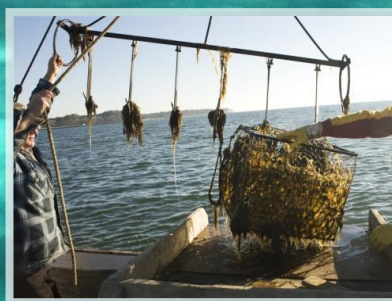
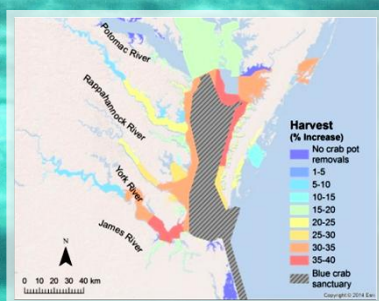
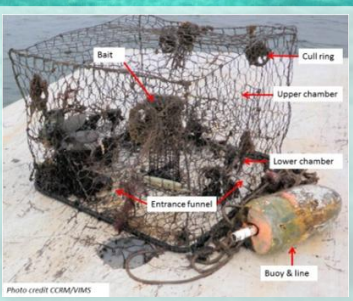


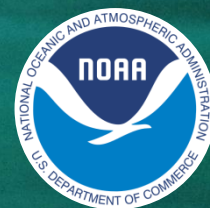
Assessing Ecological and Economic Effects of Derelict Fishing Gear: a Guiding Framework

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Executive Summary

Developing standardized protocols to assess the ecological and socio-economic effects of marine debris – especially, derelict fishing gear – is critical for the protection of natural resources and for evaluating policies and programs designed to reduce and remove debris. This document outlines a Derelict Fishing Gear Assessment Framework to guide the development and implementation of derelict gear assessment, management and mitigation. The framework draws from techniques and protocols developed to assess derelict crab traps effects in the Chesapeake Bay and on past derelict gear assessments either conducted by or known to the framework authors. However, this framework is generalized and intended to be used by any stakeholder with a need to assess the status of derelict fishing gear and its economic and ecological effects on living resources, habitats, ecosystems, and local economies. It provides a generalized pathway and processes for assessing the effects of derelict fishing gear, and is flexible and scalable so that users of the framework can make informed decisions when data are limited, and can tailor it to satisfy their specific assessment goals and objectives if a full scale assessment is not required. The framework recommends best practices for each of five key elements (**Figure 1**):

- Characterize the abundance and distributions of derelict gear and associated fisheries;
- Conduct analyses to quantify economic impacts on fishery target and bycatch species;
- Conduct analyses to determine ecological impacts on living resources and critical or sensitive habitats;
- Evaluate management implications through scenario driven economic and ecological assessments;
- Recommend appropriate management actions and strategies to mitigate negative economic and ecological impacts of derelict gear.

Descriptions of appropriate derelict gear metrics are provided with an emphasis on those variables and metrics most common among fisheries, and most likely to predict ecological or economic effects. For each of the key elements, the framework provides guidance on consistent methods for stakeholder engagement, data collection or acquisition, and data analysis.

Section 1 of this document provides a global context and motivation for assessing and managing derelict fishing gear. Section 2 outlines the framework and essential ingredients including developing conceptual models, planning an analytic approach, evaluating data, and developing quantitative models.

Sections 3, 4, and 5 describe technical details and procedures for characterizing the density and spatial distribution of active and derelict fishing gear; for mapping and quantifying vital rates to assess ecological effects of derelict gear; and for determining data needs and approaches to assess economic effects of derelict gear on fisheries. These sections emphasize detailed guidelines on required data, information, methods, approaches, protocols, as well as best practices and data gaps for each element in the framework. Each section includes descriptions of common data, data limitations, modeling, and other analytical techniques.

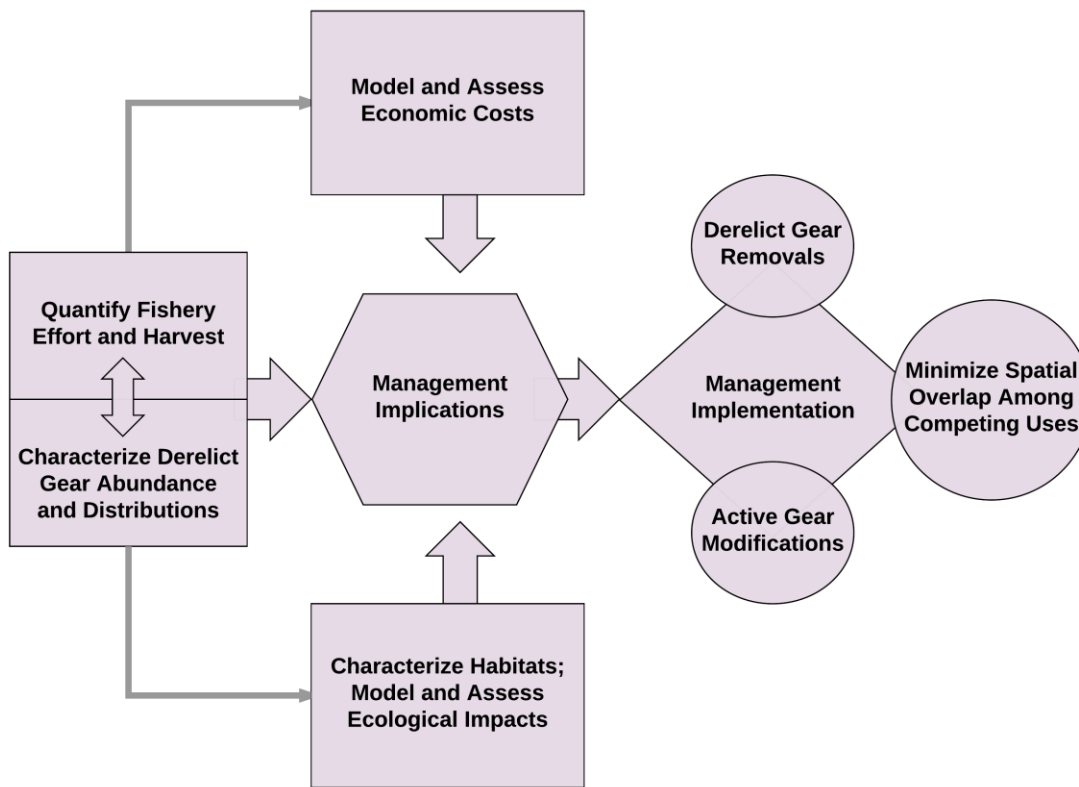


Figure 1. Conceptual assessment framework to characterize, assess, and mitigate economic and ecological impacts of derelict fishing gear on fisheries, living resources, habitats, and ecosystems.

Section 6 provides an overview of techniques used to detect and remove derelict fishing gear, so as to facilitate the collection of data needed to assess their effects on local ecosystems and economies. Many techniques to detect and remove derelict fishing gear are available and have been applied in various fisheries and habitats. A list of specific techniques and references is provided here, along with specific protocols to help guide stakeholders interested in collecting needed data to characterize derelict gear or to mitigate their effects through detection and removal programs.

The final framework element (**Section 7**) describes how a structured derelict gear assessment can be used to inform resource managers about mitigation options. This section provides guidance of how results from derelict fishing gear assessments can be used to relate the ecological and economic effects of derelict gear to management implications and understanding the factors affecting implementation of mitigating actions.

The ultimate goal of any derelict fishing gear assessment should be to determine how best to manage and mitigate derelict gear effects. This Derelict Fishing Gear Assessment Framework is designed to be a flexible, scalable, practical guide to help stakeholders meet this goal.

1. Introduction / Background

1.1 Background – NOAA’s Marine Debris Program

Marine debris (including derelict fishing gear) is a major stressor to marine ecosystems; it threatens habitats, living resources, and the provisioning of ecosystem goods and services in U.S. waters and the global oceans.¹ The Marine Debris Act, signed into law in 2006 and amended in 2012, defines marine debris as “any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or the Great Lakes.” The Marine Debris Act establishes the NOAA Marine Debris

Program “to identify, determine sources of, assess, prevent, reduce, and remove marine debris and address the adverse impacts of marine debris on the economy of the United States, the marine environment, and navigation safety.”²

Summary of Relevant Goals from the NOAA Marine Debris Program Strategic Plan

- **Marine Debris Research & Assessment** - Identify, assess and reduce the impacts of marine debris through detection, monitoring, source identification and innovative solutions.
- **Marine Debris Removal** - Support the removal of marine debris to reduce its impact on natural resources, navigational safety and the economy.
- **Marine Debris Prevention** - Prevent the introduction of marine debris through raising awareness and changing behavior.

