Naval Facilities Engineering Systems Command Pacific

Final

Literature Review:

Impacts of Military Testing and Training on Reef Fish Contaminant Bioaccumulation, Human, and Ecological Impacts in the Mariana Islands

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LIST OF ACRONYMS AND ABBREVIATIONS

°C	Degrees Celsius
µg/L	Microgram(s) per liter
%	Percent
ADNT	Aminodinitrotoluene
atm	Atmospheric
ATSDR	Agency for Toxic Substances and Disease Registry
BCF	Bioconcentration factor
BAF	Bioaccumulation factor
BDL	Below detection limit
BTAG	Biological technical assistance guide
BW	Body weight
C	Media specific concentration
CAS	Chemical Abstracts Service
CR	Cancer risk
CNMI	Commonwealth of the Northern Mariana Islands
CSF	Cancer slope factor
D	Exposure dose
DANT	Diaminonitrotoluene
DMM	Discarded military munitions
DNA	Dinitroaniline
DNB	Dinitrobenzene
DNT	Dinitrotoluene
DPA	Diphenylamine
ED	Exposure duration
EIS	Environmental impact statement
EPA	U.S. Environmental Protection Agency
FDM	Farallon de Medinilla
g/g	grams per gram
HCE	Hexachloroethane
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
HQ	Hazard quotient
HUMMA	Hawaii Underseas Military Munitions Assessment
ID	Identification
IR	Ingestion rate
IRIS	Integrated risk information system

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

IUPAC	International union of pure and applied chemistry
kg	Kilogram(s)
kg/d	Kilogram(s) per day
kg/L	Kilogram(s) per liter
lb	Pound(s)
LCL	Lower confidence limit
LY	Lifetime in years
m^3	Cubic meter
MC	Munition constituents
mg/L	Milligram(s) per liter
mg/kg	Milligram(s) per kilogram
MITT	Mariana islands testing and training
mol	Mole
Navy	U.S. Department of the Navy
ND	No data
ng/g	Nanogram(s) per gram
ng/L	Nanogram(s) per liter
NOAA	National Oceanic and Atmospheric Administration
NOEC	No observed effect concentration
NT	Nitrotoluene
OEIS	Overseas Environmental Impact Statement
PCB	Polychlorinated biphenyl
POCIS	Polar organic chemical integrative samplers
RDX	Royal demolition explosive
RfD	Reference dose
ROD	Record of Decision
SEIS	Supplemental Environmental Impact Statement
SQB	Sediment quality benchmarks
TNB	Trinitrobenzene
TNT	Trinitrotoluene
UCL	Upper confidence limit
UNDET	Underwater detonation
UXO	Unexploded ordnance

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EXECUTIVE SUMMARY

The U.S. Department of the Navy (Navy) has proposed conducting military readiness activities which include training activities (referred to as "training"), research, development, testing, and evaluation (referred to as "testing") activities in the Mariana Islands Training and Testing (MITT) Study Area, primarily within the existing Mariana Islands Range Complex. A Supplemental Environmental Impact Statement (SEIS)/Overseas Environmental Impact Statement (OEIS) was prepared by the Navy in June 2020 (Navy 2020a) to assess potential environmental impacts associated with the proposed training and testing activities that will be conducted at-sea and on Farallon de Medinilla (FDM). The SEIS/OEIS was prepared to update the Navy's assessment of the potential environmental impacts associated with proposed training and testing analyzed in the *Final Mariana Islands Training and Testing Activities Environmental Impact Statement/Overseas Environmental Impact Statement* (Navy 2015).

The Navy issued a Record of Decision (Navy 2020b) that detailed the Navy's preferred alternative. The Record of Decision details comments received on the MITT Final SEIS/OEIS. Comments addressed concerns associated with increased toxicity in the marine environment from military activities and asked for the consideration of recent scientific studies. Additionally, the comment requested additional quantitative study of the impact of activities on the food supply and fish consumption pathway for the people of the Marianas. As part of the response to this concern, the Navy stated, "the Navy will perform a supplemental literature review of reef fish bioaccumulation pathway and nearshore sediment and water quality to further assess potential pathways" (Navy 2020b).

EA Engineering, Science, and Technology, Inc., PBC was tasked by the Navy to perform this supplemental literature review of the impacts of military activities on reef fish bioaccumulation, sediments, water quality, and human health. Across all keyword searches (described in Section 1.3) and five databases, a total of 1,638 articles were reviewed for potential inclusion. Though explosives such as 2,4,6-trinitrotoluene (TNT) and royal demolition explosive (RDX) were the primary focus, other military byproducts (non-explosives) including metals were considered. The available literature focusing on the bioaccumulation of explosives in fish was summarized, as well as studies documenting the presence of explosives in sediment and water in the natural environment.

Overall, review of 14 controlled laboratory studies of fish explosive uptake demonstrated the low bioaccumulation potential of two of the major explosive compounds, TNT and RDX, with geometric mean bioconcentration factors values of 3.1 and 2.38 liters per kilogram (L/kg), respectively. Similarly, studies demonstrated low potential for trophic transfer of munitions compounds (MCs) and that the contribution of sediment exposures are negligible in terms of the overall exposure pathway. Studies documenting explosive presence in the natural environment are dominated by areas impacted by discarded military munitions, with most studies finding explosives in sediment, water, and biota in the low parts per billion range. Recent studies simulating the release of explosives from unexploded ordnance under realistic low-order detonation scenarios were highlighted for their potential application in risk assessments of military activities.

For the non-explosive byproducts of testing activities, the available literature from areas containing discarded military munitions were summarized, with metal contamination the most well studied, and significant data gaps present for other contaminants such as hydrogen cyanide and perchlorate.

To provide a generic assessment of risk associated with military activities, the available data for explosive presence in sediment and water were compared to various ecological benchmarks. Human health risks were assessed based on predicted fish bioaccumulation and assumed consumption rates based on data from the Mariana Islands. Overall, few exceedances of ecological benchmarks were observed based on the published data for explosive presence in sediment and water, with only a single study having explosive concentrations in the water column exceeding threshold levels. Similarly, a generic human health assessment based on two individual exposure scenarios and two different consumption levels found non-cancer hazards and carcinogenic risks were within acceptable levels.

Overall, the literature review did not find evidence for significant impacts of military testing and training activities on ecological and human health

1. INTRODUCTION

The U.S. Department of the Navy (Navy) has proposed conducting military readiness activities which include training activities (referred to as “training”), and research, development, testing, and evaluation (referred to as “testing”) activities in the Mariana Islands Training and Testing (MITT) Study Area, primarily within the existing Mariana Islands Range Complex. A Supplemental Environmental Impact Statement (SEIS)/Overseas Environmental Impact Statement (OEIS) was prepared by the Navy in June 2020 (Navy 2020a) to assess potential environmental impacts associated with the proposed training and testing activities that will be conducted at-sea and on Farallon de Medinilla (FDM). The SEIS/OEIS was prepared to update the Navy’s assessment of the potential environmental impacts associated with proposed training and testing within these areas that was analyzed in the *Final Mariana Islands Training and Testing Activities Environmental Impact Statement/Overseas Environmental Impact Statement* (Navy 2015).

The Navy issued a Record of Decision (ROD) (Navy 2020b) that detailed the Navy’s preferred alternative and presents comments received on the MITT Final SEIS/OEIS. Comments addressed concerns associated with increased toxicity in the marine environment from military activities and asked for the consideration of recent scientific studies. Additionally, comments requested additional quantitative study of the impact of activities on the food supply and fish consumption pathway for the people of the Marianas. As part of the response to this concern, the Navy stated, “the Navy will perform a supplemental literature review of reef fish bioaccumulation pathway and nearshore sediment and water quality to further assess potential pathways” (Navy 2020b). EA Engineering, Science, and Technology, Inc., PBC (EA) was tasked by the Navy to perform this supplemental literature review of the impacts of military activities on reef fish bioaccumulation, sediments, water quality, and human health.

1.1 BACKGROUND

The MITT Study Area (Figure 1-1) has been used by the Navy for military readiness activities for decades. Activities routinely conducted in the MITT Study Area include weapons testing and defensive countermeasures, with the specific activities conducted evolving with technological advances and changing threat assessments. To maintain compliance with the National Environmental Policy Act, the Navy prepared environmental impact statements (EIS) in 2010, 2015, and 2020 to assess potential environmental impacts associated with proposed activities. The EIS/OEIS in 2010 and 2015 included assessment of potential impacts on sediment, water and air quality, marine wildlife, and socioeconomic resources (Navy 2010a, 2015). The 2020 SEIS/OEIS documents evaluated the at sea and FDM-based activities only, with the land-based activities remaining consistent with those described in the 2015 document (Navy 2020a). New literature, changes to the planned activities, and their subsequent environmental impacts were considered in the SEIS/OEIS. Under the 2020 SEIS/OEIS, three alternatives were provided:

- The No Action Alternative represents no military readiness activities at sea or on FDM associated with the Proposed Action within the Study Area. Other military activities not associated with this Proposed Action would continue to occur.

- Alternative 1 consists of an adjustment from the level of training and testing activities analyzed in the 2015 MITT Final EIS/OEIS, accounting for changes in the types and tempo (increases or decreases) of activities necessary to meet current and future military readiness requirements beyond 2020.
- Alternative 2 (Preferred Alternative) includes the same type of training and testing activities that would occur under Alternative 1 and had been analyzed in the 2015 MITT FEIS/OEIS. Alternative 2 also considers an increase in tempo of some training and testing activities, including additional Fleet exercises and associated unit-level activities, should unanticipated emergent world events require increased readiness levels.

The ROD concluded that the Navy's preferred alternative, Alternative 2, would incur negligible impacts on water, sediment, and air quality, as well as socioeconomic and environmental justice outcomes (Navy 2020b), with the appropriate standard operation procedures and mitigation measures.

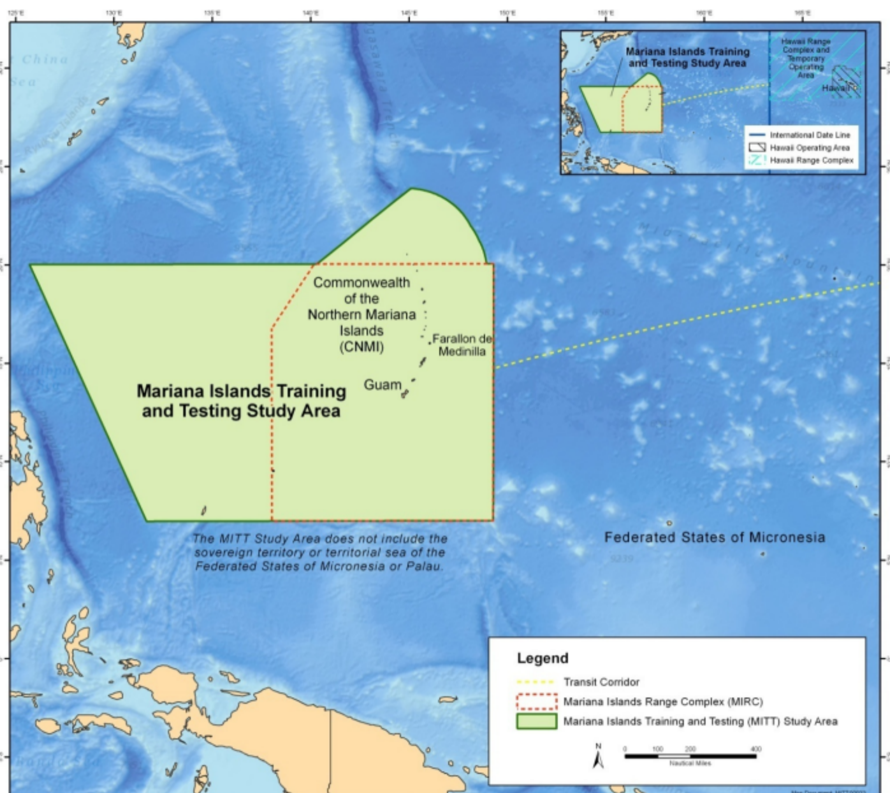

Figure 1-1. Map of the Mariana Islands Training and Testing (MITT) Study Area from the 2015 MITT EIS/OEIS.

EA completed this supplementary literature review to provide a third-party review of the Navy's methods and conclusions of impacts on sediments, water quality, and human health as a result of implementation of Alternative 2. The review focused on bioaccumulation of contaminants released during military testing and training and potential impacts on sediment, water quality, ecological, and human health. Specific objectives for the literature review are listed below in Section 1.2.

1.2 OBJECTIVES

- Perform a literature review of reef fish bioaccumulation, sediment, and water quality impacts of military testing and training activities.

- Determine whether the available literature supports the SEIS/OEIS conclusions of negligible impacts from munitions constituents on human health and the environment.

1.3 METHODOLOGY

Literature searches were conducted in July 2023 using the following databases: Google Scholar, Scopus, Defense Technology Information Center, U.S. Department of Energy's Office of Science and Technological Information database, and MetaLib. These databases were selected to provide adequate coverage of the existing academic literature as well as grey literature such as government reports, white papers, and environmental impact assessments. Searches were conducted using keywords for individual contaminant groups associated with military training and testing, such as explosives, metals, propellants, explosive byproducts, and other materials (i.e., chaff and plastic debris). Extracted studies were investigated for relevance based on the abstract and/or the main text. Only studies meeting the following inclusion criteria were retained:

- Written in the English language.
- Contains measured concentrations of explosives/non-explosive constituents in target matrix such as water, sediment, or tissue (i.e., no nominal concentrations for lab studies)
- Peer-reviewed research article or literature review, federal/institution report, reviewed risk assessment, or book chapter.

