Title

Characterization of Fish Hold Effluent Discharged from Commercial Fishing Vessels into Harbor Waters

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Abstract

Fish hold effluent and the effluent produced from the cleaning of fish holds may contain organic material resulting from the degradation of seafood and cleaning products (e.g., soaps and detergents). This effluent is often discharged by vessels into near shore waters and, therefore, could have the potential to contribute to water pollution in bays and estuaries. We characterized effluent from commercial fishing vessels with holds containing refrigerated seawater, ice slurry, or chipped ice. Concentrations of trace heavy metals, wet chemistry parameters, and nutrients in effluent were compared to screening benchmarks to determine if there is a reasonable potential for effluent discharge to contribute to nonattainment of water quality standards. Most analytes (67%) exceeded their benchmark concentration and, therefore, may have the potential to pose risk to

human health or the environment if discharges are in significant quantities or there are many vessels discharging in the same areas.

Key Words

Fishing Vessel, Water Quality, Biochemical Oxygen Demand, Vessel Discharges, Incidental Discharges, Fish Hold

Introduction

Fishing vessels are one of the most common types of commercial vessels operating in United States (US) waters. There are an estimated 70,000 commercial fishing vessels in the US that operate in coastal waters. These vessels use numerous methods to catch a wide variety of seafood (US EPA 2010; US EPA 2013). Commercial fishing vessels use different methods to keep seafood fresh (Dagbjartsson et al. 1982, Wang and Wang 2005). Most seafood is either dead when brought onboard or is killed shortly thereafter. Consequently, seafood must be stored in a refrigerated seawater holding tank. Exceptions include certain shellfish (e.g., crab, lobster) which must be kept alive. Once the vessel has unloaded its catch, the holding tank is emptied, discharging excess seawater or ice and any pollutants from the vessel that may have entered or leached into the fish hold, the ambient water, residual biological material from the seafood product, and the residues generated from the cleaning of the tanks. For this study, we conducted an analysis of the fish hold effluent and fish hold cleaning effluent from commercial fishing vessels to characterize the nature of the discharge.

Commercial fishing vessels can be defined as vessels that commercially engage in the catching, taking, or harvesting of fish or an activity that can reasonably be expected to result in the catching, taking, or harvesting of fish (46 USC § 2101). Most (between 77% and 97%) commercial fishing vessels in the U.S. are less than 24 meters (79 feet),

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4 although some can be more than 50 meters (164 feet) long and more than 1,000 gross
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6 tons (US EPA 2010). These vessels include any vessels harvesting fish (e.g., salmon,
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8 halibut, cod, rockfish), shellfish (e.g., crab, lobster, shrimp, scallops, clams, oysters,
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10 mussels) or other aquatic organisms for commercial sale. Commercial fishing vessels
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12 employ various methods of collection including nets, trawls, traps, or hook-and-line to
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14 capture the target species (Sainsbury 1996). These methods result in the use of platform
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16 types which can include dredgers, gillnetters, long-liners, purse seiners, trawlers (also
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18 known as draggers), and trollers (Moore and Jennings 2008).
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24 The scientific literature has substantial documentation of the notable
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26 environmental impacts from fishing vessels that can result from the actual fishing activity
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28 (Crowder and Murawski 1998; Dayton et al. 1995; Jackson et al. 2001; Jones 1992;
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30 Srinivasan et al. 2010). For example, some fisheries have been shown to disturb and
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32 displace benthic communities (Johnson 2002, Chuenpagdee et al. 2003, Ziegler et al.
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34 2003), alter trophic dynamics (Jackson et al. 2001, Pauly et a. 2002), or cause
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36 entanglement of marine animals in plastic debris and discarded or abandoned fishing gear
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38 (Derraik 2002). However, little work has been done to characterize the wastewater
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40 generated by commercial fishing vessels during the process of fishing or unloading their
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42 catch, and whether these effluents might have any environmental impacts.
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49 Fish hold effluent and fish hold cleaning effluent contain pollutants that could
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51 potentially pose a threat to coastal ecosystems and to human health (US EPA 2010). The
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53 water quality characteristics of fish hold effluent reflect contributions from various
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55 sources: vessel and fish hold materials and coatings, ambient water, potable/service
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57 water, and the seafood product itself. Organic material in fish hold effluent results from
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4 seafood degradation during transport or from material that drains from the seafood
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6 depending on how the fish are handled (butchered or cleaned) when caught. For
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8 example, fish caught by gillnetters and trollers are typically gutted prior to stowage, and
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10 almost all long-liners perform some fish processing immediately after fish are caught,
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12 including gutting, bleeding, heading, or cleaning. In contrast, lobster and crabs are kept
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14 alive with minimal degradation. Fish holds are also often cleaned and/or disinfected
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16 between catches. The environmental and health effects of the pollutants found in fish
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18 hold and fish hold cleaning effluent depend not only on the concentration of pollutants in
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20 the discharged effluent but also on the size of the harbor into which the effluent is
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22 discharged, the number of vessels discharging into the harbor, the amount of effluent
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24 discharged by each vessel, the residence time and circulation rate of water in the harbor,
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26 and the mixing action and other flow characteristics of the harbor.
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33 Commercial fishing vessels must chill the fish harvested to delay both
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35 biochemical and bacteriological processes in the fish and to prolong storage time (Sen
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37 2005). The goal (when not freezing onboard) is to reduce the temperature of the fish
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39 close to but not below freezing (i.e., 0°C) to maximize shelf life of the seafood product
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41 (Venugopal 2005). Different fish and shellfish species require different methods of
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43 cooling and storage, which is also dependent on voyage length. Most seafood is stored in
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45 a refrigerated seawater holding tank, and the two most common methods of cooling
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47 seawater are by mechanical refrigeration or by adding ice (Thorsteinsson et al. 2003).
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49 Standard refrigerated seawater systems recirculate seawater through the refrigeration
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51 system and storage tank to maintain the target temperature before fish are dumped into
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53 pre-chilled storage water (Thorsteinsson et al. 2003). Alternatively, ice loaded from
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shoreside facilities or produced onboard using ice machines can be added directly into the storage tanks and mixed with water before the fish are added (Thorsteinsson et al. 2003). Refrigeration systems allow for better control of temperature over longer periods, but cooling via ice allows for rapid chilling of the fish and lower energy consumption (Pineiro et al. 2004, Wang and Wang 2005). Based on our observations of sampled vessels, combined with data gathered from fishing vessel owners and operators, mechanical refrigeration is common on tenders, purse seiners, and trawlers, while chipped and slurry ice tanks are more common on trollers, long-liners, gillnetters, and some trawlers. Additionally, some vessels (e.g., large shrimping vessels in the Gulf of Mexico) use dry freezers to preserve their catches (Bono et al. 2012); however, these vessels do not produce significant amounts of effluent from the hold that comes into contact with seafood product.

