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REDUCING IMPACTS FROM SHIPPING IN MARINE PROTECTED AREAS: A TOOLKIT FOR CANADA

THE IMPACTS OF SHIPPING ON BENTHIC HABITATS

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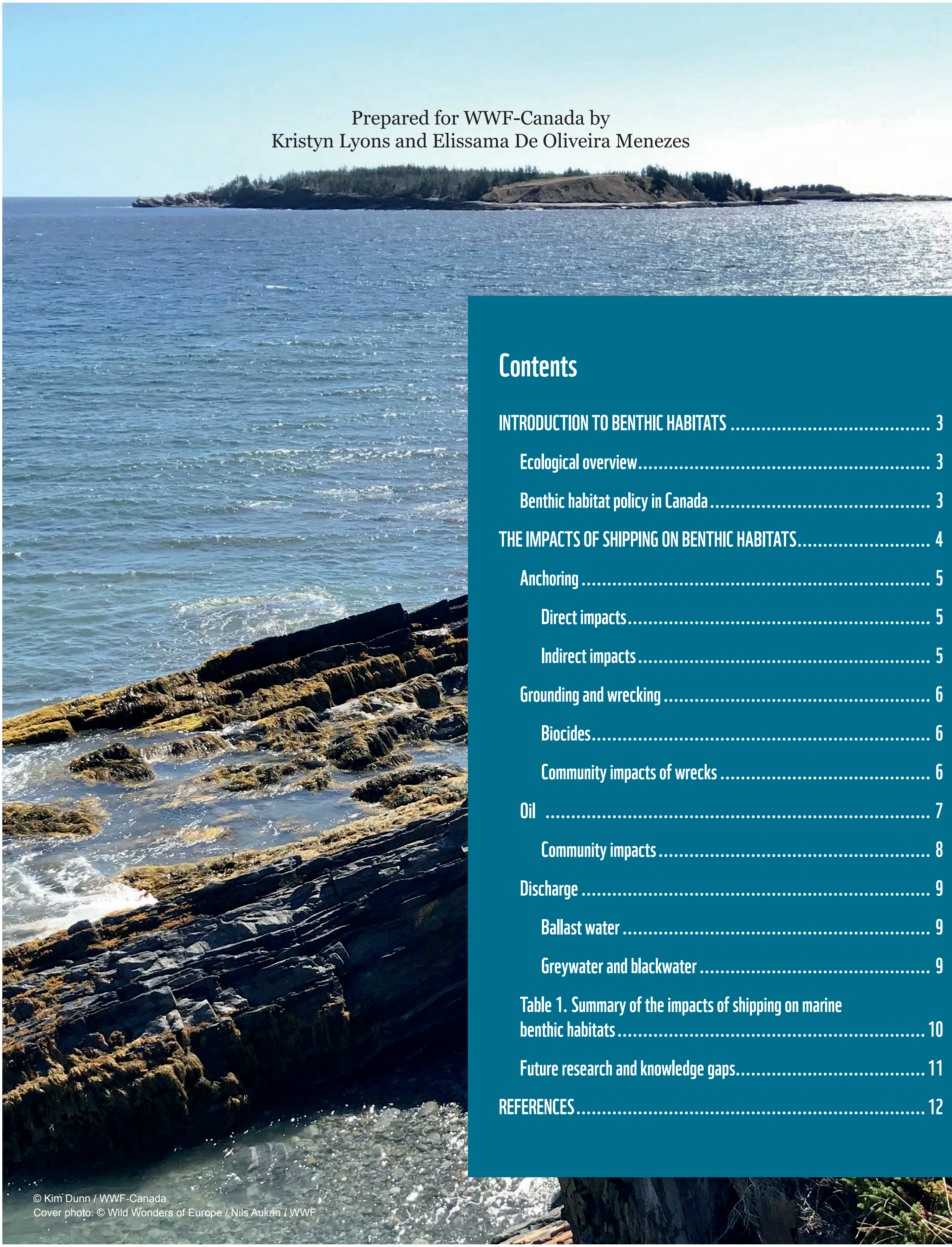