NOAA Marine Debris Program Strategic Plan: 2016 - 2020
(October 2015)

1.2 The Problem of Derelict Fishing Gear

The accumulation and effects of derelict fishing gear (traps, pots, nets) is a global problem.³⁻⁶ Traps are fished in large numbers and high rates of trap loss plague many of the world’s crustacean fisheries (**Appendix A, Table A-1; Figure 2**); as a result, fishing traps are thought to be one of the most common types of derelict gear worldwide.⁷ This framework focuses on traps and stationary nets (*i.e.* gill nets).

Derelict fishing traps, whether lost by accident or intentionally discarded, have a tendency to continually capture animals (termed “ghost fishing”) for variable amounts of time depending upon the trap construction and material type.^{4,9-13} Modern traps are often constructed from rigid and durable materials such as vinyl-coated wire or synthetic mesh^{6,14,15} which can extend the time a derelict trap remains functional over the more artisanal traps of the past which were made mostly of wood or fiber.¹⁶⁻²⁰ Experiments in the Chesapeake Bay (U.S.A.) indicate that blue crab (*Callinectes sapidus*) traps generally retain their structural integrity for two years or more.^{1,12} Derelict traps can act as a structural attractant for crustaceans or an aggregating device for fish.²¹⁻²⁵ Blue crabs and other crustaceans are known to be attracted to traps as

Derelict fishing gear can continue to capture animals and is sometimes referred to as “ghost fishing.” Some derelict traps have been shown to continue functioning for up to 15 years.

bottom structure whether or not any bait is present; with retention rates varying according to trap design and intra- and inter-species interactions.^{4,21-23,26} Animals that are captured and die in derelict traps can attract

other animals, which then become entrapped and continue a ‘self or auto-baiting’ cycle.^{12,13,27} Catch efficiencies of derelict traps can decline over time;^{10,28} however, many trap types can continue to capture, injure, and kill animals for over two years^{4,12-14,29,30} and in some cases can remain functional for at least 15 years.³¹ More durable traps made of predominantly synthetic material may cause ecological and economic damage for many years.³²

In addition to the direct loss of target species in derelict traps due to mortality, derelict traps impose an economic cost in terms of reduced trap efficiency by competing with active traps for the target species resulting in a hidden non-harvestable allotment of target species associated with derelict traps. This loss of harvest can compromise the economic vitality of fishery dependent businesses and communities.⁸

Derelict fishing gear can affect harvest by:

- **Direct mortality of target species**
- **Competition with active gear for target species.**

In the Chesapeake Bay, extensive gear removal programs between 2008 and 2014 increased blue crab harvest by 38 million pounds (23.8%) over the six year period.³³ For the U.S. Atlantic and Gulf state blue crab fisheries, extensive gear removals might increase landings by over 40%, generating US \$62 million in annual revenue benefits. However, large-scale location and removal of submerged, unbuoyed traps requires expensive equipment and may not be practical over large areas or for extended periods. Fortunately, intensive (focused) removals of derelict traps from a few heavily fished areas can also increase local harvests. In the Chesapeake Bay, removing as little as 10% of the total number of recovered derelict traps from the 10 most heavily fished areas (five in Virginia and five in Maryland) increased the Bay-wide blue crab harvest by 14%.³³

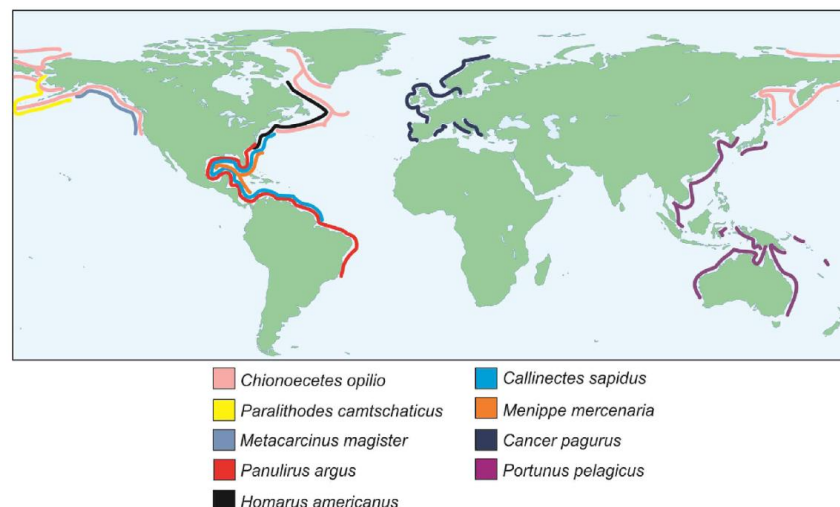


Figure 2. Global distribution of major crustacean pot and trap fisheries.⁸

Total global landings from all crustacean trap fisheries grossing US \$20 million or more annually (**Figure 2**) average 615,560 MT and are worth US \$2.5 billion (**Appendix A, Table A-2**). Together, these high-value fisheries deploy tens of millions of pots and traps, millions of which

Removal of just 10% of derelict traps in the world's largest crustacean fisheries could increase harvest by \$831,000,000 annually.

become derelict each year. Extending findings from Chesapeake Bay blue crab to global crustacean fisheries suggests that removing less than 10% of the derelict pots and traps in these

fisheries could increase landings by 293,929 MT, at a value of US \$831 million annually.^{8,33} Net benefits of removal programs will ultimately depend upon trap location and removal costs however, which may vary widely.

1.3 Purpose and Scope

Derelict fishing gear is a major concern for coastal resource managers, given its widespread occurrence and its far-reaching negative ecosystem impacts. To guide characterizations and assessments of the impacts of derelict fishing gear on marine ecosystems, and the fisheries they support, we propose a Derelict Gear Assessment Framework as a guide for local assessment and management of derelict fishing gear problems. It provides a generalized but scaled approach for assessing derelict fishing gear impacts; describes requisite data and information needs for a comprehensive assessment of ecological and economic impacts; and where possible, recommends best practices and management actions to remove and prevent accumulation of derelict fishing gear and ultimately to mitigate economic and ecological impacts.

This Framework is modeled after a recent comprehensive characterization and assessment of derelict crab traps in the Chesapeake Bay region.³³ It is applicable to the assessment of derelict fishing gear impacts in general and provides a standardized approach for managing derelict gear and mitigating their impacts on ecosystems nationally.

1.4 Intended Audience

This Framework is primarily intended for NOAA Marine Debris Program managers, policy makers, natural resource managers, and others who perform work or receive sponsorship under NOAA's Marine Debris Program or follow its guidelines and regulations concerning marine debris. The style, language, terminology and concepts described here are intended to be useful to a diverse audience including Federal, State, and local agencies, scientists, members of the general public, and other stakeholders who may need to characterize marine debris or assess its economic and ecological impacts on living resources, habitats, ecosystems, and local economies. We hope that this report will be a first step in developing a broad scientific consensus about assessments of derelict gear.