Seafood stored in refrigerated seawater tanks are typically extracted to the fish processing facility using a pierside vacuum system that removes both the fish and refrigerated seawater simultaneously, but the refrigerated seawater is generally recirculated back to the fish hold tank to provide the liquid needed to operate the vacuum system. Any excess refrigerated seawater that is not required to assist in fish extraction is typically pumped overboard pierside. Crew members onboard vessels that use chipped or slurry ice generally manually remove the seafood and then discharge the spent ice overboard while pierside. Occasionally, vessels that store their catch in ice slurry also use vacuum filtration systems (e.g., some shrimping boats in the Gulf of Mexico).

Lobster and crab boats use seawater flow-through tanks to keep lobsters and crabs alive. These tanks continuously pump surrounding water into the fish hold to maintain

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4 the highest water quality possible. The flow rate through these systems results in a nearly
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6 continuous discharge of fish hold effluent. Because the seafood product remains alive,
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8 there is little biological decay or degradation in the tank. Furthermore, because these
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10 tanks have relatively rapid flushing times and a continuous discharge, there is little
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12 accumulation of pollutants.
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16 Fish hold cleaning may simply involve rinsing the tanks with either municipal
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18 water from the dock or pumped from the surrounding ambient water, although crews
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20 sometimes add detergents (e.g., Joy or Dawn dish detergent) or disinfectants (typically
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22 bleach). Crews also often use scrub brushes to clean the walls and floor of the fish hold to
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24 maximize the removal of biological material. Therefore, fish hold cleaning effluent is a
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26 combination of residual fish hold water, ambient or municipal water, and sometimes,
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28 detergents and disinfectants.
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33 This paper seeks to characterize fish hold and fish hold cleaning effluent and their
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35 potential for environmental impact. For this study, we conducted an analysis of these
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37 effluents from commercial fishing vessels to characterize the effluent water chemistry.
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39 Furthermore, we used screening level tools, including comparing these results to several
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41 EPA water quality criteria (US EPA 1986a; US EPA 1986b; US EPA 2006) to determine
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43 if these effluents might potentially pose a risk to aquatic ecosystems when the vessels
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45 release this discharge while pierside or in other enclosed waters. .
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50 **Methods**