Studies were excluded based on the following criteria:

- Studied only other military associated contaminants such as chemical warfare agents or insensitive munitions (i.e., munitions designed to fulfil performance and operational requirements but withstand stimuli representative of severe accidents).
- Terrestrial study only (i.e., soil)

Since many studies focused on munitions dumped following World War II, no restrictions were placed on the publication date of extracted literature. For searches relating to explosive fate, transport, occurrence, and uptake in fish (keywords including "military" "testing" "explosives" "fish" "water column" "marine" "sediment"), a total of 1,638 studies were reviewed across all five databases, of which 81 were deemed to be relevant. For non-explosive compound searches (keywords including: "perchlorate" "fish" "metals" "military" "testing" "hydrogen" "cyanide"), a total of 859 studies were reviewed, of which 12 were deemed to be relevant. For other materials associated with testing activities (keywords including: "chaff" "military" "testing" "marine" "fish" "vessel" "sinking" "PCB" "marine" "debris") a total of 782 studies were reviewed, of which 8 were found to be relevant. In addition, cited literature within relevant studies was assessed for potential inclusion. Sections 2 and 3 present the results of the literature reviews for explosives and non-explosive compounds, respectively.

To provide a quantitative evaluation of ecological risk concerns associated with potential explosive exposure, the available literature providing concentration of explosives in sediment and water was compared to available ecological benchmarks following the *Review and Synthesis Regarding Environmental Risks Posed by Munitions Constituents (MCs) in Aquatic Systems* (Lotufo et al. 2017). This review represents the only published comparison of explosive concentrations in the natural environment to ecological benchmarks; thus, the same methodology was adopted for this risk evaluation. Since no data is available from the MITT area, this risk evaluation does not represent a detailed, site-specific ecological risk assessment; rather, this generic risk evaluation aimed to predict the potential for effects based on data from other studies. Only explosives that had proposed marine or combined water quality criteria were used for the analysis (i.e., compounds with freshwater benchmarks only were not included). Section 4 presents the ecological assessment.

A quantitative assessment of potential human health risks was completed using risk assessment methodology set forth by the U.S. Environmental Protection Agency (EPA) and Commonwealth of the Northern Mariana Islands Division of Environmental Quality (CNMI DEQ). Similar to the ecological assessment, no site-specific data of contamination in the MITT area is available; thus, the human health assessment is intended to provide a generic estimation of the potential for risk based on studies conducted in other areas. The human health assessment is provided in Section 5.

2. LITERATURE REVIEW: EXPLOSIVE COMPOUNDS

Proposed MITT Study Area training activities described in the 2015 EIS/OEIS and 2020 SEIS/OEIS documents involve the use of bombs, projectiles, and rockets at or just beneath the water surface, as well as mine countermeasure activities involving underwater detonation (UNDET). Ordnance used in military testing and training activities typically consume 98-99 percent (%) of the explosive materials when undergoing detonation (high-order or complete detonation), with the remainder released as discrete particles. Comparatively, incomplete, or low-order detonations consume a smaller proportion of a given explosive and release larger amounts of explosive compounds to the environment. Finally, if explosives fail to detonate, explosives may be released to the environment slowly over time as munition casing corrode. Failure rates for various ordnance used in the MITT Study Area range from 1.78 – 8.23%, with low-order detonations occurring at a rate of 0.09 – 0.16% (MacDonald & Mendez 2005; Walsh 2007). Thus, proposed training activities have the potential to introduce explosives into the environment primarily due to low-order or failed detonations. The proceeding section will focus on the presence of explosives in the marine environment, with an emphasis on additional literature not included in the 2015 EIS/OEIS and 2020 SEIS/OEIS documents.

2.1 FATE AND CHARACTERISTICS OF EXPLOSIVE COMPOUNDS

General characteristics of three of the major explosives, including physiochemical parameters, are shown in Table 2-1. Overall, 2,4,6-trinitrotoluene (TNT), 1,3,5-trinitro-1,3,5-triazinane (RDX), and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) exhibit low volatility (Henry's Law constants ranging from 1.1 – 45.7 x 10^{-8}, 0.019 – 63 x 10^{-9}, and 2.6 x 10^{-15} for TNT, RDX, and HMX, respectively, Table 2-1) and hydrophobicity. As shown in Table 2-1, the octanol-water partitioning coefficient (Log K_{ow}) values are 1.6, 0.9, and 0.17 for TNT, RDX, and HMX, respectively, indicating hydrophilicity, and that these compounds are unlikely to sorb strongly to particulates (Beck et al. 2018). Dissolution of explosives from unexploded ordnance (UXO) is dependent on environmental factors including temperature, hydrodynamics, and ionic strength/salinity (Beck et al. 2018; Maser et al. 2020). Both solubility and dissolution rates of explosives increase with temperature, with explosives shown to be moderately less soluble in seawater compared to freshwater (Luning Prak & O'Sullivan 2007). A range of studies have been conducted in the laboratory and mesocosms to simulate the fate and behavior of explosives in temperate coastal marine habitats (Ariyarathna et al. 2019, 2020; Ballentine et al. 2016; Smith et al. 2015). Previous studies have shown that the presence of sediments and sediment type have a major influence of explosive kinetics in the environment, with fine-grained sediment more effective than coarse-grained sediment in removing explosives from the water column (Smith et al. 2013).

Generally, TNT biodegradation in marine systems occurs more rapidly as compared to RDX in the presence of sediments, with TNT degradation likely controlled by sorption and surface-mediated bacterial transformation, and RDX controlled by diffusion into anoxic sediment regions and anaerobic bacterial mineralization (Smith et al. 2013). For shallow coastal marine systems, the primary fate of TNT appears to be transformation into organic derivatives which may be relatively persistent in the environment, with complete mineralization to ammonium ions (NH_4^+) a minor route of TNT processing (Smith et al. 2015). Comparatively, mineralization to dissolved inorganic nitrogen products was the dominant fate for RDX in the presence of high organic sediments, with nitrogen gas and nitrous oxide some of the primary mineralization products (Tobias 2019). Due to the rapid biotransformation of TNT in marine environments, TNT biotransformation products such as 2- and 4-aminodinitrotoluene (2-ADNT and 4-ADNT) may be found at higher concentrations in biota compared to the parent compound (Lotufo et al. 2016). Toxicokinetic studies have demonstrated that TNT is rapidly biotransformed in aquatic biota, though non-extractable biotransformation byproducts that are likely persistent have been tentatively identified (Lotufo et al. 2016). Studies have shown slower elimination for the cyclonitramines RDX and HMX in aquatic biota, but overall low bioaccumulation potential (Belden et al. 2005a; Lotufo & Lydy 2005).

Table 2-1. General Physiochemical Parameters for Three Major Explosives: TNT, RDX, and HMX

	TNT	RDX	HMX
CAS Number	118-96-7	121-82-4	2691-41-0
Chemical Formula/IUPAC ID	C_7H_5N3O6 2,4,6-Trinitrotoluene	$C_3H_6N_6O_6$ 1,3,5-Trinitroperhydro-1,3,5-triazine	$C_4H_8N_8O_8$ 1,3,5,7-tetranitro-1,3,5,7-tetrazocane
Molecular Weight (g mol^{-1})	227.13	222.26	296.16
Octanol-Water Partitioning Coefficient (Log $K_{OW)}$	1.6	0.9	0.17
Specific Gravity	1.5-1.6	1.82	1.96
Melting Point (°C)	80-82	204-205	276-286
Henry's Law Constant (atm m^3 mol^{-1})	1.1- 45.7 × 10^{-8}	0.0196-63 × 10^{-9} 2.6 × 10^{-15}	2.6 × 10^{-15}
Solubility in Water (mg/L)	130 (at 20°C)	42 (at 20°C)	5 (at 25°C)

Notes:
Adapted from Beck et al. 2018.
atm m^3 mol^{-1} = atmospheric cubic meter per mole
°C = Degrees Celsius
CAS = Chemical Abstracts Service
ID = Identification
IUPAC = International Union of Pure and Applied Chemistry
mg/L = Milligram(s) per liter

As highlighted above, temperature has been shown to have a significant impact on the fate of explosives in marine systems. For example, the half-life of TNT in microcosms containing fine sediment with high organic carbon at 7 °C was 129 days, compared with 0.77 days for similar sediment types at 25 °C (Chappell et al. 2011; Harrison and Vane 2010). Similarly, temperature is known to influence the dissolution of explosives from solid fragments, with dissolution rates increasing fourfold from 10 °C to 30 °C (Beck et al. 2018). Average monthly water temperatures in Apra Harbor, Guam, range from 26.2 °C to 29.3 °C (National Oceanic and Atmospheric Administration [NOAA] 2023); thus, conditions present in the MITT are likely to facilitate rapid dissolution and biodegradation of explosives such as TNT. The majority of studies focusing on TNT and RDX fate and transport used mesocosms designed to replicate shallow temperature coastal systems (Ariyarathna et al. 2017, 2019, 2020; Smith et al. 2015). Given that the MITT study area is a tropical system and the use of ordnance ranges in depth from nearshore to deeper offshore areas, the application of these mesocosm studies to explosive fate and transport in the MITT is unclear.

2.2 PRESENCE OF EXPLOSIVES IN SEDIMENT AND WATER

Following a systematic literature review, the majority of studies documenting the presence and fate of explosives in the marine environment are focused on munitions dumpsites from World War II (Beck et al. 2022; Briggs et al. 2016; Den Otter et al. 2023; Edwards et al. 2016; Koske et al. 2020; Maser et al. 2023; University of Hawaii at Manoa, 2014a, 2014b), including the Hawaii Undersea Military Munitions Assessment (HUMMA) (Edwards et al. 2016) and a number of studies conducted in the Baltic Sea (Beck et al. 2022; Bełdowski et al. 2019; Gledhill et al. 2019; Kammann et al. 2021; Koske et al. 2020). A total of eight studies reporting concentrations of explosives in sediment and/or water were found (Table 2-2). To contextualize concentrations of explosives with the potential for adverse effects, the available ecological benchmarks for explosives in sediment and water are given in Section 4 below.

The HUMMA study focused on a munitions disposal site located south of Pearl Harbor, Oahu, Hawaii, where approximately 16,000 bombs were disposed of in 1944 (Briggs et al. 2016). In terms of sediments collected in the vicinity of dumped munitions within the HUMMA study, explosives were not recorded above detection limits in 2009 sampling, with 2/121 sediment samples in 2012 sampling having detectable concentrations of the TNT degrade, 4-nitrotoluene (4-NT, Briggs et al. 2016). Detectable sediment concentrations of explosives were only recorded within 0.5 meters of munitions casing. However, it is important to consider that analytical and methodological advancements have facilitated lower detection limits for the analysis of explosives in sediments (i.e., < 1 microgram per kilogram [µg/kg]; Den Otter et al. 2023), thus reanalysis of certain discarded military munitions (DMM) sites may yield detections.

For the Baltic Sea studies, explosives were detected in seawater from sites located close to World War II UXO and exposed munitions, with concentrations of TNT and 1,3-dinitrobenzene (DNB) ranging from 1-5 nanograms per liter (ng/L), and trace levels (< 1 ng/L) of other compounds including RDX and TNT degradates (Gledhill et al. 2019). Similarly, a recent study of UXO and World War II ammunition dumpsites in the Netherlands by Den Otter et al. (2023) found concentrations of TNT ranging from below detection limits (BDL) to 56.7 ng/L, and significantly lower concentrations of TNT degradates (range: BDL – 13.0 ng/L for 2-amino-4,6-dinitrotoluene [2-ADNT]). For sediments collected within the same study, TNT was recorded above detection limits infrequently (2 out of 11 sites analyzed), with a maximum concentration of 1.2 nanograms per gram (ng/g) dry weight (equivalent to 0.0012 mg/kg) recorded (Den Otter et al. 2023). Detected concentrations in this study were orders of magnitude below available ecological benchmarks for both water and sediment (Section 4.1).

Several studies have considered the presence of explosives in sediment and water at the former Navy testing and training area in Vieques, Puerto Rico where broadly similar activities to the MITT Study Area have been performed (Pait et al. 2010; Porter et al. 2011; Rosen et al. 2022). Porter et al. (2011) measured concentrations of explosives in water and sediment at varying distances from a 2,000-pound (lb) (907 kg) general purpose bomb at a former Navy bombing range in Bahia Salina del Sur. The authors found aqueous concentrations ranging from 4,120 to

85,700 micrograms per liter (µg/L) for a suite of explosives within the solution cavity of the bomb, but a dramatic decrease with increasing distance, with concentrations ranging from 3.3 – 107 µg/L at 0.10 meters from the bomb (Porter et al. 2011). Similarly, sediment samples taken from the same locations indicated a range of 5.39 – 19,333 mg/kg for explosives at the breach of the bomb, but orders of magnitude lower concentrations at 0.10 meters away (0.404 mg/kg for TNT) (Porter et al. 2011). Conversely, a study of 78 sediment samples taken from around Vieques recorded no detections of a suite of 14 explosives (Pait et al. 2010). Similarly, Rosen et al. (2022) found no detections of any explosive compounds in sediment collected from the former Navy bombing range at Vieques. In an ecological and human risk assessment of a Hawaiian coral reef ecosystem impacted by UXO (Ordnance Reef, Oahu, Hawaii), a suite of 19 explosives were not recorded in seawater above the reporting limit (reporting limit range: 0.1 – 1.4 µg/L). Similarly, only 3 explosives were detected in sediment above reporting limits: 2,4-dinitrotoluene (DNT) (range: 0.03 – 3.3 mg/kg), 2,6-DNT (range: 0.09 – 0.380 mg/kg), and trinitrobenzene (TNB) (0.022 – 0.025 mg/kg). Further studies documenting the presence and potential risk of explosives in the environment are described in Lotufo et al. (2017). Excluding the Ordnance Reef study where some UXO was removed and a follow-up study conducted, remedial actions have not been conducted at any of the aforementioned sites to the author's knowledge.