Chesapeake Bay Case Study

The Chesapeake Bay Blue Crab fishery. The guiding framework detailed here was initially developed for and applied to the Chesapeake Bay³³, the largest estuary in the United States with a fishing industry worth more than \$3 billion a year and accounting for 50% or more of the nation's blue crab (*Callinectes sapidus*) harvest. The primary gear used to harvest blue crabs in the Chesapeake Bay is a rigid cube-shaped wire trap, or "crab pot," galvanized or vinyl-coated, and deployed and recovered by a line and buoy system. Commercial fishery effort is estimated to be ~600,000 pots annually.³⁴

Blue Crab management: one population, three sets of rules. Chesapeake Bay blue crab is a single population, but it is managed differently in the Maryland, Virginia, and Potomac River portions of the Bay. Management actions are partially linked to the complex life cycle of the blue crab, which involves multiple horizontal and vertical migrations, often across state boundaries. Blue crabs rely on high salinity areas in the lower Bay for egg brooding and hatching, larval development, and overwintering,³⁵⁻³⁷ they inhabit low salinity waters of tributaries and creeks in the spring and summer,³⁵ and when temperatures drop below 9°C they congregate in deeper water and bury in muddy sediments.³⁸⁻⁴⁰ Spatial patterns of fishing effort follow the crabs' migration; most crab pots are deployed in waters less than 10m deep, in the mainstem of the Bay and (in Virginia) in its tributaries.^{41,42}

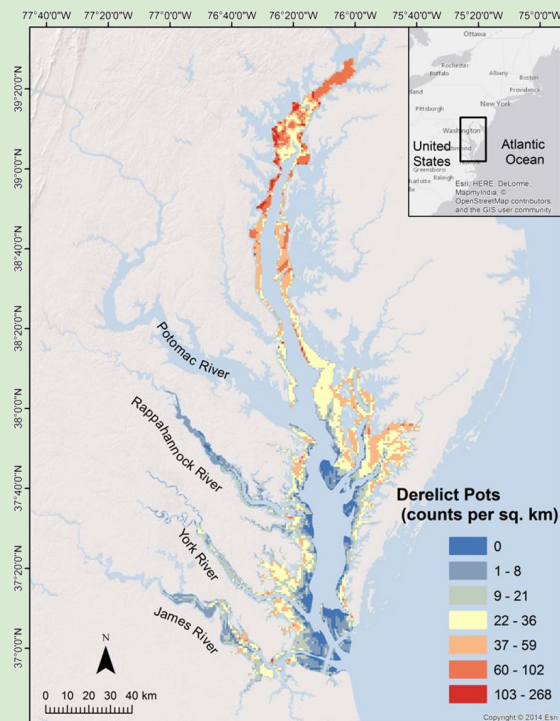


Figure 3. Spatial distribution of derelict crab pots in the Chesapeake Bay estimated through geographically weighted regression.³³

Data collection. In order to evaluate the ecological and economic impacts of derelict crab pots, information was first compiled to determine 1) the distribution and abundance of derelict pots, 2) bycatch capture and mortality, 3) potential damage to sensitive habitats, and 4) the effect on harvest due to competition with derelict traps. After learning of potential causes of pot loss from fishers and managers, the distribution of derelict pots was compared statistically with these potential causes including boat traffic, storm events, and intentional abandonment.

Data analysis. The study integrated many datasets using a Biogeographic Assessment Framework⁴³ to

- identify variables that could predict the distribution and abundance of derelict crab pots,
- model, estimate, and map the densities and spatial distributions of derelict crab traps, and their impacts on populations of crab and other fish and on sensitive habitats;
- estimate potential impacts of derelict crab trap removals on commercial blue crab harvests;
- conduct sensitivity analyses to identify ways to mitigate the impacts of derelict crab pots.

Findings and insights.

- Trap loss was due primarily to boat traffic (severing buoy lines, displacing gear) and abandonment (due to aging gear, sickness or death of fisher, other).
- Using fisheries independent effort data led to better estimations of derelict fishing gear abundance in areas with large management units such as the Maryland mainstem portions of the Bay.
- Each year, derelict pots kill over 3.3 million blue crabs across the Chesapeake Bay (4.5% of the harvest).
- 12-20% of crab pots are lost each year; this implies over 145,000 derelict pots in the Bay at any given time.
- Over 40 fish species have been reported captured in derelict pots, including economically important ones. Each year derelict pots kill over 3.5 million white perch and nearly 3.6 million Atlantic croaker.
- Extensive gear removal programs spanning 2008-2014 increased blue crab harvest by 38 million lbs over the 6 year period. In addition, targeted gear removals from a few high-density fishing areas disproportionately increased harvests Bay-wide.

Management actions.

- Minimize boat traffic in crabbing areas, and educate boat operators about avoiding pots to reduce pot loss.
- Conduct targeted derelict pot recovery programs to reduce bycatch mortality and to increase catch efficiency from lost pots. Also incentivize the removal of abandoned pots by fishers themselves.
- Equip crab pots with biodegradable escape panels to minimize bycatch mortality from lost pots.

2. Derelict Fishing Gear Assessment Framework

Like traps, other fishing gear affects both the living resources being targeted as well as the surrounding habitats in which they live. In turn, the heterogeneity of the seafloor and habitats, patchy distributions of targeted living resources, and environmental factors such as seasons, storms, and wave action, all affect the location and accumulation of derelict gear. Additionally human demography, behavior, as well as availability of access to the marine environment directly affect the location and intensity of fishing effort, which ultimately determines the occurrence of derelict gear. Developing strategies to manage derelict gear requires a comprehensive approach for characterizing the spatial and temporal distributions of derelict gear, assessing their economic and ecological effects, and implementing management strategies to mitigate their negative impacts on living resources, habitats, and the marine ecosystems.

The Framework presented here represents such a comprehensive approach. It provides a five-phased linear process model for characterizing, assessing and mitigating ecological and economic impacts of derelict fishing gear on managed living marine resources, habitats, and ecosystems (see **Figure 1, Executive Summary**). It identifies generalized pathways and processes needed to:

1. Characterize spatially explicit abundance and distributions of derelict gear and their associated fisheries
2. Conduct analyses to quantify economic impacts on fishery target and bycatch species
3. Map and characterize benthic habitats then conduct analyses to determine ecological impacts on living resources and critical or sensitive habitats
4. Evaluate management implications through scenario driven economic and ecological assessments
5. Recommend for implementation, appropriate management actions and strategies to mitigate negative economic and ecological impacts of derelict gear

Subsequent chapters provide more detailed guidelines on required data, information, methods, approaches, protocols, as well as best practices and data gaps for each phase of the framework. In addition, the Framework provides a tiered approach which allows for informed decisions based upon various levels of available data and to adaptively manage impacts of derelict fishing gear based upon the particularities of the specific fishery of interest.

Developing a comprehensive framework to manage derelict gear and mitigate their impacts involves developing conceptual models, designing an appropriate analytic approach, evaluating data to determine minimum requirements, and developing quantitative models.

Conceptual models. An important first step is to develop conceptual models based on sound ecological theory but which are also grounded in socio-economic reality (**Figure 4**). Conceptual models are hierarchical theoretical constructs visualized in flow diagrams to show qualitative relationships among components that represent dependent and independent variables within complex systems. These models are widely used in systems ecology to hypothesize about direct and indirect relationships among various biotic and abiotic elements within a defined and bounded system.^{44,45} A conceptual model will provide a systematic approach for

- (a) identifying components of the ecosystem that could be directly or indirectly affected,
- (b) evaluating their relative contribution to hypothesized ecological and economic effects, and
- (c) hypothesizing further about possible ways to mitigate negative impacts.