51 **Field Sampling**

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53 Because fishing vessels have no preset schedule for offloading their catch, we
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55 identified shoreside seafood processors or unloading docks, rather than specific fishing
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4 companies and vessels, as the means to obtain a pool of active fishing vessels for
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6 sampling. Sampling was conducted at the docks of the seafood processors during the
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8 offloading process, and all vessels that arrived were sampled (with the permission of the
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10 captains). In this way, sampling of individual commercial fishing vessels was
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12 unsystematic. However, we contacted the seafood processing facilities prior to sampling
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14 to provide sampling details (e.g., nature of the study, discharges of interest, sampling
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16 dates).
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21 We conducted vessel sampling in multiple regions in the US to increase variation
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23 in the types of fishing vessel types and seafood caught. The fish hold effluent from
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25 fishing or shrimping vessels were sampled in Gloucester and New Bedford,
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27 Massachusetts; Lafitte, Louisiana; Pass Christian, Mississippi; and Sitka, Alaska. We
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29 collected fish hold effluent samples from a total of 26 vessel fish holds from March 2009
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31 through July 2009 including 6 trollers, 5 purse seiners, 3 gillnetters, 3 ground fishery
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33 trawlers, 3 long-liners, 2 shrimp trawlers, 3 tenders, and 1 flow through lobster tank.
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35 Single grab samples were usually collected while effluent was being discharged, but
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37 samples were occasionally collected directly from the fish hold where it was infeasible to
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39 collect samples at the discharge point.
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45 Three types of fish hold tanks were sampled: tanks containing refrigerated
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47 seawater, tanks containing ice slurry, and tanks containing chipped ice. Refrigerated
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49 seawater tanks were common to tenders, purse seiners, and some trawlers, while slurry
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51 and chipped ice tanks were common to trollers, long-liners, some gillnetters, and some
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53 trawlers. For vessels with refrigerated seawater tanks, vacuum systems remove both fish
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55 and seawater; any excess refrigerated seawater that is not required to assist in fish
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4 extraction is typically pumped overboard pierside. We collected samples of the
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6 refrigerated seawater directly into a 5-gallon utility bucket lined with a new pail liner as
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8 the water was pumped overboard. The sample in the pail liner was then poured into the
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10 individual sample bottles. Because removal of fish and refrigerated seawater can take
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12 several hours depending on the vessel size, we collected the sample approximately mid-
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14 way through the fish removal process. For vessels such as trollers and long-liners, which
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16 use chipped or slurry ice, we collected a sample of the ice or slurry once the fish had been
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18 removed from the fish hold tank. Ice/slurry was collected into a utility bucket with a new
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20 pail liner and allowed to melt. Once melted, the sample was poured from the pail liner
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22 into the individual sample bottles.
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28 The captain or other operator of every vessel sampled was asked to assist in
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30 completion of a refrigerated seawater and fish hold effluent data sheet. Among other
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32 things, the data sheet recorded the size of the fish hold tank, the estimated number and
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34 location of discharges of that tank per voyage, the estimated frequency of offloading the
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36 catch, and how often tanks are cleaned. The volume of the fish hold effluent discharge
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38 was estimated by multiplying the volume of the fish hold tank by the estimated
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40 percentage of the tank occupied by effluent or ice (versus that occupied by the catch
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42 offloaded to shore) and by the frequency the tank was emptied.
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48 Operators of fishing vessels frequently clean/rinse out their hold after unloading
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50 their catch resulting in generation of additional waste water. The fish hold tank is
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52 cleaned after the catch has been off-loaded at the seafood processing facility. The
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54 frequency of fish hold cleaning depends on the type and amount of fish being caught.
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58 The fish hold cleaning wastewater is pumped overboard. We collected samples of the
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4 fish hold cleaning wastewater directly into a 5-gallon utility bucket lined with a new pail
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6 liner as the cleaning water was pumped overboard. We sampled 9 vessels for fish hold
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8 cleaning effluent (4 ground fishery trawlers, 2 tenders, 1 troller, 1 long-liner, and 1 purse
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10 seiner). Fish hold cleaning effluent was not sampled from as many vessels as fish holds
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12 because not all fishing boats cleaned their holds while at the seafood processor.
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16 We also collected samples of ambient water where the vessels were operating
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18 and, where relevant, potable water used onboard the vessels (service water) to
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20 characterize any background concentrations of pollutants that might be detected in
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22 effluent from vessel operations that use service water. This information was useful for
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24 helping determine the source of some unexpected high loads of pollutants originating
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26 from a subset of fish hold effluent.
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30 31 Laboratory Analysis 32

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34 Each of these samples was analyzed for multiple analytes (see Table 1)
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36 representing 3 pollutant groups: (1) trace heavy metals, (2) wet chemistry parameters
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38 (e.g., Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), pH, turbidity), and
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40 (3) nutrients (i.e., nitrogen and phosphorus). Additionally, we also analyzed 3 samples
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42 from fish holds for short chain nonylphenols (ASTM D 7065-06 method) and 8 samples
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44 for long chain nonylphenols (CRL Method LC/ MS 606) from fish hold cleaning effluent
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46 due to their possible addition as a result of detergent use. This comprehensive list of
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48 analytes was targeted to perform a screening-level analysis of the presence or absence of
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50 many priority pollutants (listed at 40 CFR Part 423, Appendix A), conventional pollutants
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52 defined at Section 304(a)(4) of the Clean Water Act, and some pollutants from EPA's
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54 2006 National Recommended Water Quality Criteria (NRWQC) for freshwater and
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4 saltwater aquatic life and human health, as well as many other nonconventional
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6 pollutants.
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9 Where the concentration of an analyte was below the detection limit (the presence
10 or absence of a pollutant) or if the detection limit was not reported, we replaced the value
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12 with half of the reporting limit (the level at which the concentration of a pollutant can be
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14 quantified with appropriate certainty).
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18 Data Handling and Reduction

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20 We compiled the data collected for the effluent sampled into a Microsoft (MS)
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22 Access database. For analysis, data were exported to MS Excel, and then resaved as tab-
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24 delimited ASCII text (*.txt) files. Record counts were compared between the discharge
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26 group-filtered MS Access query and the MS Excel and ASCII files to ensure that data
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28 were not lost. The ASCII data for each discharge group were read into an Interactive Data
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30 Language (IDL) (Research Systems Inc. 2003) program that carried out a series of
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32 calculations for each analyte, based on an algorithm developed for this project. That
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34 algorithm identified and averaged concentrations measured for field and laboratory
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36 replicate samples, including replacing below-detection concentrations with half of the
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38 reporting limit when at least one replicate was detected. Summary data tables were
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40 generated from these workbooks. As a QA procedure, we reproduced by hand the data
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42 reduction and statistical calculations discussed above for two randomly selected analytes.
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50 Analysis of Potential Hazard Quotients (PHQs)