Other studies have focused on simulating the release of explosives following realistic exposure scenarios, such as low-order detonations from testing activities. Rosen & Lotufo (2010) simulated the release and potential accumulation of residual explosive compounds from low-order detonations of a commonly used military explosive, composition B, in aquaria containing sediments and several marine species including polychaete worms, amphipods, mussels, and fish. Composition B is used in ordnance including torpedoes, demolition charges, and large bombs, comprising a mixture of 60% RDX, 40% TNT, and sometimes a wax desensitizer (Hobbs 2012). Several exposure scenarios were considered, including a worst case simulation in which composition B fragments were directly exposed under static conditions (i.e., not buried in sediment and no recirculating flow), and more realistic scenarios wherein explosives were partially buried in sandy sediments with flowing water (Rosen & Lotufo 2010). For the worst-case scenario experiments, aqueous concentrations of sum TNT and degradates exceeded 400 µg/L over the 35-day experiment, with RDX concentrations peaking at approximately 1.2 mg/L. However, addition of flow and partial burial of explosive fragments reduced the overlying water concentrations of sum TNT and RDX to below the reporting limit (Rosen & Lotufo 2010). Survival of all test species was not significantly reduced relative to controls across all species in the worst-case scenario simulation, with the only effect observed for mussel embryonic-larval development which was likely due to overlying water concentrations of TNT approaching the EC50 value of 0.75 mg/L (Rosen & Lotufo 2007, 2010).

Recent studies have adopted a passive sampling approach to determine the release of explosives under realistic exposure scenarios (Belden et al. 2015; Lotufo et al. 2019; Rosen et al. 2018, 2022). Passive samplers such as polar organic chemical integrative samplers (POCIS) sample chemicals in the dissolved phase, therefore better representing bioavailable contaminants compared to traditional grab sampling. Therefore, studies utilizing passive samplers may provide a better understanding of the time-weighted average concentrations of explosives bioavailable to aquatic biota compared with traditional exhaustive extractions (Lotufo et al. 2018). Lotufo et al.

(2019) simulated a low-order detonation of a commonly used military explosive (composition B) in a laboratory recirculating flume using POCIS passive samplers, finding maximum concentrations of 12.5 and 17.8 µg/L for TNT and RDX, respectively. In a second experiment simulating leaching of explosives through a small ordnance breach, concentrations of 1.27 and 1.40 µg/L were recorded for TNT and RDX, respectively. In a similar study conducted in an embayment of the Santa Rosa Sound (Pensacola, Florida), concentrations of TNT and RDX at 0.3 meters from a breached composition B fragment ranged from 9 to 103 ng/L, respectively (Rosen et al. 2018). Finally, POCIS passive samplers were deployed at the former Navy bombing range at Vieques, Puerto Rico, with concentrations of RDX ranging from 5 – 13 ng/L, and TNT concentrations BDL at all sites excluding the vicinity of a general purpose bomb, wherein concentrations of 5.3 µg/L were recorded (Rosen et al. 2022). For the Vieques studies, Navy testing and training operations were conducted from 1941 – 2003, with the Rosen et al. (2022) study conducted in 2016; thus, concentrations may have reduced over time with dilution.

Table 2-2. Summary of Studies Documenting the Presence of Explosives in Sediment and Water at Various Sites

Study	Study Location	Source of Munitions	Compound	Sediment Concentration (mg/kg)	Water Concentration (ng/L)
Briggs et al. 2016	Pearl Harbor, HI, USA	World War II Dumpsite	4-NT	0.09 – 0.12	ND
Gledhill et al. 2019	Kolberger Heide, Baltic Sea	World War II Dumpsite	RDX	ND	BDL – 1.9
			TNB		BDL – 0.27
			1,3-DNB		BDL – 9.46
			TNT		0.01 - 10.6
			Dinitroaniline (DNA)		0.0001 – 0.0049
			4-ADNT		0.001 – 0.459
			2-ADNT		0.001 – 0.114
Beck et al. 2019[1]	Kolberger Heide, Baltic Sea	World War II Dumpsite	TNT	ND	50
			1,3-DNB		10
			RDX		10
Den Otter et al. 2023	Eastern Scheldt Estuary, Netherlands	World War II Dumpsite	TNT	BDL – 0.0012	BDL – 56.7
			2,4-DNT	BDL – 0.0019	BDL – 9.0
			2-ADNT	BDL – 0.0008	BDL – 13.0
			4-ADNT	BDL – 0.0014	BDL – 11.2
			1,3-DNB	BDL	BDL – 7.8
			DPA	BDL – 0.0069	BDL – 15
			HCE	BDL – 0.7 x 10^{-6}	BDL – 24 x 10^{-3}
Maser et al. 2023	North Sea	World War II Warship Wreck	TNT	BDL – 12.6 x 10^{-7}	6.3*
			2,4-DNT	BDL	BDL
			4-ADNT	BDL – 5 x 10^{-7}	1.0*
			2-ADNT	BDL – 5 x 10^{-7}	1.3*
			1,3-DNB	BDL	0.7*
Porter et al. 2011[2]	Vieques, Puerto Rico	Former Navy Training Area	TNT	19,333	85.7 x 10^{6}
			1,3,5-TNB	30.7	11.5 x 10^{6}
			1,3-DNB	3.47	18.5 x 10^{6}
			4-NT	5.39	BDL
			2-NT	BDL	40.5 x 10^{6}
			RDX	5.32	4.12 x 10^{6}
Rosen et al. 2022	Vieques, Puerto Rico	Former Navy Training Area	TNT	BDL	BDL – 5,304
			2,6-DNT		BDL
			2-ADNT		BDL – 54
			4-ADNT		BDL – 103
			1,3-DNB		BDL
			1,3,5-TNB		BDL
			2,4-DNT		BDL – 46
			RDX		BDL – 13
University of Hawaii 2014a	Ordnance Reef, Hawaii	Munitions Dumpsite	19 Energetic Suite	BDL excluding below compounds	BDL
			2,6-DNT	0.098 – 0.380	BDL
			2,4-DNT	0.03 – 3.3	BDL
			TNB	0.022 – 0.025	BDL

Notes:
Adapted from Lotufo et al. 2017.
*Indicates average concentration

[1]Samples taken 1 – 5 centimeters away from the surface of a munition fragment. Higher concentrations observed at bomb surface.
[2]Sample taken directly from solution cavity of bomb. Lower concentrations were found at distances of 0.1 and 1 meter.
mg/kg = milligrams per kilogram
ng/L = nanograms per liter
BDL = Below detection limit
DPA = Diphenylamine
DNA = 3,5-Dinitroanaline
HCE = Hexachloroethane
ND = No data

2.3 BIOACCUMULATION OF EXPLOSIVES IN FISH

2.3.1 Laboratory Studies

As highlighted above in Section 2.1, military testing and training activities have the potential to release explosive compounds into the aquatic environment, primarily following low-order and detonation failures. Explosives may be bioavailable and accumulate in resident fish species, leading to concern for ecological and human health. Following a systematic literature review, a total of 13 studies were found documenting the bioaccumulation of explosives in fish. A summary table of the bioconcentration factors (BCFs) for individual compounds in laboratory studies is shown in Table 2-3. Overall, all compounds assessed had low bioaccumulation potential, with ranges of 0.34–9.7 L/kg for TNT, 0.7–68.7 L/kg for RDX, 0.04–52 L/kg for 2-ADNT, 0.08 – 134 L/kg for 4-ADNT, and 0.1–0.5 L/kg for HMX (Table 2-3). Chemicals with BCF values < 1000 L/kg are considered non-bioaccumulative (Gobas et al. 2009; EPA 1998) with < 2000 L/kg used by the European Chemicals Agency (Petoumenou et al. 2015). Though all BCFs in the literature were well below this threshold, the range of values (i.e., BCF values of 0.08–134 for 4-ADNT) likely reflects the use of different study designs, species, and age classes. For example, using radiotracers such as ^{14}C labelled compounds for bioconcentration studies is known to influence BCF values (Ballentine et al. 2015), as well as fish age class (Geyer et al. 2000). The geometric mean BCF values for TNT, 2-ADNT, 4-ADNT, and RDX based on the studies shown in Table 2-3 are 3.1, 3.37, 2.28, and 2.38 L/kg, respectively. Studies using sum TNT measures (i.e., sum of TNT and degradates) were not included within these calculations. A single study calculated BCFs for field-collected mixed marine species from a munitions dumpsite in the Baltic Sea (Beck et al. 2022), with higher values of 79, 105, 130, 9.4, and 17 L/Kg for TNT, ADNT, Diaminonitrotoluene (DANT), RDX, and DNB, respectively. However, this calculation utilized estimated dissolved concentrations of explosives and tissue residues for multiple species collected in the field (i.e., plankton, macroalgae, anemones, fish); thus, these values should be interpreted as estimates.

A single study considered the bioaccumulation and toxicity of TNT in fish exposed through the sediment exposure pathway (Lotufo et al. 2010). The authors exposed sheepshead minnows, *Cyprinodon variegatus*, and freckled blennies, *Hypsoblennius ionthas,* to ^{14}C-labeled TNT-spiked sandy sediment under different exposure scenarios, including direct contact with sediment, and using a mesh to prevent fish from accessing the sediment. Overall, the authors found that bioconcentration of TNT and its degradation products occurred almost entirely from the overlying water, and that contact with sediment surface did not increase summed TNT tissue residues (Lotufo et al. 2010). The authors concluded that direct contact with bed or resuspended sediments are unlikely to be significant exposure pathways for demersal fish species (Lotufo et al. 2010). Several studies have focused on bioaccumulation of explosives in individual fish tissues (Lotufo 2011; Mariussen et al. 2018; Ownby et al. 2005; Yoo et al. 2006). Lotufo (2011) studied tissue-specific accumulation of TNT and RDX in sheepshead minnows finding that bioconcentration of TNT was higher in the viscera relative to other body parts, whereas TNT degradates were primarily accumulated in the liver. Similarly, BCF values of RDX were higher in *C. variegatus* viscera relative to other organs (liver and gill), with the Beck et al. (2022) study in the Baltic Sea (Beck et al. 2022) also finding higher levels of TNT degradates in fish viscera relative to muscle. Additionally, several studies focused on the bioaccumulation of explosives through trophic transfer and dietary pathways (Belden et al. 2005b; Houston & Lotufo 2005; Lotufo & Blackburn 2010). The trophic transfer potential was assessed either via feeding of spiked pellet food (Belden et al. 2005b) or with explosive-exposed invertebrate prey items (Houston & Lotufo 2005; Lotufo & Blackburn 2010). The range of bioaccumulation factors (BAFs) calculated in these studies was 0.0004 – 0.09 grams per gram (g/g) for TNT, and 0.010 g/g for RDX (single study only, Houston & Lotufo 2005). These findings suggest that the dietary exposure route is likely to be negligible for explosives in fish.

2.3.2 Field Studies

The majority of studies assessing explosive residues in wild-caught fish are from underwater munitions dumpsites (Beck et al. 2022; Gledhill et al. 2019; Koske et al. 2020; Maser et al. 2023). Maser et al. (2023) studied the presence of explosives in filet and bile of pouting (*Trisopterus luscus*), a sedentary species known to occupy wrecks, collected from a North Sea warship wreck that housed munitions and explosives. Low concentrations of explosives were found, with concentrations of 1,3-DNB, 2,4-DNT, 2-ADNT, and 4-ADNT < 5 ng/g dry weight, and a maximum concentration of 13 ng/g dry weight for TNT (Maser et al. 2023). Koske et al. (2020) recorded explosives in the bile of 48% of Dab, *Limanda limanda*, from a munitions dumpsite in the Baltic Sea, though levels in muscle or filets were not reported. Porter et al. (2011) studied accumulation of several explosives in dusky damselfish, *Stegastes adustus*, collected from the former Navy bombing range in Vieques, Puerto Rico, finding 1,3,5-TNB concentrations of 4.6 mg/kg (equivalent to 4600 ng/g), though no other compounds (1,3-DNB, TNT, RDX, 2,4-DNT, 2-Nitrotoluene (2-NT, 4-NT) were detected within this sample. However, it is important to consider that this fish sample was collected directly from the cavity of a large bomb (Porter et al. 2011) and only a single composite sample appears to have been analyzed. In a risk assessment of a coral reef ecosystem containing discarded military munitions (Ordnance Reef, Oahu, Hawaii), concentrations of explosives in filets of locally important fish (Yellowstripe and Yellowfin goatfish, *Mulloidichthys flavolineatus*, and *Mulloidichthys vanicolensis*) ranged from 37–180 ng/g for TNT degradates, 37–420 ng/g for HMX, and 1600 ng/g for RDX. Explosives were detected infrequently, ranging from 3–24% of fish samples. In a follow-up study following munitions recovery efforts, only TNT degradates were detected in fish at a range of 39–140 ng/g, with a detection frequency of up to 11%, with RDX not detected following reanalysis (University of Hawaii at Manoa 2014b).