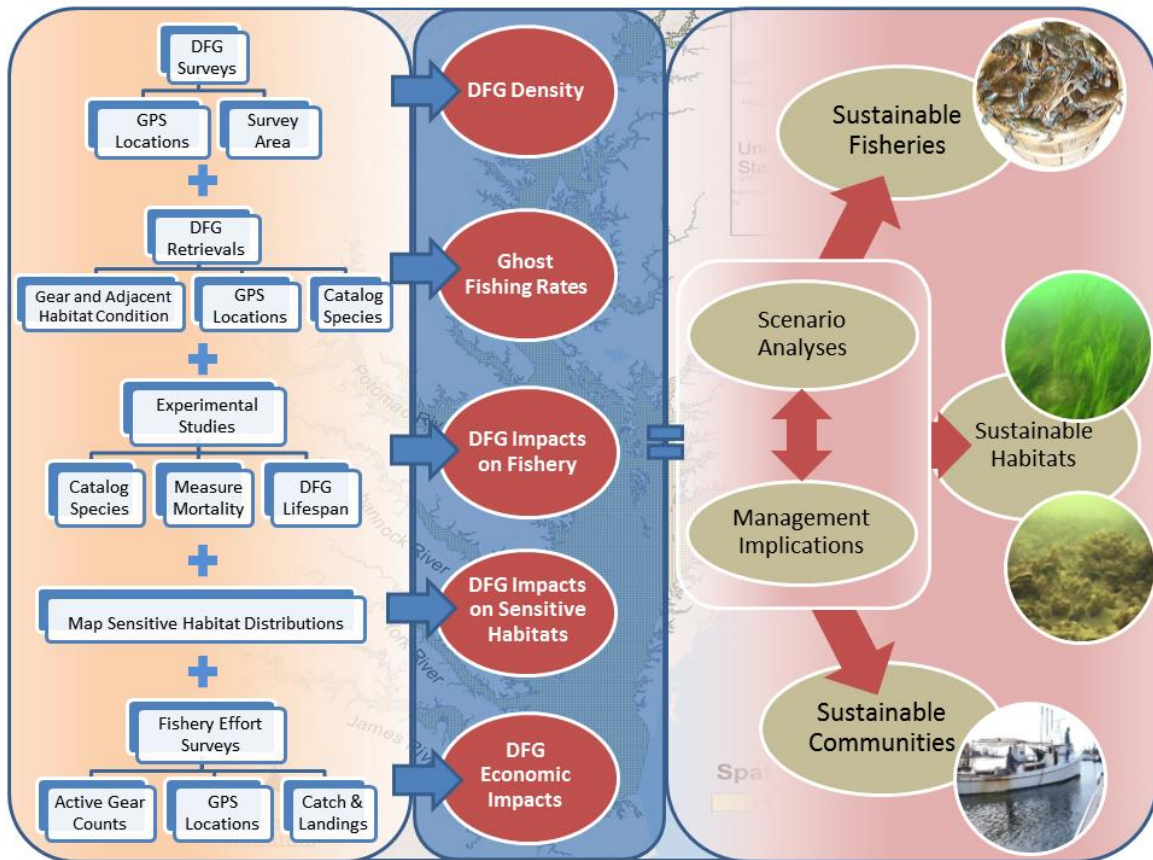


Figure 4. An operational (tiered and practical) assessment framework for derelict fishing gear. Critical / minimum data on derelict fishing gear (DFG) (left panel) enable analyses, metrics, and indicators (middle) required to mitigate DFG economic and environmental impacts for long-term sustainability (right).

It is important then that conceptual models be based on exhaustive reviews of the scientific literature on fisheries and derelict gear. In addition, input from local experts, non-scientists, and fisher-folk who are most familiar with local fishery issues will be substantially beneficial.

Design the Analytic Approach. Designing and planning a suitable analytic approach is critically important for developing a framework. Planning is useful, not only for developing higher level project goals and objectives, but also for developing specific guidelines for conducting quantitative data analyses, ensuring the use of statistically defensible analyses, and increasing the likelihood of achieving unambiguous results. Given the paucity of quantitative information regarding ecological impacts of derelict gear, it is essential to develop simple but realistic hypothesis-driven analyses that will support the higher-level goals and objectives of a derelict gear impact assessment project. At the same time, question driven analyses regarding derelict gear impacts should be developed within the broader context of the socio-economic, ecological, and management issues related to the fishery to ensure the most critical and influential factors are being considered.

Planning involves iterative refinement of the hypothetical relationships among conceptual model components as well as adding or eliminating input variables based on initial exploratory analyses of data, additional literature review, and consultation with management agencies, NGOs, and other stakeholders. During the planning stage, it is also necessary to develop a

spatial framework for analysis that defines both the spatial extent of the study area and the resolution of the data (*i.e.* level of detail) needed to characterize derelict gear and quantify ecological and economic impacts. An output from sound planning will be the identification of a reduced list of input variables that correlate significantly with dependent variables and which could be used as predictors of dependent variables that are sparse or expensive to obtain or collect (**Figure 4**). Ideally, input variables should be ubiquitous with broad spatial and temporal coverage and correlate significantly with dependent variables of interest that are sparse.

Evaluate Data and Determine Minimum Requirements. Obtaining primary data on the occurrence and distribution of derelict fishing gear can be prohibitively expensive. Hence, relevant data regarding the types, distribution, occurrence, and ecological or socioeconomic impacts of derelict gear is unavailable in most fisheries. Except for a handful of targeted derelict fishing gear removal programs (such as exist in the Chesapeake Bay), much of the existing knowledge regarding derelict gear and their impacts derive from secondary data sources and disparate programs designed to collect other fisheries-related or ecological data. Consequently, data to be used for characterizing derelict gear occurrence and distributions and inferring ecological impacts must be carefully evaluated for their suitability to these intended purposes.

Evaluating data to assess derelict gear impacts includes determining the best and most appropriate data sources; assessing each dataset's geographical, temporal, and compositional extent and associated gaps; and understanding the uncertainty, errors, and associated caveats of the data. Crucial considerations for evaluating data include the following:

- Are the data of appropriate spatial and temporal coverage?
- Do datasets contain enough observations for robust statistical analyses?
- Can disparate datasets be merged for broader spatial and temporal coverage without violating the statistical assumptions underlying the initial data collections?
- Will extrapolations of integrated data across geographic space and time provide ecologically meaningful relationships rather than spurious associations?

Develop Quantitative Models. Model development involves the use of empirical data to test and validate theoretical constructs and hypothesized relationships through explicit mathematical functions. Quantitative models consist of three main parts: a **response variable** whose value changes as observational data inputs into the model change, a **mathematical function** with main effect variables and estimated parameters that predict the value of the response variable, and **random errors** that vary systematically according to known statistical distributions. Modeling requires a fundamental understanding of how the main effects and errors are propagated through the modeling system.

A wide variety of modeling approaches are available for use; all share three common steps:

- (1) Selecting an initial model form that would be best suited to the data assembled;
- (2) Iteratively fitting the model to the assembled data to estimate unknown parameters; and
- (3) Independently validating the model results against known data to see if the underlying model assumptions are plausible.

Sections 3, 4, and 5 below illustrate the iterative use of various modeling techniques to characterize derelict gear density and spatial distribution; to assess ecological impacts to bycatch and sensitive habitats; and to determine economic impacts to the fishery.

3. Characterizing Derelict Gear Density and Spatial Distribution

3.1 Overview

Characterizing the spatial distribution of derelict fishing gear is crucial for inferring their ecological and economic impacts in marine ecosystems. The accumulation of derelict fishing gear in many aquatic systems varies spatially and temporally. To obtain unbiased estimates of the quantity and spatial coverage of derelict gear within an area of concern, it may be cost-effective to model gear abundance and distribution, especially for large areas where comprehensive detection surveys and removal programs may be too expensive. When developing a model to estimate abundance and occurrence, it is important to select a suitable spatial resolution that matches the scale at which ecological inferences will be made and at which management decisions to mitigate derelict gear impacts will be effective. Often, selection of an optimal spatial resolution for analysis is constrained by the resolution of data available and depends on the analytic specific analysis being conducted or question being investigated. Derelict gear estimation may require further data collection to refine the spatial domain and extent of analysis. A variety of approaches can be used to estimate gear abundance and occurrence, however the method and data used for these estimates will have different biases and limitations.

3.2 Use of Various Types of Datasets

Many types of fisheries-related information may be used for initial characterization of derelict gear. For example, fisheries effort data on the amount and location of active gear sets, combined with reports from fishers about their average rate of gear loss, could be used to derive estimates of derelict gear accumulation. Estimates from such data will be constrained by the size or spatial scale of the management units applicable to the fisheries data. Additionally, fisheries data and reports of gear loss from active fishers may be subject to various biases such as the number of individuals interviewed, regional differences, methods or techniques used by different fishers, or the fishery regulations under which they operate. For example, incentive programs that compensate fishers for lost gear may lead to overestimating rates of gear loss. Conversely, fishers may underreport effort data if they are subject to regulations that penalize violations of gear limits. Depending on the goal, this type of derelict gear estimation may nonetheless be adequate for a coarse understanding of amount and location of gear.

Data on derelict gear occurrence can also be obtained from gear retrieval programs. These often have a limited spatial coverage because their implementation costs are relatively high; however georeferenced data from such programs can be used to estimate (predict) gear abundance over larger spatial coverages through geospatial modeling (below).³³ However, it is important to understand potential biases inherent in this type of data. For example, interpreting and standardizing data from retrieval events requires estimating the retrieval effort: how did search efforts (number of hours, number of individuals involved) vary across the recovery area? Were there different techniques that would lead to different recovery efficiencies? *etc.* Furthermore, dataset normalization can help stem issues with false zeroes or seemingly low or high derelict gear abundances. So while overall concentrations and effects of derelict gear information can be

inferred from gear retrieval efforts, they are influenced by a wide range of factors. Before making broad spatial inferences, it's important to have a clear understanding of these factors throughout the system, and to collect data from a range of areas.