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52 To provide a context for the level of contaminant concentrations presented, we
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54 used National Recommended Water Quality Criteria (NRWQC) and several other
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56 benchmarks as a preliminary screen (Table 1). NRWQC include acute (short-term) and
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4 chronic (long-term) criteria (toxicity threshold values) for the protection of aquatic life,
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6 as well as Human Health criteria for protection of humans from consumption of
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8 contaminated water or contaminated water and aquatic organisms. These “screening-
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10 level” benchmarks chosen for this purpose generally represent the most protective
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12 concentration available for the specific analyte of interest established by the United States
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14 EPA.
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18 Comparing analyte concentrations in vessel effluent to NRWQC (or other
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20 screening benchmarks) provides a conservative screen of whether these effluents cause,
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22 have the reasonable potential to cause, or contribute to nonattainment of the water quality
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24 standards in a water body. We calculated PHQs by dividing the concentration of a
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26 particular analyte by its corresponding water quality criterion or other benchmark as an
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28 initial screen for the discharge-specific water sample data. If the concentration of a given
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30 analyte in vessel discharge is less than the applicable screening criterion or benchmark
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32 values (PHQ<1), the discharge is less likely to negatively impact the water body into
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34 which it is discharged. If the PHQ value is greater than one, then there is a possibility of
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36 ecological or human health risk as the concentration of a given analyte in vessel
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38 discharge is greater than the applicable screening criterion or benchmark values (US EPA
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40 1997). However, because discharges in this study are measured at the “end of pipe”
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42 before being released into a harbor where they are subsequently diluted, PHQ values of
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44 greater than one do not necessarily indicate that a discharge poses a significant risk to the
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46 receiving water. Further, the presence of additional environmental factors can reduce the
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48 toxicity of certain pollutants (e.g., metals) and reduce the likelihood of ecological or
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50 health risk. Additionally, many waters are continually flushed by freshwater and tidal
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4 activity. These dilution factors, in addition to the mitigating capacity of saltwater cations
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6 and organic matter, may reduce the toxicity and/or environmental impact of many of
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8 these pollutants. Nonetheless, other factors, such as cumulative acute toxicity,
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10 synergistic effects, and pre-existing conditions in a waterbody mean we cannot merely
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12 rely on dilution factors to assume there will be no environmental impact from effluent
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14 that only marginally exceeds a PHQ value.
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19 Mobile sources such as vessels complicate the PHQ analysis because they
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21 discharge into many different water bodies, but in general, greater mixing and dilution
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23 would be expected for effluent from vessels when they are in motion than effluent from
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25 stationary sources. Harbors with a low degree of flushing will reduce mixing and
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27 dilution, and areas with high vessel traffic or impaired water bodies will have increased
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29 pollutant concentrations requiring higher mixing and dilution to offset discharge effects.
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31 With these factors in mind, and assuming the data from this study are representative of
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33 the class of vessels as a whole, a PHQ marginally above a value of 1 is most likely not of
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35 significant concern. On the other hand, a PHQ value substantially above 1 (e.g., 10 or
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37 100) may be more likely to be of concern, particularly if the discharge is of significant
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39 volume, is in an area of low flushing, is in an area where there is a high degree of vessel
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41 traffic, or is in a waterbody that is already impaired or under other stress.
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48 Statistical Analysis 49

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51 Analyses were performed to examine whether differences among vessels could be
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53 explained by differences in fishing methods (nets vs. no nets, which impacts how fish are
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55 handled and/or processed once brought onboard, and therefore, the amount of biological
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57 material released on deck or in the hold) or fish hold cooling method (ice vs. refrigerated
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seawater vs. both). These analyses were performed on seven analytes (total copper, total zinc, total arsenic, ammonia, total Kjeldahl nitrogen, total phosphorus, and biological oxygen demand). These seven parameters were selected because they were discharged in the greatest concentrations or had the highest PHQ values relative to the other analytes, and because they likely originated from the fish hold effluent and not from the surrounding waters. Differences between groups were evaluated using Welch's t-test ($\alpha = 0.05$) accounting for unequal sample size and uneven variance. There were no significant differences between fishing methods or between fish hold cooling methods, and therefore, the results are not presented here.

Results

Estimated Volume of Discharges

The volume of fish hold water generated by a fishing vessel depends on the size of the vessel and the method used for keeping the product fresh. Vessels such as small salmon trollers or long-liners that frequent Alaska waters have around 5,700 L of fish hold storage. We estimated this volume based on the assumption that fish holds are occupied by approximately 50 percent fish and 35 to 40 percent ice when the vessel off-loads at the seafood processing facility. The ice, which is thrown overboard daily after the fish are unloaded, would result in a fish hold discharge of between 2,000 and 2,300 L per day for these types of fishing vessels.

We estimated that mid-size fishing vessels, such as gill netters, and purse seiners found in Alaska, and shrimp boats in the Gulf of Mexico, have fish hold volumes of between 11,000 and 19,000 liters. Assuming these vessels have between 35 and 40

percent of ice/water slurry in the fish hold tanks, they likely discharge between 3,800 and 7,600 L of fish hold water every two to three days.

Larger fishing vessels such as off-shore trawlers found off the coast of New England and tenders found in Alaska can have refrigerated seawater holding tanks or ice hold tanks with capacities as large as 57,000 L. These tanks, which contain 30 to 40 percent refrigerated seawater or ice after the seafood is unloaded, result in a fish hold discharge of between 17,000 and 23,000 L. These vessels are expected to unload seafood and discharge the fish hold water every three to five days.

On small fishing boats such as trollers and long-liners, and mid-size fishing boats such as gill netters, fish holds are typically cleaned using a garden hose at a flow rate of between 0.63 and 0.76 L/s. Fish hold cleaning is completed in 15 minutes or less, resulting in a discharge of between 570 and 680 L per day. Larger vessels such as off-shore trawlers found in New England and large tenders in Alaska also use a garden hose to wash down the fish hold tanks; however, cleaning these tanks requires approximately 30 minutes. We estimated the volume of fish hold cleaning water discharge for these vessels ranges between 1,100 and 1,400 L per cleaning.