2.3.3 Bioaccumulation of Explosives in Invertebrates

Though the focus of this literature review was primarily fish, bioaccumulation of explosives in other edible species, such as bivalves and crustaceans, is relevant to the discussion of potential impacts of military activities on ecological and human health. Thus, the available literature on bioaccumulation of explosives in invertebrates is discussed briefly here. Several studies have considered the bioaccumulation of explosives in mollusks in both the laboratory (Ballentine et al. 2015; Rosen & Lotufo 2007) and field (Appel et al. 2018; Beck et al. 2022; Strehse et al. 2017; Whitall et al. 2016). For laboratory studies, BCF values were comparable to those published for fish, with values ranging from 1.0–1.37 L/kg for TNT in *Mytilus edulis* and *Mytilus galloprovincialis* (Ballentine et al. 2015 and Rosen & Lotufo 2007), and from 0.43–0.67 for RDX (Ballentine et al. 2015 and Rosen & Lotufo 2007). For Asian shore crabs, *Hemigraspus sanguineus*, BCF values were marginally higher, being 235 and 1.97 L/kg for TNT and RDX, respectively (Ballentine et al. 2015), though this is the only laboratory study considering crustaceans to the authors knowledge.

In terms of field studies, Strehse et al. (2017) transplanted blue mussels, *M. edulis*, to an area of the Baltic Sea heavily contaminated with discarded mines from World War II. Concentrations of TNT degradates were generally low (average of 8.71 ng/g wet weight) in mussels deployed 1 meter above an explosive fragment, with the parent TNT compound not detected (Appel et al. 2018; Strehse et al. 2017). The leaching rate of explosives from explosives solids is dependent on factors including hydrodynamic conditions, temperature, salinity, and dissolved oxygen content (Maser and Strehse 2020), with dissolution rates of explosives from solids ranging from 0.5 – 50 mg/cm^2/day (Beck et al. 2019). Given the length of time that dumped munitions have been exposed and the leaching of explosive compounds into the environment, it is possible that concentrations were higher closer to the time of dumping, with subsequent effects on biota present in the area. In the Maser et al. (2023) study of a warship wreck, total concentrations of a suite of explosives (TNT, 1,3-DNB, 2,4-DNT, 2-ADNT, and 4-ADNT) in transplanted *M. edulis* individuals were in the range of 2-4 ng/g dry weight. Finally, Whitall et al. (2016) studied a suite of contaminants including explosives in Queen Conch, *Aliger gigas*, collected from several areas in Vieques, Puerto Rico, including locations impacted by the former bombing range. Analyzed samples had no explosives above the detection limit (range: 1.79–12.8 ng/g wet weight). As part of the ecological and human risk assessment at Ordnance Reef (Oahu, Hawaii), Kona crabs (*Ranina ranina*) and big blue octopus (*Octopus cyanea*) were collected and analyzed for a suite of explosives. No explosives were detected in crab samples, with the explosive HMX detected in a single octopus sample at a concentration of 62 ng/g. During the follow up investigation at ordnance reef, no explosives were detected in either Kona crabs or octopuses (University of Hawaii, 2014a, 2014b). Recent studies have focused on the potential human health implications of consuming seafood contaminated with explosives (Beck et al. 2022; Maser & Strehse 2020, 2021), including calculating permissible daily intake for potential consumers. These studies are discussed in Section 5 of this literature review.

Table 2-3. Summary of Laboratory Studies Documenting the Bioaccumulation of Munitions Compounds in Fish

Study	Study Species	Tissue	Compound	Duration (d)	BCF (L/kg)
Mariussen et al. 2018)	Atlantic salmon, *Salmo salar*	Muscle	TNT	2	4.1 – 6.3
			2-ADNT	2	0.04 – 1.2
			4-ADNT	2	0.08 – 1.1
Lotufo et al. 2010)	Sheepshead minnows (*Cyprinodon variegatus*) and Freckled blennies (*Hypsoblennius ionthas*)	Whole Body	TNT and degradates	7	3.9 – 8.6
Ballentine et al. 2016)	Atlantic wreckfish, *Polyprion americanus*	Whole Body	RDX	21	1.67 – 68.7
Yoo et al., (2006)	Fathead minnow, *Pimephales promelas*	Whole Body	TNT and degradates	4	5.5 – 9.2
Yoo et al. (2006)	Fathead minnow, *Pimephales promelas*	Whole Body	TNT and degradates	10	1.7 – 2.7
Belden et al. (2005a)	Channel catfish (*Ictalurus punctatus*)	Whole Body	RDX	0.7	2.1
Lotufo & Lydy, 2005)	Sheepshead minnow, *Cyprinodont variegatus*	Whole Body	TNT	0.25	9.6 – 9.7
			2-ADNT		13.1 – 13.2
			2,4-DANT		0.5
			RDX		1.7
			HMX		0.5
Ownby et al. (2005)	Channel catfish (*Ictalurus punctatus*)	Whole Body	TNT	1	0.78
Lotufo et al. (2016)	Sheepshead minnow, *Cyprinodon variegatus*	Whole Body	TNT	1	4.0
Leffler et al. (2014)	Atlantic salmon, *Salmo salar* (Alevins)	Whole Body	TNT	40	0.34
			2-ADNT	40	52
			4-ADNT	40	134
Kendall et al. (2006)	Zebrafish (*Danio rerio*)	Whole Body	RDX	84	1.4
Lang et al. (1997)	Carp (*Cyprinus carpio*)	Whole Body	2,4-DNT	3	9.2
Wang et al. (1999)	Goldfish, *(Carassius auratus)*	Whole Body	2,4-DNT	20	4.5
Wang et al. (1999)	Goldfish, *(Carassius auratus)*	Whole Body	2,6-DNT	20	1.7
Mukhi & Patiño (2008)	Zebrafish (*Danio rerio*)	Whole Body	RDX	28 – 84	1.01 – 2.23
Lotufo (2011)	Sheepshead minnow, (*Cyprinodon variegatus*)	Whole Body	TNT	1	3.3
			RDX	1	0.7
			HMX	1	0.1

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3. LITERATURE REVIEW: NON-EXPLOSIVE COMPOUNDS

3.1 PRESENCE OF METALS FROM MILITARY TESTING AND TRAINING IN SEDIMENT AND WATER

Military testing and training activities conducted within the MITT Study Area may introduce metals into the environment. A range of military expended materials contain metals, including ordnance (bombs, projectiles, missiles, and torpedoes), sonobuoys, chaff (radar countermeasure made of aluminum and glass fiber) cartridges, batteries, electronic components, and anti-corrosion compounds coating the surfaces of munitions. Metals typically found in military expended materials include lead, manganese, phosphorus, sulfur, copper, nickel, tungsten, chromium, molybdenum, vanadium, boron, selenium, columbium, and titanium. UXO, including bomb fragments and mines, may corrode and subsequently leach metals into the surrounding seawater and sediments in military training areas. The following section aims to summarize the available literature regarding metals in the environment as a result of military testing and training activities.

Following systematic literature review, no studies other than those already documented in the 2015 EIS/OEIS documents (Naval Facilities Engineering Command 1993; Navy 2010b) considered the effects of active military testing on metal concentrations in seawater and sediment. The majority of literature regarding metals released from military testing and training activities are focused on small arms ranges on land and soil contamination (reviewed in Barker et al. 2021). Consistent with data for explosives, most of the available literature regarding metal contamination associated with military activities comes from areas impacted by dumped munitions. Excluding the Ordnance Reef study, remedial activities such as removal of dumped munitions have not occurred at these sites. Generally, few studies considered levels of metals in seawater samples, due to the particle reactive nature of heavy metals and subsequent partitioning into the solid phase (i.e., sediments or particulate material) at typical seawater pH (Bruland 1983). In the HUMMA study, concentrations of heavy metals collected in 2009 from dumped munitions areas were found to be below EPA marine sediment screening benchmarks, with the exception of Pearl Harbor dredged material samples that were elevated in copper, lead, and zinc (Briggs et al. 2016). A follow-up investigation in the same area in 2012 found that levels of heavy metals in sediments from dumped munition sites were not statistically different from control sites located > 50 meters away from the munitions-impacted site (Briggs et al. 2016).

In the risk assessment of Ordnance Reef, Hawaii, levels of copper and lead in sediments were higher in dumped munitions areas (range: 3.0–2500 mg/kg and 1.7–549 mg/kg for copper and lead, respectively), relative to control areas (range: 3.0–24.3 mg/kg and 2.7–136 mg/kg for copper and lead, respectively). However, no consistent correlation between distance from the dumped munitions site and levels of metals in sediment was observed (University of Hawaii 2014a, 2014b). In the Den Otter et al. (2023) study of the Eastern Scheldt dumpsite, a suite of metals was measured in both sediment and seawater in the vicinity of dumped ammunition. Concentrations of metals were generally well below EPA Marine screening benchmarks, though levels of copper (range: 0.9–13.2 µg/L) exceeded both acute (4.8 µg/L) and chronic (3.1 µg/L) toxicity benchmarks at multiple sites (Den Otter et al. 2023; EPA 2006). Conversely, levels of metals in sediments were low, ranging from 0.032–0.72 mg/kg dry weight for copper, and

0.023–0.215 mg/kg for zinc, significantly lower than published marine screening benchmarks (EPA 2006). Available water and sediment ecological benchmarks for metals associated with military activities are given in Section 4.

Other studies have considered sediment metal contamination in the former Navy training area in Vieques, Puerto Rico. Porter et al. (2011) studied arsenic, lead, and mercury residues in areas next to a warship wreck (USN Killen) and in the vicinity of dumped munitions. Concentrations of lead in sediment ranged from BDL – 80.3 mg/kg in the vicinity of the wreck, with concentrations in the dumped munitions area below detection limits, compared to 32.3 mg/kg in the control area (Hatillo, Puerto Rico). Similarly, Pait et al. (2010) studied sediment contamination of a suite of metals in Navy training areas in Vieques, finding generally low concentrations, though maximum levels of nickel and zinc exceeded the National Oceanic Atmospheric Administration's threshold effect levels (i.e., concentration above which adverse effects to benthic communities are expected to rarely occur), but not probable effect levels (i.e., adverse effects expected to occur). In the Mariana Islands, (Denton et al. 2006, 2009, 2014, 2016, 2018) studied heavy metal contamination in soils, nearshore sediments, and biota from dumpsite-impacted areas around Saipan, including locations where military waste was deposited. Exceedance of CNMI Department of Environmental Quality (DEQ) and EPA human and ecological screening benchmarks was observed for several compounds in nearshore beach sediments, including cadmium, copper, and zinc (Denton et al. 2016). However, some of the studied dumpsites received wastes from sources other than military munitions and UXO (i.e., municipal, construction, or medical waste); thus, apportioning the observed contamination solely to military operations is challenging.

3.2 PRESENCE OF METALS FROM MILITARY TESTING AND TRAINING IN BIOTA

Several of the previously highlighted studies of explosives in biota also considered the presence of heavy metals. In the HUMMA study, concentrations of copper in deep sea shrimp, *Heterocarpus ensifer*, ranged from 5.1–16 mg/kg, below the Food and Agriculture Organization's legal limits for seafood of 30 mg/kg (Food and Agriculture Organization [FAO] 1983). For the ordnance reef risk assessment, levels of a suite of metals including copper, zinc, lead, and nickel were assessed in species of local importance for consumption (crab, goatfish, and octopus). For fish (Yellowstripe and Yellowfin goatfish) collected from near DMM, metal concentrations were generally low, with copper levels ranging from 0.19–1.1 mg/kg, and nickel and lead concentrations ranging from 0.13–0.180 and 0.06–0.031 mg/kg, respectively (University of Hawaii 2014a). For octopus, elevated levels of copper (maximum concentration of 90.3 mg/kg) were found in individuals collected from near military munitions relative to control areas (maximum concentration of 23.2 mg/kg). In a study of queen conch collected from areas impacted by the former naval bombing range in Vieques, Puerto Rico, levels of metals in tissue were found to be within the range of other areas of the Caribbean (Whitall et al. 2016). In the Porter et al. (2011) study at Vieques, levels of arsenic in two fish samples were found to exceed EPA's allowable risk-based concentration for human health, though lead and mercury were not detected. Concentrations of metals in biota were not considered in the Baltic Sea studies highlighted previously (Beck et al. 2022; Gledhill et al. 2019; Koske et al. 2020; Maser et al. 2023).

3.3 PERCHLORATE PRESENCE AND ACCUMULATION IN AQUATIC BIOTA

Under the proposed activities in the MITT Study Area, chemical contaminants other than metals and explosives would be released to the environment. For missiles and projectiles, the largest chemical constituent is solid fuel propellant, which is primarily made up of the oxidizing agent, ammonium perchlorate (i.e., 50–85% by weight) (Navy 2020a). Though missiles consume 99-100% of their propellant under normal functioning, remaining solid propellant fragments (i.e., ≤ 1% propellant mass) will release ammonium and perchlorate ions to the surrounding environment (Navy 2020a). Consequently, a systematic literature review using keyword searches such as “perchlorate” “military testing” and “fish” was conducted and is discussed briefly here. Overall, few studies documenting the presence of perchlorate in the aquatic environment were found; a total of nine relevant studies were extracted following a Google Scholar search.