Depending on the amount and quality of data available, a wide range of spatial techniques may be used for estimating derelict gear quantity – from simple multiplication, kriging, and interpolations, to advanced spatial modeling. Modeling requires (i) an understanding of the factors that may lead to gear loss and accumulation, (ii) spatial data for those factors, and (iii) a known relationship between them. This relationship can be developed using training data or a set of locations with known derelict gear abundance along with corresponding factor data at those locations. A key advantage of this technique is being able to predict gear abundance at different locations when only condition or factor data is available. However, the model's prediction power is only as strong as the modeling relationship between known derelict gear and contributing factors. As with many modeling techniques, it is important to limit predictions within spatial coverage of the training data and training factor values.

4. Assessing Ecological Effects of Derelict Gear

4.1 Overview

Ecological effects of derelict gear can occur at a variety of spatial and temporal scales and through several pathways ranging from simple direct interactions with habitat and living organisms to more indirect but complex relationships among dynamic populations, sensitive habitats, and the fishery. For most managed areas and fisheries, sufficient data do not exist at the required spatial coverage or temporal and spatial scales to fully define the ecological relationships between derelict gear and the various components of the marine ecosystem. As such, the framework provides a systematic and scalable approach for integrating existing data and other information on derelict gear, target and bycatch species, and sensitive habitats to characterize and assess ecological impacts from derelict gear over broad spatial scales. The approach involves using GIS-based models to

- (1) predict densities and define the spatial distribution of derelict gear,
- (2) apply estimated derelict gear capture and mortality rates obtained from experimental studies to spatial distributions of target and bycatch species, and
- (3) define the spatial overlap between derelict gear distributions and sensitive habitats.

4.2 Mapping / Quantifying Bycatch Species

Quantifying ecological impacts of derelict gear on bycatch species requires information on catch species composition, rates of gear capture and mortality, and spatial distribution of non target species. Experimental field studies can provide crucial and representative data on catch composition and mortality rates if they are conducted over extended periods and investigators track and record the condition of trapped individuals with enough frequency. However, field experiments require rigorous and time intensive field work that may be too difficult and expensive to implement over large areas and sample sizes. In addition to field experiments, valuable but conservative data on species composition, capture, and mortality from gear could be

obtained also from large retrieval programs that periodically remove gear, if the composition and condition of the catch is noted when gear is removed. One caution is that seasonal and spatial variability may prevent the use of incidental bycatch data in deriving annual catch and mortality estimates for derelict gear. In addition, observed estimates of mortality, even from experimental studies, may underestimate actual gear mortality unless delayed mortality from injury, stress, infection, and fatigue are also considered.^{6,10,44}

Bycatch species in derelict gear may include both managed and unmanaged species. Economically important non-target species or threatened/endangered (T&E) species that are managed and/or well-studied may have available data on distributions, abundance, and harvest that can greatly help inform potential adverse effects from derelict gear including direct and indirect mortality or damage to essential habitat. There may also be enough of the requisite data available for non-target non-fisheries species that are well-studied. For example, Diamondback terrapin (*Malaclemys terrapin*) is a species that is at high risk to mortality from active or derelict crab traps.^{47,48} In many regions, there are limited data on population sizes for this non-fisheries species; however, the habitat requirements for terrapin are well understood and mapping important habitats could serve as a surrogate measure for potential risk to the population. This approach could also be used for other T&E species with historically low populations that make mortality estimates challenging. Those species that are not managed or well-studied may require additional directed studies to assess specific capture and mortality rates caused by derelict gear.

4.3 Quantifying Mortality Rates

In order to establish a sustainable fishery, it is necessary to effectively manage the primary sources of fishing mortality, including losses due to derelict gear.⁴⁹ Animals captured in derelict gear, including invertebrates, finfish, turtles, birds, and mammals can starve, cannibalize each other, drown, develop infections, and become diseased.^{4,10,48} Certain crustaceans are known to be aggressive and cannibalistic (*e.g.*, blue crab, *Callinectes sapidus*), and confinement in traps causes death or injury to conspecifics and bycatch.^{4,23,25} Mortality rates in derelict traps vary among fisheries. For example, in the Korean blue crab (*Portunus trituberculatus*) fishery, the elimination of ghost fishing mortality by derelict traps was modeled to have a 14% increase in catch⁵⁰ while Dungeness crab mortality in derelict traps is estimated at 7%, 4.5%, and 2.2% of the harvest in various locations along the west coast of North America.^{27,28,30} In the Chesapeake Bay, mortality due to derelict crab pots is estimated at about 5% of the harvest.³³

Cryptic or unaccounted mortality resulting from derelict gear has been increasingly recognized as a source of mortality that can be managed.^{6,33,49,51} Collecting essential baseline data for calculating instantaneous and annual bycatch mortalities by gear type is an important consideration for any derelict gear recovery program⁵² but adequate data is often lacking and, thus, is not routinely accounted for in fisheries management.

Data on mortality rates require experimental studies and field observations. Ghost-fishing mortalities can be estimated either by monitoring the number and fate of animals that became captured, or by placing captive animals in the gear and monitoring their fate over time, with monitoring conducted *in situ* directly by divers and video surveys, or by retrieving a subset of the derelict gear at various time intervals.⁴⁹ Various methods for deriving mortality per unit period of time for derelict traps and nets are discussed in some detail elsewhere.^{4,6,49,53,54}

4.4 Mapping Sensitive Habitats

Benthic habitat and living resource maps often characterize and delineate the spatial extents of important ecological areas such as areas of high productivity and biodiversity (hotspots); locations of special features, communities and key species that are critical to ecosystem function and resiliency (*e.g.* submerged aquatic vegetation, coral reefs, or oyster beds); or rare, endangered or functionally vulnerable marine resources (*e.g.*, sea turtles). When these maps are combined with georeferenced data on derelict gear occurrence, density, and distribution, the degree of spatial overlap between derelict gear and sensitive habitats can be measured and used as a proxy for estimating ecological effects at a broader ecosystem level.

The most obvious ecological effect of stationary fishing gear is direct physical disturbance to the seafloor. In addition to direct observations of fisheries gear-habitat interactions from field and experimental studies, the cumulative ecological effects of derelict gear deployed over large areas can be estimated. If the locations and spatial extents of fishing gear and important habitats are known, then the degree of interactions between derelict gear and sensitive habitat could be inferred through geospatial modeling. In the U.S., large investments in mapping by government agencies (*e.g.*, BOEM, NASA, NOAA, USGS) and the private sector (*e.g.*, Google, ESRI), along with recent improvements in remote sensing technologies (*e.g.*, satellite, lidar, hydro-acoustic sonar) have created a plethora of high resolution (< 100m) benthic and living resource distribution maps for many managed areas. Where such maps are not available, qualitative data from fishers and other local experts on intensity of various human uses and location of targeted resources can be captured through participatory mapping and used to delineate perceived ecologically important areas.

Important caveats are that maps should be comprehensive in their spatial coverage (*i.e.* fully represent the study area of interest), have suitable spatial resolutions, and have relatively high map accuracy (*i.e.* users must have a high degree of confidence in the map) if they are to be used effectively in identifying ecological effects over broad spatial scales. As an example, when modeled distributions of derelict pots in the Chesapeake Bay were intersected with distribution maps of two sensitive habitats (submerged aquatic vegetation and oyster beds), results suggested minimal spatial overlap between derelict gear and these habitats of concern.³³ It is likely that blue crab operators generally may be avoiding crabbing in submerged aquatic vegetation and oyster habitats. However, anecdotal data from trap removal studies suggest that derelict traps do occur in some areas with submerged aquatic vegetation. One likely explanation is that National Environmental Policy Act requirements restricted derelict pot removal from sensitive habitats, and that model predictions of derelict trap spatial occurrence may have been underestimated. In addition, although extensive portions of the Chesapeake Bay have been mapped for sensitive habitats, spatial coverage of the maps is not 100%, and this could also have led to underestimating the degree of spatial overlap between sensitive habitats and derelict trap distributions.

