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TECHNICAL GUIDELINES ON METHODOLOGIES AND INDICATORS FOR THE ESTIMATION OF THE MAGNITUDE AND IMPACT OF ILLEGAL, UNREPORTED AND UNREGULATED FISHING (IUU FISHING) VOLUME 3.2: A CATALOG OF EXAMPLES FOR ESTIMATING IUU FISHING

TECHNICAL GUIDELINES ON METHODOLOGIES AND INDICATORS FOR THE ESTIMATION OF THE MAGNITUDE AND IMPACT OF ILLEGAL, UNREPORTED AND UNREGULATED FISHING (IUU FISHING)

VOLUME 3.2

A Catalog of Examples for Estimating IUU fishing

Fisheries Global and Regional Processes Team
Fisheries and Aquaculture Division
Food and Agriculture Organization of the United Nations

Executive Summary

Quantification of the amount of IUU fishing may be important for invoking appropriately precautionary management, helping design effective monitoring, control and surveillance measures, and generating political will to combat the problem. Although there is a growing number of studies estimating IUU fishing, it can still be challenging for fisheries managers to identify pertinent examples that can serve as models for their own estimates.

This document links to a number of previous technical guidance documents on planning and executing IUU estimation studies by providing a catalog of 26 estimation methodologies from published studies. These methodologies encompass a wide range of locations, fishing gear and IUU fishing types. The catalog is organized around two ways to identify relevant methodologies: based on the IUU estimation approach and based on the primary available data source. The five types of IUU fishing estimation approaches include: 1) estimating total catch minus reported catch; 2) total catch partitioned into IUU/not IUU; 3) sum individual IUU events to a total amount; 4) estimate “true” catches for vessels or fleets; and 5) determine relative amounts or trends in IUU. The four types of primary data sources include: 1) fishery models; 2) commercial sources; 3) operational data; and 4) expert judgement, comparisons to catch compilations and stakeholder surveys.

The two search algorithms help to identify methods that are presented as concise, individual 1-2 page summaries. Each method is presented in terms of the key elements needed and how they can be sourced, the specific steps involved in constructing the estimate, and guidance on the applicability of the method. The goal of this document is to facilitate the selection of appropriate methods for those wishing to undertake estimates of IUU fishing, thereby promoting robust assessments of the effectiveness of fisheries monitoring, control and surveillance systems.

Contents

1 Introduction

Estimating amounts of illegal, unreported and unregulated (IUU) fishing will always be fraught with uncertainty. This is because IUU fishing is, by definition, carried out in contravention of the law, perpetrated without being immediately detected by monitoring and surveillance, or conducted without the constraints of any regulatory system. The information on which to base an estimate of IUU fishing will therefore always be at the periphery of our vision, and the methodologies we use will need to be opportunistic and astute.

These challenges can be daunting for many fisheries managers. Nevertheless, quantification of the amount of IUU fishing may be important for invoking appropriately precautionary management; helping design effective monitoring, control and surveillance (MCS) measures; and generating political will to combat the problem. Those seeking to develop their own IUU fishing estimates can look to a growing number of studies on particular fisheries or regions for inspiration. But it can still be difficult to know which studies provide the most pertinent examples to follow and how to adapt those methods to a new scenario.

The aim of this document is to catalog a range of IUU fishing estimation methods and to summarize their basic elements as a template for new estimates. Previous documents in the Food and Agriculture Organization of the United Nations (FAO) series entitled "Technical Guidelines on Methodologies and Indicators for Estimation of the Magnitude and Impact of IUU Fishing" provide guidance on defining objectives for, planning and carrying out estimation studies (FAO 2018, 2021). The catalog of methods presented in this new volume adds to those scoping and execution guidelines to further populate the IUU fishing toolbox. Planned volumes on IUU indicators and impacts (including valuation) will complete the set.

2 IUU Fishing Estimation Examples

Each IUU fishing estimation scenario is unique. It is therefore impossible to provide detailed guidance –for example, on which datasets to use or discard, which analytical procedures to attempt or avoid, or how to handle various types of uncertainty--that would be universally appropriate. The previous volumes in the above-cited series contain useful material on defining objectives, selecting a type of approach, and managing an IUU fishing estimation study, and should be consulted as a first step. However, when it comes to methodology the best way to convert theory into practice is through examples. Finding the right example to emulate can mark the turning point between anticipating and executing an IUU fishing estimation study.

Examples from past studies exist in the form of scientific journal articles, project reports and other governmental and non-governmental publications. Compendiums such as Macfadyen et al. (2016) and Pauly & Zeller (2016a) provide an introduction to a wide range of studies but are designed to document or critique what was done rather than guide the reader to relevant examples for their own use. Whether searching for studies independently or via a compendium it is easy to become lost in methodological details and difficult to discern how the basic steps might apply to different fisheries.

This document draws an analogy between finding an appropriate IUU fishing estimation methodology and selecting a recipe. Both require consideration of the availability and quality of ingredients (data or information), the tools and steps required, and the desirability of the final result. Like a recipe, there will be times when not all of the ingredients for an IUU fishing estimation are available or suitable, and thus substitutions will be necessary. There may also be a need for cautions to prevent common mistakes or hints about how to present the results. The remainder of this document presents a kind of 'cookbook' of methods (the catalog) along with various ways of indexing the catalog to assist the reader in finding the most relevant examples.

2.1 Introducing the Catalog

A selection of 26 studies, representing a variety of fisheries, locations, objectives and methodologies have been summarized in the catalog. These studies were selected, in part, for the range of geographic locations and fisheries they represent (Figure 1). Two of the studies (Agnew et al. (2009) and Pauly & Zeller (2016b)) were global in scope and had no particular area of focus. Others had a specific regional focus covering multiple nations' waters and often including high seas areas (Restrepo (2004), BOBLME (2015), FAO (2015), Doumbouya et al. (2017), Oozeki et al. (2018), Oliveros-Ramos et al. (2019), Wilcox et al. (2021), MRAG Asia-Pacific (2021)). Trade-based studies included in the catalog usually concentrated on specific end-markets but drew conclusions about IUU fishing happening in areas in other parts of the world (Lack & Sant (2001), Clarke et al. (2006), Pramod et al. (2014, 2019)). The remainder, and the majority, of studies were focused on specific fisheries in national waters.

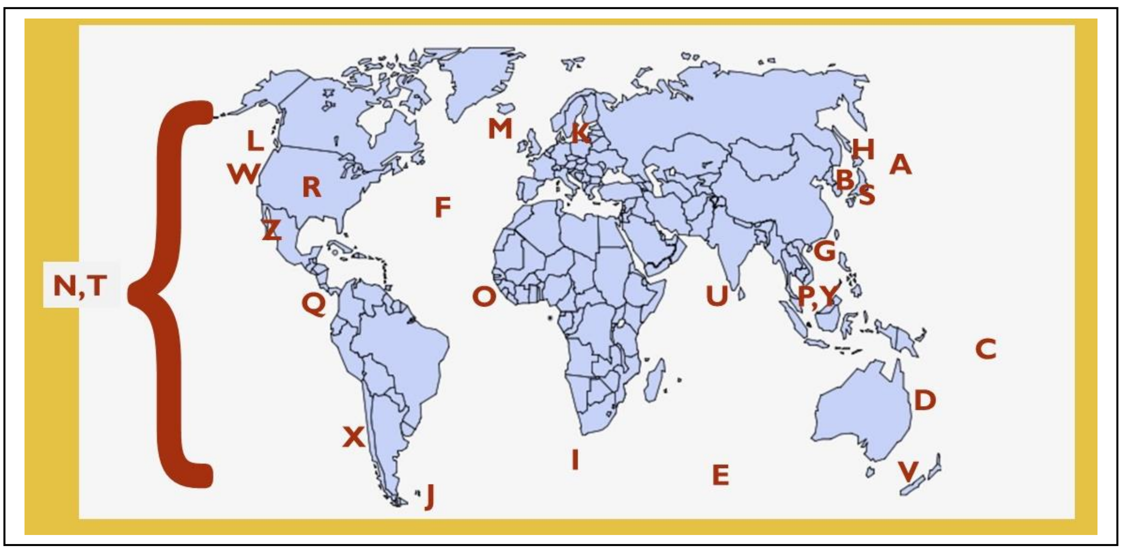

Figure 1. Geographic representation of the IUU fishing estimation studies. A. Oozeki et al. (2018), B. Park et al. (2020), C. MRAG Asia Pacific (2021), D. Williamson et al. (2014), E. Lack & Sant (2001), F. Restrepo (2004), G. Clarke et al. (2006), H. Clarke et al. (2009), I. Plagányi et al. (2011), J. Payne et al. (2005), K. Hentati-Sundberg et al. (2014), L. Wernerheim & Haedrich (2007), M. Pitcher et al. (2002), N. Pauly & Zeller (2016b), O. Doumbouya et al. (2017), P. FAO (2015), Q. Oliveros-Ramos et al. (2019), R. Pramod et al (2014), S. Pramod et al. (2019), T. Agnew et al. (2009), U. BOBLME (2015), V. Bremner et al. (2009), W. Lewis (2015), X. Donlan et al. (2020), Y. Wilcox et al. (2021), Z. Johnson et al. (2017).

The selection of studies in the catalog also represents a number of gear types operating in fisheries of different scales. The catalog contains methods for estimating IUU fishing in the world's largest industrial tuna fishery (e.g. MRAG Asia Pacific (2021)), small commercial fisheries in national waters (e.g. Payne et al. (2005)), recreational fisheries (e.g. Williamson et al. (2014)), and small-scale and artisanal fisheries (e.g. Oliveros-Ramos et al. (2020)). Gear types include pelagic longlines (Restrepo (2004), bottom longlines (Wernerheim & Haedrich (2007)), pelagic trawls (Hentati-Sundberg et al. (2014)), bottom trawls (Bremner et al. (2009)), squid jiggers (Park et al. (2020)), purse seine (MRAG Asia Pacific (2021)), drift nets (Clarke et al. (2009)), bright light net fishing (Oozeki et al. (2018)), and diving (Plagányi et al. (2011), Lewis (2015)). The global and regional studies usually estimate IUU over a diverse range of gear types (e.g. Agnew et al. (2009), BOBLME (2015), FAO (2015), Pauly & Zeller (2016b), Wilcox et al. (2021)). Some studies, such as the trade-based estimates of Clarke et al. (2006) and the small-scale estimates of Johnson et al. (2017), do not specifically reference gear type.

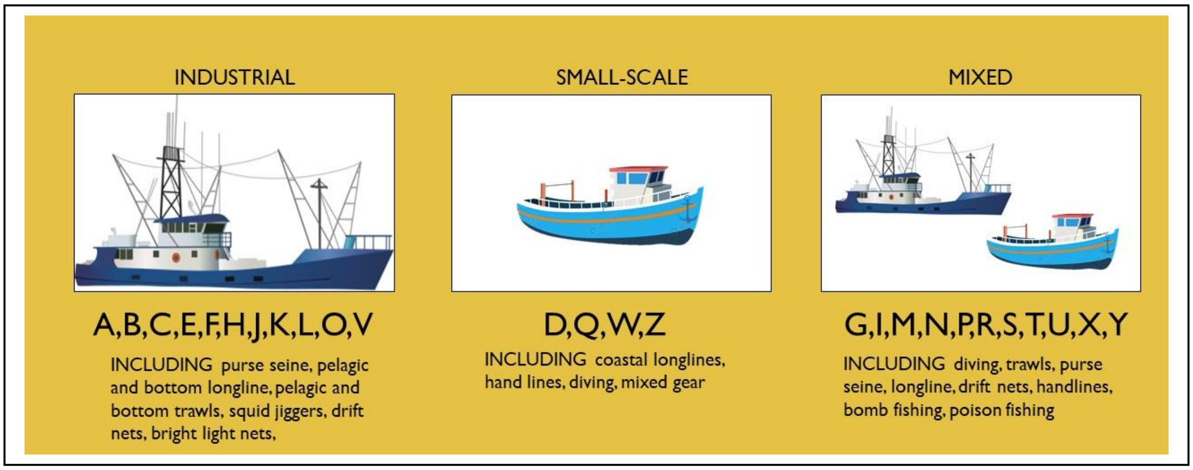

Figure 2. Sectoral and gear representation of the IUU fishing estimation studies in the catalog. See Figure 1 caption for the letter key to individual studies.

Another potential way of subsetting the catalog is to consider which type of IUU fishing is being estimated by each study. These types—illegal, unreported and unregulated—are defined in the International Plan of Action to Prevent, Deter, and Eliminate Illegal, Unreported and Unregulated Fishing (FAO 2001) but are not always applied explicitly or consistently in estimation studies (see Macfadyen et al. 2016 for a detailed discussion). This is not surprising given that i) the nature of IUU fishing will vary as a consequence of the legal framework in place; ii) I, U and U categories may overlap one another; and iii) each study is free to focus on the types of IUU fishing that are deemed most important for the fishery in question (FAO 2018). Given these circumstances, and unless the authors define it themselves, mapping the quantities of IUU fishing estimated by each study to one or more of the FAO-defined categories would be arbitrary. Nevertheless, it is clear from some of the authors' definitions that a wide range of potential I, U and U activities are covered by the examples in the catalog ranging from, *inter alia*:

- unlicensed fishing (e.g. Oozeki et al. (2018));
- unreported discards (e.g. Wernerheim & Haedrich (2007));

- species mis-reporting (e.g. Hentati-Sundberg et al. (2014));
- illegal transshipment (e.g. BOBLME (2015));
- non-compliant gear (e.g. MRAG Asia Pacific (2021));
- encroachment of protected areas (e.g. Williamson et al. (2014));
- harvest of protected species (e.g. Wilcox et al. (2021));
- criminal poaching (e.g. Plagányi et al. 2011); and
- violations of national or international law (e.g. Park et al. (2020)).