Two of these studies considered perchlorate concentrations in water and freshwater fish collected in the vicinity of weapons manufacturing plants in east-central Texas (Smith et al., 2001; Theodorakis et al., 2006). Smith et al. (2001) studied perchlorate contamination in sediment, water, and a range of ecological receptors including mice, amphibians, and fish at areas in the vicinity of a military ammunition plant. For water samples, concentrations in all sampled areas were below 85 µg/L (0.085 mg/L), excluding a pond receiving groundwater discharge of treated water from the plant, where concentrations reached 776 µg/L (0.776 mg/L, Smith et al. 2001). For sediments, concentrations ranged from below detection limits to 0.704 mg/kg, with residues in mixed fish species ranging from below detection limits to 0.207 mg/kg (Smith et al. 2001). Theodorakis et al. (2006) found only sporadic detections of perchlorate in a range of fish species collected from areas impacted by a naval weapons manufacturing plant, with maximum perchlorate concentrations of 3.961 mg/kg recorded in spotted gar, *Lepisoteus oculatus*.

Other studies have focused on the bioaccumulation and toxicokinetics of perchlorate in laboratory studies (Bradford et al. 2006; Furin et al. 2013; Liu et al. 2006; Park et al. 2007). Overall, all toxicokinetic studies indicate that perchlorate shows rapid uptake and elimination in fish and has low bioaccumulation potential. Published BCF values ranged from 0.06–0.70 L/kg, with half-life values ($t_{1/2}$) ranging from 0.41–1.07 d^{-1} (Bradford et al. 2006; Dean et al. 2004; Liu et al. 2006; Park et al. 2007), suggesting rapid elimination. Two additional studies considered the potential trophic transfer and biomagnification of perchlorate in fish (Furin et al. 2013; Park et al. 2005), with biomagnification potential between trophic levels found to be low, though both studies demonstrated that dietary sources may act as an additional perchlorate source to fish. No studies to the author’s knowledge have considered the uptake and accumulation of perchlorate in marine fish. Given that perchlorate is thought to occur naturally in seawater (Martinelango et al. 2006), the application of studies based on freshwater fish to marine organisms is unclear.

Another non-explosive compound of potential concern with regards to testing and training activities in the MITT Study Area is hydrogen cyanide. Hydrogen cyanide is a minor byproduct of UNDET using RDX, as well as a byproduct of propellant combustion used in torpedoes (Navy 2015). Cyanides are highly toxic to aquatic biota, with a value of 1 µg/L suggested by the EPA for acute and chronic criteria maximum concentration (EPA 2009). A systematic literature review found no additional studies detailing the potential exposure of aquatic biota to hydrogen cyanide following military testing and training activities; thus, this contaminant is not discussed further in this report.

3.4 OTHER MILITARY EXPENDED MATERIALS: FATE AND ACCUMULATION

Under the proposed activities, other military expended materials will be released into the MITT Study Area, including chaff, debris, and polychlorinated biphenyls (PCBs) from vessel sinking exercises. Chaff is comprised of thin glass fibers coated with aluminum and is used to obfuscate radar monitoring systems in vessels. Cylinders containing chaff are released either from aircraft or a surface vessel and tend to float on the surface following release to the aquatic environment (Navy 2020a). Since aluminum coating is used for chaff, the primary concern associated with chaff exposure is increased aluminum exposure which has been shown to be toxic at higher levels in aquatic and terrestrial species (Wilson et al. 2002). Following a systematic literature search, only two additional studies focusing on chaff release and potential effects were found that were not included in the Navy EIS/OEIS documents (Spargo et al. 1999; Wilson et al. 2002). Wilson et al. (2002) studied the effects of 25 years of chaff release in the Chesapeake Bay area on aluminum levels in soil and sediment, finding a slight increase in levels of organic monomeric aluminum in the training area, but lower levels of inorganic monomeric aluminum compared to the background area. Given that inorganic aluminum is of greater toxicological importance, the authors concluded that the release of several hundred thousand pounds of chaff over 25 years of training has not appreciably increased aluminum levels. The Spargo (1999) study summarized previous investigations of chaff toxicity conducted by System Consultants, the findings of which are already highlighted within the EIS/OEIS documents. Briefly, exposure to chaff at levels 10–1000 times the typical environmental exposures had no significant effect on several species, including water fleas, *Daphnia magna*, blue crabs, *Callinectes sapidus*, and killifish.

During vessel sinking exercises, PCBs released to the environment are of concern due to their presence in a range of vessel materials including insulation, wiring, felts, and rubber gaskets. PCBs are considered persistent organic pollutants, are known to biomagnify in aquatic food webs, and may induce deleterious effects including endocrine disruption (Buha Djordjevic et al. 2020; Ngoubeyou et al. 2022). It is important to consider that proposed sinking exercises in the MITT Study Area are scheduled to decline to a single sinking event per year under the 2020 proposed activities, vessels are cleaned or remediated for PCB contamination in accordance with EPA protocols prior to sinking, and sinking exercises are conducted greater than 50 nautical miles (NM) offshore in areas deeper than 6,000 feet (Navy 2020a). A previous risk assessment conducted by the Navy focused on the potential release of PCBs and consequences for aquatic biota from a warship sank in deep waters off the coast of San Diego (Naval Information Warfare Center Pacific 2006). Bioaccumulation and potential toxicity of PCBs in aquatic biota exposed to sediments from the site were considered, as well as potential leaching of PCBs to the water column around the shipwreck. Overall, the risk assessment concluded that no significant differences were observed between the shipwreck area and a reference site in terms of sediment PCB concentrations, sediment toxicity, and PCB bioaccumulation in biota (Naval Information Warfare Center Pacific 2006). Furthermore, potential human health impacts were considered from consumption of sablefish, *Anoplopoma fimbria*, from commercial fisheries, with no significant risk found (Naval Information Warfare Center Pacific 2005). This study focused on a shipwreck that was not subject to prior cleaning, with the proposed activities occurring in the MITT Study Area involving vessels that are remediated according to EPA protocols prior to use in sinking exercises (Navy 2015). Given that no significant impacts on contamination, toxicity, or human health were associated with a large shipwreck that was not cleaned prior to sinking, it is assumed that a single sinking event per year of a remediated vessel is unlikely to contribute to significant PCB contamination in the MITT Study Area.

4. ECOLOGICAL SCREENING BENCHMARKS AND RISK ASSESSMENT

To contextualize the findings of the literature review in terms of potential toxicity or ecological effects, benchmark values for explosives and select metals were collated and are presented in the following section. Table 4-1 contains the available benchmarks for marine surface water (adapted from Lotufo et al. 2017), including values from the EPA biological technical assistance guide (BTAG) Region 3, which are used to evaluate data from superfund sites (EPA 2006). Values for a suite of metals commonly associated with military activities are included. These values are used to facilitate screening-level ecological risk assessments at contaminated sites and assist in determining which contaminants are of potential concern and require further studies. Other values are proposed water quality criteria for the protection of aquatic life from Nipper et al. (2009), Lotufo et al. (2017), and ENSR International (2005). Table 4-2 displays the contaminant-specific hazardous concentration for 5% (HC_5) as well as lower confidence limits (LCLs) and upper confidence limits (UCLs) based on species sensitivity distributions analyzed in Lotufo et al. (2017). Proposed sediment quality benchmarks (SQBs) for explosives summarized by Pascoe et al. (2010) and revised in Lotufo et al. (2017) are given in Table 4-3. Pascoe et al. (2010) used chronic water screening benchmarks, no observed effect concentrations (NOECs), and organic carbon partitioning coefficients (K_{oc} values) to calculate SQBs using the equilibrium partitioning method (EPA 2008). Low and high values were provided to encompass the range of reported K_{oc} values in the literature. Finally, Lotufo et al. (2017) provided revised SQB values based on proposed adjustments to the equilibrium portioning method for low $LogK_{OW}$ values (Table 4-3). The application of these values for determining potential ecological risk is demonstrated in Section 7.1.

Table 4-1. Provisional Benchmarks For Explosives and Select Metals in Marine Surface Waters

Compound	Type of Value	Value (mg/L)	Source
Munition Compounds			
TNT	EPA BTAG Screening Value	0.100	EPA BTAG Screening Values (2006)
TNT	Acute Water Quality Criteria	0.085	Nipper et al. (2009)
TNT	Chronic Water Quality Criteria	0.028	Nipper et al. (2009)
TNT	Acute Water Quality Criteria	0.398	Lotufo et al. (2017)
1,3,5-TNB	Acute Water Quality Criteria	0.189*	Lotufo et al. (2017)
1,3,5-TNB	Chronic Water Quality Criteria	0.025*	Lotufo et al. (2017)
2,4-DNT	Acute Water Quality Criteria	0.977*	Lotufo et al. (2017)
2,4-DNT	Chronic Water Quality Criteria	0.900*	Lotufo et al. (2017)
RDX	Acute Water Quality Criteria	0.859	ESNR (2005)
RDX	Chronic Water Quality Criteria	0.853	ESNR (2005)
Metals			
Copper	EPA BTAG Screening Value	0.003	EPA BTAG Screening Values (2006)
Zinc	EPA BTAG Screening Value	0.081	EPA BTAG Screening Values (2006)
Lead	EPA BTAG Screening Value	0.008	EPA BTAG Screening Values (2006)
Nickel	EPA BTAG Screening Value	0.008	EPA BTAG Screening Values (2006)
Cadmium	EPA BTAG Screening Value	1.2E-04	EPA BTAG Screening Values (2006)
Chromium (Total)	EPA BTAG Screening Value	0.058	EPA BTAG Screening Value (2006)
Arsenic	EPA BTAG Screening Value	0.013	EPA BTAG Screening Value (2006)

*Indicates a combined value from marine and freshwater studies.

Table 4-2. Hazardous Concentrations of Explosives from Lotufo et al. (2017)

Compound	HC5 (µg/L)	LCL (µg/L)	UCL (µg/L)
LC50/EC50 Values			
2,4,6-TNT	116	27	488
2-A-4,6-DNT	1,239	496	3,094
4-A-2,6-DNT	1,983	1,167	3,371
1,3,5-TNB	114	35	373
1,3-DNB	274	118	636
2,4-DNT	615	245	1,540
2,6-DNT	710	189	2,661
RDX	2,074	1,511	2,846
HMX	NS	NS	NS
NOEC Values			
2,4,6-TNT	34	6	188
2-A-4,6-DNT	NS	NS	NS
4-A-2,6-DNT	NS	NS	NS
1,3,5-TNB	27	9	83
1,3-DNB	39	6	263
2,4-DNT	43	13	150
2,6-DNT	107	42	273
RDX	4,560	2,681	7,755
HMX	2,097	1,745	2,521

Table 4-3. Proposed Sediment Quality Benchmarks Based on a Range of Organic Carbon Portioning Coefficients and a 1% Organic Carbon Sediment (Pascoe et al. 2010) and Revised Values from Lotufo et al. (2017)

Compound	Selected toxicity value (µg/L)	K_{oc} Value Pascoe et al. (2010)		SQB at 1% organic carbon (mg/kg, Pascoe et al. 2010)		Revised SQB (1% organic carbon and 70% solids, mg/kg, Lotufo et al. 2017)	
		low	high	low	high	low	high
TNT	28.4	37.4	451	0.011	0.128	0.023	0.14
2-A-4.6-DNT	19	65.9	81	0.013	0.015	0.021	0.024
4-A-2.6-DNT	30	116	ND	0.036	--	0.048	-
2,4-DA-6-NT	19	4.88	ND	0.0009	--	0.009	-
2,6-DA-4-NT	19	4.88	ND	0.0009	--	0.009	-
2,4-DNT	2400	88.4	300	2.1	7.2	3.2	8.2
2,6-DNT	1800	116	150	2.1	2.7	2.9	3.5
2-NT	3400	182	ND	6.2	--	7.6	-
3-NT	750	256	ND	1.9	--	2.2	-
4-NT	320	214	ND	0.68	--	0.82	-
1,3-DNB	17	29.2	210	0.005	0.036	0.012	0.043
1,3,5-TNB	11	14.5	77	0.0016	0.0086	0.0063	0.0132
3,5-DNA	59	72.1	ND	0.0426	0.0678	-	
HMX	330	1.15	130	0.0038	0.43	0.1452	0.6

Compound	Selected toxicity value (µg/L)	K_{oc} Value Pascoe et al. (2010)		SQB at 1% organic carbon (mg/kg, Pascoe et al. 2010)		Revised SQB (1% organic carbon and 70% solids, mg/kg, Lotufo et al. 2017)	
RDX	186	6.26	42	0.012	0.078	0.091	0.2

Table 4-4. Marine Sediment Screening Benchmarks for Selected Metals

Compound	Type of Value	Value (mg/kg)	Source
Copper	EPA BTAG Screening Value	18.7	EPA BTAG Screening Values (2006)
Zinc	EPA BTAG Screening Value	124	EPA BTAG Screening Values (2006)
Lead	EPA BTAG Screening Value	30.2	EPA BTAG Screening Values (2006)
Nickel	EPA BTAG Screening Value	15.9	EPA BTAG Screening Values (2006)
Cadmium	EPA BTAG Screening Value	0.68	EPA BTAG Screening Values (2006)
Chromium (Total)	EPA BTAG Screening Value	52.3	EPA BTAG Screening Value
Arsenic	EPA BTAG Screening Value	7.24	EPA BTAG Screening Value

4.1 ECOLOGICAL RISK

To provide a generic assessment of potential ecological risk associated with exposure to explosives, the available literature providing concentration of explosives in sediment and water was compared to available benchmarks following Lotufo et al. (2017). As highlighted previously, no site-specific data for the MITT area was available; thus, this assessment represents a generic evaluation of potential risk based on studies from other areas. Only explosives that had proposed marine or combined water quality criteria were used for the analysis (i.e., compounds with freshwater benchmarks only were not included). Except for TNT where an EPA marine screening value for surface water is available (EPA 2006), proposed chronic water quality criteria described above in Table 4-1 were used for comparisons. As shown in Table 4-5, exceedances of benchmarks were only observed for the Porter et al. (2011) study of Vieques, Puerto Rico, where concentrations of all 5 compounds measured at the solution cavity of a 2000-lb general purpose bomb exceeded benchmarks, as well as TNT concentrations at 0.1 meters from the bomb. Concentrations of explosives in all other studies were typically orders of magnitude below benchmark values.