5. Assessing Economic Costs of Derelict Gear

5.1 Overview

Economic costs imposed by derelict gear can result through a variety of mechanisms, which may vary according to attributes of the fishery, ecosystem, and broader region under consideration. Major categories of costs include: decreased harvests, habitat damage, hazards to navigation, and replacement gear.³³ To measure these costs, a number of different models can be applied to collected and available data. Assessing the economic impacts of derelict gear frequently requires comparing *status quo* economic outcomes and valuations against a hypothetical of no or minimal levels of derelict gear (*i.e.*, what economic outcomes or values would be without derelict gear). This section discusses fisheries data and four categories of economic costs, together with general models and data needed for empirical estimation.

5.2 Characterizing Fishing Effort and Harvest

Integral to understanding the distribution and the potential impact of derelict fishing gear is the knowledge of both fishery effort and fishery harvest. Fishing effort, or the measure of amount of fishing activity, is often estimated through the combination of effort put into the fishery such as the number of hours or days spent fishing and the amount of gear used. Harvest data is generally reported as the amount of the target species caught and retained from a given area for a given period of time.

Both effort and harvest data can be collected from fishery-dependent sources (direct reporting from the fishery such as vessels or seafood dealers) or from fishery-independent sources. Fisheries scientists or managers often collect fishery-independent data while conducting resource-monitoring projects. Although fisheries-dependent data is often easier and cheaper to obtain, it is hard to determine its accuracy especially if there is skepticism for potential bias. As noted earlier (Section 3.2), special consideration should be taken to review all potential sources of bias when fisheries-dependent data is used and to plan for ways to mitigate the bias either through conversion or using different sources. Fishery-independent sources often provide less biased information and can be tailored to specific applications. Furthermore, effort data reported at the state level or for large management units may be too coarse to be used in impact assessments when derelict gear presence may vary at more fine spatial scales. Depending on the fishery and the spatial and temporal scale of the derelict gear assessment, it may be necessary to use fisheries-independent data to obtain the spatial and temporal resolution needed.

5.3 Decreased Harvests

Derelict gear may decrease commercial and recreational harvests of target and bycatch species. Reductions in harvests arise as a result of reductions in stock as well as from the reduced efficiency of actively fished gear. Stock reductions may be significant in fisheries with high rates of capture and mortality of target and bycatch species by derelict gear. If derelict gear leads to large stock reductions, commercial and recreational harvests may also decrease as there is less biomass available to the fishery. Decreased gear efficiency may be significant in fisheries where effort is spatially concentrated and where derelict gear acts as an attractant to

target and bycatch species (*e.g.*, as artificial habitat). If derelict gear attracts and/or captures a substantial amount of target or bycatch stocks, commercial and recreational fishers might catch and harvest less than they would otherwise (*i.e.*, active gear will be less efficient in the presence of derelict gear). The economic costs of harvest reductions can be quantified in terms of lost revenues (commercial), lost utility (recreational), or increased fishing costs (commercial and recreational). Note that recreational fishers may derive non-consumptive benefits through catch-and-release fishing, in which case changes in catch, and the associated changes in utility, would be most relevant.

To evaluate economic losses arising from harvest reductions, commercial and/or recreational harvests should be modeled. A common specification for harvest is:

1.
$$H = qEX$$

In equation (1), harvests (H) are specified as a function of effort (E), the stock of fish (X), and a scale factor known as a catchability coefficient (q). Derelict gear may affect both the stock of fish (stock reduction) as well as catchability (efficiency reduction). The total difference in harvest attributable to derelict gear can be specified as:

2.
$$\Delta H = H - \tilde{H} = qEX - \tilde{q}\tilde{E}\tilde{X}$$

where \tilde{H} , \tilde{q} , and \tilde{X} are the harvest, catchability, and fish stock, respectively, in the absence of derelict gear. Equation (2) is thus the difference between harvests with and without derelict gear. If derelict gear significantly reduces the stock or gear efficiency, (2) would yield a negative value indicating harvests would be higher if derelict gear were not present.

The data needed to evaluate (2) will depend on which mechanism of harvest loss is being modeled. In all cases, data on harvests, effort and stock is required. When modeling harvest losses arising from stock reductions, it is necessary to estimate \tilde{X} . This can be done using population models which explicitly incorporate the effects of derelict gear (*e.g.*, as an additional source of mortality). Data on derelict gear mortality rates and other factors entering a model of stock dynamics (*e.g.*, growth and maturity rates) would therefore be necessary in estimating \tilde{X} . Modeling losses due to decreased gear efficiency requires estimating \tilde{q} . An estimate of \tilde{q} can be derived through comparison of harvests across areas and/or times when derelict gear is and is not present, or is present to varying degrees, controlling for the effects of differences in effort and stock. Scheld *et al.*⁸ derived an estimate of \tilde{q} by incorporating derelict gear removals into a spatially explicit harvest model. Data on the amounts and location of derelict gear (or removals) and harvest is required to estimate \tilde{q} .

5.4 Habitat Damage

Derelict gear can cause physical damage to coastal and marine habitats, primarily as a result of gear movement and scouring. The economic costs of habitat damage may be significant in areas with sensitive or ecologically important habitats, where strong currents, tides, or storm events cause substantial movement of derelict gear. Assessing the economic costs of habitat damage requires estimates of habitat value and the response of habitat to derelict gear.

Habitat may be valued as an input to production of ecosystem goods and services (*e.g.*, clean water or biomass) or as an offset to expenditures on man-made goods/services (*e.g.*, for storm protection). Values for these goods and services can be drawn from available data and the

published literature or estimated by the analyst. Once value estimates are obtained, a mechanistic model is necessary to understand how a particular habitat provides the good or service and how changes in the amount or extent of that habitat affect provision, and therefore habitat value.

The impact of derelict gear on a specific habitat can be found through observation and experimentation. Once habitat response to derelict gear has been determined, this information can be used together with value estimates and the mechanistic model to assess changes in value resulting from changes in the amount or location of derelict gear. Total costs or losses from derelict gear can be found through counterfactual comparisons (*i.e.*, comparing habitat value with and without derelict gear). Data requirements will depend on the habitat being valued and the specific empirical models used, though in general, data on the amounts and values of ecosystem goods and services provided by the habitat, as well as habitat response to derelict gear will be necessary.

5.5 Navigational Hazard

Derelict gear may pose a navigational hazard to commercial or recreational vessel traffic. Economic costs result from necessary changes in navigation to avoid derelict gear as well as damage to vessels and equipment. Costs may be significant in areas with heavy commercial or recreational traffic.

Quantifying the costs of derelict gear resulting from increased hazards to navigation requires a model of route planning or navigation decision-making and/or vessel and equipment damage assessments. Fuel, labor, and materials/equipment costs of vessel traffic patterns with and without derelict gear can then be evaluated and used to assess costs. Data on vessel traffic, vessel and equipment damage, as well as amounts and location of derelict gear would be necessary to evaluate these costs.

5.6 Replacement Gear

Fishers may ultimately need to replace the derelict gear. Replacement gear represents an economic loss if it would have been more cost effective had the gear not become derelict. These costs may be significant when gear is costly, when behavioral changes to reduce loss are inexpensive, or if derelict gear physically damages active gear. Note that simply summing expenditures on new gear to replace that which becomes derelict will likely produce an overestimate of economic losses.

To accurately assess the economic costs of replacement gear, depreciation in value for the gear which became derelict would need to be estimated. Additionally, if gear loss could have been avoided through changes in fishing practices (*e.g.*, spatial or temporal shifts in effort), the costs of such behavioral modifications should be deducted (*i.e.*, current fishing practices offer cost savings which should be accounted for). If derelict gear physically damages active gear through movement or entanglement, the costs of these damages should also be included. The replacement costs or lost value of purposely abandoned gear should not be considered—had the gear been of any value to the fisher it would not have been abandoned. The data necessary to evaluate replacement gear costs include the cost of new gear, depreciation rates, age of gear when it becomes derelict, the costs of behavioral modifications to avoid loss, and estimates of damage to actively fished gear.

6. Detecting and Removing Derelict Fishing Gear

6.1 Overview

Derelict fishing gear detection and removal methods depend upon the type of gear and the physical characteristics of the environment in which the lost gear is located. However, some basic guidance and essential baseline data collection is applicable across a suite of stationary gear types and can be helpful in providing critical information on the ecological and/or economic impacts resulting from derelict gear.

