthly cleanups at local beaches, and an annual cleanup of one remote beach (Surfrider, 2012). However, this initiative doesn't extend to Northern Vancouver Island. All of these organizations ask volunteers to count and catalogue debris prior to its disposal in order to develop a data set that can be used for future comparisons, and to measure the success of the initiative.

Fishing Gear Removal Initiatives

Unlike shoreline debris cleanups, the removal of derelict fishing gear is a highly technical and expensive process. This is largely due to the fact that derelict gear is often submerged under water, and can be pose a safety hazard to those removing it. It can also be difficult to locate derelict gear, and often requires the use of sidescan sonar, which is able to map large areas of the sea floor (NWSI, 2011). It requires qualified divers, specialized equipment and vessels, and therefore can be a very time and labor intensive process. In British Columbia, the removal of derelict fishing gear has been undertaken by both public and private entities. In 2011, the BC Ministry of Environment, aided by the Northwest Straits Conservation Initiative, removed over 200 traps and one large gillnet from BC waters (NWSI, 2011). Marine mammal rescue organizations, including the Cetus Society Conservation Organization have also committed to help deal with derelict fishing gear, due to its impact on marine mammals (Cetus Society, 2012). There are many examples of multiple agencies, both public and private, partnering together on derelict gear removal projects. One highly successful initiative is the California Lost Fishing Gear Recovery Project (Gilardi & Renzullo, 2012). This is a collaboration of several non-governmental organizations and University of California Davis, with funding from NOAA and the California Wildlife Conservation Board. Between 2006 and 2012, the project has removed over 60 tonnes of derelict gear from California's coastal waters. This project has a strong volunteer component, and encourages fishermen, divers and others who spend time in or around the ocean to report the presence of derelict gear. This project combines technical expertise with public outreach, which has been a key factor in its success.

Derelict Vessel Removal Initiatives

Derelict vessel removal is also a highly technical and expensive process. The Ministry of Environment has stated that "derelict vessels and wrecks can be dangerous, either because of what is contained within or because their structural integrity has been compromised. Therefore, they should be treated with the same caution afforded suspected hazardous materials (BC MOE, 2012b, 12)." In the United States, removal of derelict vessels is largely handled by state-level government. For example, in Washington State, the Department of Natural Resources runs the successful Derelict Vessel Removal Program (Ferris, 2012). This program provides funding and expertise to public entities in order to deal with the state's derelict and abandoned vessels. The program is funded from vessel permit fees, private donations and a one-time injection of USD$3 million from the federal government. Several different government agencies are partially responsible for derelict vessels in British Columbia, including Transport Canada, Environment Canada, Department of Fisheries and Oceans and BC Ministry of Environment (BC MOE, 2012b). However, the government only intervenes in situations where the vessel poses a serious and immediate threat, such as an oil spill risk or major safety hazard. There are also non-governmental organizations that address the problem of derelict vessels, but largely through government lobbying and public education. These organizations include Islands Trust, the Union of BC Municipalities and the Harbour Authority Association of British Columbia. However, there remain few resources to deal with this growing problem.

Conclusion

The preceding review has attempted to examine the potential impacts that marine debris could have on the ecology and economy of the RDMW. It is clear from this review that while there is substantial research on certain topics, large research gaps remain. This is particularly true in the case of derelict vessels, since there is almost no primary research on their ecological impact in temperate waters. It is also clear that little research has been conducted on marine debris within British Columbia, particularly outside the Salish Sea. While there are a few examples of primary research (Breen, 1987; Williams, 2011), much of the research from the Northwest Pacific has come from Washington State, which devotes more resources, public and private, to both study and remove different kinds of marine debris. This review has demonstrated that there are major environmental and economic costs to ignoring the growing issue of marine debris. However, it is also clear that there are actions that can be undertaken to both remove existing debris and potentially reduce future debris through public education.

As British Columbia prepares for a potential influx of tsunami debris, it is important to remember that this is not simply a short-term environmental problem brought about by a natural disaster. The amount of marine debris that resulted from the Tohoku earthquake is dwarfed by the amount that enters our global marine ecosystems incidentally every single year. While this is a global problem that requires large-scale solutions, it also necessitates action on a local level in order to address the debris that is already causing ecological damage. This will help to ensure that our marine and coastal ecosystems are protected for future generations.

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