Table 4-5. Comparison of Maximum Aqueous Concentration of Explosives and Water Quality or Screening Benchmarks

Study	Study Area/Laboratory Design	Compound	Maximum Aqueous Concentration (mg/L)	Benchmark Value (mg/L)	Benchmark Type
Field Studies					
Porter et al. (2011)	Vieques, Puerto Rico (0 meter distance from bomb)	TNT	**85.7**	0.100	Screening Value (BTAG)
		1,3,5-TNB	**11.3**	0.025	Chronic Water Quality Criteria
		1,3-DNB	**18.5**	0.076	Chronic Water Quality Criteria
		2,4 + 2,6-DNT	**82.5**	0.900	Chronic Water Quality Criteria
		RDX	**4.120**	0.853	Chronic Water Quality Criteria
Porter et al. (2011)	Vieques, Puerto Rico (0.1 meter distance from bomb)	TNT	**0.105**	0.100	Screening Value (BTAG)
		1,3,5-TNB	0.015	0.025	Chronic Water Quality Criteria
		1,3-DNB	0.023	0.076	Chronic Water Quality Criteria
		2,4 + 2,6-DNT	0.107	0.900	Chronic Water Quality Criteria
		RDX	0.005	0.853	Chronic Water Quality Criteria
Gledhill et al. (2019)	Kolberger Heide, Germany	RDX	1.9×10^{-6}	0.853	Chronic Water Quality Criteria
		1,3,5-TNB	0.3×10^{-7}	0.025	Chronic Water Quality Criteria
		1,3-DNB	9.5×10^{-6}	0.076	Chronic Water Quality Criteria
		TNT	1.1×10^{-5}	0.100	Screening Value (BTAG)
		2-ADNT	1.1×10^{-7}	0.034	Chronic Water Quality Criteria
Beck et al. (2019)	Kolberger Heide, Germany	TNT	0.05	0.100	Screening Value (BTAG)
		DNB	0.01	0.076	Chronic Water Quality Criteria
		RDX	0.01	0.853	Chronic Water Quality Criteria
Rosen et al. (2022)	Vieques, Puerto Rico	TNT	0.0053	0.100	Screening Value (BTAG)
		2-ADNT	5.4×10^{-5}	0.034	Chronic Water Quality Criteria
		1,3-DNB	4.6×10^{-5}	0.076	Chronic Water Quality Criteria
		RDX	1.3×10^{-5}	0.853	Chronic Water Quality Criteria
Den Otter et	Eastern Scheldt, Netherlands	TNT	5.7×10^{-5}	0.100	Screening Value (BTAG)
		2-ADNT	1.3×10^{-5}	0.034	Chronic Water Quality Criteria

Study	Study Area/Laboratory Design	Compound	Maximum Aqueous Concentration (mg/L)	Benchmark Value (mg/L)	Benchmark Type
al. (2023)		1,3-DNB	7.8×10^{-6}	0.076	Chronic Water Quality Criteria
Maser et al. (2023)*	North Sea	TNT	6.3×10^{-6}	0.100	Screening Value (BTAG)
		2-ADNT	1.3×10^{-6}	0.034	Chronic Water Quality Criteria
		1,3-DNB	7×10^{-7}	0.076	Chronic Water Quality Criteria
Laboratory/Field Simulations					
Lotufo et al. (2019)	Recirculating flume	TNT	0.013	0.100	Screening Value (BTAG)
		RDX	0.018	0.853	Chronic Water Quality Criteria
Rosen et al. (2018)	Santa Rosa, Florida (0 meters from source)	TNT	0.013	0.100	Screening Value (BTAG)
		RDX	0.0026	0.853	Chronic Water Quality Criteria
	Santa Rosa, Florida (0.3 meters from source)	TNT	1.0×10^{-4}	0.100	Screening Value (BTAG)
		RDX	9.7×10^{-5}	0.853	Chronic Water Quality Criteria

Notes:
Adapted from Lotufo et al. (2017).
Bolded values indicate exceedances of benchmarks.

For the sediment comparison, revised sediment quality benchmarks from Lotufo et al. (2017) were used for analysis (see Table 4-3). Benchmark exceedances were observed for sediment concentrations of a suite of explosives in the Porter et al. (2011) study at Vieques, as well as for two compounds at Ordnance Reef: 2,4-DNT and 1,3-TNB. It is important to consider that studies that did not record any detections above reporting limits were not included (Briggs et al. 2016; Pait et al. 2010; Rosen et al. 2022), therefore the presented data may overestimate potential risk.

Table 4-6. Comparison of Maximum Sediment Concentration of Explosives and Proposed Sediment Quality Benchmarks

Study	Study Area	Compound	Maximum Sediment Concentration (mg/kg)	Benchmark Value (mg/kg)
Briggs et al. 2016	Pearl Harbor, HI, USA	4-NT	0.12	0.82
Den Otter et al. 2023	Eastern Scheldt Estuary, Netherlands	TNT	0.0012	0.023
		2,4-DNT	0.0019	3.2
		2-ADNT	0.0008	0.021
		4-ADNT	0.0014	0.048
Maser et al. 2023	North Sea	TNT	12.6×10^{-7}	0.023
		4-ADNT	5×10^{-7}	1.0*
		2-ADNT	5×10^{-7}	1.3*
Porter et al. 2011	Vieques, Puerto Rico (0 meter from bomb)	TNT	**19,333**	0.82
		1,3,5-TNB	**30.7**	0.0063
		1,3-DNB	**3.47**	0.012
		4-NT	**5.39**	0.82

Study	Study Area	Compound	Maximum Sediment Concentration (mg/kg)	Benchmark Value (mg/kg)
		RDX	**5.32**	0.091
University of Hawaii, 2014a	Ordnance Reef, Hawaii	2,6-DNT	0.380	2.9
		2,4-DNT	**3.3**	3.2
		1,3-TNB	**0.025**	0.0063

Notes:
Adapted from Lotufo et al. (2017)
Bolded values indicate exceedances of benchmarks

For metals, a small number of studies facilitated comparison with marine sediment screening benchmarks. Maximum concentrations of copper, lead, nickel, and zinc exceeded marine sediment screening benchmarks at the initial Ordnance Reef study (University of Hawaii 2014a), as well as lead concentrations at the wreck of the USN Killen conducted by Porter et al. (2011).

Table 4-7. Comparison of Maximum Sediment Concentration of Metals and Marine Sediment Screening Benchmarks (EPA BTAG 2006)

Study	Study Area	Compound	Maximum Sediment Concentration (mg/kg)	Benchmark Value (mg/kg)
Den Otter et al. 2023	Eastern Scheldt Estuary, Netherlands	Copper	0.072	18.7
		Nickel	0.007	15.9
		Lead	0.016	30.2
		Zinc	0.215	124
		Chromium	0.027	52.3
University of Hawaii 2014a	Ordnance Reef, Oahu, Hawaii	Copper	**2500**	18.7
		Lead	**549**	30.2
		Nickel	**125**	15.9
		Zinc	**408**	124
Porter et al. 2011	Vieques, Puerto Rico	Lead	**80.3**	30.2

Notes:
Adapted from Lotufo et al. (2017).
Bolded values indicate exceedances of benchmarks

Overall, these comparisons suggest limited evidence for ecological risk associated with explosive exposure in aquatic biota. The concentrations compared to benchmarks are mostly from the immediate vicinity (i.e., < 0.5 meters in distance) from point-sources of explosives, including large quantities of dumped munitions and explosives. Despite this, aqueous concentrations from all studies, excluding Porter et al. (2011), were significantly lower than water quality or screening benchmarks. The Porter et al. (2011) study where exceedances were recorded is based on measurements taken from the solution cavity of a bomb, with concentrations shown to rapidly decline with increasing distance. Therefore, these measurements represent an extreme worst-case scenario, and reflect the relative lack of ecological risk for all except organisms in the immediate vicinity of sources. This indicates that population and community-level impacts are unlikely in these areas; though none of the studies directly assessed biological effects on ecological receptors exposed to explosives. Though fewer studies recorded sediment concentrations of explosives above detection limits, a similar finding was observed for the sediment benchmark comparison (Table 4-6). It is important to consider that these conclusions are limited to the effects of explosive chemicals on aquatic organisms, and do not consider potential acoustic and physical impacts associated with underwater detonations in the MITT area. The 2015 and 2020 EIS documents describe the potential for acute adverse effects on fish communities in the immediate vicinity of underwater detonations from acoustic and physical stress (Navy 2015, 2020).

5. HUMAN HEALTH

To address concerns from the local community for potential health effects associated with fish consumption, a quantitative risk assessment was performed to evaluate those compounds associated with Navy testing and training identified as a potential concern in Sections 2 and 3. Site-specific contamination data was not available for the MITT area; thus, this assessment utilized concentrations of explosives from studies conducted in other areas to provide a generic, predictive risk evaluation. The risk assessment follows methodology set forth by EPA guidance (1989) and CNMI DEQ and EPA (CNMI Division of Environmental Quality and Guam Environmental Protection Agency 2017). The methodology follows a four-step process: hazard identification, exposure assessment, toxicity assessment, and risk characterization. The following sections detail each of these steps.

5.1 EXPOSURE ASSESSMENT

In the exposure assessment, the receptors of concern and potential exposure pathways are identified. Chemicals in site environmental media are converted into systemic doses, taking into account chemical concentrations, rates of contact (e.g., ingestion rates), and absorption rates of different chemicals. For the purposes of this study, the chemicals evaluated are identified as the potential munitions constituents that may be introduced into the environment through the Navy's testing and training. The magnitude or concentration, frequency, and duration of these exposures are then integrated to obtain estimates of daily doses over a specified period of time (e.g., lifetime, activity-specific duration). To evaluate potential effects to the marine environment and potential resulting human health concerns from the proposed training and testing, potential human health exposure pathways were determined. Exposure pathways begin from potential sources and progress through the environment via fate and transport processes to potential human receptors. An exposure pathway describes a mechanism by which a population or individual may be exposed to chemicals within the area evaluated. A completed exposure pathway requires the following four components (EPA 1989):

- Source and mechanism of chemical release to the environment,
- Environmental transport medium for the released chemical,
- Point of potential human contact with the contaminated medium, and
- Human exposure route at the point of exposure.

All four components must exist for an exposure pathway to be complete and for exposure to occur. Incomplete exposure pathways do not result in actual human exposure and are not a concern for human health. A conceptual site model sets forth the sources, migration pathways, and potential receptors. The following paragraphs detail the conceptual site model.

Chemical sources are primarily the ordnances (e.g., bombs, missiles, etc.) that the Navy uses for testing and training. Chemicals can be introduced to the waters within the MITT Study Area either through detonation and/or corrosion of non-detonated materials. As discussed in Sections 2 and 3, the fate and transport of explosive and non-explosive compounds varies significantly.

Studies that considered the presence of explosives in sediment and water at the former Navy testing and training area in Vieques, Puerto Rico, where broadly similar activities to the MITT Study Area, have been performed (Pait et al. 2010; Porter et al. 2011; Rosen et al. 2022). Porter et al. (2011) measured concentrations of explosives in water and sediment at varying distances from a 2,000-pound (lb) (907 kg) general purpose bomb at a former Navy bombing range in Bahia Salina del Sur. Aqueous concentrations ranging from 4,120 to 85,700 µg/L for a suite of explosives were detected within the solution cavity of the bomb, but a dramatic decrease with increasing distance, with concentrations ranging from 3.3 – 107 µg/L at 0.10 meters from the bomb (Porter et al. 2011). Similarly, sediment samples taken from the same locations indicated a range of 5.39 – 19,333 mg/kg for explosives at the breach of the bomb, but orders of magnitude lower concentrations at 0.10 meters away (0.404 mg/kg for TNT) (Porter et al. 2011). Conversely, a study of 78 sediment samples taken from around Vieques recorded no detections of a suite of 14 explosives (Pait et al. 2010; Rosen et al. 2022). In an ecological and human risk assessment of a Hawaiian coral reef ecosystem impacted by UXO (Ordnance Reef, Oahu, Hawaii), a suite of 19 explosives were not detected in seawater above the reporting limit (reporting limit range: 0.1 – 1.4 µg/L). Similarly, only 3 explosives were detected in sediment above reporting limits: 2,4-dinitrotoluene (DNT) (range: 0.03 – 3.3 mg/kg), 2,6-DNT (range: 0.09 – 0.380 mg/kg), and trinitrobenzene (TNB) (0.022 – 0.025 mg/kg).

Other studies have considered sediment metal contamination in the former Navy training area in Vieques, Puerto Rico. Pait et al. (2010) studied sediment contamination of a suite of metals in Navy training areas in Vieques, finding generally low concentrations. In the Mariana Islands, (Denton et al. 2006, 2009, 2014, 2016, 2018) heavy metal contamination in soils, nearshore sediments, and biota from dumpsite-impacted areas around Saipan were studies. Exceedance of EPA screening benchmarks was observed for several compounds in nearshore beach sediments, including cadmium, copper, and zinc (Denton et al. 2016). However, some of the studied dumpsites received wastes from sources other than military munitions and UXO (i.e., municipal, construction, or medical waste); thus, the observed contamination could not be attributed solely to military operations.