Metals

Concentrations of all 30 metal analytes were detected in one or more fish hold effluent samples (Table 1), and the range of mean concentrations spanned several orders of magnitude (Figure 1). Concentrations of 5 dissolved metals and 6 total metals were detected in all fish hold water samples (total aluminum and total and dissolved barium, cobalt, iron, vanadium, and zinc). However, some metals appear to be primarily a result of background concentrations in the ambient water (aluminum, barium, and iron).

Concentrations in at least one sample of fish hold effluent exceeded the screening benchmark for 5 total metals (aluminum, arsenic, copper, iron, and manganese) out of 9 that have screening benchmarks (Figure 1A) resulting in PHQs above 1. Although all of the samples collected had concentrations of total aluminum and total iron that exceeded the screening benchmark, both analytes were primarily influenced by ambient water concentrations (680 ± 40 $\mu\text{g/L}$ and 993 ± 478 $\mu\text{g/L}$, respectively). Total arsenic was detected in 62% of the samples collected, and all of those samples had concentrations that exceeded the low screening benchmark of 0.018 $\mu\text{g/L}$. PHQ values for total arsenic ranged from more than 100 to more than 20,000. Total copper concentrations and total manganese only exceeded the benchmark by a small fraction in two and three samples, respectively.

Concentrations in at least one sample of fish hold effluent exceeded the screening benchmark for 7 out of 9 dissolved metals that have screening benchmarks (arsenic, cadmium, copper, lead, nickel, selenium, and zinc). Of these 7 dissolved metals, only copper and selenium had concentrations that resulted in a PHQ value of 10 or higher. Copper was detected in concentrations ranging from non-detect to 920 $\mu\text{g/L}$ (PHQ value of approximately 297) with only 4 samples that had PHQ values of 10 or higher. Selenium was detected in only 6 samples collected, with the highest concentration detected at 61 $\mu\text{g/L}$ (PHQ value of 12.2).

The majority of mean dissolved metals concentrations were slightly lower for fish hold cleaning effluent than for fish hold effluent, but the majority of mean total metal concentrations were slightly higher for fish hold cleaning effluent than for fish hold effluent. Concentrations of only 17 metal analytes were detected in one or more fish hold

cleaning effluent (Figure 1B), and only total copper and total and dissolved aluminum were detected in all samples. Similar to the fish hold effluent results, the metals with the highest PHQ values for fish hold cleaning effluent were total arsenic and dissolved copper.

Wet Chemistry Parameters

Fourteen wet chemistry parameters were detected in one or more fish hold effluent samples (Table 1), and the range of mean concentrations again spanned several orders of magnitude (Figure 2). BOD and Chemical Oxygen Demand (COD) were highly elevated. The majority of these concentrations were higher than those of raw domestic sewage (as reported in Tchobanoglous et al. 2003) ranging from about 1 mg/L to 5,130 mg/L. Consequently, DO concentrations were low with hypoxic conditions (< 2 mg/L) in three cases and marginal hypoxia (< 5 mg/L) in 19 cases.

Other pollutants that exceeded their benchmark for at least one sample included Hexane Extractable Material (HEM), sulfide, Total Residual Chlorine (TRC), and Total Suspended Solids (TSS). HEM and SGT-HEM concentrations were generally low in concentration with only one HEM sample exceeding the benchmark of 15 mg/L with a concentration of 16 mg/L. Sulfide was detected in 28% of collected samples, the majority of which were found in samples from New England ground fishery trawlers. However, all samples that had detections of sulfide were at concentrations that exceeded the screening benchmark of 0.0020 mg/L, with the highest concentration measured at 0.16 mg/L (a PHQ value of 80). TRC was detected in 38% of the samples; of the detected samples, all had concentrations that exceeded the screening benchmark of 0.0075 mg/L with PHQ values from 1 to 40. Almost 90% of samples had a TSS concentration that

exceeded the screening benchmark of 30 mg/L, with the highest concentration of 1,100 mg/L (a PHQ value of 37). Similarly, turbidity, which measures cloudiness, was also elevated with concentrations ranging from 9 NTU to 450 NTU.

Mean concentrations of most wet chemistry parameters, with the exception of BOD and TSS, were higher for fish hold cleaning effluent compared to fish hold effluent. Although still elevated in fish hold cleaning effluent, BOD and TSS were more diluted than for fish hold effluent, and higher DO concentrations were measured in fish hold cleaning effluent with only 67% of samples having concentrations less than 5 mg/L.

Nutrients

Fish hold and fish hold cleaning effluent were analyzed for nutrient parameters that included ammonia ($\text{NH}_3\text{-N}$), nitrate/ nitrite ($\text{NO}_3/\text{NO}_2\text{-N}$), total Kjeldahl nitrogen (TKN), and total phosphorus (TP). There were considerable variations exceeding two orders of magnitude in the concentrations of $\text{NH}_3\text{-N}$, TKN, and TP from both fish hold and fish hold cleaning effluent (Figure 3). Most samples had concentrations of $\text{NH}_3\text{-N}$ and TP that exceeded the screening benchmarks with concentrations that were comparable to those of untreated domestic sewage. Despite lower concentrations of $\text{NO}_3/\text{NO}_2\text{-N}$, concentrations were also similar to those expected in raw sewage effluent.