As detailed above the catalog provides a diverse but compact set of examples to serve as a starting point. For further background reading, or for types of studies not covered in the catalog, readers are encouraged to consult the broader range of IUU fishing estimation studies compiled in Macfadyen et al. (2016), Pauly & Zeller (2016a) and the previous volumes in this technical guidelines series.

2.2 Navigating the Catalog

It is important for the catalog to contain a range of geographies, fishing gears and types of IUU fishing as described above, but these features do not necessarily provide the best way of organizing the catalog according to methodological similarities. This is because, as described in Volume 3.1 of this technical guidelines series (FAO 2021), methodologies are driven by a combination of objective and priority setting, as well as available data. It is these two considerations – the study approach and the available data—that are used to organize the catalog to assist in efficiently locating the most suitable examples for future studies. Subsetting existing studies based on study approach and primary data sources will produce different groups and highlight the similarities between studies in different ways (Figure 3).

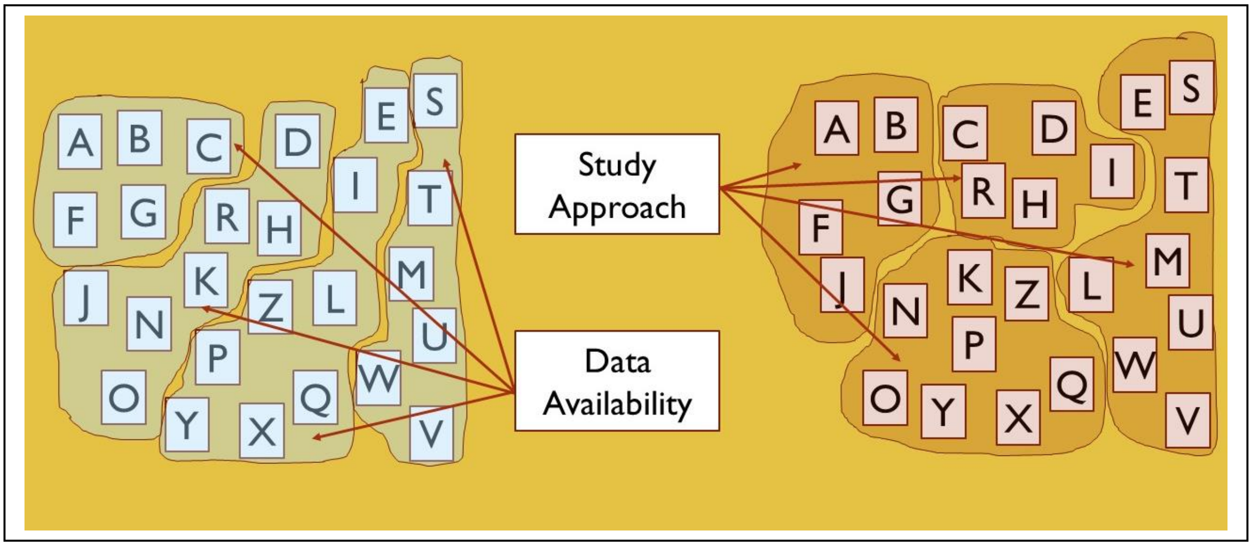

Figure 3. Conceptual diagram showing how the studies in the catalog can be organized into different groups depending on study approach and available data. These groups are for illustration only.

Although it is possible to search for appropriate methodologies only on the basis of study approach or only on the basis of data availability, ideally both should be considered together to ensure the combination will produce a successful estimation (FAO 2021). It is therefore suggested to work through both the study approach-based search and the data availability-based search described below, and focus on those studies that are highlighted in the results of both searches. The number of studies returned from each search may depend on how explicitly the intended estimation study can be defined. In other words, if there is no clear idea about what kind of estimation should be done the number of potentially relevant example studies will be large. However, it is also true that some estimation methods are more commonly used than others and thus some methodological groups have more example studies than others. This means that even highly focused searches may return a relatively large number of example studies.

Ultimately, the two types of searches (approach-based and data-based), and the catalog itself which is arranged by lead authors' name and coded for study approach (by color) and primary data source (by number), are meant as a time-saving guide to relevant studies. If these searches do not provide appropriate examples, readers are free to browse the catalog as a whole, refer to the compendiums introduced above, or undertake internet-based searches for appropriate methods with hopefully a more precise conceptualization of the kind of example needed.

2.2.1 Organization of Studies by Approach

The approach adopted for a prospective IUU estimation study begins with a project scoping exercise as defined in FAO (2021)'s Task 1.1. It includes such considerations as:

- the study objectives (e.g. improved stock assessment, better targeting of enforcement resources, or new policy advice);
- the scope of the estimation (e.g. sectors, species, areas, timeframe); and
- the specific IUU fishing risks to be estimated (see Table 1 in FAO (2018) for a categorization of risks).

Explicitly considering these issues during the project scoping process will not only sharpen the focus of the prospective IUU estimation study overall, it will provide a critical foundation for selecting an appropriate estimation methodology (FAO 2021 (Figure 2, Task 1.2)). This catalog can assist in identifying useful example methodologies by organizing existing studies according to their overall approach to IUU fishing estimation.

The catalog has been organized according to five study (methodological) approaches:

- **Estimate Total Catch Minus Reported Catch:** Start by constructing an estimate of total catch and if it is greater than reported catch then subtract the reported catch and infer that the difference is (or may be) due to IUU fishing (Yellow Approach Group);
- **Total Catch Partitioned into IUU/Not IUU:** Start with the known or estimated total catch (or fishing mortality), and partition it, sector by sector, to identify which portions and amounts are taken through IUU fishing and which are not (Green Approach Group);
- **Sum Individual IUU Events to a Total Amount:** Start by identifying particular activities, incidents, locations or fleets suspected or proved engaging in IUU fishing then estimate and sum the IUU amounts from each to produce a total IUU estimate (Blue Approach Group);
- **Estimate "True" Catches for Vessels or Fleets:** When there is a concern that the true catch amount of certain vessels or fleets is not well-understood, without categorizing the behavior as IUU fishing per se, use available vessel or fleet information to estimate the true catch amount above and beyond any reported amounts (Purple Approach Group);
- **Determine Relative Amounts of, or Trends in, IUU:** Without aiming for a quantitative estimate of IUU fishing determine relative amounts of IUU, or trends, for a fishery, location or type of behavior (Red Approach Group).

Figure 4 illustrates how the studies in the catalog align with these approaches. To search for an appropriate example, identify the approach from the list above that best aligns with the proposed study. Note the color group and authors' name of the studies associated with the preferred approach(es), and the numbers in brackets which refer to the primary data sources, before proceeding to Section 2.2.2 to narrow the list of examples further (if possible).

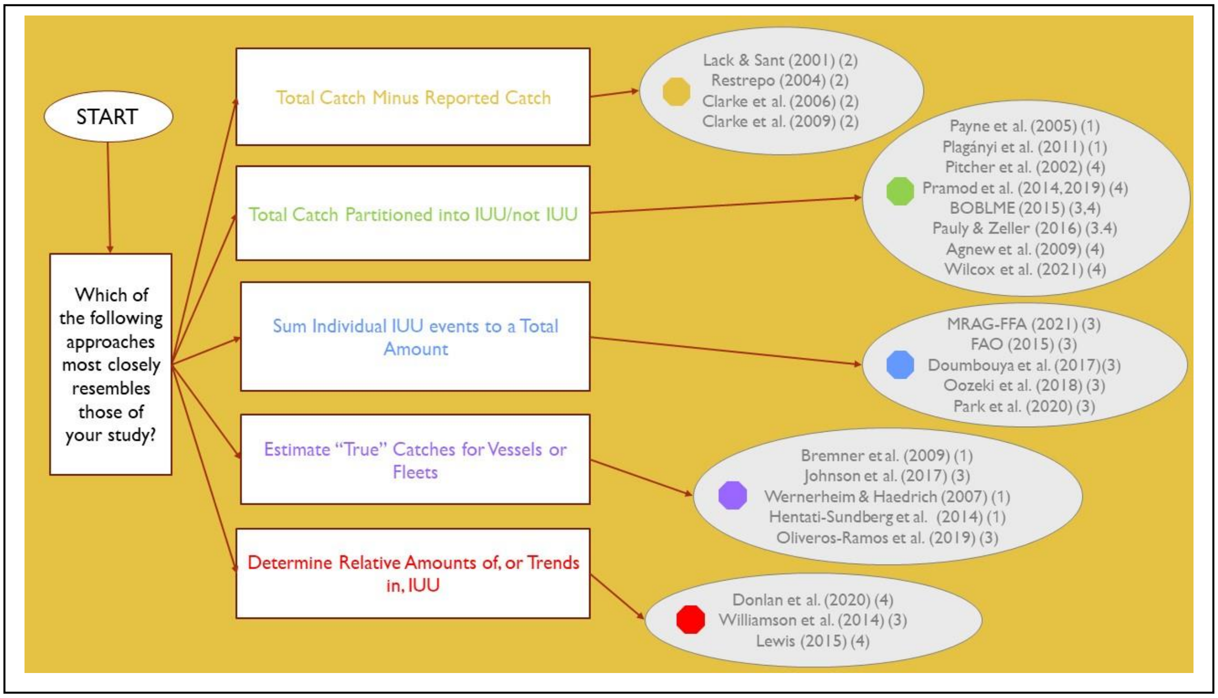

Figure 4. Flowchart classifying studies by study (methodological) approach as shown in rectangles. The studies in each group (ovals) are summarized individually in Appendix A. The numbers in brackets following each author's name indicate the data group (see Section 2.2.2).

2.2.2 Organization of Studies based on Primary Data Source

The second key determinant in designing a methodology is the availability of data (FAO 2021 (Section 1.1.3)). This consideration includes not only the quantity but also the quality and accessibility of data. Scenarios for IUU estimation may be based on data that are copious or scarce in term of data quantity, and reliable or highly uncertain in terms of data quality. There may also be cases where data exist but are either not available to the study team or would be prohibitively costly or time-consuming to utilize (e.g., voluminous paper records).

According to a typology provided earlier in this series (FAO 2021), some of the main sources of data relevant to IUU fishing estimations are:

- licensing/vessel registry information,
- logbooks,
- observer records,
- electronic monitoring,
- port sampling/landings records,
- vessel monitoring systems (VMS),
- automatic identification systems (AIS),

- ship-based surveillance or inspections,
- prosecutions,
- aerial surveillance,
- satellite imagery,
- stock assessments,
- trade/market data,
- stakeholder surveys, and
- expert judgement.

Often more than one of these data sources will be applicable to the planned estimation but it is important to identify the data source that provides the strongest signal of IUU fishing activity and then to select a method that relies primarily on that data source. If possible, other data sources and other methods should be used to triangulate[1] outputs from the primary estimation method and strengthen confidence in the estimate of IUU activity (see FAO 2021, Section 1.2.3). For instance, expert judgement has been used in a number of studies to substantiate other primary data sources.

To assist in pointing toward useful examples based on the primary source of data, this catalog has been organized into four main data groups (Figure 5) and several sub-groups within each main group (Figures 6-9).

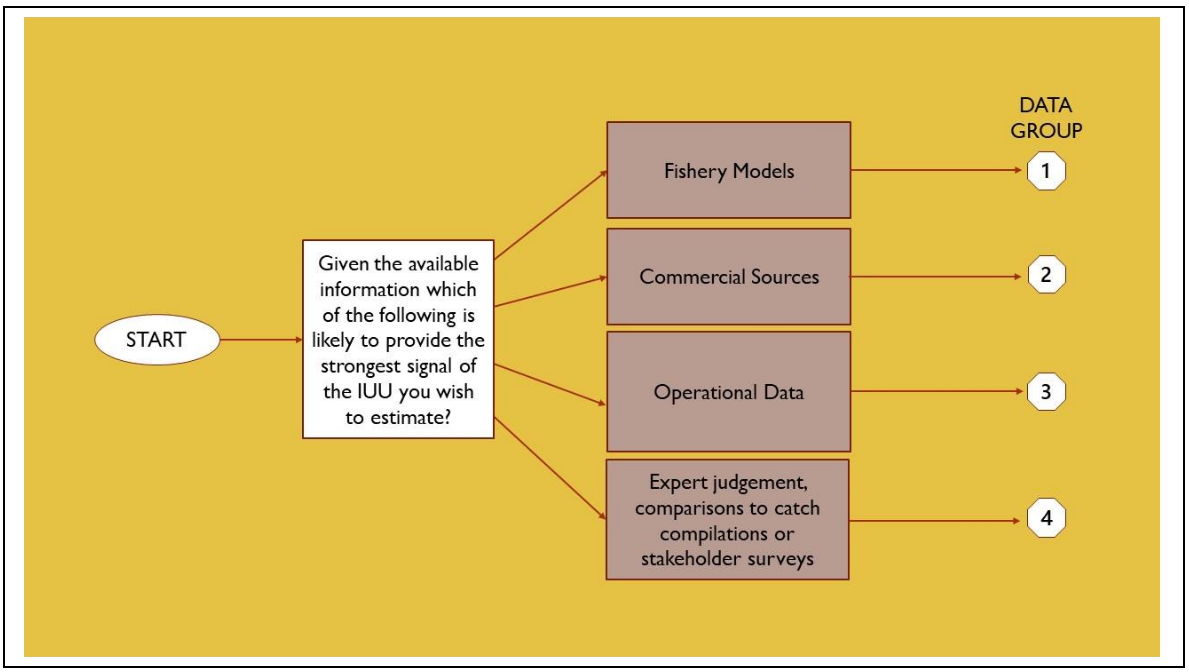

Figure 5. Flowchart classifying studies by the primary source of data (rectangles). See Figures 6-9 for the subgroups in Data Groups 1-4.