Additionally, the presence of other chemicals in surface water and sediment (i.e., perchlorate, PCBs, chaff, etc.) were not considered significant or not detected. Therefore, explosives are the primary chemicals that may be presented in environmental media. From these environmental media, the chemicals may be bioaccumulated by fish and other marine organisms. Therefore, potential environmental media that may be affected by explosives as a result of Navy activities include: sediment, water, and fish/marine organisms.

The SEIS/OEIS identified the following receptors that may be affected by the testing and training activities that occur within the MITT Study Area (Navy 2020a):

- Commercial fishers,
- Recreational fishers, and
- Traditional fishers

The focus of this document are the traditional and recreational fishers (i.e., local residents) who may be impacted by the proposed testing and training that will occur at-sea and on FDM. These groups represent both recreational and subsistence fishing and were identified in the 2015 EIS/OEIS and the 2020 SEIS/SOEIS (Navy 2015, 2020a).

Recreational and subsistence fishing activities primarily occur in the shallow water (< 500 ft. [< 152 m]) and occur within 3 miles from the shore (Navy 2015). In the waters around FDM, a permanent danger zone extends out to 3 NM from shore for public safety, preventing fishing in these areas. For the area around Saipan, fishing is limited to daylight hours within a 30 mi. (48.2 km) radius. These limitations are associated with the distances to nearby ports and the typical size of the vessels (usually less than 24 ft. [7.3 m] in length) (Western Pacific Regional Fishery Management Council 2005). Based upon the areas used for traditional fishing and the methods used for fishing, the traditional fishers are expected to contact sediment, surface water, and fish/marine species within 3 NM of Guam and the CNMI. The following exposure pathways are assumed completed for the traditional fishers:

- Direct contact with sediment (incidental ingestion and dermal contact with skin surfaces);
- Direct contact with surface water (incidental ingestion and dermal contact); and
- Ingestion of fish and other marine species (applies to both the traditional fishers and their families and social circles)

Testing of ordnance and other materials occurs at-sea, outside the 3 NM area. Additionally, impact areas on the FDM are routinely cleared of unexploded ordnance and other range debris (Navy 2020a). This clearance limits the erosion and subsequent runoff of explosives or other chemicals and chemical by-products into the nearshore waters. Any traditional fishing activities that occur within the nearshore waters (excluding FDM where fishing is not permitted in the nearshore area) are likely to have minimal direct contact with sediments. Contact with sediment is only expected to occur dermal to the hands, forearms, feet, and lower legs. Additionally, any sediment that adheres to these skin surfaces are expected to wash off or not remain on the skin for extended time due to the sandy nature of the sediments in the nearshore waters. Therefore, the direct contact with sediments within the nearshore waters are expected to be an insignificant exposure pathway that would not contribute to human health concerns for a traditional fisher.

Similar to sediment, direct contact with surface water would likely occur during fishing activities. The surface water contact could be similar to sediment (i.e., just the hands, forearms, feet, and lower legs) but would likely also include a full-body swimming scenario. Explosive compounds have been detected within waters near testing sites (Porter et al. 2011). However, concentration of the explosives showed a significant decrease (orders of magnitude) with increasing distance from the munitions. Therefore, the direct contact with surface water within the nearshore waters are expected to be an insignificant exposure pathway that would not contribute to human health concerns for a traditional fisher.

Traditional fishing is likely similar to a subsistence fishing scenario, which assumes the consumption of noncommercial fish is a primary source of protein (Navy 2015). As a result, traditional fishers tend to consume non-commercial fish or shellfish at higher rates than other populations who fish, and for a greater percentage of the year, because of cultural customs or economic factors (Navy 2020a). Less than 3 percent of the working age population in Guam and approximately 3 percent of the working age population in the CNMI reported participating in a subsistence activity in the year 2010, which is likely to be fishing, but does not exclude other activities, such as growing crops (Navy 2020a). In a 2005 survey of fishing communities on Saipan, fishermen reported going fishing an average of 71 days a year, with reef fish the most frequently caught (54% of fishermen) followed by bottomfish (23%) and reef invertebrates for a median monthly catch of 40 lbs per person (Allen and Amesbury 2012). Both the CNMI and Guam are categorized as "fishing communities" based upon the portion of the population that is dependent upon fishing for subsistence, the economic importance of fishery resources to the islands, and the geographic, demographic, and cultural attributes of the communities (Western Pacific Regional Fishery Management Council 2009). Traditional fishing is more than an economic necessity; it is an important part of the cultural and social identity of indigenous peoples and Asian immigrant communities living in Guam and in the CNMI (Navy 2020a). Additionally, consumption of fish and other marine species can occur indirectly through the sharing of fish with family and social circles (Navy 2015; Labrosse et al. 2006; Allen and Bartram 2008). Therefore, the consumption of fish and other marine species is a significant exposure pathway for the traditional fisher.

To determine potential consumption rates for a subsistence user (i.e., the traditional fisher), a hierarchy has been set forth by the EPA in the development of Aquatic Water Quality Criteria (AWQC) for the protection of human health was used. The EPA recommended, "the use of local or regional data over default values as more representative of target population groups" (EPA 2000) The EPA has recommended a preference hierarchy for the determination of fish consumption rates (EPA 2000). The preference hierarchy includes:

1. Results from fish intake surveys of local watersheds;
2. Results from existing fish intake surveys that reflect similar geography and population groups;
3. Select intake rate assumptions for different population groups from national food consumption surveys; and
4. Use fish intake default rates from AWQC guidance.

An important variable in evaluating potential human health concerns associated with the consumption of fish and other marine species exposure pathway is the seafood consumption rates and trends for the local communities. The following sections detail literature review and collection of information to inform this variable.

5.1.1 Consumption in the CNMI and Guam

A total of seven relevant studies were found documenting the dietary patterns and seafood choices of Pacific Islanders (Allen and Bartram 2008; Charlton et al. 2016; Cuetos-Bueno & Houk 2015; Dewailly et al. 2008; Guillemot et al. 2009; Labrosse et al. 2006; Pobocik et al. 2008). Of these citations, four considered consumption patterns in the CNMI, which includes the MITT Study Area (Charlton et al., 2016); Cuetos-Bueno & Houk 2015; Allen & Bartram 2008; Pobocik et al. 2008). Therefore, these studies were used to determine consumption rates rather than rates from national food consumption surveys or default fish intake rates from the AWQC guidance.

The study of Allen & Bartram (2008) synthesized the available literature regarding Guam as a fishing community, including per capita seafood consumption, fishing methods employed, and types of fish targeted. The report highlighted that traditional fish harvest in Guam utilizes pulse fishing and targets seasonal runs of juvenile rabbitfish (*Siganidae* spp.), goatfish (*Mullidae* spp.), bigeye scad (atulai, *Selar Crumenophthalmus*), and members of the jacks family (i.e., family *Carangidae*). The study found that existing data suggested that annual seafood consumption in Guam is 60 lbs per capita (equivalent to 27 kg/year), with an estimated 57% of the fish consumed in households coming from inside or outside local coral reefs, and the remaining 43% imported from the US mainland or other Pacific islands. However, this per capita consumption rate is lower than the subsistence consumption rate determined in Charlton et al. (2016), which is expected since per capita estimates are based upon a total population that consumes fish and not a specific population. The average fish consumption ranged from 55 kg to 110 kg per person per year for Pacific Island countries and territories. Labrosse et al (2006) found that the average weekly consumption of fish was 4.8 meals per week with an average quantity of fish consumed at a meal was 233 grams (0.233 kg). This results in an annual consumption rate of approximately 58 kg, which is within the range determined by Charlton et al. (2016). Therefore, the annual consumption rate of 58 kg (0.159 kg/day) was selected for the traditional fishers. This rate is assumed to apply to adult traditional fishers. Due to the cultural importance of fishing within the local communities, children and adolescents are also an important receptor when considering fish ingestion. A child represents the age range of infant to 6 years of age, and the adolescent represents the age range of 6 years to 16 years of age (EPA 1989, 2014). The consumption rate for the child receptor is assumed at 50 percent of the rate for adults. (ATDSR 2003). Previous risk assessments have assumed seafood consumption rates of 50 percent for children, including the studies conducted at the former bombing range in Vieques (ATSDR 2003). Due to the wide range of consumption estimates for the adolescent receptor group (EPA 2011), adolescents were conservatively assumed to have the same consumption rate as adults.

It is important to note that the consumption rates are based upon the total amount of fish ingested. Access to waters around FDM between 3 and 12 NM was restricted for an average of 159 days per year (Navy 2020a). Based on data from October – December 2011, access restrictions were in place for an average of 11.6 hours per day, though it is unclear how this applies to the rest of the year (Navy 2015). Access to waters within 3 NM of FDM is restricted at all times (Navy 2020a). Therefore, the fish consumption rate for the traditional fisher is not expected to only include fish caught within the MITT Study Area. The fraction of fish ingested from the MITT Study Area is assumed at 50% based upon the number of days that access is restricted.

5.1.2 Estimation of Intake

$$Intake\ (ADI)\ (mg/kg - day)\ = \frac{Chemical\ conc.\ x\ IR\ x\ FI\ x\ EF\ x\ ED}{AT\ x\ BW}$$

where:

ADI	=	Average daily intake
IR	=	Ingestion/Consumption rate (kg/day)
FI	=	Fraction ingested from contaminated source (unitless), assumed 50%

EF	=	Exposure frequency (365 days/year)
ED	=	Exposure duration (years – based upon the age evaluated)
AT	=	Averaging time (days) Non-carcinogen (ED × 365 days/year) Carcinogen (70 years × 365 days/year = 25,550 days).
BW	=	Body Weight (kg)

The determination of explosives chemical concentrations within fish tissue was modeled based upon surface water concentrations. The use of surface water only was based upon Lotufo et al. (2010) that found the bioconcentration of TNT and its degradation products occurred almost entirely from the overlying water, and that contact with the sediment surface did not increase summed TNT tissue residues (Lotufo et al. 2010). It was concluded that direct contact with bed or resuspended sediments are unlikely to be significant exposure pathways for demersal fish species (Lotufo et al. 2010). As noted in Section 2.3, all explosives compounds assessed have low bioaccumulation potential, with ranges of 0.34–9.7 L/kg for TNT, 0.7–68.7 L/kg for RDX, 0.04–52 L/kg for 2-ADNT, 0.08 – 134 L/kg for 4-ADNT, and 0.1–0.5 L/kg for HMX (Table 2-3). Chemicals with BCF values < 1000 L/kg are considered non bioaccumulative (Gobas et al. 2009; EPA 1998). TNT and RDX were the two explosive compounds selected for human health assessment. Based on the literature review, aqueous TNT concentrations were consistently higher than its degradation products, both in field and laboratory simulation studies (Section 2.2), thus providing a more conservative assessment of risk. RDX is the major component of explosive ordnance used in the MITT Study Area (i.e., composition-4), and has been consistently detected in field and laboratory studies of explosives (Section 2-2). Furthermore, both compounds are well-studied with regards to bioaccumulation in aquatic organisms and potential human health impacts, with a lack of data for several of the degradation products such as nitrobenzenes (TNB and DNB).

The average maximum aqueous concentrations of explosives in water from laboratory and field studies and geometric mean bioconcentration factors (from Table 2-3) were used to determine fish tissue concentrations. The aqueous concentrations of TNT and RDX used for assessments were 0.00113 and 0.00131 mg/L respectively for the lab/field simulations, and 2.53×10^{-4} and 6.27×10^{-6} mg/L for TNT and RDX measured in field studies, respectively. Predicted concentrations in fish tissue for the lab/field simulations were 0.0035 and 0.0011 mg/kg for TNT and RDX, respectively. For the field studies scenario, estimated fish tissue concentrations were 7.86×10^{-4} and 1.49×10^{-5} mg/kg for TNT and RDX, respectively.

Table 5-1. Estimated Water Concentrations, Benchmark Values, Bioconcentration Factors, and Predicted Fish Tissue Concentrations for TNT and RDX Based on Controlled Laboratory/Field Simulations of Explosive Release and Data from Field Studies

Compound	Aqueous Concentration (mg/L)	Bioconcentration Factor (L/kg)	Estimated Fish Tissue Concentration (mg/kg)
Concentration Data from Lab/Field Simulations			
TNT	0.00113	3.1	0.0035
RDX	0.00131	2.38	0.0031

Concentration Data from Field Studies			
TNT	2.53×10^{-4}	3.1	7.86×10^{-4}
RDX	6.27×10^{-6}	2.38	1.49×10^{-5}

To evaluate potential human health concerns, the intake is compared to toxicity values determined for each chemical. The toxicity values consider the types of potential adverse health effects associated with exposures to chemicals, the relationship between the magnitude of exposure and potential adverse effects, and related uncertainties, such as the weight of evidence of a particular chemical's carcinogenicity in humans. The toxicity values used in this evaluation were set forth by the EPA (EPA 2023). The following tables presents the toxicity values:

Table 5-2. Oral Reference Doses (RfD) and Cancer Slope Factors for Selected Explosives

Compound	Oral RfD (mg/kg/d)	Cancer Slope Factor (per mg/kg/d)
TNT	5×10^{-4}	3×10^{-2}
RDX	4×10^{-3}	8×10^{-2}

Potential human health concerns are determined for both noncancer effects and potential cancer risks. Human health concerns associated with non-carcinogens is expressed as a hazard quotient and is determined based upon the following equation:

$$HQ = \frac{ADI}{RfD}$$

where

HQ	=	Hazard Quotient; ratio of average daily intake level to acceptable daily intake level (unit less)
ADI	=	Calculated non-carcinogenic average daily intake (mg/kg/day or mg/m^3)
RfD	=	Reference dose (mg/kg/day)

If the average daily dose exceeds the RfD, the HQ will exceed a ratio of one (1.0) and there may be concern that potential adverse systemic health effects will be observed in the theoretically exposed populations. If the ADI does not exceed the RfD, the HQ will not exceed 1.0 and there will be no concern that potential adverse systemic health effects will be observed.. To summarize noncancer risk for both contaminants of concern, the HQs were summed to generate a hazard index (HI) value. Exceedance of 1.0 for HI indicates a need for segregation of potential risks by organ or critical effect for further risk evaluation (EPA 1989).