6.2 Derelict Gear Detection

In remote sensing there are generally two important criteria: detection and identification. Detection refers to the observation of a potential object of interest while identification reveals the object as a specific type.⁵⁵ Various remote sensing survey methods exist in regard to derelict fishing gear ranging from visual to acoustic (**Table 1**). Visual surveys can utilize divers with or without surface supplied air or involve surface observers scanning an area for easily observable lost gear. Acoustic surveys (*i.e.* side scan sonar) are a form of remote sensing where the acquisition of information is obtained using a detection system based on the reflection of underwater sound waves. Morison and Murphy⁵⁶ summarize projects using these methods to detect and identify derelict traps. The basic approach and application of these methods could be used to detect and identify any type of derelict fishing gear. Side scan sonar has been shown to be very useful in detecting and identifying derelict fishing gear not only because of the detection capability but also the GPS tagging of the object location for future recovery.

Bottom trawling or grappling is a direct survey method that usually involves dragging a hook and line type device on the bottom of an area in an effort to capture derelict gear. NRC⁵⁷ describe both trawling and diver type surveys with accompanying pros and cons. The appropriate survey method used will vary depending on the survey area environment and gear target type and ultimately involves a trade-off between data acquisition and expense.

Regardless of the survey method used, training on various images that will be potentially encountered during the survey is critical. The collection of an image database from which image calibration and validation can be conducted increases the ability of the observer to differentiate between derelict gear and other marine debris and is an important component of any survey.¹³ An image catalog can be developed by deploying target gear in various aspect configurations and degrees of decay from which observers can be trained on image identification.

A vital piece of information to obtain during derelict gear surveys is the specific location of the identified item. In sonar surveys, this is usually obtained via GPS¹² or, in the case of towed divers, by vessel/diver coordinated timed transects.⁵⁸ Collection of spatially explicit data increases the likelihood of derelict fishing gear recovery and provides enhanced analysis in regard to the geospatial distribution of derelict gear, relationships to harvest and fishing effort, and bycatch distribution as well as the capacity to resurvey the area to obtain gear loss rates.

Table 1. General survey methods to detect and remove derelict fishing traps and nets.

Method	Expertise	Advantages	Challenges	References
Side Scan Sonar - Hull Mounted	Minimal	Low cost, GPS marked gear, can be programmed to scan transects	Limited to relatively shallow zones (15m). Limited utility in high relief areas	12, 59
Side Scan Sonar - AUV	High	GPS marked gear, can be programmed to scan transects, can scan deeper than hull mounted	Limited utility in high relief areas, entanglement risk, expensive	60
Side Scan Sonar - Towed	Moderate	GPS marked gear, can be programmed to scan transects, can scan deeper than hull mounted	Limited utility in high relief areas, moderately expensive	13, 30
Diver	Moderate (shallow) to High (deep)	Maneuverability, can both identify and remove debris	Survey area limited, water clarity limited, expensive depending on depth, entanglement risk	57, 61
Towed diver	Moderate	Versatile in various bottom structure conditions, potential for multiple data collection along survey transect	Survey area limited, water clarity limited, restricted movement, some entanglement risk	58, 62, 63
Cameras - submersible /towed	High	GPS marked gear, visual record, access to depths	Limited camera views, limited in low visibility situations, can be expensive depending on platform	60, 64
Bottom trawling / grappling by transect	Minimal	Removal of gear during survey	Depending on transect length - limited geospatial information on gear, benthic habitat impacts due to indiscriminate bottom trawling / grappling	32
Visual observation at or near the surface	Minimal	Removal of abandoned gear with attached floats	Limited to easily observable gear, misses submerged / un-buoyed gear	65

6.3 Derelict Gear Removal

Determining the regional primary drivers for gear loss (*i.e.* accidental, abandonment, storms, vandalism, equipment failure) is critical for the implementation of any management action. Information on the primary drivers of gear loss can be gathered by conversations with fishers and management personnel or through surveys of the lost gear. Stakeholders, in particular commercial fishers and resource management personnel, have regional expertise on derelict gear location and the causes of gear loss critical to a successful program. Early involvement of commercial fishers and management personnel in the program design, data collection, and program modification provides a positive interactive experience with the scientific and governmental aspects of natural resource management.⁶⁶

Derelict Gear Removal Highlights

- Engage commercial fishers and resource managers early in the planning
- Where appropriate, hire commercial fishers for data collection and derelict gear removal
- Obtain GPS coordinates for all gear removed
- Take pictures of all gear removed
- Collect data on derelict gear bycatch
- Collect data on derelict gear condition

Establishing two-way interactions that produce positive outcomes enhances program legitimacy and can be crucial to implementation of management scenarios while direct involvement in data collection enables peer to peer knowledge transfer among the stakeholder community. The North Carolina Coastal Federation, in partnership with NC Sea Grant, developed a simple electronic tablet app for derelict trap data collection (<http://www.nccoast.org/crabpot>) which they have successfully implemented with NC commercial fishers.

Educational materials on derelict trap removal and data collection are available at

http://ccrm.vims.edu/marine_debris_removal/.

Retrieval methods for derelict gear differ based upon the gear type and the habitat in which the gear is located^{61,66} and, in some cases due to the potential for damage to benthic habitats during removal efforts, it may be necessary to assess the cost / benefit of removing derelict gear from sensitive habitats.^{1,4,12}

A protocol for survey and removal of derelict fishing gear

- 1) Determine Primary Drivers of Gear Loss
 - a) Survey of fishers
 - b) Survey of management personnel
- 2) Survey of Derelict Gear
 - a) Image catalog: Quality Assurance/Quality Control (QA/QC) for derelict gear identification
 - b) Development of a survey design
 - c) GPS location of derelict gear (critical information)
 - i) Location relative to sensitive habitat
 - ii) Location relative to boating activity
 - iii) Location relative to fishery management areas
 - iv) Spatial distribution and density
- 3) Removal of Derelict Gear
 - a) Pictures of items collected and bycatch (also serves as QA/QC for removed gear)
 - b) Bycatch Documentation
 - i) Species
 - ii) Sex
 - iii) Size
 - iv) Living/injured/dead
 - c) Gear Documentation
 - i) Functional/nonfunctional (still capable of trapping animals?)
 - ii) Buoyed/un-buoyed
 - iii) Location relative to sensitive habitat (seagrass, marsh, reefs, etc.)
 - iv) Identifying features, labels, tags
 - v) Escape panels present?
 - (1) functional/nonfunctional
 - vi) Biofouling on gear
- 4) Post Removal of Derelict Gear
 - a) Match removal data with fishery management areas
 - i) Harvest data
 - ii) Fishing effort
 - b) Dispose of gear responsibly

7. Evaluating Management Implications

The framework presented in this document offers a strategy for characterizing derelict gear distributions and associated impacts to ecosystems and the fisheries they support. It provides guidance on the key data requirements, data collection methods, and analytic approaches that could be used to assess the scope and extent of the derelict gear problems within managed fisheries. Through modeling scenarios based on a recent Chesapeake Bay assessment,³³ the framework identifies practical and effective management options that can be used for mitigating derelict gear impacts within a defined region. Furthermore, the framework can be used to structure existing and future derelict gear removal and reduction initiatives so that they collect and synthesize baseline data that is essential for informing management actions. Based on lessons learned from the Chesapeake Bay assessment, the following are key recommendations for assessing derelict gear distributions and mitigating associated environmental and economic impacts.

7.1 Spatial and Temporal Management of the Fishery

Lesson learned: The way in which a fishery is managed can influence the amount of gear that becomes derelict and may ultimately determine the level to which derelict gear negatively impacts the fishery, target and non-target species, and habitats.

Recommendation: Review spatial and temporal management of the fishery.

Process:

1. Convene meetings of resource managers and fishers to discuss management and primary drivers of derelict gear within the fishery.
2. Identify regulations that may contribute to increased abundance of derelict fishing gear and their effects. This exercise could also help to guide the approach for identifying geographic locations where derelict gear may be more persistent than other areas. Examples of these types of regulations include:
 - 2.1. Areas designated as no fishing for a particular gear or off limits to all fishing activity (*e.g.*, marine protected areas) tend to have high densities of fishing gear along their boundaries, and may have greater concentrations of derelict fishing gear.
 - 2.2. Temporal regulations that would increase the likelihood that certain gear types might become derelict. Gear loss could be attributed to instances when certain fishing areas are opened for short durations, or opened during seasons when weather events contribute to greater gear loss.
3. Evaluate how changes to regulations such as additional enforcement, modifying rules (*e.g.*, allowing fishers to remove abandoned gear), spatial and temporal management changes, and other mitigation strategies or incentives (*e.g.*, functional cull rings, biodegradable panels, derelict gear removal efforts) could modify the effects of derelict gear in a particular fishery or environment.
4. Develop scenarios and quantify how modifications identified above would change the effects of derelict gear in the fishery or environment.
5. Monitor to determine if any subsequently implemented actions are having the desired effect and recruit fishers in the data collection.

7.2 Data Reviews, Compilation, and Synthesis

Lesson learned: The collection of spatially explicit data on derelict gear location, target and non target species harvest, and fishing effort allows for robust modeling of ecological and economic impacts for management consideration.

Recommendation: Conduct comprehensive and exhaustive data reviews, compilation, and synthesis.

Process:

1. Review active gear, derelict gear, and harvest data to determine spatial extent, collection method, and potential biases.
2. Review sensitive habitat spatial distribution data (*e.g.*, locations of reefs, shellfish beds, aquatic vegetation).
3. Review spatial information on resource overlap between competing interests (*e.g.* commercial fishers, recreational boating).
4. Evaluate spatial resolution of data to determine appropriate alignment between management information (*e.g.*, harvest and effort data) and location and abundance of derelict gear.
5. Modify collection and reporting of harvest and effort data to the appropriate spatial and temporal scales.

7.3 Data Collection Plans to Fill Critical Data Gaps

Lesson learned: Critical information gaps on spatial patterns of human use hinder assessments of ecological and economic impacts from derelict gear.

Recommendation: Develop and implement data collection plans to fill critical data gaps.

Process:

1. Consider the use of participatory mapping when engaging managers and stakeholders to identify spatial use patterns.
2. Review and explore the use of secondary social science data to identify spatial demographic patterns over large areas and obtain economic profiles of users.
3. Develop and implement data collection plans such as user and fishing effort surveys to quantify recreational fishing effort and recreational uses. For example, anecdotal data and information from local fishers in the Chesapeake Bay suggest that recreational crabbing is a likely source of derelict gear, but the intensity of recreational fishing effort in the Chesapeake Bay is not fully known.

Relating derelict gear location and removal activities to ecological and economic management implications, and understanding the factors affecting implementation of mitigating actions, are critical to addressing the global issue of derelict fishing gear. This Framework provides a tiered approach, based upon various levels of available data, to inform stakeholders and to help them adaptively manage derelict fishing gear impacts based upon the needs of the particular fishery.

Appendix A.

Global Derelict Fishing Gear Estimates

Table A-1. Documented effects on select trap fisheries of derelict fishing gear constructed with wire or synthetic materials. (Modified from Bilkovic et al.⁵)

Region (U.S.A. unless noted)	Traps deployed	Annual gear loss (%)	Capture or mortality in derelict traps (individuals per trap per year unless noted)	References
Blue Crab - <i>Callinectes sapidus</i>				
Maryland	~400,000	10 – 20%	21 (mortality)	13, 67
Virginia	392,175	10 – 30%	50.6 (capture)	12, 66
Virginia	~250,000	20%	18 (mortality)	68
North Carolina	>1 million	14 – 21% 12 – 17%	20-30 (mortality); 40.4 (capture) (44% mortality in derelict pots)	29, 59, 69
Chesapeake Bay	600,000 – 800,000	12 - 20%	23 (mortality) totalling 3.3 million / year (~5% of harvest)	33
Florida - Gulf Coast	361,912	30 – 50%	–	46
Alabama	26,100	25%	–	46
Mississippi	–	20 – 30%	–	46
Louisiana	870,220	up to 100%	25.8 (mortality)	10, 46
Texas	51,800	35 – 50%	–	46
American Lobster - <i>Homarus americanus</i>				
Maine	3.2 million	20 – 25%	≥ 33% mortality	70, 71
Caribbean spiny lobster - <i>Panulirus argus</i>				
Florida Keys	~500,000	18 - 22%	3.0 – 6.8	20, 72
Dungeness crab - <i>Cancer magister</i>				
British Columbia, Canada	26,250	11%	9.3 (7% of the catch in the Fraser River)	28
California	-	100,000 traps	-	73
Washington state	–	12,193 traps	0.058 (mortality) (4.5% of recent harvest)	27
Alaska, southeast	23,000 - 92,000	-	Capture: 4.47% of harvest Mortality: 2.2% of the harvest	30
Tanner crab - <i>Chionoecetes bairdi</i>				
Bering Sea, Alaska	–	10 – 20%	39% mortality	74
Red king crab - <i>Paralithodes camtschatica</i>				
Alaska	–	10%	2–7% mortality	75
Womens Bay, Kodiak Island, Alaska	-	-	40 – 56% mortality	76
Blue swimmer crab - <i>Portunus pelagicus</i>				
Queensland, Australia	~9,000	70%	3–223	14
Octopus - <i>Octopus vulgaris</i>				
northeast Atlantic Ocean, south coast of Portugal	217,929	24%	0.87	77
Sablefish - <i>Anoplopoma fimbria</i>				
British Columbia, Canada	–	–	15–30% of the commercial catch (1977–1983)	78
Various fish and invertebrates				
Sultanate of Oman (also used in Arab Persian Gulf states)	17,442	20%, 88%	80.51 kg	79, 80

Region (U.S.A. unless noted)	Traps deployed	Annual gear loss (%)	Capture or mortality in derelict traps (individuals per trap per year unless noted)	References
Fish traps				
St. Thomas & St. John, U.S. Virgin Islands	6,500	10 - 20%	22.9 kg	81
Barbados, Caribbean	-	25%	-	82, 83
Iskenderun Bay, Istanbul, Turkey	~5000	11% (traps) 13-65% (nets)	-	84, 85
Lobster and fish traps				
Guadeloupe (French West Indies)	40,000	50%	-	86
Eel traps				
Korea	~1 million	15.6%	-	87

Table A-2. Gear loss and global landings for major crustacean pot and trap fisheries.
Annual averages, 2003-2012. (after Scheld et al.⁸)

Species	Gear Loss (%) ^a	Landings (MT)	Revenues (US\$)	Major Producers
Blue swimmer crab <i>Portunus pelagicus</i>	70	173,647	\$199M ^a	China, Philippines, Indonesia, Thailand, Vietnam
American lobster <i>Homarus americanus</i>	20-25	100,837	\$948M	Canada, USA
Blue crab <i>Callinectes sapidus</i>	10-50	98,418	\$152M	USA
Queen crab/snow crab <i>Chionoecetes opilio</i>	NA	113,709	\$401M	Canada, St. Pierre and Miquelon (France), USA
Edible crab <i>Cancer pagurus</i>	NA	45,783	\$49M ^b	United Kingdom, Ireland, Norway, France
Dungeness crab <i>Metacarcinus magister</i>	11	35,659	\$169M	USA, Canada
Spiny lobster <i>Panulirus argus</i>	10-28	34,868	\$500M ⁹⁰	Bahamas, Brazil, Cuba, Nicaragua, Honduras, USA
King crab <i>Paralithodes camtschaticus</i>	10	10,137	\$99M	USA
Stone crab (claws only) <i>Menippe mercenaria</i>	NA	2,502	\$24M	USA
TOTAL		615,560	\$2.5B	

Notes on Table A-2:

Data from: NOAA Office of Science and Technology, National Marine Fisheries Service, Commercial fisheries statistics <http://www.st.nmfs.noaa.gov/st1/commercial>; Food and Agriculture Organization, United Nations, Fisheries and Aquaculture Department, <http://www.fao.org/fishery/search/en>, Fisheries and Oceans Canada <http://www.dfo-mpo.gc.ca/stats/commercial/sea-maritimes-eng.htm>.

^a Based on an average price of US \$1.15/kg.⁸⁸

^b Based on 2004-2012 average price of US \$1.07/kg.⁸⁹

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