[1] Triangulation, or cross-checking, involves testing the plausibility of model outputs using alternate sources of data or alternative analytical models (FAO 2021).

- **FISHERY MODELS (Data Group 1):** These estimations derive from a model of the fishery, or a model of vessels in the fishery, that is capable of predicting the true amount of catch even if that catch is not recorded. Such methods may use stock assessment, logbook, observer, market/trade, and prosecutions data sources. Specific sub-groups included in the catalog are (Figure 6):

    - Stock assessment models;
    - Bio-economic models; and
    - Predictive catch models (e.g. generalized linear models (GLM)).

  These studies have methodological approaches which place them in the green (catch partitioned into IUU/not IUU) and purple (estimate "true" catches for vessels or fleets) approach groups in Figure 4. One of the studies (Plagányi et al. 2011) is based primarily on modelling data but also uses data from commercial sources (customs statistics; see Figure 7).

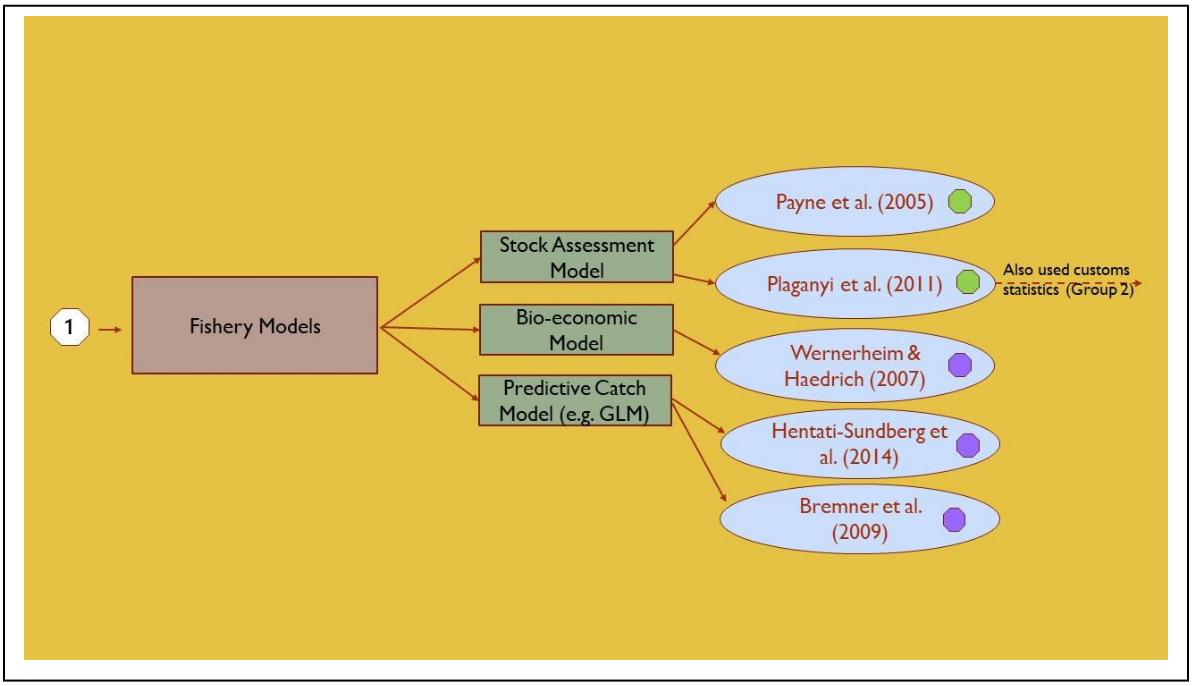

Figure 6. Flowchart showing the sub-groups of studies using fishery models (Data Group 1) as the primary data. The studies in each sub-group are summarized in Appendix A.

- **COMMERCIAL SOURCES (Data Group 2):** These estimations are based on a conspicuous, traded product that can be used to back-calculate catch (Data Group 2; Figure 5). These estimations are obviously heavily reliant on market/trade data types also often rely on expert judgement to specify the conversion factors necessary to relate product weights to whole weights. Some studies have used simulation to estimate uncertainty (see Data Group 4). Specific categories of commercially-sourced data-based methods included in the catalog are (Figure 7):

  - Customs statistics;
  - Market records; and
  - Catch documentation schemes.

  These studies mainly use the 'Estimate Total Catch Minus Reported Catch' methodological approach (Figure 4, Yellow Approach Group). Three studies classified in other data groups (Plagányi et al. 2011, Pramod et al. 2014, 2019) because they use modelling data (Data Group 1) or expert judgement (Data Group 4), respectively, as their primary data source, but also employ customs statistics (see Figures 6 and 9). These three studies use a different methodological approach based on partitioning total catch into IUU/not IUU portions (Green Approach Group).

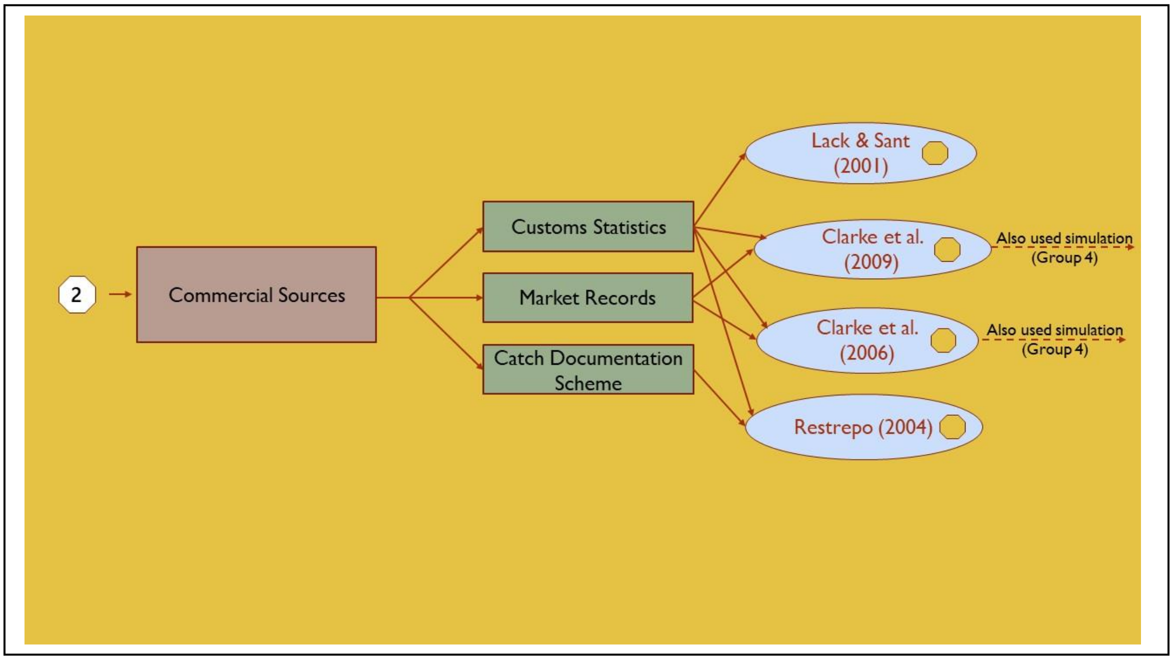

Figure 7. Flowchart showing the sub-groups of studies using commercial sources (Data Group 2) as the primary data. The studies in each sub-group (ovals) are summarized in Appendix A.

- **OPERATIONAL DATA (Data Group 3):** These estimations are based predominantly on counts or estimates of the number of actors (vessels, fishers, etc.) and the amount of IUU they take (Data Group 3; Figure 5). These studies often rely heavily on standard fisheries enforcement data systems but may also use more novel sources of information. Studies in the catalog have used (Figure 8):

    - Satellite imagery;
    - Aerial photography;
    - Vessel lists/fleet size;
    - Logbook or landings records;
    - Monitoring, control and surveillance data (MCS); and
    - Control site comparisons.

  These studies often employ the 'Sum Individual IUU Events to a Total Amount' methodological approach (Figure 4, Blue Approach Group). However, some studies are focused on estimating true catches for vessels or fleets (Purple Approach Group), partitioning IUU from not IUU catches (Green Approach Group), or determining relative amounts of IUU (Red Approach Group). Many of the studies in this data group also draw upon expert judgement, simulation techniques or survey data (Data Group 4) to supplement the available data.

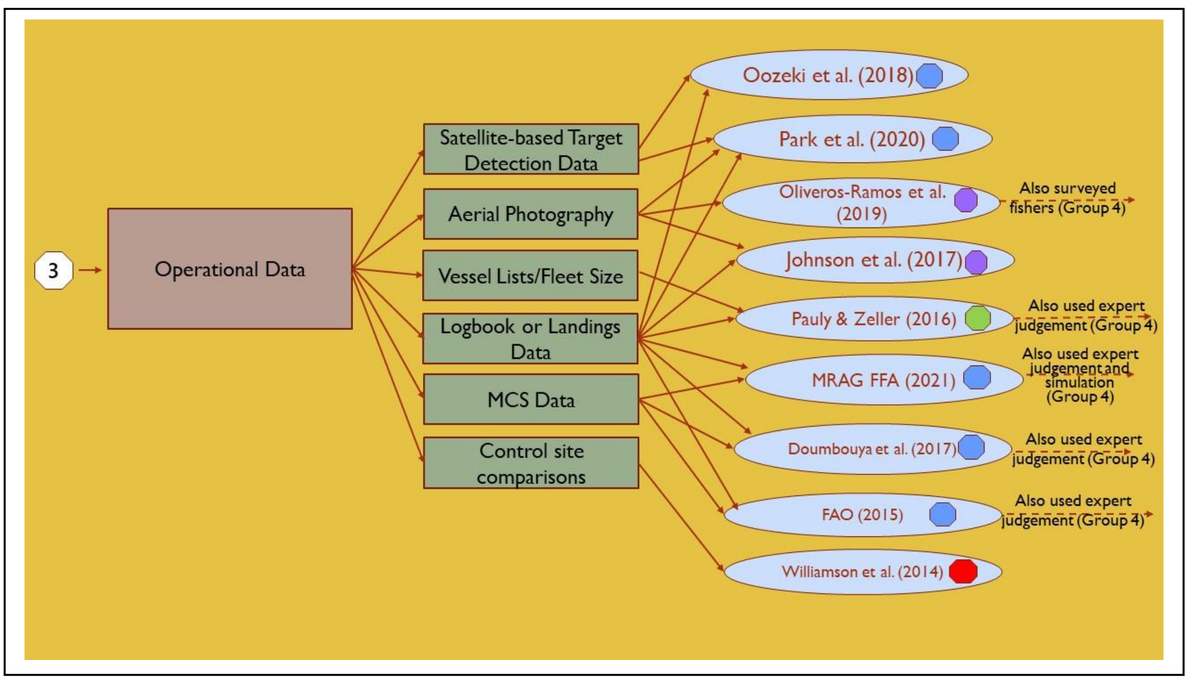

Figure 8. Flowchart showing the sub-groups of studies using operational data (Data Group 3) as the primary data. The studies in each sub-group (ovals) are summarized in Appendix A.

- **EXPERT JUDGEMENT OR SURVEYS (Data Group 4):** These estimations have some grounding in fishery data but rely heavily on expert judgement from the research team, comparisons to other catch compilation databases, or surveyed stakeholders, to produce the final results (Data Group 4; Figure 5). The catalog contains examples of the following techniques:
    - Use of expert judgement to fill missing data or assign trends;
    - Use of expert judgement to set ranges for uncertain data points;
    - Use of simulation techniques to more formally account for uncertainty;
    - Comparison to existing global catch compilation databases; and
    - Surveying fishers, inspectors or other experts.

  Many of the studies applying the "Total Catch Partitioned into IUU/not IUU" approach (Green Approach Group) use the expert judgement of the study team to determine the partition and thus are classified into Data Group 4 (Pitcher et al. 2002, Agnew et al. 2009, BOBLME 2015 and Pramod et al. 2014, 2019). In contrast, the other studies in this data group rely on the expert judgement of surveyed experts rather than the study team itself (Lewis 2015, Donlan et al. 2020 and Wilcox et al. 2021).

  It is difficult to escape the use of expert judgement entirely, and almost every study in the catalog has relied on it to some extent. The studies classified as Data Group 4 show a relatively larger dependence on expert inputs—whether from the study team or surveyed experts—and a relatively smaller reliance on granular modelling, trade or operational data (Data Group 1-3). The Data Group 4 studies often use catch compilation databases, such as FAO capture production data (FAO 2022) or the Sea Around Us Project (Pauly & Zeller 2016a), to anchor the expert opinion to specific, quantified estimates of IUU fishing. Some of the studies for which expert judgement played an important role in triangulating or supporting other primary data are indicated in Data Group 3 (Figure 8).