Carcinogenic risk is calculated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen. The numerical estimate of excess lifetime cancer risk is calculated by multiplying the ADI by the risk per unit dose (the SF):

$$\text{Risk} = \text{ADI} \times \text{SF}$$

where

Risk = Unit less probability of an exposed individual developing cancer
ADI = Average daily intake (mg/kg/day)
SF = Cancer slope factor $(mg/kg/day)^{-1}$.

The interpretation of the significance of the cancer risk estimate is based on the appropriate public policy. EPA in the NCP (40 Code of Federal Regulation Part 300) (1990) states that:

> *"...For known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an excess upper bound lifetime cancer risk to an individual of between 10^{-4} and 10^{-6}."*

This risk range represents EPA's generally acceptable risk range for site-related exposures, or a 1 in 10,000 to 1 in 1,000,000 chance, respectively, of an individual developing cancer. Carcinogenic risks that are below the lower end of the acceptable risk range (i.e., 10^{-6}) are considered *de minimis* and require no action.

5.1.3 Risk Results

Table 5-3 presents the risk assessment results. Under all scenarios, non-cancer hazards were below 1 for all calculations, indicating that non-cancer health risks were negligible for seafood consumption under these parameters. Similarly, estimated cancer risk was below 1 x 10^{-6} for all scenarios, suggesting that excess cancer risk was negligible.

Table 5-3. Non-Cancer Hazards And Carcinogenic Risk For Consumption Of Seafood Contamination With Explosives

Receptor	Chemical	Non-Cancer Hazard Quotient	Estimated Carcinogenic Risk
Concentration Data from Lab/Field Simulations			
Adult	TNT	0.002	9 x 10^{-9}
	RDX	0.0009	8 x 10^{-8}
	Total	0.0029	9 x 10^{-8}
Adolescent	TNT	0.002	9 x 10^{-9}
	RDX	0.0009	8 x 10^{-8}
	Total	0.0029	9 x 10^{-8}
Child	TNT	0.006	7 x 10^{-9}
	RDX	0.002	6 x 10^{-8}
	Total	0.008	7 x 10^{-8}
Concentration Data from Field Studies			
Adult	TNT	0.002	7 x 10^{-9}
	RDX	0.000004	3 x 10^{-10}
	Total	0.002	7 x 10^{-9}
Adolescent	TNT	0.002	4 x 10^{-9}
	RDX	0.000005	2 x 10^{-10}
	Total	0.002	4 x 10^{-9}
Child	TNT	0.0004	5 x 10^{-10}

Receptor	Chemical	Non-Cancer Hazard Quotient	Estimated Carcinogenic Risk
	RDX	0.00001	3×10^{-10}
	Total	0.004	5×10^{-10}

5.1.4 Uncertainties and Limitations

It is important to consider that these calculations represent a highly simplified assessment of risk based on assumptions that may not be representative of realistic exposure scenarios. Firstly, estimated water concentrations were based on either laboratory/controlled field simulations of explosive release (using composition B), or from field studies of areas impacted by dumped munitions. For both scenarios, concentrations were typically assessed in the immediate proximity of explosive sources (i.e., 0.1 – 0.3 meters in distance from munitions fragments). It is assumed that the concentrations of munitions materials from field studies are significantly greater than those expended or proposed for future use in the MITT Study Area. For example, the German waters of the Baltic and North Sea, where multiple studies of explosive presence were performed (Beck et al. 2022; Gledhill et al. 2019; Maser and Streshe 2020, Maser et al. 2023), received approximately 1.6 million metric tons of toxic conventional explosives. Comparatively, the amounts of residual explosives estimated to be generated per year under the 2015 EIS/OEIS in the MITT Study Area were 4.4 metric tons per year (Alternative 1, Navy 2015). Therefore, it is important to consider that concentrations of explosives and assessments of risk based on dumped munitions sites are likely greater than those released during controlled military activities.

Secondly, these calculations only considered fish explosive exposure and accumulation from surface waters, with the contribution of sediment and diet to fish tissue residues not considered. However, measured dietary bioaccumulation factors for TNT and RDX in fish are low (range: 0.004–0.010 g/g d-1), suggesting that this route of exposure is negligible (Section 3.2.1). Similarly, the contribution of sediments to explosive uptake and accumulation in fish is low (Lotufo et al. 2010), with water being the primary route of exposure. Furthermore, these calculations did not consider the potential biotransformation products of TNT and RDX, or other contaminants such as perchlorate, hydrogen cyanide, and metals that may be produced following low-order or failed detonations. Though a few studies have assessed metal contamination in biota from areas impacted by dumped munitions, oral RfDs are not available for many of the metals associated with military testing (i.e., lead), and insufficient data is present to assess potential exposure following routine military activities. Similarly for perchlorate, a few studies were found documenting perchlorate exposure in freshwater fish from weapons manufacturing plants (Smith et al. 2001; Theodorakis et al. 2006). Though perchlorate detections in fish were sporadic, maximum levels observed (3.961 mg/kg) would likely exceed the EPA's oral RfD of 0.7 micrograms per kilogram per day. However, the applicability of these studies to perchlorate occurrence from military testing in seawater, where perchlorate is thought to occur naturally (Martinelango et al. 2006), is unclear.

Furthermore, calculation of risks was based on daily consumption of seafood that was collected from the immediate proximity of explosive sources for a period of 70 years, which is highly unlikely. BCF values used to estimate fish tissue concentrations were based on whole-body measurements, which may be an overestimation given that some studies found lower accumulation of explosives in edible portions such as filets (Beck et al. 2022; Lotufo et al. 2011). However, consumption of entire small fish has been documented in Pacific Island communities (Charlton et al. 2016); thus, the use of whole body BCFs is appropriate. Finally, measurements taken from the solution cavity of a general-purpose bomb at Vieques, Puerto Rico (85.7 and 4.12 mg/L for TNT and RDX respectively, Porter et al. 2011) were not used for health risk assessments, given that all other studies conducted measurements at greater distances from explosive sources (typically 0.1 – 1 meter). However, estimated fish tissue explosive concentrations and subsequent exposure doses based on these measurements (estimated fish tissue concentrations of 266 and 11.5 mg/kg for TNT and RDX, respectively, leading to non-cancer HQ values > 1 and carcinogenic risk > 1 x 10^{-6} for both compounds) would exceed non-cancer and carcinogenic risk thresholds by several orders of magnitude. As highlighted throughout this report, the Porter et al. (2011) study represents an extreme worst-case scenario wherein biota are inhabiting cavities of large, UXO on the benthos, leading to significant explosive bioaccumulation. The weight of evidence from other studies of areas impacted by dumped munitions suggests lower aqueous, sediment, and biota concentrations, therefore the concentrations described in Porter et al. (2011) were not used for human health risk calculations.

5.2 HUMAN HEALTH RISK ASSESSMENTS LITERATURE REVIEW

Several recent studies have considered the potential human health risks of consuming seafood contaminated with explosives and other military associated pollutants (Beck et al. 2022; Maser et al. 2023; Maser & Strehse 2020, 2021; University of Hawaii 2014a, 2014b). Most of these studies are from areas of the Baltic Sea impacted by dumped military munitions (i.e., Beck et al. 2022 Maser & Strehse 2020, 2021; Maser et al. 2023). Beck et al. (2022) analyzed the consumer risk associated with fish and mussels collected from munitions dumpsites in Kolberger Heide, Germany, using the EPA's cancer and noncancer toxicity values for TNT. Based on median concentrations of TNT in analyzed seafood products, daily consumption of 7 kg of seafood would be required to exceed a level of concern, which is higher than the estimations for Guam and the CNMI of 58 kg per year (equivalent to 0.159 kg/d) highlighted previously (Beck et al. 2022; Allen & Bartram 2008). However, consumption of mussels that contained the highest levels of TNT (maximum of 2.5 mg/kg) would exceed a level of concern, though this is based on assumed regular consumption of the most contaminated mussels from an area that is closed to marine traffic and fishing activities (Beck et al. 2022).

In a similar study, Maser & Streshe (2020) transplanted blue mussels (*Mytilus* spp.) to areas at Kolberger Heide either directly adjacent to corroding mines, or next to explosive chunks arising from recent low-order detonations during blast-in place operations and assessed levels of explosives in tissue. Mussels transplanted adjacent to corroding mines were found to offer low carcinogenic risk for potential consumers, though mussels collected from adjacent to explosive chunks were found to increase cancer risk (Margin of Expoure [MOE] lower than 25,000) based on regular consumption. Similar to the Beck et al. (2022) study, this estimate represented a worst-case scenario. Finally, the Maser et al. (2023) study of the North Sea wreck containing munitions found low concentrations of explosives in fish filets (median of 4 μg/kg TNT) that were not a concern to seafood consumers.

More relevant to the assessment of potential impacts on seafood consumers in the MITT Study Area is the human health risk assessment conducted during the ordnance reef study (University of Hawaii 2014a, 2014b). This study utilized locally important seafood species such as goatfish and Kona crab for contaminant analysis, some of which are also of importance in the CNMI. The human health risk assessment concluded that the seafood items collected (fish, invertebrates, and seaweed) presented acceptable risk to seafood consumers under average consumption scenarios, based on calculated carcinogenic risk following the EPA and Hawaii Department of Health guidelines. Seafood consumption levels for the average consumer were based on the levels recorded within the local Wai’ane community. Exceptions were noted for the hypothetical ‘high-end’ seafood consumer, defined as an individual who consumes an extremely large amount of seafood relative to the local community, where non-carcinogenic risk was elevated above levels of regulatory concern (University of Hawaii et al. 2014a). However, the ‘high-end’ seafood consumer scenario was calculated to provide a highly conservative estimate of risk that is not feasible, given this involves an unsustainable level of harvest entirely from the munitions impacted areas of the reef, and seafood consumption significantly greater than local levels. Additionally, the study considered human exposure to energetics and barium in sediments, finding no risks. Several studies conducted by the ATSDR assessed potential human consumption risks for seafood and land crabs collected from Vieques, Puerto Rico, including a site located within the naval testing area (ATSDR 2003, 2006, 2013). Based on analysis of metals and explosives, the ATSDR concluded that there were no human health risks associated with consumption of land crabs and fish (ATSDR 2003, 2006).

6. CONCLUSIONS

The present report aimed to review the literature relating to the impacts of explosives and other contaminants associated with military activities on sediments, water quality, ecological and human health. Though the review focused primarily on explosive compounds, such as TNT and RDX, metals and other byproducts were included in the review. A generic ecological and human risk assessment was performed, based on the available data for explosive presence in the natural environment or laboratory/mesocosm simulations of contaminant release. No data was available for the MITT area; thus, the assessment was not site-specific and represents a generic evaluation for potential risk. The overarching aim of the report was to determine whether the available literature supports the major conclusions of the Navy's OEIS/EIS that there are no potentially unacceptable impacts of munitions constituents on human health and the environment at the MITT Study Area. It is important to consider that the EIS/OEIS documents from 2015 and 2020 acknowledge the possibility for short-term, localized impacts on sediments, water quality, and aquatic biota (Navy 2015, 2020a); however, these are considered negligible in terms of overall impacts.

Considering the weight of evidence presented throughout this literature review, it is concluded that there are no potentially unacceptable risks from testing and training activities in the MITT Study Area on sediments, water quality, ecological and human health based on the evaluation conducted. This conclusion was based on several factors:

1. The low bioaccumulation potential of the major explosives, TNT and RDX (mean values of 3.1 and 2.38 L/kg respectively) in aquatic biota;
2. Studies focusing on explosive contamination in sediment and water at areas impacted by DMM found few exceedances of ecological benchmark values; and
3. A human health risk assessment based on the average of maximum explosive concentrations recorded across multiple studies found no elevated human health concerns associated with seafood consumption.

It is important to consider that this conclusion does not rule out the possibility for any short-term or localized impacts of military testing and training activities, only that insufficient evidence for significant long-term impacts was found. Furthermore, the majority of data found following literature review comes from areas impacted by DMM from World War II. As highlighted throughout this report, the applicability of data from these studies to exposures following routine military testing and UNDET operations is unclear. Recent laboratory studies have begun to address this issue by utilizing passive samplers and recirculating aquaria or mesocosms to assess bioavailable fractions of explosives following simulated low-order detonations (Belden et al. 2015; Lotufo et al. 2019; Rosen et al. 2018). Secondly, though some studies have considered other contaminants associated with military testing such as metals, limited information is available to assess the actual concentrations of byproducts release to the environment following routine military activities. Metal contamination in terrestrial soils and groundwater as a result of military training activities has been relatively well characterized (reviewed in Skalny et al. 2021); however, no studies are available for testing activities in the marine environment to the authors knowledge.

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