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INTRODUCTION TO BENTHIC HABITATS

ECOLOGICAL OVERVIEW

Marine organisms use many habitat types. From coastal mudflats, mangroves, estuaries, salt marshes and intertidal zones to the open ocean, coral reefs and kelp forests, the world's oceans provide a variety of habitats for marine creatures. Marine habitat types are often divided into two categories, coastal and open ocean habitats. Most ocean life can be found in coastal habitats, many of which are benthic. Important benthic habitats are also found farther offshore,[1] such as deep-sea hydrothermal vents, calcareous tubeworm thickets, macroalgal beds, methane or cold seeps, sea pen fields, sponge gardens and cold-water corals.[2] Such habitats, the communities they support and the ecosystem services they provide are often overlooked when it comes to the identification and protection of important marine habitats.[3] Benthic habitats create dimension in otherwise homogenous sedimented environments.[4] This is known to increase biodiversity, provide important habitats for fish and invertebrates (including many ecologically, economically and culturally important species) and support complex food chains.[5]

BENTHIC HABITAT POLICY IN CANADA

While there are no policies specific to the impacts of shipping on benthic habitats in Canada today, Fisheries and Oceans Canada (DFO) offers policy and management guidance for other industrial extractive sectors, including fishing and oil and gas. For example, the *Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas* outlines a process for identifying sensitive benthic areas, as well as provides a set of guiding principles, many of which could be adapted for shipping.[6] This policy is complemented by the *Ecological Risk Assessment Framework (ERAF) for Coldwater Corals and Sponge Dominated Communities*, which aims to guide the risk assessment process for sensitive benthic areas with respect to fishing.[7] More recently, DFO has assembled literature for the purposes of oil and gas exploration, through which they discuss areas with defined benthic conservation objectives as including "benthic species (demersal fishes and invertebrates); benthic habitats (spawning, nursery and feeding grounds); and Sensitive Benthic Areas (SBAs) (corals, sponges, canyons, seamounts and hydrothermal vents)."[8] As with the fishing policies, some of this information could be considered in the context of impacts from shipping.

1 NPS, 2016.
2 Doherty, Johnson and Cox, 2018; MacDiarmid, et al., 2013.
3 Kritzer, et al., 2016.
4 Huvenne, Bett, Masson, Bas and Wheeler, 2016.
5 DFO, 2009; Doherty, Johnson and Cox, 2018.
6 DFO. 2009. *Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas*. dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/benthi-eng.htm#n6
7 DFO. 2019. *Ecological Risk Assessment Framework (ERAF) for Coldwater Corals and Sponge Dominated Communities*. dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/risk-ecolo-risque-eng.htm
8 Oak, T.G. 2020. *Oil and Gas Exploration and Production Activities in Areas with Defined Benthic Conservation Objectives: A Review of Potential Impacts and Mitigation Measures*. DFO Canadian Science Advisory Secretariat Resource Document 2020/040. vi + 55 p.

THE IMPACTS OF SHIPPING ON BENTHIC HABITATS

Shipping can negatively impact benthic habitats, both directly and indirectly. Anchoring, grounding and wrecking all have direct impacts by causing physical damage, but they may also have indirect impacts such as resuspension of sediment.[9] Conversely, other shipping-related risks like greywater and blackwater discharge may have indirect impacts on benthic habitats by changing water chemistry and nutrient load,[10] while oil spills may impact the structure of benthic communities.[11] This report provides an overview of available literature examining the impacts of shipping on benthic habitats, as well as providing a summary of all activities and impacts in Table 1.

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9 Huvenne, Bett, Masson, Bas and Wheeler, 2016; Leatherbarrow, 2003.
10 VARD, 2018.
11 Kotta, Aps and Herkül, 2008.