Nonylphenols

Nonylphenols, which have historically been used in liquid detergents and soaps, were analyzed for in a limited number of samples. Among the eight vessels for which fish hold cleaning effluent samples were analyzed for nonylphenols, four used detergents, two did not use detergents, and detergent use was not known for the remaining two. Neither short-chain nonylphenol ethoxylates nor total nonylphenol were detected in the

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4 small number of fish hold effluent samples analyzed ($n = 3$). However, several long
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6 chain nonylphenol (nonylphenol polyethoxylates and octylphenol polyethoxylates) were
7
8 detected in the fish hold cleaning effluent (Figure 4). There is no benchmark value for
9
10 these analytes, and no samples were collected to measure ambient or source water
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12 concentrations.
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15 16 **Discussion** 17

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19 The analytes detected in both the fish hold and the fish hold cleaning effluent come
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21 from the vessel, from the ambient water and potable/ service water, and from the seafood
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23 product itself. These discharges from fishing vessels have the potential to impact surface
24
25 water quality based on exceedances of NRWQC, but the actual environmental impact will
26
27 depend on a combination of the volume of discharge, vessel traffic, and the characteristics of
28
29 the receiving water body. The volume of water discharged as fish hold effluent and fish hold
30
31 cleaning effluent can vary greatly, and the wide variety of coastal harbor environments
32
33 potentially impacted by these vessel discharges makes evaluating the cumulative effects
34
35 difficult. However, our characterization of the magnitude of pollutants discharged by fishing
36
37 vessels in combination with information about a given harbor environment and vessel
38
39 population could be used to develop a harbor specific water quality model.
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45 A large number of analytes exceeded the benchmark concentration in fish hold (19
46
47 out of 48 analytes detected) and fish hold cleaning effluent (15 out of 35 analytes detected)
48
49 and may have the potential to pose risk to human health or the environment. However, the
50
51 realized risk likely posed by these analytes, relative to pollutant loadings from other sources,
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53 background concentrations, and source water contaminant levels, is potentially low with only
54
55 a few noteworthy analytes that have the potential for water quality and human health
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57 impairment (e.g., arsenic, copper, BOD, COD, TSS, DO, $\text{NH}_3\text{-N}$, TKN, and TP).
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4 The concentrations of many of the metals that were detected in fish hold discharges
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6 are not unexpected and may come from ambient water, exposed metal surfaces, hull coatings,
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8 contributions from pumps used to add water, and contact run off from metallic fishing
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10 equipment and deck surfaces. Dissolved copper and total arsenic are the two metals detected
11
12 that represent the greatest environmental concern, and appear to result largely from
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14 mechanically refrigerated water used to cool the sea water, from ice that is added to the
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16 holds, from the seafood catch itself, or from a combination of the three.
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21 Dissolved copper was detected in 23 of 26 samples with PHQs from 1 to 300.
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23 Additionally, the total copper concentrations, which was detected in 24 of 26 samples but
24
25 only exceeded the human health criteria by a small fraction, could pose further potential risk
26
27 to aquatic organisms because it is likely that some of the particulate copper will convert to
28
29 dissolved copper after being discharged and therefore be bioavailable to aquatic life,
30
31 particularly benthic organisms. The impacts from high concentrations of copper can include
32
33 reduced primary production, accumulation in sediment, and chronic low-level toxicity to
34
35 aquatic organisms (Baldwin et al. 2011; Flemming and Trevors 1989; Roussel et al. 2007).
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39 Likewise, total arsenic was detected in 16 of 26 samples with concentrations greatly
40
41 exceeding the benchmark and PHQs well over 100. The exceptionally high PHQ values are
42
43 due in large part to the low human health value for total arsenic used as a benchmark.
44
45 Additionally, the highest measured concentrations of total arsenic might be slightly elevated
46
47 due to matrix interference that affected the measurements, but most of the samples were
48
49 absent positive interference representing reasonably true effluent concentrations for the
50
51 discharge. Arsenic concentrations found in fish hold and fish hold cleaning effluent may be
52
53 biological in origin as marine organisms have been shown to have elevated levels of arsenic
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55 (Phillips, 1990; Francesconi and Kuehnelt 2002) or from the entrainment of arsenic
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57 contaminated sediments on nets since each of the vessels with highest arsenic values used
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4 nets that drag the ocean floor (USEPA 2010). Arsenic is easily absorbed by aquatic
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6 organisms having a variety of acute and chronic toxic effects (Ventura-Lima et al. 2011).
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8 The greatest impact of high arsenic is primarily via the food chain and subsequent
9
10 bioaccumulation in seafood consumed by humans (Borak and Hosgood 2007).
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13 Several wet chemistry parameters detected in fish hold and fish hold cleaning effluent
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15 may pose a localized water quality impact in confined water bodies or where the background
16
17 concentrations of these pollutants are significant. BOD and COD pose one of the greatest
18
19 potential risks to receiving waters, particularly in areas where many vessels sequentially or
20
21 simultaneously discharge fish hold effluent, because detected concentrations were higher
22
23 than raw sewage. These high levels of oxygen-demanding compounds result from the
24
25 degradation of organic material and its by-products in the fish hold, and the variability among
26
27 ships may be due to whether fish are kept on top of ice, in ice water slurry, or in refrigerated
28
29 seawater. The impact of elevated BOD and COD will depend on harbor characteristics along
30
31 with season and water temperature. For example, fish hold effluent may be more saline and/
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33 or cooler than the surrounding water and more likely to sink to the bottom of the harbor when
34
35 discharged. This delivers the BOD load to the deeper layers of the receiving water body