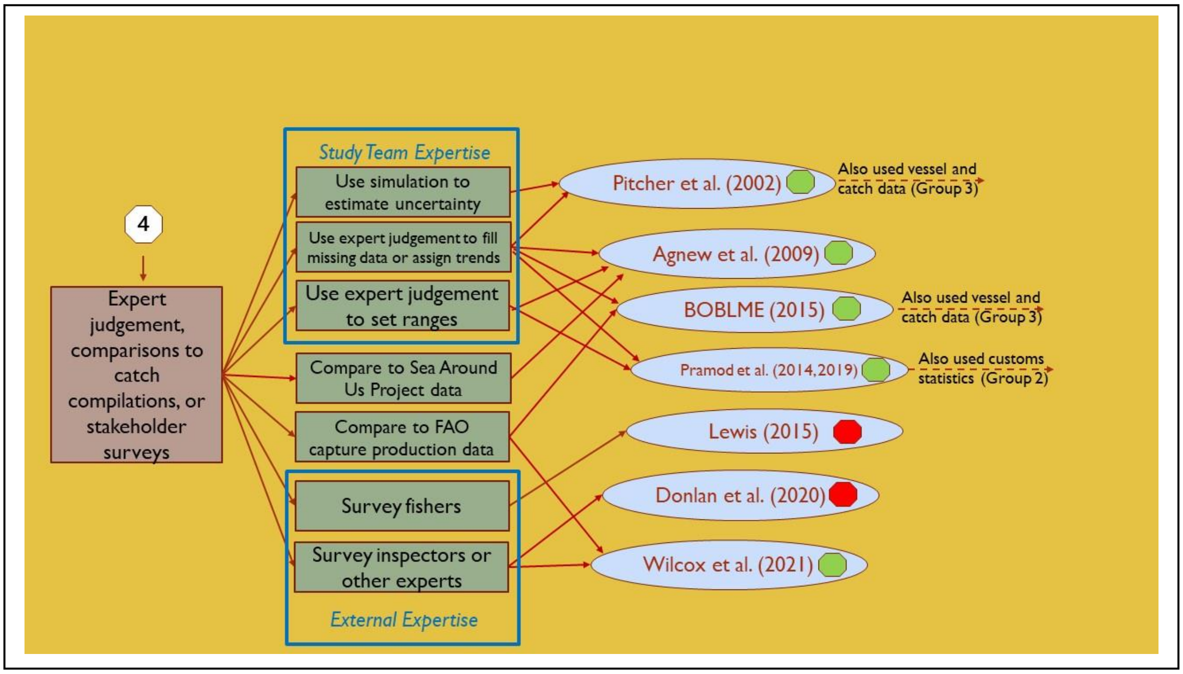

Figure 9. Flowchart showing the sub-groups of studies using expert judgement, comparisons to catch compilations or stakeholder surveys (Data Group 4) as the primary data. The studies in each sub-group (ovals) are summarized in Appendix A.

After using Figures 5-9 to identify the most appropriate Data Group (1-4), compare the list of useful examples based on study approach (Section 2.2.1) and on primary data source (this section). If the list of useful examples is short, it may also be helpful to consider other example studies in the same approach (color codes) or data (number codes) groups to provide a broader range of methodological options.

2.3 Following the Recipe

After one or more potentially relevant example studies are identified from the approach- or data-based searches described above in Section 2.2, the reader can find a summary of the studies listed under the primary author's name in Appendix A. Each study[2] is summarized into a "recipe card" format consisting of:

- The primary author's name and year of publication (see Section 4 for a full reference list);
- A simple, one-sentence summary of what the study did;
- Classification by type of study approach and primary data source used (see Section 2.2);
- "Ingredients" – key constituents of the estimate, how they were sourced by the study, and how else they might be sourced (i.e. alternative approaches);

[2] Note that Pramod et al. (2014) and Pramod et al. (2019) apply the same methodology, therefore although these are separate studies of two different markets, they are combined into one recipe card.

- “Recipe” steps – a description of what each step entails, what was achieved in each step in the example study, and cautions associated with each step; and
- A list of conditions for which the method is suitable and for which it is difficult to apply.

Although the authors of the studies in this catalog were contacted to review the summaries in Appendix A, and many did provide clarifications and comments, the definitive sources of information are their original papers. These, as listed in the references, should be consulted whenever a “recipe” is followed.

3 Conclusion

Like all worthwhile culinary endeavors, an IUU estimation should not be rushed. In making any recipe one’s own, ingredients may need to be substituted, techniques may need to be adapted in creative ways, and the entire process will only become smooth and efficient through iterative practice. There is much to be learned from the experience of others, but each situation will be unique and require a tailored approach.

No matter what methodological approach is adopted, IUU estimations can be technically challenging and resource-intensive, as well as potentially controversial. Nevertheless, in fisheries for which there are important benefits to be gained from undertaking an IUU estimation this document is designed to facilitate identification of an appropriate methodology. For other fisheries it may be sufficient to develop and apply indicators of IUU fishing, rather than a full-fledged IUU estimate. Indicators measure something that provides insight into, but does not actually estimate, the level of IUU fishing in absolute or relative terms. An indicators approach has the advantage of being simpler to calculate, therefore easier to update and track as a time series, and is thus more accessible to a wide range of fisheries management systems. Guidance for developing and using IUU indicators will be the subject of the next document in this FAO technical guidelines series.

The most important point to bear in mind when quantifying the amount of IUU fishing is that it is a means to an end. Assuming the amount is not zero, it should lead to a more informed consideration of how fisheries MCS measures need to be strengthened. Using IUU estimates to design countermeasures and assess their performance is where the true value of the exercise can be appreciated.

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Appendix A. Catalog of IUU estimation methodologies in alphabetical order by first author's name

HEADER	***Citation***	Agnew et al. (2009)		
	Simple Summary	Factored area- and fishery-specific catches by estimated ranges of IUU fishing (derived from various sources including expert opinion) to provide global estimates of IUU catch.		
	Approach Group	Total Catch Partitioned into IUU/Not IUU	Green Approach Group	
	Data Group	Expert judgement/surveys	Data Group 4	
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Quantity of annual catch in each area (EEZ or high seas area) – total and by fishery/species	Sea Around Us Project	·FAO FishStatJ ·National catch statistics ·RFMO catch statistics	
	2. High and low estimates of the range of annual IUU catch per fishery/species per area	Surveillance data, trade data, stock assessments and expert opinion	·Previous studies ·Formal surveys	
	3. Scaling factors to adjust the high and low IUU estimates for 5 year periods	Expert opinion	·Previous studies ·Formal surveys	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Compile total and fishery-specific catches for all the areas of interest by year	Identified the highest volume species in 69 areas for a total of 292 fishery estimations per year	·Some catch data may be reported in units that do not exactly match the areas of interest, so spatial adjustment may be needed Catch data may be missing for some areas, fisheries or years	
	2. Define the high and low range (%) of IUU catch for each area and fishery	Sources identified the range of IUU catch differently so the authors' chose to use the extreme high and low estimates	In cases where only a point estimate is available the range will depend on expert judgement ·Extreme high or low estimates can unduly influence the result—inputs should be screened carefully.	
	3. Estimate the confidence interval of the IUU catch for each area and fishery	Monte Carlo simulation using a uniform distribution defined by the high and low estimates of IUU x total catch	·Other distributions could be used to weight some estimates more than others (e.g. triangular distribution) ·Beware of double-counting when combining national and regional estimates (the latter may include the former)	

	4. Sum the estimates for each fishery to obtain the total IUU per area (anchor point)	Summed the highest estimate for each fishery	·Rather than selecting the highest estimate in each case, could use the Monte Carlo simulation to produce the sum
	5. Adjust the area estimates over time for changes in IUU levels (influence table)	Authors provide midpoint estimates for IUU in each area over 5-year intervals for 1980-2003.	·Reliability of results will strongly depend on the reliability of the expert inputs. ·Recommend groundtruthing the influence table against measured trends in the fishery
APPLICABILITY	Best suited to: • Integrating a diversity of information covering various fisheries, species, areas and time periods • Providing a large-scale, broadbrush overview • Generating simple messages for media or campaigns		Difficult to apply when: • There are divergent expert opinions about the magnitude, range and trends in IUU fishing • A detailed and rigorous quantitative estimate is required

HEADER	***Citation***	BOBLME (2015)		
	Simple Summary	Used a wide range of information to rank and specify IUU risks as a percentage of reported catch for 17 countries and territories		
	Approach Group	Total Catch Partitioned into IUU/Not IUU		Green Approach Group
	Data Group	Expert Judgement/Surveys		Data Group 4
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Catches by species for the area of interest	FAO capture production data	Other national or academic sources of catch data	
	2. A list of fishing fleets and the species they catch	Media sources and other published reports	Interviews, surveys	
	3. Values in 5 categories from low to high for the risk of IUU	Media sources and other published reports used as the basis for expert judgement	Interviews, surveys	
	4. A numerical range of IUU specified (as a percentage of catch) based on the risk category and the certainty of evidence	Expert judgement	Interviews, surveys	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. List all the risks faced by a fishery and assign them one of five categories from low to high	For one fishery 11 risks were identified, 4 of which were "high" (rank=4) and 7 of which were "severe" (rank=5)	·Need a consistent methodology for scoring different types of risks· ·There may be risk sub-components (for example, in this case, incentives and deterrents contributing to a likelihood ranking, and catch level and vulnerability contributing to an impact ranking) which may also need to be scored	
	2. Assign each risk a percentage range, under either "illegal" or "unreported" based on its severity (rank) and certainty of evidence	In this example fishery, five risks were considered to be 5-200% whereas the IUU catch of another six risks were considered to be accounted for in the first five.	·Rationale for the percentage assignments should be consistent and well-documented (e.g. use a core group to assign the percentages) Percentages need to be assigned consistently across risks and fisheries ·It may be difficult in practice to determine to which risks IUU catch should be assigned so as to avoid double-counting	
	3. Multiply the reported catch by the percentages to obtain the increment of catch that is due to	In this example fishery, illegal catch contributed 14-55%, and	·Ranges will be large when uncertainty is high thus making it difficult to draw a precise conclusion	

	IUU (where possible apply risks to specific fleets and the species they catch)	unreported catch 27-62%, in addition to the reported catch.	·Based on the methodology, the percentage is specified over all years, thus the annual trend of IUU will follow the annual trend in the reported catches ·The IUU may target certain species but available data may be too aggregated to reflect this
APPLICABILITY	Best suited to: • Deriving estimates from sparse and/or anecdotal data • Providing a broad-brush overview of a country or region with inconsistent datasets • Studies capable of cataloging highly diverse sources of information		Difficult to apply when: • Supporting information is difficult to gather (e.g. press or unpublished sources) • The reported catches do not represent a consistent time series (e.g. reporting practices changed significantly) • Estimates require a rigorous, quantitative basis

HEADER	***Citation***	Bremner et al. (2009)		
	Simple Summary	Used observer data to predict catch for unobserved vessels and compared predicted value to reported catch to assess the extent of under-reporting of bycatch in a hoki trawl fishery.		
	Approach Group	Estimate "True" Catches for Vessels or Fleets	Purple Approach Group	
	Data Group	Fishery Models	Data Group 1	
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Fisher-reported catch by species and operational variables for each fishing set	Logbooks and catch landing forms submitted to government agency	·Fishery cooperative records ·Co-variates sourced from other published and unpublished data	
	2. Observer-reported catch and operational variable for each fishing sets	National observer program	-	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Build a model, using observer data, to predict catch rates based on operational variables	Gear type, time of day, season, depth, and location for 978 tows were significant predictors of bycatch species catch	·Models may fail to fit the data if the data are noisy and/or explanatory variables are missing or mis-specified ·The amount and representativeness of observer coverage will influence the reliability of the model	
	2. Predict catch for unobserved fishing operations from the observer-based model	Catch of 19 bycatch species was predicted from the observer data model for 2170 unobserved tows	·Ideally reporting practices for each vessel should be taken into account (i.e. a vessel effect) but this would require data for each vessel under observed and unobserved conditions	
	3. Construct a confidence interval for the predicted catches	Bootstrapping was used to construct a 95% confidence interval for the predicted catch	·Other techniques could be used but it is important to account for uncertainty in the predicted catch in some way	
	4. Compare the confidence interval of the predicted catch to the reported catch for unobserved vessels to assess the extent of mis-reporting	Eleven species were under-reported, five species were over-reported, and three species' were neither over- nor under-reported (i.e. within the confidence interval)	·It is also important to consider the uncertainty associated with onboard estimation of catch, i.e. practical difficulties in obtaining accurate weights ·It is often the case that reporting rates for target species are more accurate than reporting rates for bycatch species ·Depending on objectives, it might be important to exclude over-reported quantities from estimates of IUU fishing	

APPLICABILITY	Best suited to: • Fisheries with an established catch reporting and observer programs • Fisheries for which catches can be robustly predicted based on available operational variables	Difficult to apply when: • There are few or no observer records or other independent means of verifying reported catch • Confidence intervals for predicted catch are wide (i.e. it will be more difficult to identify under-reporting)