ANCHORING

Direct impacts

Anchoring is a common practice in both commercial shipping and recreational boating. The anchor and associated chains and cables have the potential to cause significant damage to benthic habitats since they drag along the seafloor and can wrap around reef organisms.[12] The impacts of anchoring were first studied in the 1970s when researchers found that anchoring had damaged approximately 20 per cent of a coral reef in Florida.[13] This damage is a direct, and now widely studied, impact of this practice. When anchors are lowered, they can cause physical damage to benthic habitats by either crushing organisms buried within the sediments or by breaking off pieces of coral and other benthic structures.[14] The extent of the damage done by anchors is dependent upon their size and the type of anchor used.[15] In addition to the damage it does to corals, anchoring is also known to impact seagrass beds. Swaths of seagrass may be pulled up when anchors are retrieved or removed by boat anchors scouring the seafloor,[16] dislodging rhizomes and leaves of these easily disturbed grasses. Both seagrass beds and coral reefs are known to be slow to recover from disturbances, although seagrass recovery is thought to be species-specific.[17] Studies show that some seagrass beds may take over a year to recover from the impacts of anchoring, leaving habitat fragmented and organisms vulnerable during the recovery period.[18] Coldwater corals and sponges have been known to be extremely slow to recover from physical disturbance because of their long lifespans and slow growth rates. A recent literature review from DFO points to the importance of avoiding impacts, especially for deep-sea corals and sponges.[19]

Indirect impacts

The physical damage caused by anchoring may lead to other indirect impacts. Damage to benthic habitats is known to reduce habitat complexity overall, especially in three-dimensional habitats like coral reefs.[20] The indirect impacts on associated fauna can be extremely detrimental, especially for organisms closely associated with impacted habitats.[21] For example, in New Zealand, researchers observed a decrease in abundance of a pinnid bivalve (*Atrina zelandica*) because of the impacts of anchoring.[22] In the Mediterranean Sea, anchoring has threatened the populations of two endemic mussels, *Pinna nobilis* and *P. oceanica*. The impacts of anchoring on these two species are especially pronounced in shallow waters where recreational boating is more common.[23] Additionally, direct destruction of benthic habitat, such as seagrass beds is likely to lead to a reduction in food availability for surrounding filter feeders. Seagrasses are known to increase food supply for filter feeders by reducing the current flow and trapping food particles.[24] Commercially and recreationally important fish and invertebrate species may also be affected by the indirect impacts of anchoring due to damage of their habitat.[25] Finally, habitat loss caused by anchoring may lead to the establishment of invasive species. When benthic habitat is damaged by anchoring, competition from native species is reduced, making it easier for opportunistic invasive species to move in and colonize.[26]

Resuspension of sediments caused by anchoring can also be a major issue for benthic species. Organisms may be smothered by an increase of particulate matter in the water column, reducing the health

12 Giglio, Ternes, Mendes, Cordeiro and Ferreira, 2017.
13 Vázquez-Luis, Borg, Morell, Banach-Esteve and Deudero, 2015.
14 Giglio, Ternes, Mendes, Cordeiro and Ferreira, 2017.
15 Milazzo, Badalamenti, Ceccherelli and Chemello, 2004.
16 Leatherbarrow, 2003.
17 Milazzo, Badalamenti, Ceccherelli and Chemello, 2004.
18 Leatherbarrow, 2003; Vázquez-Luis, Borg, Morell, Banach-Esteve and Deudero, 2015.
19 Oak, T.G. 2020. *Oil and gas exploration and production activities in areas with defined benthic conservation objectives: A review of potential impacts and mitigation measures*. DFO Canadian Science Advisory Secretariat Resource Document 2020/040. vi + 55 p.
20 Giglio, Ternes, Mendes, Cordeiro and Ferreira, 2017; La Manna, Donno, Sarà and Ceccherelli, 2015.
21 Hendriks, et al., 2013; Milazzo, Badalamenti, Ceccherelli and Chemello, 2004.
22 Backhurst and Cole, 2000.
23 Vázquez-Luis, Borg, Morell, Banach-Esteve and Deudero, 2015.
24 Hendriks, et al., 2013.
25 La Manna, Donno, Sarà and Ceccherelli, 2015.
26 Ibid.