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37 where oxygen levels are more likely to be lower. Therefore, the high BOD in our samples
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39 likely contributed to the pervasively low DO levels. Furthermore, the high TSS
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41 concentrations are also probably caused by the high amount of organic material related to the
42
43 seafood product.
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46 Nutrient parameters, particularly $\text{NH}_3\text{-N}$, TKN, and TP, were also measured at
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48 concentrations similar to raw sewage and therefore are a potential concern in fish hold and
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50 fish hold cleaning effluent. Sources of these nutrients are likely the organic material from the
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52 seafood product. Ammonia is produced within fish when proteins are digested, and
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4 excreted through the gills and in urine. TKN measures both ammonia and organic forms
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6 of nitrogen, such as that contained in fish tissues and blood. Inorganic phosphorus is a
7
8 key element in DNA, RNA, and ATP present in the tissue and blood of fish. The primary
9
10 water quality impact of concern for nutrients is eutrophication which can cause significant
11
12 degradation of aquatic ecosystems (Smith et al. 1999). Increased ambient levels of nutrients
13
14 often are followed by increases in the density and biomass of planktonic algal community.
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16 The increased algal biomass can block light, reduce water clarity, contribute to nuisance algal
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18 blooms, and result in declining DO concentrations. The environmental effects of nutrients
19
20 are driven by site-specific environmental conditions including what nutrient is limiting,
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22 nutrient background concentrations, other sources of impairment, and ecosystem structure
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24 and organisms present in the water body. Hence, nutrients in vessel discharges may
25
26 contribute to an environmental effect in one water body but not another.
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33 Fishing vessels also have the potential to discharge other pollutants to surrounding
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35 waters,, some of which may produce notable environmental impacts such as anti-foulant hull
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37 coatings (Matthiessen et al. 1999, Matthiessen and Law 2002, Andersen 2004, Hospido and
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39 Tyedmers 2005), engine effluent and exhaust (Thrane 2006, Tyedmers et al. 2005), fueling
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41 operations, spills, and bilgewater (Lin et al. 2007, Vazquez-Rowe et al. 2010, Chanthamalee
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43 et al. 2013, McLaughlin et al. 2014), and on a limited number of fishing vessels, ballast water
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45 (Carlton 1989; Drake et al. 2007; Ruiz et al. 1997). Industrial fishing operations, such as
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47 seafood processing, also have the potential to produce significant local loadings of pollutants
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49 (Nair 1990, Islam et al. 2004, Chowdhury et al. 2010). On the other hand, other fishing
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51 vessel discharges such as firemain discharges or noncontact engine coolant water are likely to
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53 result in few pollutants being discharged (US EPA 2010). These other potential pollutant
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4 sources have not been discussed in this paper, but where notable loadings could occur, they
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6 would contribute to any overall environmental impact the vessel may have.
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9 While an individual fishing vessel may only have a minimal environmental impact,
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11 the impact caused by vessels in general is potentially significant where there is high vessel
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13 traffic, low circulation of water, additional stressors, or high pollutant loadings from other
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15 sources. Reducing discharges and pollutants in discharges such as fish hold and fish hold
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17 cleaning effluent may result in environmental benefits in those waters that could be most
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19 impacted by the discharges. A harbor or water body specific analysis, examining water
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21 bodies with significant fishing vessel activity, and considering other pollutant loadings from
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23 sources such as sewage treatment plants, agricultural inputs, background concentrations and
24
25 other upstream loading sources, could identify specific water bodies where there would be
26
27 the greatest potential environmental impact from these discharges. Most likely these
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29 discharges are not an issue in open waters because of increased dilution effects when
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31 discharged while underway and the limited need for discharge at sea.
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37 In this study, we described the magnitude of pollutants discharged by fishing vessels
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39 from fish hold tanks and discussed whether those discharges exceeded a benchmark
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41 concentration which could indicate a potential for environmental effect. This information
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43 could be used in models aimed at evaluating the cumulative effects of discharges from a
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45 population of such vessels operating in a given receiving water body. Traditionally, fishery
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47 management has focused mainly on quota regulations and environmental regulations of the
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49 processing stage, but the environmental impact of the fishing activity can be substantial
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51 (Thrane 2006). Additionally, fishing vessel discharge impacts on water quality could be
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53 considered in impact category development for life cycle assessments to allow for a more
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55 comprehensive evaluation of the myriad of environmental costs of seafood production.
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Table Legends:

Table 1. List of analytes measured in fish hold effluent and fish hold cleaning effluent, the method used for measurement, the water quality benchmark concentration used to screen the effluent concentrations, and the source of the benchmark value.