HEADER	***Citation***	Clarke et al. (2006)			
	Simple Summary	Converted records of shark products from a centralized commercial market to whole shark equivalents, then extrapolated to the total quantity in trade and compared to reported catches.			
	Approach Group	Estimate Total Catch Minus Reported Catch		Yellow Approach Group	
	Data Group	Commercial Sources		Data Group 2	
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***		
	1. Quantity of product traded per unit time	Compiled market (auction) records showing trade name, product sizes and quantities	·Repeated observational market surveys (e.g. photos, counts) ·Published records of wholesale markets (if product is a standard weight/size)		
	2. Species identity of product	Used genetic testing to match trade name to species	·Rely on market names to be species-specific, or use expert judgement to make an allowance for mixing ·If doing market observational surveys, use visual identification ·Gather and apply expert judgement		
	3. Conversion factors from product to whole fish	Used morphometrics from literature and sampling whole fish	·Use measurements from photographs ·Gather and apply expert judgement		
	4. Conversion factors from sampled market to entire market	National customs statistics from major markets	·Trade compendiums e.g. FISHSTATJ or COMTRADE ·Gather and apply expert judgement ·Estimate from sales quantity or value figures		
	Steps	***Example***	***Cautions***		
RECIPE	1. Estimate the total product quantity traded per unit time	Each auction handles 400 kg of shark fins. Auctions are held on Mondays. 400 kg x 52 = 20.8 t of shark fins per year.	Account for variability in quantities traded May need to fill in missing data Some trade data are only available monthly or yearly		
	2. Break the total quantity into species-specific quantities	Of 20.8 t of shark fin per year, and half is blue shark = 10.4 t of blue shark fins.	Account for uncertainty in species proportions If species identification not available, estimates may need to stay at a higher taxonomic level		
	3. Convert the product to whole fish	If dried fins are 2% of wet weight, 10.4 t of blue shark fins represents 520 t of blue shark.	Conversion factors may vary by species Products may not all be the same size Need to account for uncertainty in the conversion		
	4. Extrapolate the quantity of whole fish to the total volume of trade	If one of three equally-sized markets were sampled, a total of 3 x 520 t=1560 t of blue shark were traded (live equivalent).	Products in unsampled markets may differ Ideally the size of each market is known from trade statistics, but domestic supplies may also be present		

<table>
<tr><td></td><td>5. Compare estimate to catch</td><td>1560 t of blue shark is X% of reported catch</td><td>This comparison will be most meaningful if the sampled market is a centralized outlet for a majority of the catch
There may be a time lag between catch and trade</td></tr>
<tr><td>APPLICABILITY</td><td colspan="2">Best suited to:
Conspicuous and valuable internationally traded products
There is a central market node which can represent a large portion of the trade
Situations where fishery data are lacking or likely to be less reliable than trade data</td><td>Difficult to apply when:
Products are not distinguished (or mixed) in trade/market statistics
There are many or diverse markets
Conversion factors are imprecise or unavailable
Personnel are not familiar with statistical methods for incorporating uncertainty</td></tr>
</table>

HEADER	***Citation***	Clarke et al. (2009)	
	Simple Summary	Constructed catch and trade models to compare quantities and determine whether estimates of "excess" catch of Russian sockeye salmon in markets might represent IUU fishing	
	Approach Group	Estimate Total Catch Minus Reported Catch	Yellow Approach Group
	Data Group	Commercial Sources	Data Group 2
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***
	1. Annual imported quantity	Customs statistics from main markets (Japan, China and Korea)	Trade compendiums e.g. FISHSTATJ or COMTRADE
	2. Annual quantities sold through markets	Published market data from Japan	Trade information sources (e.g. Globefish) Government market statistics Fishery cooperative statistics
	3. Annual catch quantities	Catches reported to Russian and Japanese authorities	FISHSTAT database Other governmental or non-governmental sources
	4. Conversion factors to allow comparison between catches and traded products	Various published and unpublished (interview) sources	-
RECIPE	***Steps***	***Example***	***Cautions***
	1. Estimate the amount of foreign and domestic catch based catch records, and convert to primary processed weights	For 2005, Russian catch was estimated at 14,000-17,000 t and all catch was estimated at 16,000-20,000 t	·If different sources report the catch differently it may be necessary to estimate the true catch as a range ·Uncertainty in conversion factors may compound the variance in the result
	2. Estimate the amount of foreign catch based on imports converted to primary processed weights	For 2005, the amount of imports of Russian sockeye was estimated at 20,000-37,000 t	·Need to assume that all catch is destined for the main import market It may be necessary to consider indirect trade (e.g. fish are first shipped to a processing country before entering the main import market)
	3. Estimate the amount of product in the market from both foreign and domestic sources converted to primary processed weights	For 2005, the amount of Russian sockeye in the market (from all catch sources) was estimated at 22,000-59,000 t	·There may be trade outside of the markets which publish statistics ·There may be transfers between markets that could lead to double-counting ·Some product may not be identified to species in trade statistics

			·Some data necessary for the estimation may only be available through the expert judgement of traders
	4. Use a probabilistic model to compare catch and trade quantities to calculate the probability of "excess catch" (i.e. trade quantity more than catch quantity)	For 2005, "excess catch" was estimated as 4,000-22,000 t for Russian catch, and 4,000 to 41,000 t for all catch.	·This approach ignores stockpiling, i.e. assumes catch and trade occurs in the same year ·These methods may provide some insights into whether foreign or domestic fishing is contributing to the "excess" but cannot trace it to specific operations ·Uncertainty at multiple steps will result in a wide range
APPLICABILITY	Best suited to: • Distinctive products traded into limited markets • Catch data are likely to under-represent the true take • Comparing quantities reported by various sources and various stages of the supply chain		Difficult to apply when: • Products are not distinguished (or mixed) in trade/market statistics • There are many or diverse markets • Conversion factors are imprecise or unavailable

HEADER	***Citation***	Donlan et al. (2020)		
	Simple Summary	Surveyed fisheries enforcement officers in Chile about the level of IUU in 20 fisheries, including identifying specific activities, actors and infrastructure		
	Approach Group	Determine Relative Amounts of, or Trends in, IUU		Red Approach Group
	Data Group	Expert Judgement/Surveys		Data Group 4
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. A survey asking respondents to assign ranks to various fisheries and components	Developed the survey and circulated it online	·Use a similar format but adapt questions to fit other situations ·Use survey software	
	2. A model to adjust the survey responses according to the respondent's experience	Developed a statistical model to process survey results	·Use other techniques to remove bias from survey responses	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Develop the survey questions	Survey covered 20 fisheries, 6 activities, 6 actors and 7 infrastructure types	·Survey design should consider issues of confidentiality, consent, potential coercion and conflicts of interest ·Responses could be influenced by prevailing opinions (e.g. from recent press or research reports)	
	2. Circulate the survey and compile responses	The response rate to each question was between 56-75%; median sample size (over all questions) was 48.	·Questions that are ambiguous or sensitive may not generate useful information ·Need to ensure that the survey is sent to knowledgeable respondents and that a sufficient number respond	
	3. Adjust for respondent's experience to account for potential bias	Each answer was predicted from a model using the survey results and each respondent's self-reported experience score. High risk fisheries and supply chain points were identified.	·This kind of modelling can be done with publicly available software but requires specialist knowledge ·Self-reported experience may not necessarily reflect knowledge of IUU ·Experienced respondents may not be equally knowledgeable about all fisheries and activities.	
APPLICABILITY	Best suited to: • Obtaining an overview of diverse fisheries for prioritizing issues • Situations for which there are little or no data to estimate IUU in a more specific and quantitative way		Difficult to apply when: • More detailed information on how to tackle IUU problems is required • Respondents are unlikely to give accurate information • Sample size of informed respondents is small	

HEADER	***Citation***	Doumbouya et al. (2015)		
	Simple Summary	Used anecdotal information on illegal fishing offenses and the vessels involved to estimate total illegal catch in West Africa over a 6 year period		
	Approach Group	Sum Individual IUU Events to a Total Amount		Blue Approach Group
	Data Group	Operational Data		Data Group 3
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. A compilation of occurrences of illegal fishing including vessels, offenses and sanctions	Media sources, IGOs and NGOs, national government MCS units		
	2. Data on vessel capacity and catch rates from areas in which illegal vessels were operating	Media sources, IGOs and NGOs, national government MCS units and published studies		
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Inventory the number of fishing vessels involved in illegal activities and their size/capacity and extrapolate to an annual value	During one week in 2014, eight vessels were found fishing illegally in Guinea Bissau. Assumed 52 vessels in 2014.	·This approach assumes the sample is representative of the year. ·Extrapolation rationales should be consistent across various data types. ·Some situations may have no reliable basis for extrapolation.	
	2. Multiply the number of vessels by an appropriate catch rate	Assumed a catch of 1200 t per vessel per year would be necessary for economic viability (1200t x 52=62,400 t)	·Identifying an appropriate catch rate may be difficult ·Uncertainty in catch rates should be taken into account	
	3. Interpolate values for missing years to produce an estimate of illegal catches over a six year period.	Interpolated between the estimate for 2014 and a previous data point (18,000 t in 2010).	·Interpolation assumes there is an underlying trend, which may not be the case, especially if there are scarce data available ·The application of expert judgement needs to be well-documented	
APPLICABILITY	Best suited to: • Deriving estimates from sparse and/or anecdotal data • Providing a broad-brush overview of a country or region with inconsistent datasets		Difficult to apply when: • There are little or no data on the vessels and catch rates • External influences on the fishery, e.g. disruptions in enforcement, cause abrupt changes in trends • Estimates require a rigorous, quantitative basis	

HEADER	***Citation***	FAO (2015)		
	Simple Summary	Developed an estimate of IUU by foreign fishing vessels in the Asia Pacific region from a variety of specific incidents and information types		
	Approach Group	Sum Individual IUU Events to a Total Amount	Blue Approach Group	
	Data Group	Operational Data	Data Group 3	
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. List of IUU fishing hotspots	Literature and media review; interviews	·Expert judgement	
	2. Number of vessels, species and approximate illegal catch	Literature and media review; interviews; expert judgement	-	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Develop a list of IUU fishing hotspots through research and consultation	Listed 33 hotspots ranging in size from <100 km to >1000 km across the Asia-Pacific region	·The selection of hotspots may be influenced by media or expert biases Covering a large study region could lead to ignoring unique details in specific locations	
	2. Describe number of vessels, capacity, effort and species and calculate IUU catch (tonnes per unit time)	Methods vary from case to case but many estimates built up from numbers and sizes of vessels, and some based on a proportion of total landings	·Some of the case studies could not produce an estimate due to lack of detailed information (5 of 33 studies) ·The detail and reliability of information for each case study varies resulting in varying levels of uncertainty ·It can be difficult to combine estimates with different levels of uncertainty	
	3. Tally the IUU catch across the case studies to produce a regional total	Authors estimated 2.0-2.5 million tonnes of IUU catch. Frequencies of different types of IUU were also presented.	·The estimate is a minimum as it is based on a case study approach rather than the regional fishery as a whole ·If case studies focus on foreign fishing vessels, domestic contributions to IUU will not be included in the estimate	
APPLICABILITY	Best suited to: • Compositing a wide range of incidents and information covering multiple countries, gear and species into a single estimate • Highlighting patterns, trends or key issues in a region without focusing on a precise total figure		Difficult to apply when: • There is no basis for quantitative estimates for some parts of the fishery/region (such case studies will have zero IUU) • Estimates are likely to be challenged (as the method is highly dependent on assumptions)	

HEADER	***Citation***	Hentati-Sundberg et al. (2014)		
	Simple Summary	Developed a model to predict catches based on standard explanatory variables and variables designed to represent factors influencing mis-reporting.		
	Approach Group	Estimate "True" Catches for Vessels or Fleets		Purple Approach Group
	Data Group	Fishery models		Data Group 1
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Catch and effort data along with potential explanatory variables	Government datasets	Fishery cooperative records Co-variates sourced from other published and unpublished data	
	2. Other potential co-variates that could influence the extent of mis-reporting of catch	Calculated from other available datasets or published sources		
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Build a model to predict catch using effort data and standard explanatory variables	Used standard explanatory variables such as month, gear, mesh size, area, depth, trip length, engine power, total effort, etc. to predict catch over a 14-year period.	·Models may fail to fit the data if the data are noisy and/or explanatory variables are missing or mis-specified	
	2. Determine whether the fit of the model to the observed catch data can be improved with the addition of other explanatory variables that could influence mis-reporting	Tested the addition of variables relating to technology creep, fleet over-capacity, and the discrepancy between resource abundance and quota levels, and found the model improved.	·It may be difficult to quantify influences on mis-reporting (e.g. changes in enforcement climate or market circumstances) ·Although models may improve with the addition of new variables there may not in fact be a relationship between those variables and reported catch	
	3. If so, use the model with the new explanatory variables to determine the optimal values for the other co-variates and re-run the model to predict	Determined the optimal values for the standard explanatory values, then used these without the quota and over-capacity variables (thus assuming the correct reporting) to predict	·The approach is more complicated if multiple species are involved ·A further test of the predicted catch series could involve comparing it to what is known about stock dynamics	

	the correct catch (without mis-reporting)	that the true catch was significantly higher than the reported catch in recent years.	
APPLICABILITY	Best suited to: • Distinct, and well-documented fleets where the quantity of catch is the majority uncertainty • Fisheries for which logbooks provide operational details pertinent to each catch event (e.g. haul)		Difficult to apply when: • There is no existing predictive catch model • Influences on mis-reporting are unknown and/or unquantifiable • It is necessary to establish the cause of the misreporting

HEADER	***Citation***	Johnston et al. (2017)	
	Simple Summary	Estimated effort and catch in small-scale fisheries in the Gulf of California using population data and numbers of fishing vessels	
	Approach Group	Estimate "True Catches for Vessels or Fleets	Purple Approach Group
	Data Group	Operational Data	Data Group 3
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***
	1. Geo-referenced population data	National statistical institute	·Other governmental, inter-governmental or non-governmental sources
	2. Number and location of small-scale fishing vessels	Photos from over-flights and Google Earth images	·Other high resolution satellite technologies
	3. Vessel tracking information for at least part of the study area	Voluntarily provided by fishers under an academic research project	·Independent source of aerial imagery ·Land-based observations of departures ·Surveys of fishermen
	4. Landings records from 31 fisheries monitoring offices in the area of interest	Government fisheries agency	·Observed landings ·Surveys of fishermen
RECIPE	***Steps***	***Example***	***Cautions***
	1. Use the relationship between population and number of vessels to predict fishing effort	Created a grid of 500km^2 along the coast and assigned number of vessels and humans to each cell	·The relationship can be biased by the selection of grid size Need to consider the fishing range of the small-scale vessels being modelled and define the grid size accordingly
	2. Check (validate) the predicted effort using vessel tracking data showing how many vessels actually fished in each area	The relationship between population/vessel numbers and fishing effort was found to be highly significant	·Even though the relationship is logical it should be verified with independent data ·Each vessel was considered to have the same fishing power (may not be true) ·Protected areas were not taken into account
	3. Correlate predicted effort with catch (landings) to allow any "missing" catch (landings) to be predicted from population and number of vessels	The relationship between fishing effort and catch (landings) was highly significant and asymptotic (because catch is limited by ecosystem carrying capacity)	·The relationship is logical but should be verified with independent data (this may not be possible for areas which do not compile landings) ·If the model is validated using under-reported landings, the predictions will also be under-reported

APPLICABILITY	Best suited to: • Small-scale fisheries without other means of monitoring • Estimates of overall effort and catch without regard to species or type of fishing	Difficult to apply when: • There are no data to verify where vessels are operating • There are no catch data to validate the model • Population density is independent of fishing pressure (e.g. urban areas not dependent on fishing)

HEADER	***Citation***	Lack & Sant (2001)		
	Simple Summary	Compiled and converted customs statistics to obtain the amount in trade and subtracted reported catches to obtain an estimate of IUU catch of Patagonian toothfish		
	Approach Group	Estimate Total Catch Minus Reported Catch		Yellow Approach Group
	Data Group	Commercial Sources		Data Group 2
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Quantities imported by major markets and exported by major producers	National customs statistics	·Trade compendiums e.g. FISHSTATJ or COMTRADE	
	2. Reported catch quantity	CCAMLR catch data	·National catch reports ·Estimate catch from vessel data or other MCS sources	
	3. Conversion factors to adjust traded quantities to whole fish equivalents	CCAMLR conversion factors	·Previous studies ·Survey of industry experts	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Tally the total volume in trade	Assumed most toothfish trade would be captured by tallying imports by Japan, US, Canada and EU, and exports by Chile, Australia & EU to other markets	·Trade to minor markets could be missed Trade that is not labelled as the species of interest would be missed. ·Possibility of double-counting if there is processing in a third country	
	2. Adjust the volume in trade to whole fish equivalents	Applied a conversion factor of 2.2 to traded fillets, and a factor of 1.7 to all other traded products (mostly heads)	·It can be difficult to know the form of products marked only as "other" and thus conversion will be considerably uncertain ·Conversion factors themselves are likely to be uncertain and this variance should be taken into account.	
	3. Subtract the reported catch from the traded whole fish sum to obtain the IUU catch	Under conservative assumptions authors' trade-based estimate of IUU catch was comparable to, or exceeded, CCAMLR's estimate of IUU catch	·Results can vary based on which assumptions are applied (e.g. which markets are included), therefore sensitivity and alternatives should be tested	

APPLICABILITY	Best suited to: • Distinct products traded through a limited number of known markets • Providing an alternative or relative estimate or indicating a general trend, rather than a precise estimate • Identifying where market interventions may be warranted	Difficult to apply when: • Markets for the product of interest are unknown, extremely diverse, or highly dynamic • There are not distinct customs codes for the product of interest (or the product is mixed with other species in trade) • Conversion factors and/or product forms are not well understood

HEADER	***Citation***	Lewis (2015)		
	Simple Summary	Conducted a repeated survey of non-compliant behaviors in a recreational California abalone fishery to assess trends in IUU fishing		
	Approach Group	Determine Relative Amounts of, or Trends in, IUU		Red Approach Group
	Data Group	Expert Judgement/Surveys		Data Group 4
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. A survey designed to conceal individual responses and protect respondent privacy	Used an in-person randomized response technique	·Use anonymized online survey techniques	
	2. Repeated sampling to establish a trend	Surveyed in 2007 and again in 2011	·Can choose to sample over any period of interest	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Develop the survey	Survey consisted of 7 questions regarding non-compliance with licensing, size or bag limit requirements	·Questions can focus on whatever are the compliance issues of interest but respondents may still choose to give false information	
	2. Administer the survey	Surveys were conducted in person using paper survey forms (n=291)	·In-person surveying can take considerable time particularly if survey targets are difficult to access ·A large sample size is necessary because some of the responses will be discarded (see Step 3) ·Some respondents may not understand the randomization and so give incorrect answers (see Step 3)	
	3. Analyze the results	The respondent was instructed to answer truthfully or not based on the result of a coin toss. Analysis removed the untruthful responses allowing the author to identify a reduction in illegal take across most violation types.	·This method does not allow direct calculation of the amount of IUU catch, only whether it is getting better or worse ·It may be necessary to use other, non-randomized questions to assess potential reasons for non-compliance and thus highlight management priorities (e.g. lack of understanding of regulations)	

APPLICABILITY	Best suited to: • Fisheries in which the participants are accessible and willing and able to answer a survey • Establishing a trend in IUU rather than a specific level of take	Difficult to apply when: • The survey response rate is expected to be low • Repeated surveys are not likely • Rapid results are necessary (administering the survey takes time)

HEADER	***Citation***	MRAG Asia Pacific (2021)		
	Simple Summary	Identified specific IUU activities in Pacific tuna fisheries and determined "best", minimum and maximum estimates for each activity using MCS data and expert judgement, then modelled each activity and summed them to produce an overall IUU estimate.		
	Approach Group	Sum Individual IUU Events to a Total Amount		Blue Approach Group
	Data Group	Operational Data		Data Group 3
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. List of IUU risks	Held a workshop with relevant officials to agree the list of risks	·Allow the study team to specify the risks based on existing information (e.g. NPOA IUUs) ·Conduct a survey of experts, stakeholders, etc.	
	2. Best, maximum and minimum estimates of the level of activities contributing to each risk	Used extensive MCS databases along with expert judgement/ground-truthing to estimate	·Only use data (would require that every risk be monitored) ·Only use expert judgement (workshop, study team or survey)	
	3. Probability distributions reflecting uncertainty	For most risks the best estimate was considered most likely (triangular); if highly uncertain, used a uniform distribution	·Assign different probability distributions ·Assign the distribution within the study team or based on a survey	
	4. Monte Carlo model	Used "@Risk" software	·Other risk-focused software applications ·Program in Excel or other environment (e.g. R)	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Identify the IUU risks	One identified risk was under-reporting of target tuna species in longline catches.	·A thorough understanding of the fishery, preferably based on monitoring data, is required ·In a complex fishery there may be numerous risks to estimate	
	2. Analyze available data/information	Since longline observer coverage is limited, comparisons between logsheets and unloadings records were used.	·If the MCS system is weak, the data will not be informative ·Ideally, more than one source of information should be used	
	3. Specify the best, maximum and minimum estimates and the probability distribution	For one fleet, the best estimate of under-reporting of bigeye tuna was 13% (with min/max of 7-17%), and a triangular distribution was specified.	·Values can be specified on the basis of expert judgement alone, but the results may be considered more subjective. ·Values may vary depending on which dataset is used, thus some expert judgement may be required.	

	4. Simulate each risk	The total quantity of under-reported BET in the fleet was most likely 890 t.	·Both the estimates and the distribution will influence the results
	5. Tally the amount of IUU over all identified risks	For this fleet, misreporting was by far the largest component of the estimated total IUU fishing.	·If monitoring data are lacking, or lower quality, for some risks, these risks could be inadvertently downplayed in the results.
APPLICABILITY	Best suited to: • Fisheries with comprehensive and robust MCS programs with accessible data analysis systems • Fisheries for which there is likely to be consensus on the nature, range and scale of IUU fishing risks		Difficult to apply when: • Monitoring data are lacking, not suitable for analysis or not covering the main areas of IUU fishing risk, as heavy reliance on expert judgement could appear subjective • There is no detailed understanding of where, how or by whom IUU fishing may be occurring • Personnel lack the capacity to program/operate risk-based models

<table>
<tr><td rowspan="4">HEADER</td><td>Citation</td><td colspan="2">Oliveros-Ramos et al. (2020)</td><td></td></tr>
<tr><td>Simple Summary</td><td colspan="3">Mapped landing sites and number of vessels, then interviewed fishers to model catch rates and obtain order-of-magnitude estimates of catches at each site over a one-year period.</td></tr>
<tr><td>Approach Group</td><td colspan="2">Estimate “True” Catches for Vessels or Fleets</td><td>Purple Approach Group</td></tr>
<tr><td>Data Group</td><td colspan="2">Operational Data</td><td>Data Group 3</td></tr>
<tr><td rowspan="4">INGREDIENTS</td><td>Key constituents</td><td>How they sourced it</td><td colspan="2">Other ways to source it</td></tr>
<tr><td>1. Information on landing sites and number of vessels</td><td>Government, NGO and fishing company reports and registries</td><td colspan="2">Interviews, surveys</td></tr>
<tr><td>2. Satellite imagery of landing sights</td><td>Google Earth</td><td colspan="2">Other satellite imagery sources
Aerial photographs</td></tr>
<tr><td>3. Information on minimum, maximum and typical catches per trip, and number of trips per week, by site, season and environmental conditions</td><td>Interviews with fishing vessel captains or crew</td><td colspan="2">Landings records</td></tr>
<tr><td rowspan="4">RECIPE</td><td>Steps</td><td>Example</td><td colspan="2">Cautions</td></tr>
<tr><td>1. Compile a map of all potential landing sites</td><td>Used historical records, satellite imagery and site visits to identify 795 landing sites in 5 countries based on presence of fishing vessels, site layout, access roads, processing facilities, etc.</td><td colspan="2">·Some landing sites were not visible in satellite imagery due to vegetation and were only discovered during site visits
·Relying on historical information only might not reliably identify currently used sites</td></tr>
<tr><td>2. Collect information on number of vessels operating at each site and their catch rates</td><td>Used vessel registries, satellite imagery, site inspections and interviews to estimate number of vessels at each landing site</td><td colspan="2">·Imagery data may need to be reviewed over multiple periods due to fluctuating numbers of vessels by season or weather conditions
·There may be budgetary and safety concerns to address when obtaining information from fishers at each site</td></tr>
<tr><td>3. Estimate the weekly catch rate per vessel at each site</td><td>Used Monte Carlo simulation to estimate the number of trips per week (by season and environmental conditions) and catch per trip to obtain weekly</td><td colspan="2">·This method is most reliable for obtaining recent catch levels; recollections of historical catches may be less accurate
·With more complex modelling this method can also incorporate information on life stage and gear type
·Models can also be used to predict catch data for unsampled sites</td></tr>
</table>

		catch rates over a one-year period at each landing site	
	4. Compute order-of-magnitude catch estimates using catch rates x number of vessels	Multiply Monte Carlo results by an estimated number of active vessels at each landing site (results not yet available)	·Producing an estimate of effort may require expert judgement if data sources are inconsistent ·Further *in situ* sampling would be needed to address species or size composition
APPLICABILITY	Best suited to: • Small-scale fisheries which make frequent trips from fixed landing sites • A large number of port samplers are able to conduct fisher interviews and gather accurate information		Difficult to apply when: • Species or size composition data are required other methods are under development by the authors) • Information on historical catch trends is required • There are major shifts in the landings sites and quantities from year to year

#6

HEADER	***Citation***	Oozeki et al. (2018)		
	Simple Summary	Estimated the number of vessels fishing for chub mackerel outside of the Japan EEZ using satellite-based illumination intensity measurements and calculated potential catch based on capacity and activity patterns.		
	Approach Group	Sum Individual IUU Events to a Total Amount		Blue Approach Group
	Data Group	Operational Data		Data Group 3
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Satellite-based illumination intensity measures (VIIRS)	Publicly available from NOAA	·Use data from another satellite ·Use other remote sensing methods to obtain number of vessels	
	2. List of vessels operating in the area	Publicly available vessel lists, national patrol vessels	·Use AIS vessel identification information ·Press reports or other observations	
	3. Navigation track information (AIS)	Obtained from a commercial service provider	·Other commercial service providers ·Non-governmental organizations	
	4. Information on catch rates, hold capacity, transfer times, etc.	Interviews with fishing companies, publicly available vessel lists	Interview similar operators ·Use published information or expert judgement	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Count and group the number of vessels using the satellite data, cross-checked with AIS and vessel lists	Numbers of fishing vessels, factory ships and fish carriers were tallied.	·This method is applied to a fishery using bright light fishing; other darker fishing activities may require different methods ·Some vessels may be able to escape detection altogether	
	2. Estimate catch using fishing vessel numbers and information on catch rates and freezing capacity	Estimated >153K t caught in a three month period	·This method could be difficult to apply to mixed species fisheries unless species distributions can be predicted (e.g. using sea surface temperature data).	
	3. Estimate carriage using number of carriers/factory ships and their capacity and transit times	Number of ships obtained from vessel lists, satellite data or AIS; transit times estimated from AIS and interviews. Capacities from interviews. Estimated 230-568K t carried.	·Use of different information and methods is desirable but in this case it led to estimates having a wide range. However, using more than one source of information prevents over-reliance and avoids "blindspots". ·Non-fishing vessels may be carrying other species or supplies, and so should be identified (e.g. using transshipment reports) and excluded from the estimate.	

	4. Compare estimated quantities to total allowable catch and/or reported catch	Authors found that estimated catch is more than double the amount reported.	·If uncertainty in estimates is high it may be difficult to draw precise conclusions about how much catch is illegal or unreported.
APPLICABILITY	Best suited to: • Cases where a clear signal of fishing vessels is provided by illumination intensity as detected by satellites • Making an estimate for a given area as a whole (i.e. separating legal and illegal vessels in the same area may be difficult)		Difficult to apply when: • Mixed species are caught but only one is of interest • Illegal vessels can easily operate without being detected (e.g. "dark" fishing) • There is limited capacity for processing raw satellite data

HEADER	***Citation***	Park et al. (2020)		
	Simple Summary	Applied a combination of four satellite technologies, at-sea observations and historical catch data to estimate the number of illegal vessels and catch of Japanese flying squid in North Korean waters		
	Approach Group	Sum Individual IUU Events to a Total Amount	Blue Approach Group	
	Data Group	Operational Data	Data Group 3	
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Satellite-based illumination intensity measures (VIIRS)	Publicly available from Colorado School of Mines	·Use data from another publicly available source (e.g. Global Fishing Watch)	
	2. Synthetic aperture radar (SAR) to identify large metal objects	Publicly available government sources and a commercial provider (K-SAT)	·Other commercial service providers ·Non-governmental organizations ·Publicly available government sources	
	3. Navigation track information (AIS)	Global Fishing Watch and partners	·Commercial service providers ·Non-governmental organizations	
	4. High resolution satellite imagery	Obtained from a commercial provider (Planet)	·Other commercial service providers ·Non-governmental organizations ·Publicly available government sources	
	5. Information from at-sea observations and historical catch rates, fishing access agreements, hold capacity, transfer times, etc.	Interviews with patrol officers, media coverage, published catch information for similar vessels, desktop research	Other published information ·Expert judgement	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Count the number of vessels using VIIRS for those fishing with lights and SAR/imagery for others (pair trawlers)	Summed the maximum count from each source in each two week period, 2017-2018	·Using the maxima could over-estimate but is mitigated by gaps in coverage, or unfavorable weather conditions, for some periods (i.e. when gaps occur count=0 or less than the real number of vessels) ·Some vessels may be able to escape detection altogether	
	2. Determine national origin using AIS, light intensity or vessel types	AIS showed pair trawlers' home ports and fishing grounds; VIIRS can distinguish fleets by brightness of fishing lights; some types of vessels originate only from certain countries	·In some cases the proportion of vessels broadcasting AIS signals is low ·Not all fleets can be distinguished based on fishing light brightness ·Some types of fishing vessels can originate from multiple countries	

	3. Convert vessel counts to fishing days and cross-check with other sources	Applied the count maxima across each 14 day period; estimates were similar to, but lower than, Coast Guard counts on the water	·Some vessels may be present but not fishing due to weather or equipment malfunctions ·Some fleets may remain on fishing grounds for <14 days, therefore the survey period should be adjusted accordingly
	4. Estimate catch per fishing day based on catch rates for similar vessels	Applied catch rates per day from South Korean and Chinese vessels; alternatively applied catch rates per vessel per year. These estimates were similar.	·Can be difficult to know whether catch rates from other fleets fishing in other areas are applicable
	5. Estimate the amount of IUU catch	Subtract allowable catch in access agreement from total estimated catch	·Obtaining copies of non-public access agreements may be difficult ·Other types of IUU fishing (e.g. mesh size or species) may occur but are difficult to detect
	6. Compare quantities to reported catch by legal fleets	Authors found that estimated illegal catch is comparable to the total legal catch in surrounding waters.	·If uncertainty in estimates is high it may be difficult to draw precise conclusions about how much catch is illegal or unreported.
APPLICABILITY	Best suited to: • Cases where a majority of vessels are expected to be detectable using the satellite technologies available (i.e. vessel size and type) • Making an estimate for a given area as a whole (i.e. separating legal and illegal vessels in the same area may be difficult) • Fishing grounds with publicly available access agreements		Difficult to apply when: • Legal and illegal vessels operate in the same geographic area (would require positive vessel identification) • There is a need to identify specific vessels that are fishing illegally (method is better suited to fleet level identification) • There is limited capacity for processing raw satellite data

HEADER	***Citation***	Pauly & Zeller (2016)		
	Simple Summary	Estimated total global catch by combining data from a wide variety of sources and interpolating missing values with results considerably exceeding previously reported catch levels.		
	Approach Group	Total Catch Partitioned into IUU/Not IUU	Green Approach Group	
	Data Group	Expert Judgement/Surveys	Data Group 4	
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Baseline time series of reported catches by sector, time period, species, and gear	FAO data	Other national or regional sources	
	2. Available estimates of catches for sectors, time periods, species or gears that are not included in the baseline catch data	Published and unpublished records; interviews	Surveys	
	3. "Pedigree" score for the uncertainty associated with each sector, time period, species or gear data series	Expert judgement assigned categories of +/-10, 20, 30 and 50%	Apply other scoring criteria Carry through uncertainty in individual estimates	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Gather available estimates of catches not reported in the baseline database, and use interpolation to fill any missing data points	Commercial fisheries interpolated linearly (except in the case of natural disasters) and subsistence/ recreational catches interpolated with per capita rates.	·Ideally, the ratio of available to interpolated data points would be high, but this may be difficult for some fisheries ·Different sources of information may have very different degrees of reliability	
	2. Sum the baseline and interpolated time series (from Step 1 above) to produce a total reconstructed catch	For 2000, the global reported catch was 84 million t and the total reconstructed catch was 124 million t (~40 million t of illegal or unreported catch)	·Documenting the inputs and assumptions for global catch reconstruction can be a daunting task ·The process of "harmonizing" to ensure there is no double-counting of catch within and outside the baseline dataset is critical	
	3. Apply the mean weighted percentage uncertainty ("pedigree" score) over all countries and sectors to the	For 2000, the uncertainty bounds on the estimate of 124 million t ranged from 65 to 183 million t (Note: the authors revised the range to 115 to 135 million t	·The variance assigned under the pedigree approach could under-or over-represent the variance in some data sources	

	summed annual values to obtain the upper and lower uncertainty bounds	in a subsequent paper (Pauly & Zeller 2017))	·Summing uncertainty across numerous fisheries and countries is likely to produce wide confidence intervals which can complicate drawing robust conclusions
APPLICABILITY	Best suited to: • Compositing a wide range of information covering multiple countries, gear and species into a single estimate • Accounting for subsistence, recreational and discarded catches not captured in other catch datasets • Highlighting patterns, trends or key issues		Difficult to apply when: • Objective information is lacking and most values need to be supplied through expert judgement • Expert opinions vary widely • Estimates are likely to be challenged (as the method is highly dependent on assumptions)

HEADER	***Citation***	Payne et al. (2005)	
	Simple Summary	Used a stock assessment model to estimate unreported catches of Patagonian toothfish	
	Approach Group	Total Catch Partitioned into IUU/Not IUU	Green Approach Group
	Data Group	Fishery Models	Data Group 1
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***
	1. Stock assessment model	Used an existing age-structured production model	·Use another type of existing stock assessment model ·Develop a new stock assessment model
	2. Catch per unit effort time series (11 years)	Observer and daily catch reporting (logbooks)	·Could use only observer data or only logbook data, but it's necessary to have either one or the other
	3. Biological (life history) parameters	Sourced from a previous study and the observer program	·Compile from the scientific literature on the species of interest ·Compile from other similar species' studies
RECIPE	***Steps***	***Example***	***Cautions***
	1. Set up and run the model	Used AD model builder to construct an age-structured production model	·Age-structured models can be data-demanding. ·Simpler models are possible but may not be able to estimate "extra" catch.
	2. Observe whether the model fits the observed catch rate series	There is a conspicuous lack of fit during years when IUU is suspected	·The cause of poor fit may be due to other reasons including model parameter mis-specification or unknown factors. ·Ancillary data (e.g. anecdotal, records of infractions or IUU sighting) should be used to understand which discrepancies may be due to "extra" (IUU) catch.
	3. Allow the model to estimate the "extra" (IUU) catch that would have been taken to maximize the fit to the other information.	The model estimated almost 5000 t of extra catch in one of the years with previously poor fit	·This method is premised on there being a discrepancy between catch and biomass trends at a time when changes in IUU fishing activity are suspected. ·Sensitivity testing should be done to ensure the improved fit is not at the expense of fitting other important parameters.

APPLICABILITY	Best suited to: • Fisheries with existing, robust and widely-accepted stock assessment model • Fisheries with a reliable catch rate index giving a clear signal of stock abundance • Fisheries where specific IUU activity is suspected over a discrete set of years to provide contrast with non-IUU years	Difficult to apply when: • There is no existing model and the data to support model development are limited • There is an existing model but its results are highly uncertain across multiple parameters • There are many, and variable, sources of unaccounted catch such as discarding; or where there is a continuous low but variable level of IUU/unknown catch.

HEADER	***Citation***	Pitcher et al. (2002)		
	Simple Summary	Estimated rates of IUU fishing and applied them to the total reported catch to obtain quantities of IUU catch in Icelandic and Moroccan fisheries		
	Approach Group	Total Catch Partitioned into IUU/Not IUU		Green Approach Group
	Data Group	Expert Judgement/Surveys		Data Group 4
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Existing estimates of IUU catch as a proportion of reported catch by species, fleet and year	Published studies which used sampling, questionnaires or processing statistics	Survey or interviews Expert judgement	
	2. A table of the incentives for IUU by species, fleet and year (or range of years)	Expert judgement	Published studies Survey or interviews	
	3. Time series of total reported catch by species, fleet and year	National and RFMO data	FISHSTATJ or other academic sources	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Gather existing data to fill a matrix of IUU rates by species, fleet and year	Data for Iceland were readily available but data for Morocco were sparse	·Ideally, the majority of the matrix would be filled from existing information, but this may be difficult for some fisheries ·Existing information needs to be standardized across sources into common units ·Different sources of information may have very different degrees of reliability	
	2. Fill in any missing values in the matrix and specify all rates as a range	Used the incentives information and other expert judgement to interpolate missing values; where only point estimates were available the range was specified as +/-5%	·It is important to document how interpolated values were derived and to apply interpolation rules consistently across the matrix ·Conflicts between expert judgement and existing data need to be handled on a case-by-case basis	
	3. Multiply the completed rate matrix by the total reported catches to obtain the range of IUU catch quantities	IUU catch was estimated at up to 28% of reported catch in Iceland and up to 50% in Morocco	·IUU catch is defined as a proportion of reported catch so the overall trend will necessarily be determined by the trend in reported catch ·The method is vulnerable to under-reporting of the total catch	

	4. Conduct Monte Carlo simulation to obtain the mean and 95% confidence interval of IUU catch	Used a triangular distribution and 5000 replicates for the simulation	·A triangular distribution requires a midpoint and range; can use a uniform distribution if only a range is available ·If uncertainty is high it may be difficult to draw meaningful conclusions
APPLICABILITY	Best suited to: • Fisheries for which there is an expected relationship between reported and IUU catch (e.g. percentage of discards or catches of threatened species) • Prompting the provision of better information from as yet undisclosed sources by providing a first estimate		Difficult to apply when: • Objective information is lacking and most values need to be supplied through expert judgement • Total reported catch values are dubious • Expert opinions vary widely

HEADER	***Citation***	Plagányi et al. (2011)	
	Simple Summary	Used a stock assessment model, in combination with confiscations data and customs statistics, to estimate illegal catches of abalone in specific sectors	
	Approach Group	Total Catch Partitioned into IUU/Not IUU	Green Approach Group
	Data Group	Fishery Models	Data Group 1
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***
	1. Stock assessment model partitioned by fishing sector and zone	Used an existing age-structured production model	·Use another type of existing stock assessment model ·Develop a new stock assessment model
	2. Time series of confiscations per unit of policing effort for each zone	Police and marine inspector records	·Unofficial information sources such as a tally of media-reported quantities ·Expert judgement
	3. An estimate of the proportion of illegal take that is confiscated	Field observations	·Interviews and/or expert judgement
	4. Trade statistics showing the amounts exported and imported	Provided by an NGO	·Trade compendiums e.g. FISHSTATJ or COMTRADE
RECIPE	***Steps***	***Example***	***Cautions***
	1. Set up and run the model	Used AD model builder age-structured production model which explicitly estimates illegal catches and includes spatial effects to help separate causes of mortality.	·Age-structured models can be data-demanding; this model used commercial CPUE, survey abundance data, and catch-at-age data. ·Simpler models are possible but may not be able to estimate illegal catch, particularly by sector or area.
	2. Add the confiscations time series to allow the model to identify the maximum annual illegal catch (in numbers) as well as the amounts in other years. Check amounts against the field observations.	Observed population declines could not result from reported catches alone; in total millions of abalone were estimated to have been taken illegally.	·Other plausible alternatives for stock declines should be investigated. ·Method assumes the relationship between the number of confiscations and enforcement effort holds over varying levels of enforcement effort

			·Need to check that the model estimates of total illegal take are compatible with the recorded confiscations and/or export data
	3. Compare the model's estimate of illegal take to the amount of abalone received in markets that is greater than what was legally exported (assumes the proportion of illegal catch that is exported is well understood).	Model estimates were compatible with the estimated illegal trade in volume and trend.	·Need to be able to distinguish the product of interest (source and species) in the destination markets. ·Stockpiling or indirect trade may obscure the comparison with stock assessment-based annual estimates.
APPLICABILITY	Best suited to: • Fisheries with existing, robust and widely-accepted stock assessment models • Fisheries with standardized, available enforcement data and some direct or indirect information on enforcement success rates • Products that are readily distinguishable in trade and traceable back to source fisheries		Difficult to apply when: • There is no existing model and the data to support model development are limited • Enforcement effort and results are difficult to quantify • The product of interest is not recorded in customs statistics or is easily mixed with products from other fisheries

HEADER	***Citation***	Pramod et al. (2014, 2019)		
	Simple Summary	Selected an end-market of interest and identified its top product-source country combinations, then defined the IUU range for each combination and tallied the total IUU in the market.		
	Approach Group	Total Catch Partitioned into IUU/Not IUU	Green Approach Group	
	Data Group	Expert Judgement/Surveys	Data Group 4	
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Import data (source country and product) for the market of interest	Government trade statistics (export and/or import countries)	·Trade compendiums e.g. FISHSTATJ or COMTRADE	
	2. Proportion of the imports that are wild-caught (by source country and species)	Published and unpublished sources; interviews	·Expert judgement	
	3. Upper and lower bounds of illegal and unreported fishing for each source country-species combination	Published and unpublished sources; interviews	·Surveys ·Expert judgement	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Compile imports by source country and product for the market of interest	Identified the top 10 suppliers to the market of interest (e.g. US) and the top 3 seafood products for each	·The recorded source country may be the processing country rather than the country where the fish was caught ·The method is based on a "snapshot" but markets may diversify or shift quickly in response to supply and price	
	2. Adjust imported quantities so that they reflect only wild caught fish	According to industry sources ~10% of shrimp imported by the US from Ecuador was wild-caught	·In many cases trade statistics will not distinguish between wild and farmed products and adjustments may thus need to be based on qualitative information	
	3. Establish the range of illegal and unreported fishing for each source country-species combination	Range was 2-70% across 30 country-product combinations	·Use of information from unpublished and/or confidential sources may be difficult to document and defend ·IUU information for different source country-products may represent different points in time but need to be applied to a given year of imports	
	4. Multiply the upper and lower ends of the range by the quantity of wild imports;	Estimated that 20-32% of wild-caught seafood imports to the	·Estimates are likely to be uncertain and this variance should be taken into account.	

	extrapolate to the entire market	US in 2011 were from illegal and unreported catches	·The subset of investigated imports may not be representative of the market as a whole
APPLICABILITY	Best suited to: • Studies for which an indicative or broadbrush approach is acceptable • There is reliable, and preferably publicly available, information on IUU activities		Difficult to apply when: • Most available information is confidential • Products reach the destination market via third-country processing hubs where fish from various sources could be mixed

HEADER	***Citation***	Restrepo (2004)		
	Simple Summary	Unreported Atlantic bluefin tuna catch was estimated by subtracting the amount of reported catch from the amount of imports to major markets		
	Approach Group	Estimate Total Catch Minus Reported Catch		Yellow Approach Group
	Data Group	Commercial Sources		Data Group 2
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Catch reported to the management body	ICCAT catch database	·National catch reports ·Estimate catch from fishing days, etc.	
	2. Quantities of imports to major market states	ICCAT Statistical Document Program (now Catch Documentation Scheme)	·National customs statistics for the major markets ·Trade compendiums e.g. FISHSTATJ or COMTRADE	
	3. Factors to convert traded products to whole fish equivalents	Published information/expert judgement	·Fishery-specific measurements	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Sum the reported catches from all sources	Summed the annual catch of Atlantic bluefin tuna reported to ICCAT by national members	·Reported catch would include both internationally traded and domestically consumed bluefin	
	2. Tally import quantities from major markets and convert them to whole fish equivalents	ICCAT obtained imports from the statistical document programme and applied standard conversion factors	·Imports may not be reported by all countries receiving product If using customs statistics, imports may not be labelled to species ·Conversion factors are likely to be uncertain and this variance should be taken into account	
	3. Subtract reported catches from converted imported quantities; the remainder is unreported	ICCAT's calculations suggested that 1-5% of Atlantic bluefin catches were unreported	·Domestically consumed bluefin should be excluded from the calculation as it should reported as catch but not as trade	
APPLICABILITY	Best suited to: • Species and products that are usually exported to a few primary export markets • Where the quantity traded is distinctly reported in customs statistics or a catch documentation scheme • Situations where conversion factors are well known		Difficult to apply when: • The amount of domestic consumption is difficult to ascertain • The traded form of the product is not documented or well-understood • The traded product is a mixture of species or fisheries	

HEADER	***Citation***	Wernerheim & Haedrich (2007)		
	Simple Summary	Calculated unreported fishing mortality using a bio-economic model of the Pacific halibut fishery to estimate the propensity to discard at sea given the price premium for the optimal target (species or size) and the opportunity cost of fishing		
	Approach Group	Estimate "True" Catches for Vessels or Fleets		Purple Approach Group
	Data Group	Fishery models		Data Group 1
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***	
	1. Bio-economic model	Previous study of the fishery	Build a new model	
	2. Biology, prices, harvesting costs, discarding costs and probabilities of catching target and non-target fish as inputs to the model	Previous study + necessary updates of economic factors	Studies of similar species, markets or fisheries	
RECIPE	***Steps***	***Example***	***Cautions***	
	1. Use the model to predict the level of fishing effort necessary to optimize the economic value of a fishery using a homogeneous fleet	Discarding less valuable fish and setting again to catch more valuable ones (i.e. unreported catch) was estimated to occur 5 times per trip in the Pacific halibut fishery.	·It is likely that only well-studied fisheries will have the data inputs necessary to reliably support this kind of bio-economic model ·Additional model elements to capture a reduced cost of fishing (e.g. subsidies, cost cutting through lack of compliance with safety standards or labour practices) may be necessary for some IUU estimations	
	2. Calculate the cumulative amount of unreported catch that would result from the modelled economically-optimal behavior	The cumulative amount of discards per trip was estimated at ~550 t.	·This method was developed specifically for discarding and high-grading, but the approach of estimating the necessary economic return from fishing and the catch required to earn that amount is more broadly applicable. ·	
	3. Estimate the error in the available catch statistics as: unreported catch / (reported + unreported catch)	Since the reported catch was 433 t, the error in the reported landing statistics was estimated at 56% (550/(550+433)).	·In this example, the reported error is only that arising from discarding--it would not include any other forms of error such as under-reporting of landed catch. ·The example is based on the unit of trip, but the method could also estimate reporting error at the fishery or stock level.	

APPLICABILITY	Best suited to: • Fisheries for which operational behavior and economic incentives are well understood • Obtaining a theoretical, rather than evidence-based, estimate of unreported catch • Fisheries unable to support a more data-intensive model but for which an approximation of the size of the IUU problem is required	Difficult to apply when: • There is no existing biological model with which to combine known economic information, and there is a lack of time, resources or expertise to apply/modify modelling framework • The vessels or fleets suspected of under-reporting have varying, diverse or unknown economic incentives or costs

HEADER	***Citation***	Wilcox et al. (2021)	
	Simple Summary	Surveyed fishery officials on levels of IUU fishing for 25 marine faunal groups in the Asia-Pacific region, and adjusted and applied the responses to reported catches to quantify IUU amounts.	
	Approach Group	Total Catch Partitioned into IUU/Not IUU	Green Approach Group
	Data Group	Expert Judgement/Surveys	Data Group 4
INGREDIENTS	***Key constituents***	***How they sourced it***	***Other ways to source it***
	1. Reported catch of marine faunal groups in the area of interest	FISHSTATJ Capture Production Dataset	Other national or academic sources of catch data
	2. The categorical amount of IUU fishing (none, little, <half, >half, almost all, all) occurring for each marine fauna group	Online survey	Interviews Expert judgement based on review of available information
RECIPE	***Steps***	***Example***	***Cautions***
	1. Survey fisheries officials across the region of interest regarding the degree of IUU	45 officials were surveyed across 15 countries regarding categorical IUU levels for 25 marine faunal groups	·It may be difficult to secure a representative sample if there are language and/or internet access issues ·Although a large sample size might be desirable, an alternative could be to request responses from known experts only
	2. Control for the quality of the survey responses	Responses were given more weight if the respondent a) had experience; b) answered survey questions consistently; and c) did not give the same answer to most questions.	·Quality checks are important but they cannot fully control for biases or lack of knowledge among respondents ·If the survey is anonymous it can be more difficult to confirm that only knowledgeable experts responded. ·Asking a question for which the response is known can also be used as a quality control check
	3. Multiply the reported catch of each marine faunal group in each area by the adjusted category of IUU reported by the survey respondents	Used a model to predict the range of IUU amounts for each area and marine faunal group and proportioned FISHSTATJ data to estimate the total IUU in the Asia-Pacific region	·Care is required when translating categorical responses (e.g. "little", ">half") into quantitative estimates ·Unless responses are evenly balanced by area and species, some estimates will be more robust than others ·The approach assumes that illegal catches are included in the reported catches, although this may not be true in all cases

APPLICABILITY	Best suited to: • Fisheries for which there is little objective information (e.g. logbooks, observers) on which to base a quantitative estimate • Providing a broad-brush overview of a country or region with inconsistent datasets • Rapid, low cost estimate methods are needed	Difficult to apply when: • Obtaining expert responses is complicated by language or other access issues • Estimates require an objective basis • The quantities of IUU fishing are not likely to be related to reported catch figures

<table>
<tr><td rowspan="4">HEADER</td><td>Citation</td><td colspan="2">Williamson et al. (2014)</td></tr>
<tr><td>Simple Summary</td><td colspan="2">Accumulation rates of abandoned gear used to assess relative rates of IUU fishing on no-take and fishable reefs</td></tr>
<tr><td>Approach Group</td><td>Determine relative amounts of, or Trends in, IUU</td><td>Red Approach Group</td></tr>
<tr><td>Data Group</td><td>Expert Judgement/Surveys</td><td>Data Group 3</td></tr>
<tr><td rowspan="3">INGREDIENTS</td><td>Key constituents</td><td>How they sourced it</td><td>Other ways to source it</td></tr>
<tr><td>1. A measure of the rate of accumulation of abandoned gear in fished and fishing-prohibited areas</td><td>Removed all abandoned gear from some sites and counted accumulated gear 32 months later using underwater visual census techniques</td><td>Remote sensing (if gear is above water)
Other sampling methods</td></tr>
<tr><td>2. A measure of the efficiency of sighting abandoned gear at various sites</td><td>Calculated from the number of gear sighted before clean-up and the number of gear removed during clean-up</td><td>May be possible to estimate from repeated sightings under different conditions for various methods</td></tr>
<tr><td rowspan="4">RECIPE</td><td>Steps</td><td>Example</td><td>Cautions</td></tr>
<tr><td>1. Estimate the true amount of abandoned gear at fished and fishing-prohibited areas by adjusting counts for sighting efficiency</td><td>Underwear visual censuses detected 21-100% of the abandoned gear present due to reef habitat differences</td><td>·If gear disintegrates rapidly its use as proxy for fishing effort may be limited
·Gear must remain visible for surveys to detect it
·It may be difficult to accurately estimate sighting efficiency</td></tr>
<tr><td>2. Re-sample the same sites at one or more intervals to establish a rate of accumulation</td><td>All gear was removed from some sites, hence all gear observed in the second period was newly deposited</td><td>·Sighting efficiency may vary between sampling periods
·Need to ensure that only newly accumulated gear is counted (may need to remove or mark existing gear)</td></tr>
<tr><td>3. Compare accumulation rates at fished and fishing-prohibited sites to assess the degree of illegal fishing</td><td>The abandoned gear accumulation rate in fishing-prohibited areas was one-third that of areas open to fishing</td><td>·Need to control for differential rates of gear deposition that reflect factors other than fishing effort (e.g. dispersal patterns, gyres)
·Must be able to determine whether the prohibited activity occurred before or after management was put in place</td></tr>
</table>

APPLICABILITY	Best suited to: • Situations where the amount of visible abandoned gear is a good proxy for the level of illegal fishing • Abandoned gear that can be easily censused over time • The location of illegal fishing and the location of the abandoned gear are the same (or proximal)	Difficult to apply when: • Illegal fishing does not leave behind evidence • There is no budget or time for repeated sampling • Both legal and illegal fishing may contribute to the abandoned gear