of the organisms.[27] Suspended sediment may also decrease light penetration in the water column. If light is unable to reach the seafloor as usual, primary productivity may be impacted. Additionally, resuspended sediments may rerelease nutrients into the water column, changing the nutrient load of the surrounding waters, which can increase the potential of phytoplankton blooms.[28] Sediment resuspension can potentially affect oxygen concentrations and the exchange of organic carbon and can impact the distribution of benthic fauna.[29]

GROUNDING AND WRECKING

Some of the impacts of a ship grounding (contacting the seafloor) or wrecking are similar to the impacts of anchoring. Like anchoring, grounding or wrecking causes physical damage to benthic habitats by crushing or gouging the seafloor. This may displace organisms that had been living in or near the affected area and resuspend sediments. Changes in species composition and abundance may also occur.[30] Additionally, invasive algae may colonize areas impacted by grounding,[31] as is seen in areas impacted by anchoring.

Biocides

Unlike anchoring, another issue of ship grounding is the potential release of biofouling compounds into the marine environment.[32] In a 2002 study, Marshall and colleagues discuss the damage caused by the grounding of the *Bunga Teratai Satu* vessel from Malaysia on the Sudbury Reef off the coast of Australia in November of 2000. The vessel caused localized physical damage, destroying approximately 1,500m^2 of the reef. Arguably the worst of the damage resulted from the antifouling paint that was scraped off the ship's hull; the paint contained a biocide known to be extremely toxic to marine organisms. This biocide was then distributed by ocean currents and the propellers of the ship, damaging or killing hard and soft corals in the vicinity of the grounded vessel.[33] Additionally, biocides may attach to particulate matter in the water column, eventually settling onto the seafloor as sediment.[34] In 2008, the International Maritime Organization (IMO) enforced the *International Convention on the Control of Harmful Anti-fouling Systems on Ships*, controlling the use of harmful biocides.[35] Despite enforcement of this convention, the harmful substances are still used on vessels in many developing countries.[36]

Community impacts of wrecks

In addition to the dangers of crushing organisms in benthic environments, which is common between wrecking and grounding,[37] wrecking may result in other changes to benthic habitats. The presence of a wreck on the seafloor can impact sediment topography, morphology and characteristics, all of which affect how suitable an area is for benthic organisms.[38] Turbulence and flow velocities may increase around shipwrecks as well, and wrecks may lead to site-specific hydrodynamic processes that impact the organic content of the surrounding waters.[39] Wrecks may also lead to changes in water chemistry as chemicals from metals and contaminants leech into the marine environment over time. These impacts are likely to have varying and context-specific impacts on benthic communities.[40]

27 CSAS, 2015.
28 Leatherbarrow, 2003.
29 Thompson, et al., 2017.
30 CSAS, 2015; Schroeder, Green, DeMartini and Kenyon, 2008.
31 Schroeder, Green, DeMartini and Kenyon, 2008.
32 Marshall, et al., 2002; Sonak, 2009.
33 Marshall, et al., 2002.
34 Sonak, 2009.
35 NOAA, 2008.
36 Costa, Zamprogno, Pedruzzi, Dalbem and Tognella, 2013.
37 Davies, Duffy, Bennie and Gaston, 2014.
38 Ruuskanen, et al., 2015.
39 Ibid.
40 Davis, Carlson and Caselle, 2018.

Changes in seafloor geomorphology and organic content are likely to impact surrounding communities, with some studies showing negative impacts on downstream communities due to sediment accumulation.[41] Conversely, materials leeching from wrecks may promote growth in some benthic species, which may outcompete local species that pre-existed the wreck. A shift in benthic community composition may occur as opportunistic species have the potential to become the more dominant species in the community. Such shifts are difficult, and in some cases, impossible to reverse. Impacted corals may take decades or even centuries to recover from wreck-related disturbances.[42] Some organizations interested in ecotourism or the easy disposal of an unwanted vessel may be interested in sinking a vessel to create an artificial reef. In 2011, Smith and colleagues found that, in most cases, any boosts in biodiversity observed from purposefully sinking a ship are probably temporary because any sedimentological differences are unlikely to last after the shipwreck has eroded away.[43] Finally, one study shows that some corals may be able to extend their range by colonizing artificial structures like wrecks and oil and gas platforms, the impacts of which are likely case-specific.[44]

Grounding and wrecking may also release ballast water, fuel, oil, discharge and goods carried by ship into the environment.[45] The sections below on oil and discharge elaborate on how their release via may impact benthic habitats.

OIL

Oil spills resulting from shipping frequently occur because of the large quantities of oil being transported.[46] While the results of an oil spill can be devastating for marine organisms, the impacts are dependent upon the properties of the oil, toxicity, volume, ecosystem and species affected.[47] Oil coats shorelines, leading to immediate impacts on organisms that utilize coastal habitats, but the impacts on subtidal habitats are more subtle and not as well understood.[48] Tidal movements and oceanographic currents spread spilled oil, moving it into different habitats, often including benthic areas.[49] The impacts of oil on benthic organisms are largely dependent upon the organisms' mobility. Many benthic organisms are sedentary, meaning they are unable to escape the impacts of an oil spill if their habitat is affected.[50] Any organisms that are unable to leave the affected area will likely be impacted in some way, but how and to what extent they are impacted depends on the ways in which they use the habitat and their life history.[51] Additionally, the feeding mode of benthic organisms may play a role in the impacts an oil spill has. For example, Kotta and colleagues point out in a 2008 study that suspension feeders depend on pelagic productivity, while benthic grazers rely on the production of both micro- and macroalgae, and deposit-feeders need sedimenting debris to survive. Because different functional groups are impacted by different environmental changes and factors, a high degree of variability can be expected in the response of benthic organisms to oil spills.[52]

41 Ruuskanen, et al., 2015.
42 Davis, Carlson and Caselle, 2018.
43 Smith, Kregting, Fern and Fraser, 2011.
44 Coolen, et al., 2015.
45 CSAS, 2015.
46 Stevens, et al., 2012.
47 Etkin, 2009.
48 Kotta, Aps and Herkül, 2008.
49 Egres, Martins, Oliveira and Lana, 2012.
50 Egres, Martins, Oliveira and Lana, 2012; Kotta, Aps and Herkül, 2008.
51 Abdulla and Linden, 2008.
52 Kotta, Aps and Herkül, 2008.

Community impacts

Despite the variability benthic organisms exhibit in their responses to oil spills, some community-wide impacts have been frequently observed. Oil spills may suffocate organisms or become toxic when ingested. These effects may impact habitat characteristics and potentially lead to the deterioration of important habitat-forming species, which is likely to have indirect impacts on other benthic life.[53] Oil spills have also been known to reduce macrofauna feeding activity, suppress photosynthesis of phytoplankton in some species, impact metabolism in benthic organisms, reduce biomass and diversity of benthic fauna, and decrease the density of small benthic invertebrates.[54] Community composition may also change, as species more tolerant to the impacts of oil spills may thrive while more sensitive species decrease in abundance.[55] These impacts are likely to alter the function of the benthic communities and cause major changes when combined with the impacts of other stressors.[56] Finally, these effects may persist for long periods of time. The results of oil spills on benthic communities have been known to last up to 20 years,[57] and experimental data has shown that the toxicity levels remain high after five years.[58]

Although many benthic habitats have been observed to have suffered significant negative impacts from oil spills, others have shown resilience.[59] Strong seasonality, high exposure, strong wave action and short generation times can all help benthic communities to recover more quickly from oil spills, and therefore be more resilient.[60]

53 Ibid.
54 Egres, Martins, Oliveira and Lana, 2012; Lee and Lin, 2013.
55 Egres, Martins, Oliveira and Lana, 2012.
56 Abdulla and Linden , 2008.
57 Kotta, Aps and Herkül, 2008.
58 Polmear, Stark, Roberts and MicMinn, 2015.
59 Abdulla and Linden, 2008.
60 Kotta, Aps and Herkül, 2008.

DISCHARGE

Shipping-related discharge, including sewage, greywater, ballast water, garbage, cargo and bilge water, pose threats to marine organisms.[61] These threats are known to scientists and managers, but the impacts and risks to specific organisms and benthic communities are not clear. Despite what is known about these threats, they are incidental to normal shipping operations and therefore occur regularly.[62]

Ballast water

The threats posed to marine organisms differ depending on what substance is being discharged from vessels. Ballast water exchange poses major threats to both marine and freshwater ecosystems. Water carried in vessels may contain non-native species that could colonize the environments they are released in, potentially resulting in changes to regional and local ecosystems.[63] The most well-known example of this is the spread of the zebra mussel (*Dreissena polymorpha*), a bivalve native to Europe. Zebra mussels were introduced to North America in the late 1980s, and while the specific time and method are uncertain, it is known that the organism made its way to North America by ship and was released during a ballast water exchange. As a well-known biofouling organism that has rapid dispersal, the presence of the zebra mussel in North America has caused many issues for shipping companies and ecosystems.[64]

Greywater and blackwater

Greywater and blackwater (sewage) discharge from ships can also cause major issues for marine organisms. Sewage released into marine environments may contain pathogenic bacteria, viruses, fungi, organic material and other chemicals.[65] The increase in organic material may promote algal growth, which may limit the amount of light that reaches the seafloor. This could impact benthic organisms that photosynthesize, as well as corals that have symbiotic relationships with algae called zooxanthellae. Less light reaching the seafloor could result in reduced growth for these corals. Additionally, raw or partially treated sewage has the potential to make corals less resilient to other stressors[66] and contaminate shellfish beds.[67] Greywater also contains high nutrient levels and oxygen demanding substances, like sewage, causing similar issues.[68] Additionally, greywater associated with vessels' washing machines is a source of microplastic in the ocean, which can impact all levels of the food web and enhanced risk of other pollutants, such as pesticides.[69]

61 Transport Canada, 2010; World Shipping Council, 2019.
62 World Shipping Council, 2019.
63 Ibid.
64 Griffiths, Schloesser, Leach and Kovalak, 1991.
65 Aronson, Thatje, McClintock and Hughes.
66 Thomas, 2007.
67 Nowlan and Kwan, 2001.
68 Ibid.
69 De Falco, Di Pace, Cocca and Avella, 2019; Kanhai, Gardfeldt, Krumpen, et al., 2020.

Table 1. Summary of the impacts of shipping on marine benthic habitats

Stressor	Direct impacts	Indirect impacts
Anchoring	Crush, dislodge or otherwise physically damage benthic organisms[70]	• Reduce habitat complexity[71] • Cause decline of organisms closely associated with corals and/or seagrass beds[72] • Reduce available food for filter feeders[73] • Increase risk of invasive species colonizing an impacted area[74]
	Resuspension of sediment[75]	• Risk of smothering benthic organisms, impacting organism health[76] • Decreased light penetration to seafloor could impact primary productivity[77] • Increase nutrient load in the water column, leading to phytoplankton blooms[78]
Grounding	Physical damage to benthic organisms[79]	• Displace organisms, change community composition, resuspend sediments, and increase risk of non-native species colonizing the impacted area[80]
	Release of biofouling compounds[81]	• Negatively impact coral health and other benthic organisms[82]
Wrecking	Physical damage to benthic organisms[83]	• Alter chemical makeup in the water column, leading to phase shift and negatively impacting organisms like corals[84]
	Impact on flow velocity and turbulence surrounding the wreck[85]	• Alter chemical makeup in the water column, making habitats less suitable for some organisms[86]
	Leeching chemicals[87]	• Cause change in community composition as more resilient organisms thrive[88]
Oil	Suffocate organisms or become toxic to organisms when ingested[89]	• Cause deterioration of habitat-forming species, impacting habitat characteristics and other benthic life[90] • Reduce feeding activity in macrofauna, supress photosynthesis, impact metabolism of organisms, reduce biomass and diversity of benthic fauna, and decrease the density of invertebrates[91] • Change community composition[92]

70 Giglio, Ternes, Mendes, Cordeiro and Ferreira, 2017; Leatherbarrow, 2003.
71 Giglio, Ternes, Mendes, Cordeiro and Ferreira, 2017; La Manna, Donno, Sarà and Ceccherelli, 2015.
72 Vázquez-Luis, Borg, Morell, Banach-Esteve and Deudero, 2015.
73 Hendriks, et al., 2013.
74 La Manna, Donno, Sarà and Ceccherelli, 2015.
75 CSAS, 2015.
76 Ibid.
77 Leatherbarrow, 2003.
78 Ibid.
79 CSAS, 2015; Schroeder, Green, DeMartini and Kenyon, 2008.
80 Ibid.
81 Marshall, et al., 2002; Sonak, 2009.
82 Marshall, et al., 2002.
83 Davis, Carlson and Caselle, 2018.
84 Davies, Duffy, Bennie and Gaston, 2014.
85 Ruuskanen, et al., 2015.
86 Ibid.
87 Davies, Duffy, Bennie and Gaston, 2014.
88 Ibid.
89 Kotta, Aps and Herkül, 2008.
90 Ibid.
91 Egres, Martins, Oliveira and Lana, 2012; Lee & Lin, 2013.
92 Egres, Martins, Oliveira and Lana, 2012.

Stressor		Direct impacts	Indirect impacts
Discharge	Ballast water exchange	Potential release of non-native species[93]	• Change habitat composition of nearby ecosystems [94]
	Blackwater and greywater	Increase organic content in water[95]	• Promote algal growth, limiting the penetration of sunlight to the seafloor, and impacting photosynthesis of benthic organisms[96] • Make corals less resilient to other stressors[97] • Contaminate shellfish beds[98]

FUTURE RESEARCH AND KNOWLEDGE GAPS

Despite all risks that shipping poses to benthic habitats, there is a general lack of knowledge surrounding their potential impacts. In addition to the risks described above, other risks like light pollution, anthropogenic noise and chronic oiling could have devastating impacts on benthic communities. Growing evidence shows that ocean noise can impact a wide range of species, though research has previously focused on the impacts on marine mammals and acute impacts of noise resulting from seismic air guns, sonar and pile driving, rather than the chronic noise resulting from shipping.[99] Species' activities and function of ecosystems may be impacted by chronic anthropogenic noise, but knowledge on the subject is still limited.[100] Additionally, some research shows that artificial light can impact biomass and community composition of benthic primary producers. This could have far-reaching impacts for benthic communities, but more research is necessary to determine how organisms are impacted and how to move forward with management.[101] Finally, the impacts of chronic oiling on benthic habitats are seldom discussed in the literature. One study found that a site near an oil refinery lacked species found in other similar areas,[102] but the impacts of chronic oiling on benthic habitats, in general, appear to be understudied. Overall, more research is needed on the impacts of shipping on benthic habitats specifically, so that the risks can be better understood by regulators and marine

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93 World Shipping Council, 2019.
94 Griffiths, Schloesser, Leach and Kovalak, 1991; World Shipping Council, 2019.
95 Aronson, Thatje, McClintock and Hughes.
96 Thomas, 2007.
97 Ibid.
98 Nowlan and Kwan, 2001.
99 Chen, et al., 2017.
100 Solan, et al., 2016.
101 Grubisic, et al., 2017.
102 Egres, Martins, Oliveira and Lana, 2012.

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