Tables:

Table 1:

Pollutant	Method	Benchmark	Units	Source ^{1 & 2}
<u>Metals</u>	EPA 200.8 or EPA 200.7			
Aluminum, total		87	µg/L	EPA 2006 FW CCC
Aluminum, dissolved		N/A		
Arsenic, total		0.018	µg/L	EPA 2006 HH W + O
Arsenic, dissolved		36	µg/L	EPA 2006 SW CCC
Barium, total		1000	µg/L	EPA 2006 HH W + O
Barium, dissolved		N/A		
Cadmium, total		N/A		
Cadmium, dissolved		0.25	µg/L	EPA 2006 FW CCC
Chromium, total		N/A		
Chromium, dissolved		11	µg/L	EPA 2006 FW CCC
Cobalt, total		N/A		
Cobalt, dissolved		N/A		
Copper, total		1300	µg/L	EPA 2006 HH W + O
Copper, dissolved		3.1	µg/L	EPA 2006 SW CCC
Iron, total		300	µg/L	EPA 2006 HH W + O
Iron, dissolved		N/A		
Lead, total		N/A		
Lead, dissolved		2.5	µg/L	EPA 2006 FW CCC
Manganese, total		50	µg/L	EPA 2006 HH W + O
Manganese, dissolved		N/A		
Nickel, total		610	µg/L	EPA 2006 HH W + O
Nickel, dissolved		8.2	µg/L	EPA 2006 SW CCC
Selenium, total		170	µg/L	EPA 2006 HH W + O
Selenium, dissolved		5	µg/L	EPA 2006 FW CCC
Silver, total		N/A		
Silver, dissolved		1.9	µg/L	EPA 2006 SW CMC

Vanadium, total		N/A		
Vanadium, dissolved		N/A		
Zinc, total		7400	µg/L	EPA 2006 HH W + O
Zinc, dissolved		81	µg/L	EPA 2006 SW CCC
<u>Wet Chemistry Parameters</u>				
Biochemical Oxygen Demand (BOD)	SM 5210B	30	mg/L	FR 1984
Chemical Oxygen Demand (COD)	Hach 8000 or EPA 410.4			
Conductivity	Hydrolab sensor			
Dissolved Oxygen	Hydrolab sensor			
Hexane Extractable Material (HEM)	EPA 1664A	15	mg/L	MARPOL 1973/78
Silica Gel Treated HEM (SGT-HEM)	EPA 1664A	15	mg/L	MARPOL 1973/78
pH	Hydrolab sensor			
Salinity	Hydrolab sensor	250,000	µg/L	EPA 2006 HH W + O
Sulfide	SM 4500-S2	0.002	mg/L	EPA 2006 FW & SW CCC
Temperature		N/A		
Total Organic Carbon (TOC)	SM 5220 D or EPA 415.1			
Total Suspended Solids (TSS)	SM 2540D	30	mg/L	FR 1984
Total Residual Chlorine (TRC)	SM 4500-Cl G	0.0075	mg/L	EPA 2006 SW CCC
Turbidity	SM 2130 B			
<u>Nutrients</u>				
Ammonia [As N]	EPA 350.1/ SOP C-80	1.2	mg/L	EPA 2006 SW CCC
Nitrate + Nitrite [As N]	EPA 353.2	10	µg/L	EPA 2006 HH W + O
Total Kjeldahl Nitrogen (TKN)	EPA 351.2			
Phosphorus (TP)	EPA 365.4	0.1	mg/L	EPA 1986, The Gold Book
<u>Nonylphenols</u>				
Short chain	ASTM D 7065-06	1.7	µg/L	EPA 2006 SW CCC
Long chain	CRL LC/ MS 606	1.7	µg/L	EPA 2006 SW CCC
Sources:				
1. EPA. 1986. "Quality Criteria for Water (The Gold Book) Office of Water."				

EPA 440/9-76-023

EPA. 2006. "National Recommended Water Quality Criteria. 2006" U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology. Washington, D.C., Available Online at: <http://epa.gov/waterscience/criteria/wqcriteria.html>

FR. 1984. Secondary Treatment Effluent Limits, 49 Federal Register 37006 (September 20, 1984), p 582.

MARPOL 1973/ 78. " International convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978.

2. FW CCC: freshwater chronic

SW CCC: salt water chronic

SW CMC: salt water acute

HH W + O: human health for the consumption of water + organism

Figure Legends:

Figure 1. Mean concentrations of metal analytes from A. fish hold effluent and B. fish hold cleaning effluent samples compared to benchmark concentrations determined as the National Recommended Water Quality Criteria (NRWQC), when available.

Concentrations on the y-axis are on a log-scale. Error bars illustrate standard error, and n = number of samples/number of samples with the dissolved metal analyte detected/number of samples with the total metal analyte detected.

Figure 2. Mean concentrations of wet chemistry parameters from fish hold effluent and fish hold cleaning effluent samples compared to benchmark concentrations determined as the National Recommended Water Quality Criteria (NRWQC), when available.

Concentrations on the y-axis are on a log-scale. Error bars illustrate standard error, and n = number of fish hold effluent samples/number of fish hold samples with detectable concentrations/ number of fish hold cleaning effluent samples/ number of fish hold cleaning samples with detectable concentrations.

Figure 3. Mean concentrations of nutrient analytes from fish hold effluent and fish hold cleaning effluent samples compared to benchmark concentrations determined as the National Recommended Water Quality Criteria (NRWQC), when available.

Concentrations on the y-axis are on a log-scale. Error bars illustrate standard error, and n = number of fish hold effluent samples/number of fish hold samples with detectable concentrations/ number of fish hold cleaning effluent samples/ number of fish hold cleaning samples with detectable concentrations.

Figure 4. Mean concentrations of nonylphenol and octylphenol analytes from fish hold cleaning effluent samples. Concentrations on the y-axis are on a log-scale. Error bars

illustrate standard error, and n = number of fish hold cleaning effluent samples/ number
of fish hold cleaning samples with detectable concentrations.

Figures:

Figure 1:

Figure 2:

Figure 3:

Figure 4: