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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 3.1: A PRACTICAL GUIDE FOR UNDERTAKING IUU FISHING ESTIMATION STUDIES

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

VOLUME 3.1: A PRACTICAL GUIDE FOR UNDERTAKING IUU FISHING ESTIMATION STUDIES

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List of acronyms

AIS	Automatic Identification System
EM	Electronic monitoring
IUU fishing	illegal, unreported and unregulated fishing
MCS	monitoring, control and surveillance
SAR	synthetic aperture radar
VMS	vessel monitoring system

Executive summary

Illegal, unreported and unregulated (IUU) fishing undermines sustainable fisheries management and is a serious threat for marine ecosystems, leads to the loss of short- and long-term social and economic opportunities and has negative impacts for the livelihoods of legitimate fisherfolk and on coastal communities around the globe, particularly in developing countries. IUU fishing occurs both in coastal waters and on the high seas and has been associated with organized crime.

This Practical Guide for Undertaking IUU Estimation Studies provides a tool for practitioners who aim at designing a study on the magnitude and impacts of IUU fishing, or a particular component of IUU fishing, for a specific fishery or region. The practical guide sets out details of the theoretical steps involved in a logical sequence that will result in a successful study, starting with a clear outline of the objectives, scope, and the indicators of IUU fishing in the selected fishery, leading to the identification of available data and the design of the methodology and eventually the study execution and presentation. It provides additional information on how to examine and catalogue data that may be available for the study, and how to match these with the objectives of the study to arrive at a sensible and robust suite of estimation methods.

This Practical Guide is the first part of Volume 3 of the Technical Guidelines on Methodologies and Indicators for the Estimation of the Magnitude and the Impact of IUU fishing, planned to consist of several volumes. It builds on Volume 2 covering guiding principles of and approaches to estimating the magnitude and impacts of IUU fishing, and Volume 1, the so-called “Study of Studies”, a compilation and analysis of all relevant existing studies to estimate the extent of IUU fishing around the globe at the time of that study. The overarching objective of the guidelines is to strengthen the quality and consistency of IUU fishing estimation studies, irrespective of the methodology chosen or the nature and scope of the study.

This practical guide is complemented with Volume 3.2, the Field Guide on the Estimation of the Magnitude and Impact of IUU fishing, focusing on a range of concrete scenarios, representing different characteristics, for instance regarding the fisheries, geographical range, species composition, data availability, exploitation status, management regime and timeframe to exemplify the selection of approaches and methodologies suitable for a given study. The field guide applies seven steps of planning a study, illustrating these with the practical examples of the scenarios and leading to the appropriate selection of a model for the respective case study to be undertaken. In cooperation with partners, these case studies can be conducted as full assessments in order to test the models.

Background and context

The Technical Guidelines present the issues that practitioners preparing IUU fishing estimation studies should consider. They also provide a compendium of specific examples in the form of previous studies from which to take ideas that may be applied in the study.

This practical guide sets out the detail of the steps involved in a logical sequence that will result in a successful study. It provides additional information on how to examine and catalogue data that may be available for the study, and how to match with the objectives of the study to arrive at a sensible and robust suite of estimation methods.

The components of this guide are consistent with the guiding principles identified in section 3.1 of Volume 2 on study design and incorporate the best practice study design measures set out in section 3.2 of Volume 2 on study methods. Although there is some flexibility around the ordering of some components, the best IUU fishing estimation studies will incorporate each of these features at a minimum. In particular, in the planning stages researchers will ensure there is a clear relationship between the objectives of the study, the nature of the data available and the approach and methodology chosen for estimation.

It is recommend that studies follow a plan involving three phases:

1. Study planning
2. Study execution
3. Study presentation

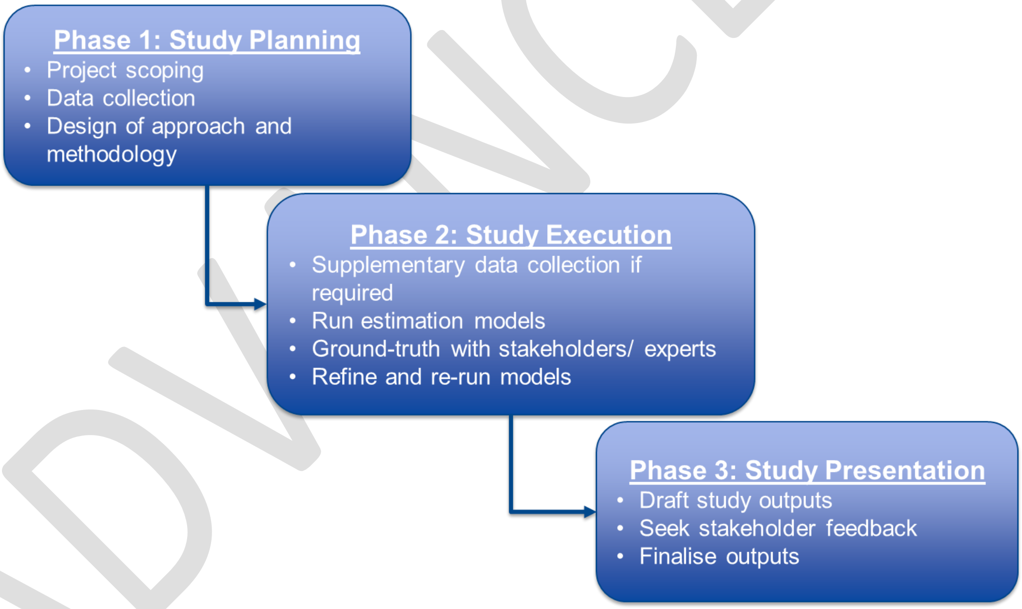


Figure 1: High level overview of IUU fishing estimation study process.

The study planning phase focuses on defining the scope and objectives of the exercise, identifies available data and other information and identifies appropriate estimation methods. The phase is essential in "setting the study up" properly.

The study execution phase focuses on the development and running of estimation models to produce preliminary results, ground-truthing these with stakeholders and experts and refining and re-running models as necessary. In practice, most models (and model inputs) are likely to be refined across multiple iterations before arriving at an accepted version.

The study presentation phase focuses on drafting the outcomes of the study (including clearly explaining the methodology, data inputs and gaps and assumptions used), seeking feedback from stakeholders (and peer reviewers if appropriate) and producing a final version for publication. The study presentation phase may also incorporate a range of other measures to ensure uptake of results.

Across each of these phases, the best studies will incorporate robust processes for stakeholder participation and expert ground-truthing.

The following sections set out the critical tasks in each of these three phases.

Phase 1: Study planning

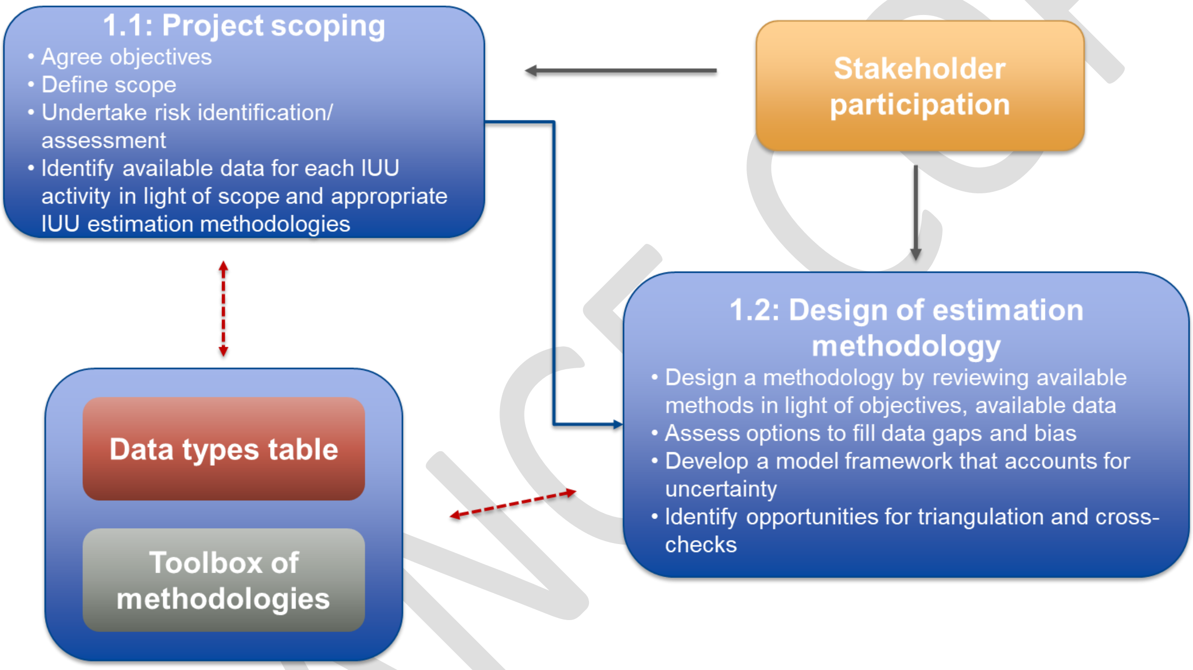


Figure 2: Overview of the study planning stage.

Task 1.1: Project scoping

1.1.1 Agree objectives

A key initial task for any IUU fishing estimation study is to agree and define the objectives of the exercise, starting by being explicit about why to identify IUU fishing. Some key reasons are given in section 2.2 of the Volume 2:

- Improving stock assessments and policy advice for conservation
- Improving socioeconomic conditions for fishers
- Better targeting of monitoring, control and surveillance (MCS) resources, or monitoring their effectiveness
- Advocacy
- Monitoring changes in IUU fishing activity over time

At this stage the level of information required should be defined – for instance, some studies may be interested only in producing a single estimate of overall "missing catch" to inform stock assessments, while others may be interested in a granular analysis of the nature and scale of each type of IUU fishing to assist in compliance planning.

The nature of the objectives chosen will have a big influence over the types of methodologies able to be used.

The objective/s should be agreed with the participation of interested stakeholders and relevant experts. Defining the objectives clearly upfront also serves to keep the project "on track" and allows for a judgement at the conclusion about whether the exercise has been a success.

1.1.2 *Agree scope*

The scope of the estimation exercise should be agreed with as much precision as possible. Referring to section 3.1.2 of Volume 2, the following should be decided:

- Which fisheries/sectors?
- Which species? E.g. either selected specific species or all?
- Which area/region?
- Which timeframe?
- Which parts of IUU fishing (for categorization see example in Table 1 in Volume 2)?

These questions should be answered in the context of the objectives agreed in 1.1.1, and with a clear eye towards practicality, feasibility and the resources available. Given the intention to quantify IUU fishing activity with as much precision as possible, every attempt should be made to limit ambiguity. The boundaries around each component of the scope should be clearly defined (species included; geographical boundaries) and structured to minimise the potential for overlaps and double counting, or alternatively to exclude key areas of IUU fishing activity.

The nature of the IUU fishing to be estimated should be considered in the context of both the objectives of the study (for example, are we attempting to estimate only one form of IUU fishing – say illegal foreign fishing – or all forms of IUU fishing within a fishery/area?) and by the legal frameworks in place in the study area. Fishing activities which are IUU fishing in one place may not be in another.

As with the study objectives, the scope of the project should ideally be agreed with the participation of interested stakeholders.

At this stage, it is very important to be explicit about what different types of activity will be considered as IUU fishing, and what different types of IUU fishing should be estimated. Legal frameworks can be complex or require some interpretation/agreement when identifying what is illegal and what is not, so drawing on the expertise of local experts in the prevailing legal frameworks within the study area is often highly valuable at this stage. Where multiple IUU fishing activities are estimated within a particular fishery/area, clear definitions of each IUU fishing activity should be provided to limit ambiguity and opportunities for double counting.

Pay particular attention to unreported discarding. This is often not strictly illegal or against regulation, and if so, it is also not strictly unreported as IUU fishing is described in Article 3 of the FAO International Plan of Action to Prevent, Deter and Eliminate IUU Fishing (which requires that not reporting or misreporting of catches should be illegal to be considered IUU fishing). However, unreported discarding is increasingly considered to be an important part of describing IUU fishing. It should be explicitly stated how the study will consider the issue of unreported discarding.

There are other elements to unreported fishing, such as unreported recreational or artisanal/subsistence fishing. These are much less often considered IUU fishing unless the actions are strictly against regulation. Again, it is important to be explicit about whether these issues will be considered.

1.1.2.1 Undertaking a risk assessment

Where the objective of the study is to assess total (or at least multiple forms of) IUU fishing within a defined fishery unit, a formal process of IUU fishing risk identification and/or risk assessment can assist in ensuring the full scope of IUU fishing activities are captured and appropriate distinctions/definitions are made between each. In the context of IUU fishing estimation, risk identification is the process of identifying and defining the risks of fishing activities being linked to IUU fishing practices within a fishery unit (for example unlicensed fishing, under-reporting target species, non-reporting of bycatch, illegal transhipping, etc.). An example categorisation of common types of IUU fishing activity relevant to estimation studies is provided in Table 1 in Volume 2, although the specific risk types of relevance will be influenced by the legal frameworks in place for the relevant area.

The process of clearly defining IUU fishing risks/activities through a formal risk identification exercise can help ensure comprehensiveness as well as minimise opportunities for double counting. Where the objective of the study is to estimate total volume and species composition of IUU caught fish within a fishery area, the process of risk identification also has the very practical benefit of helping break the IUU fishing problem down into its components, each of which can be estimated individually and aggregated to arrive at an overall estimate.

Where resources are limited, a process of risk assessment may help to focus the study on the main activities contributing to the overall IUU fishing problem.

The process of risk identification/assessment is best undertaken in a participatory manner with stakeholders and can often be done as part of an integrated exercise which involves the definition of study objectives and scope, risk identification/assessment, and identification of possible data sources to support estimation.

Where the objective of the study is simply to estimate a total amount of missing catch (without quantifying the contribution of each IUU fishing activity), a process of risk identification may not be necessary.

1.1.3 Identify available data

Once the full range of IUU fishing activities has been identified within the study's scope, the next main task is to identify the types of available data which can be used to help quantify the scale of each IUU fishing activity.

The four elements of design – objective, scope, data, and method – need to work together. It is important to understand what data are available in respect of each element of scope, and what combinations of method and data type can be used to estimate a particular type of IUU fishing.

For example, the best information to estimate the scale of unlicensed fishing within an area may be aerial or at sea surveillance data combined with vessel monitoring system (VMS) for licensed vessels and average catch rates for the licensed fleet (assuming unlicensed vessels are of similar size and use similar gear). By contrast, the best information to estimate under-reporting of target species by licensed vessels may be vessel catch logs compared against independent observer reports, at sea or dockside inspection reports or e-monitoring.

To assist in identifying the main types of data that might be available, Table 1 provides a summary of the main data types most commonly used in IUU fishing estimation studies together with their potential uses and the main considerations in using each data type. Recommendations to follow:

- first reading section 4 in the Volume 2 (toolbox of methodologies) to understand the different types of estimation methods that can be used and the uses to which data can be put;
- then using Table 1 to systematically understand and document the types of data that are available to help with the estimation of the IUU fishing scope elements;
- in Column 2 of Table 1, document the extent of each data holding, in relation to the sectors, species, areas and timeframes identified in section 1.1.1 under Scope.

The process of identifying the data available is best worked through with the participation of interested stakeholders (Box 1), including fishery managers and MCS practitioners who will likely have a detailed familiarity with the nature and quality of information available. Depending on the nature of the study, the involvement of industry at this stage can be helpful in identifying potentially useful sources of privately held data.

Bearing in mind that triangulation is highly desirable in IUU fishing studies, the combined use of different data sets is highly recommended. For instance, satellite surveillance on its own is of limited use, but when combined with Automatic Identification System (AIS)/VMS data and observers, it is possible to make a good estimate of the number of unlicensed vessels operating in an area and the likely catch rates they experience. Table 1 helps to understand which data are available to assist with triangulation.

Box 1: Stakeholder participation

The active participation of stakeholders in the design and execution of IUU fishing estimation studies can be highly valuable for a range of reasons, including assisting to identify the key IUU fishing risks and activities, identifying and providing information to support estimates, providing expert judgement to help fill data gaps and ground-truthing of preliminary outcomes. The involvement of stakeholders at all stages of the estimation process also helps to build 'ownership' and acceptance of the outcomes and ensures a greater likelihood that recommendations stemming from results will be adopted. Conversely, studies completed in isolation from interested stakeholders run the risk of focusing on "the wrong things", missing important IUU fishing activity and arriving at conclusions that may not be plausible.

A range of options exist to facilitate stakeholder participation in the study process. These include the establishment of a study steering committee or advisory committee to oversight the process, holding a series of workshops (for example project scoping, ground truthing), involving stakeholders on study teams where appropriate or undertaking stakeholder interviews.

The mechanisms to allow for stakeholder participation may differ based on the nature and objectives of the study, but should be sufficient to give key stakeholders confidence that their inputs have been heard and to adequately capture the benefits of their knowledge. Mechanisms for stakeholder participation should be agreed at the earliest practical time in the study process to ensure relevant stakeholders have an opportunity to contribute to the project scoping tasks in stage 1.1.

Table 1: Main data types commonly available for use in IUU fishing estimations, potential uses and key considerations in the use of each data type. Make notes in column 2 in relation to the data available to the study.

Type of data	Availability by scope element[1] (refer to section 1.1.2)	Data content and potential use	Considerations
Information on the licenced fleet capable of quantifying the likely impact of "unseen" activity by the licenced and unlicenced fleet; and identifying licenced fleet non-compliance			
Licensing/vessel registry information		Numbers of licensed vessels, types, gear/spatial/temporal authorisations, vessel characteristics, capacity, hold sizes, etc.	
Catch and effort data		Reported catch and effort from the licensed fleet. • Can serve as baseline data against which estimates of IUU fishing catch are compared. • Can help estimate typical catch rates for particular area/gear type/target species combinations that would be applied to "unseen" activity.	• The impact of any IUU fishing activity (for example under-reporting, non-reporting) on the integrity of baseline data should be considered. • Where catch and effort data from licensed vessels are used to estimate likely catch rates/species compositions from "unseen" activity either of licenced or unlicensed vessels, any likely differences in vessel characteristics, gear used and fishing operations between license and unlicensed vessels should be considered.
Fisheries observer data		Independent source of catch, effort and other information against which vessel reporting can be compared. • Often the only information source capable of quantifying the level of discarding. • Often the only information source capable of quantifying impact on the ecosystem, for example incidental mortality of birds/mammals/reptiles/fish and impacts on sensitive benthic habitat. • Most useful for providing an estimate of the likely performance of	• Where observer coverage is partial (i.e. observers are not present on all boats, or on all trips), there will often be a bias in the data, because the behaviour of vessels having observers and those not having observers (or trips on which observers are present and those where they are not present) is likely to be different. These potential biases need to be explored. They can both be controlled for: e.g. comparison of logbooks and landed catch from observed and unobserved boats operating in the same fishery at the same time and place; or comparison of the logbooks of a vessel at times when it has an observer compared to when it does not. When only partial

[1] i.e. is the data available for all sectors? All species? All areas? All timeframes? Are there any gaps in the data?

Type of data	Availability by scope element[1] (refer to section 1.1.2)	Data content and potential use	Considerations
		"unseen" activity, either by unlicensed vessels or by licenced vessels that are not being observed. • May provide direct observations of some IUU fishing activity by the observed vessel, e.g. fishing with illegal gear types, fishing in closed areas, shark finning, etc., but not usually reliable for identifying other vessels that might be IUU fishing.	coverage is available and the use of observer data is needed, statistical help to separate observer effects should be considered. • Observer data will be unable to generate information on the activities of prohibited gears, e.g. if the legal fleet is required to have seal escape panels in their nets and the unlicensed fleet does not have them, observer data will not allow estimation of this impact of unseen activity.
Electronic monitoring (EM) data		Similar uses to observer data, but will vary according to coverage and objectives of EM systems.	• Need to consider implications of coverage, camera placement and image quality on capacity to detect different types of IUU fishing activity (e.g.: Are cameras operating on all operational areas of the vessel, or only at the site of gear deployment and retrieval? Are cameras operating at all times, or only when gear is being actively deployed and retrieved? Is image quality sufficient to detect undersized or prohibited species?). • As with observers, need to consider impacts of any biases in coverage (e.g.: Do all vessels in fleet have cameras? If not, are some vessel/gear types over/under-represented?) and proportion of fishing activity reviewed. • Need to consider potential changes in fisher behaviour where EM is present. Are there effective comparisons between EM and non-EM trips?
Dockside catch monitoring data		Provides independent record of catch. Landed catch records can be compared with vessel logbook data to identify mis-reporting or under-reporting.	• Provides information on landed catch only and no information on discards • Can provide useful independent baseline dataset where under-reporting of catch (e.g. to evade quotas) or mis-declaration of species is suspected.

Type of data	Availability by scope element[1] (refer to section 1.1.2)	Data content and potential use	Considerations
VMS data		High resolution position information for the licenced fleet. • Can be used to identify IUU fishing with a spatial/temporal component (e.g. fishing in an exclusive economic zone without a valid license; fishing in a closed area). • VMS data from multiple vessels (e.g. fishing vessels/carrier vessels) can be used to highlight potential illegal transshipment.	• VMS data provides position information, but by itself does not confirm whether fishing is taking place. Additional analysis of VMS track history or signatures may be required and usually high temporal frequency of reporting (polling) is required to detect whether fishing is likely to be occurring. • The influence of polling rates on the capacity of VMS to detect offences should be considered (e.g. a vessel with a polling rate of once per day may be polled outside a closed area on consecutive days, but spend a portion of their (non-polled) time within it).
AIS data		AIS is a transponder based tracking system maintained by larger vessels for safety at sea purposes. • Potentially useful for the detection of vessel position information (for example may be coupled with VMS data to detect instances of illegal fishing or transhipment activity).	• Commercially available through services such as www.marinetraffic.com and www.vesselfinder.com • Only compulsory on vessels >300 GT under International Maritime Organization (IMO), but other jurisdictions have compulsorily required it for some fleets (all EU fishing vessels >15m). • Need to consider rates of coverage and voluntary switch offs for fleets in which AIS is not compulsory.
Objective inspection derived data capable of determining the "unseen" activity of licensed and unlicensed fleets, and licensed fleet non-compliance			
At-sea surveillance and dockside or at-sea inspection data		Reports from inspections conducted dockside or at sea, using standard procedures. • Independent quantitative and usually standardised data on rates of non-compliance across IUU fishing activities (e.g. rates of offence/inspection for different offences; rates of unlicensed vessel detection per patrol hour).	• Surveillance by sea-borne assets (inspection vessels) is costly and MCS authorities generally try to maximise their efficiency by targeting vessels with a history or behaviour that suggests that they will be at high risk of being non-compliant against some regulation. Non-compliance levels derived from such data cannot therefore be applied uncritically across the fleet. Data need to be stratified, and should be analysed after consultation with MCS authorities.

Type of data	Availability by scope element[1] (refer to section 1.1.2)	Data content and potential use	Considerations
		• At-sea inspections can provide data on infringements not easily detected through land-based or aerial surveillance, e.g. the use of illegal gear or the possession of prohibited species. They may also detect discarding.	• The effectiveness of inspections may also need to be considered, i.e. proportion of offences likely to be detected by inspections.
Prosecutions data		• Can provide a record of volumes and species composition per infringement. • May be used in combination with other approaches (for example expert judgement) to scale up across sector.	• Can be small datasets and influenced by single large events, e.g. large busts. • Need to consider extent to which available prosecution data is likely to be representative of all illegal activity (e.g.: Are only large infringements taken to prosecution? Is compliance effort only focused on higher level crimes?).
Aerial surveillance data		Reports from overflights of the vessels seen and their positions. • Can provide some quantitative basis for infringement rates (e.g. rates of unlicensed vessels detected per patrol hour or numbers in a particular area), which may be used to scale up across wider area/time. • Can provide information on some infringement types (e.g. use of some illegal gears detectable from the air) but not others (e.g. possession of illegal species in vessel holds).	• As above, need to consider influence of compliance strategies and targeting (i.e. non-randomness of compliance effort) on dataset – although these are often less likely than with sea-borne assets. • Need to consider likely effectiveness of inspection (i.e. proportion of different types of offences likely to be detected by inspections). For instance, sea-borne inspections may detect discarding or slipping of the catch, but aerial surveillance is unlikely to. • Aerial surveillance data may not be sufficient to detect whether vessels were fishing.
Satellite – passive visual images or synthetic aperture radar (SAR)		Satellite imagery requires complex processing, but historical images are often available at low cost (real-time images are costly). • Can detect presence of vessels across large areas of remote ocean.	• Satellite surveillance is restricted by the type of imagery required, the availability of satellites to undertaken this, the area that an image covers and the resolution delivered.

Type of data	Availability by scope element[1] (refer to section 1.1.2)	Data content and potential use	Considerations
		• Can be coupled with other forms of data (e.g. VMS, AIS) to identify unauthorised vessels, transshipment.	• Passive visual satellite images can be hindered by clouds. SAR is not hindered by clouds, but has inability to detect small vessels or those with low radar image (wood, fiberglass) and can be confused by some sea states and floating objects (e.g. icebergs). • Satellite surveillance may be able to detect vessels, but cannot distinguish between fishing and other vessel types (except by size) nor identify if fishing is taking place.
Data for top-down estimates of IUU fishing			
Stock assessments		A stock assessment model can be set up to estimate unreported catches where there exist inconsistencies between modelled stock trajectories and the source data: reported catch, age/length distributions in the catch and independent indicators of stock abundance such as catch per unit effort or independent surveys. • Can be compared against reported catch data to estimate total unaccounted for catch. • Can be used as a cross-check to determine plausibility of IUU fishing estimates given known biological productivity of stocks	• Require robust, reliable stock assessments. • Although good estimates of unreported catch quantity can often be made, these methods cannot determine the source of unreported catches. • Methods work best when there are periods of high contrast, for instance when a period of high compliance is followed by a period of low compliance.
Trade/market data		Trade data are regularly collected by authorities in many jurisdictions. • Data on exports or imports can be matched against catch reports from legal fishers to identify any discrepancies.	• Trade-based approaches work best where a high proportion of the product is exported, preferably to a limited number of destination markets, and where the species is easily identified and recorded in trade: for instance blue fin tuna is individually recorded, but most gadoids are simply whitefish.

Type of data	Availability by scope element[1] (refer to section 1.1.2)	Data content and potential use	Considerations
			• Relies on having clear customs codes matchable between import and export destinations. • Need to consider issues such as different product types and conversion factors to whole fish, potential for double counting, re-exports of fish, latency in the supply chain and the possibility of misclassification under generic product names.
Additional data complementing the main methods above, useful in triangulation or risk assessments.			
Expert judgement		Can be used to “fill in blanks” and triangulate/scale up estimates using other data.	• May be main/only source of information where empirical data are limited • Requires robust elicitation processes to ensure information credible and replicable where necessary
Stakeholder surveys		Specific surveys of stakeholders designed as part of an IUU fishing study. • Can be used to seek a collective stakeholder view on the nature and scale of IUU activities. • Can be used to identify likely IUU fishing activities and may serve as a cross-check on estimates	• Survey design should seek to limit subjectivity, ensure replicability • Rarely likely to be the primary data source for estimates, but may serve as a useful cross-check for data-based estimates.

Type of data	Availability by scope element[1] (refer to section 1.1.2)	Data content and potential use	Considerations
Confidential informant (CI)		May be used to generate “inside” information where publication of the source would otherwise mean the information is not available. • Best used during a risk assessment when planning the IUU fishing study rather than as a source of information for the study itself, except when it is used as a means of triangulation of other IUU fishing estimates derived by the study.	• Not easily able to be verified by a third party, and subject to individual bias on behalf of the informant. • Should not be used as a primary source of information in an IUU fishing estimation study. Should be used sparingly and only for the purposes of corroboration/triangulation of alternative sources of information/data.
Media reports/anecdote		Can be used to identify high profile IUU fishing activities and cases in different areas. • Best used during a risk assessment when planning the IUU fishing study rather than as a source of information for the study itself, except when it is used as a means of triangulation of other IUU fishing estimates derived by the study.	• Typically of limited value in estimation given reporting tends to focus on high profile cases (for example large busts, detention of foreign flagged vessels, large successful prosecutions), with limited reporting on more mundane IUU fishing activities and limited access to the details of cases settled out of court.
Independent field surveys		Specifically designed studies to quantify elements of IUU fishing. Can be targeted towards IUU fishing activities of interest (for example presence of illegal gear in the water). • If well-designed, can support robust, data-driven estimates of IUU fishing activity.	• Need to consider relationship between surveyed sample and broader population/fishery if results are scaled up.

Type of data	Availability by scope element[1] (refer to section 1.1.2)	Data content and potential use	Considerations
Gear trials		Specifically designed study to examine how illegal gear performs. • Can be used to estimate the catch rates of target and bycatch fish species as well as impacts on birds, mammals and the seabed, of different gears, including gears likely to be used in IUU fishing. • Will complement observer data.	• As noted above, observer data cannot provide information on the use of illegal gears or the lack of use of mandatory gears, because the licenced fleet on which they operate will not be using these gears. • Experiments must be managed well, and the judgement made that acquiring the data on the performance of the "unseen" activity justifies what will be an adverse environmental impact of the experiment itself.
Local market surveys		Can be used to identify prevalence of illegal products (for example prohibited species, under-sized individuals) in local markets. • Best used during a risk assessment when planning the IUU fishing study rather than as a source of information for the study itself, except when it is used as a means of triangulation of other IUU fishing estimates derived by the study.	• Unlikely to be able to estimate IUU fishing quantitatively • Need to ensure representativeness/rigour in survey design • Need to consider local social factors (for example willingness to display prohibited species) and extent to which relevant species are traded through local markets vs other supply chains.

Task 1.2: Design of estimation methodology

1.2.1 Review available estimation methods (Volume 2, section 4) in the context of study objectives and available data

Once the study objectives have been agreed and available data identified and reviewed, the different types of estimation approaches should be reviewed to identify the most appropriate for the circumstances of the study. Available estimation methodologies, together with their pros, cons and main data needs, are summarised in Section 4 and Table 2 of the Volume 2. A diagrammatic decision tree is additionally presented in Figure 3.

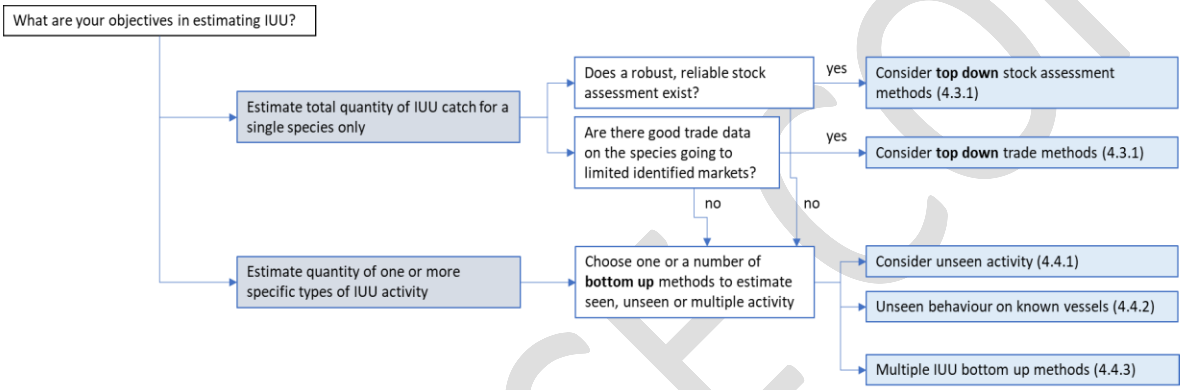


Figure 3: Simplified decision tree for finding an appropriate IUU fishing estimation methodology with references to Volume 2, section 4.

Broadly, where the objective is simply to estimate an overall quantity of missing catch, *top down approaches* may be used (section 4.3 in Volume 2). Where the necessary data exist, these approaches can often be used cost effectively, but they provide no information on the relative contribution of different types of IUU fishing activity to the overall IUU fishing problem.

Where the objective is to quantify the extent of an individual IUU fishing activity, or multiple individual activities (or sectors) to get an estimate of total IUU fishing, *bottom up approaches* are typically the most appropriate (section 4.4 in Volume 2). Bottom up approaches involve detailed analysis of information at a granular scale in an effort to build an accurate picture of IUU fishing activity. Bottom up approaches typically require the estimation of the *quantity* of the activity (for example the number of unlicensed fishing days) and the *impact* of the activity (for example catch rates by illegal vessels per day). The quantity is multiplied by the impact to produce an overall estimate, usually with some estimate of statistical confidence. Typically, this is expressed as a *best estimate* with confidence intervals around it.

Bottom up approaches can be time consuming and often there is a need to work with patchy and incomplete data, but can lead to more accurate, granular estimates of the nature and scale of IUU fishing than broad scale top down approaches.

Where necessary resources and data exists (or could be collected), the best studies will use multiple approaches to triangulate estimates. This could be either using multiple independent data sources to triangulate estimates within a single methodology – for example, using multiple data sources to

inform best estimates, maximum and minimum ranges and distributions within a Monte Carlo simulation bottom up based approach – or using multiple methodologies – for example, stock assessment and trade based approaches – to arrive at independent estimates of the same problem (the total volume of unaccounted for catch).

1.2.2 Develop conceptual approach/model

Once a basic approach has been chosen based on objectives and data availability, the development of a high level conceptual model to set out the logic of the estimation approach is often a valuable first step in developing a detailed estimation model. Ideally, conceptual models should be relatively straightforward and set out in plain terms the basic logic of how the researcher intends to estimate IUU fishing (for each different activity/sector and at the aggregate level, if relevant). Conceptual models should set out the main data sources and any key assumptions required at each stage of the estimation process. Because conceptual models should be succinct and avoid the use of jargon, they can be a very useful tool to help check and refine the basic thinking behind the proposed estimation methodology with stakeholders and independent experts.

Figure 4 sets out two very simple examples of conceptual models for estimating illegal harvest including the conceptual approach, basic logic and main data sources. It is very important at this stage to identify the assumptions in the approach (for further explanation, see 3.1.6 in Volume 2).

(a) Estimation of illegal harvest by unlicensed vessels using a bottom up approach

Conceptual approach:

Estimated # of fishing days by unlicensed vessels ✖ Average catch rate and species composition/day = Estimated volume and species composition of unlicensed fishing

Basic logic:

The volume and species composition of fish harvested by unlicensed vessels in area X during time period Y will be estimated by multiplying the estimated number of fishing days undertaken by unlicensed vessels by the average catch rate and species composition for similar vessels using similar gear types in the area. The number of days fished by unlicensed fished will be estimated primarily by scaling up aerial surveillance data (accounting for any biases in targeting and coverage). This will be supplemented by, and ground-truthed against, surface surveillance data, industry intelligence (e.g. sightings of unlicensed vessels) and VMS records of licensed vessels. Average catch rates for unlicensed vessels will be estimated primarily from catches and species composition of licensed vessels fishing in the same area using the same gear type at the same time. These estimates will be ground truthed and adjusted where necessary against boarding and inspection reports for prosecuted vessels and other relevant information (e.g. size of vessels and amount of gear in comparison to licensed vessels).

Data sources:

- Aerial surveillance data
- Surface surveillance data
- Industry intelligence
- VMS data (for licensed vessels)
- Catch rates and species composition for licensed vessels
- Boarding and inspection reports for unlicensed vessels
- Industry/enforcement officer intelligence

Assumptions:

- Catch rates and species composition for unlicensed vessels similar to licensed vessels using same gear
- Gear used by unlicensed and licensed vessels similar, or can be adjusted (e.g. based on inspection data).
- Combination of aerial, VMS, satellite and other data provides reasonable estimate of unlicensed activity by sector/species/area

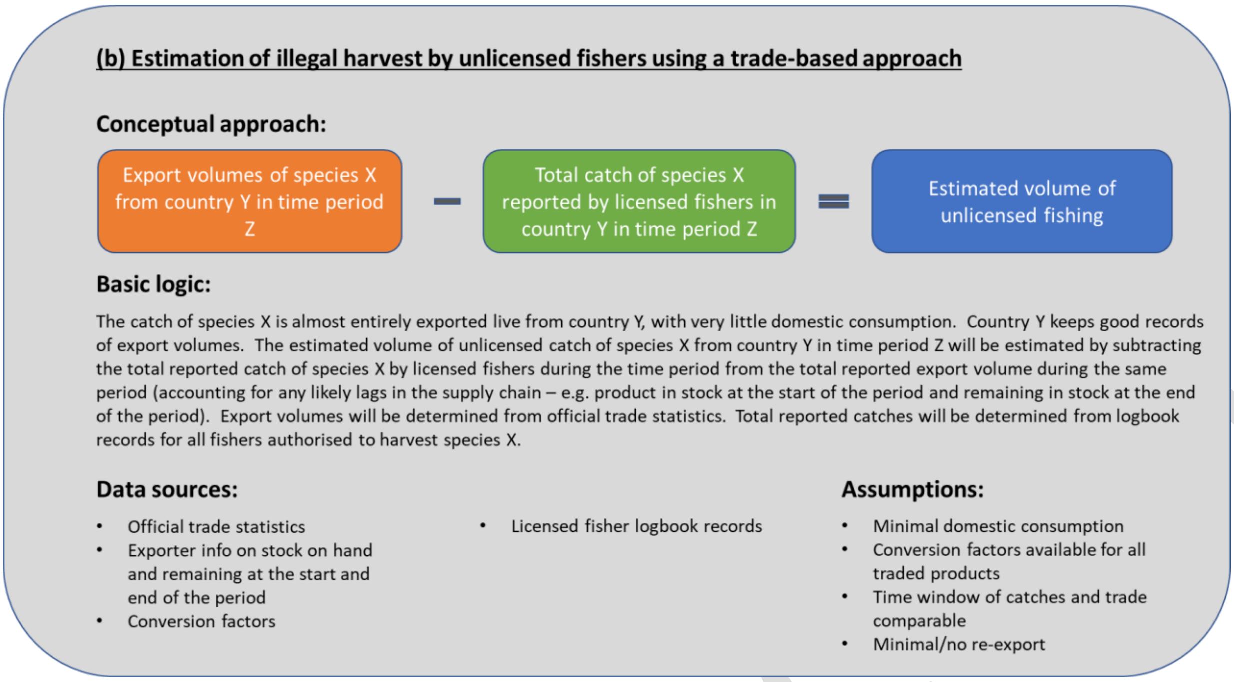


Figure 4: Examples of basic conceptual models for (a) estimating overall catch and species composition by unlicensed vessels using a bottom up scaling approach and (b) estimating illegal harvest using a trade based approach.

Where multiple forms of IUU fishing activity are estimated using a bottom up approach, the development of a detailed conceptual model setting out each of the IUU fishing activities and the approach to estimation can highlight areas of potential overlap between IUU fishing activities and minimise the risk of double counting.

1.2.3 Identify opportunities for triangulation

Following (or in parallel with) the development of the base model to estimate IUU fishing, study coordinators should consider whether opportunities exist to cross-check or triangulate outputs using independent sources of data or alternative estimation approaches. Here the term triangulation is used to describe a practical means of testing the plausibility of model outputs using *alternate sources of data* or *alternative analytical models* (Volume 2, section 3.1.5).

Where necessary data and resources exist, the best studies will aim to use a number of estimation methods to triangulate estimates of the same IUU fishing problem. There are a number of examples in the Volume 2, particularly in section 4.4, which illustrate the wide variety of approaches to triangulation. For example, estimates of the likely catch of an unlicensed vessel (Figure 4a) could be generated by multiplying the catch per effort of licenced vessels by the estimated number of days fishing; or it could be generated by estimating the hold capacity of the fishing vessel and information from port visits combined with the time between port visits or transhipments (see Oozeki *et al,* 2018). VMS records might be used as a primary source of data to estimate the extent of fishing in closed waters in a trawl fishery, and aerial and surface surveillance reports may be used to help verify the VMS data and/or extent of infringements. Bottom up estimates of illegal harvest from a particular stock could be cross-checked against stock assessment results to determine whether estimates of illegal harvest (when combined with legal harvests) are biologically plausible given the known productivity of the stock.

1.2.4 *Assess options to fill data gaps and deal with bias*

Once the basic approach and conceptual model/s for estimation have been agreed, study coordinators should examine the likely implications of any data gaps on the integrity/robustness of estimation outputs as well as options to fill them. These will often be determined by the time and resources available, but can be broadly categorised into two types: (i) additional data collection and (ii) statistical approaches to deal with data gaps or biases.

The capacity to undertake additional data collection will often be influenced by the types of data used for estimation. For example, where the primary source of data used is aerial surveillance data, the chances of contracting additional flights for the purposes of estimation are likely to be small. Similarly, where pre-existing data sets are used as the primary basis for estimations (for example trade figures, historical logbook records) there may be little prospect of gathering additional data (unless the scope is changed, for example to add additional years). Nevertheless, where the estimation is based on current/ongoing sources of data (for example observer/EM coverage, dockside inspections) or independent surveys it may be practical to target additional data collection to address keys gaps.

Data biases and gaps that cannot be sorted by new data acquisition may be amenable to being treated statistically. For instance, gaps in temporal or spatial series may be amenable to interpolation, and biases in sampling design (particularly with observers and inspections) can be dealt with through post-sampling stratification. These techniques may not be simple, but if a Monte Carlo approach is being used to estimate the variance of IUU fishing estimates bias and interpolation may be used together with high assumed uncertainty. Ideally, options to address data gaps should be reviewed with the involvement of a trained statistician to (a) ensure the approaches used are robust and (b) are undertaken in the most cost-effective manner.

Where no practical options exist to fill data gaps, any uncertainty arising should be reflected in final estimates of IUU fishing activity (for example by having a wider range of plausible estimates and/or broader statistical confidence intervals).

1.2.5 *Develop model framework, including estimation algorithms and mechanisms to account for uncertainty*

Once the conceptual approach to estimation has been agreed and the main features of the available data understood, study coordinators should move on to developing the detailed model framework including estimation algorithms for each relevant IUU fishing component as well mechanisms to account for uncertainty. In practice, algorithms and mechanisms to account for uncertainty will often be considered together as part of an integrated model.

The nature and complexity of the algorithms used will be dependent on the methodology adopted and underlying data. Simple estimates of single IUU fishing activities may be relatively straightforward, while estimates of multiple IUU fishing activities across multiple sectors may be computationally complex with large numbers of parameters. In all cases, algorithms used should be set out in sufficient detail to allow a reader to make an informed judgement of their reasonableness.

A number of mechanisms to account for uncertainty have been used in studies to estimate IUU fishing. While these guidelines do not seek to be prescriptive, the key requirement is that they be statistically robust and ultimately present an accurate reflection of uncertainty given the information available to the study. Two of the most common approaches used include:

- **Monte Carlo simulation** is a widely-used analytical technique for calculating probability distributions of possible outcomes by performing a large number of trial runs, in which variables are substituted randomly from within a specified range. Monte Carlo simulation has previously been used by a number of authors in attempts to estimate IUU fishing activity (for example Pitcher *et al*, 2002; Ainsworth, C.H., Pitcher, T.J., 2005; Agnew *et al*, 2009). The approach has a number of benefits over 'single point' or deterministic models in that it produces probabilistic results. Monte Carlo simulations can be performed by writing bespoke code in a number of programming packages, or alternatively through a number of commercially-available software packages;
- **Bootstrapping** is a similar technique to Monte Carlo simulation, although differs by resampling only from pre-existing data (i.e. whereas Monte Carlo simulation samples from a *theoretical* distribution within defined parameters, bootstrapping resamples the *data as given* over and over). Bootstrapping has the advantage of not requiring assumptions about the underlying distribution of the data or its properties, and might be used in preference to Monte Carlo simulation where a strong data set exists. Nevertheless, in many cases data available for IUU fishing estimation is patchy and Monte Carlo simulations may have more utility.

Bayesian frameworks may also be used but require specialist knowledge of such approaches.

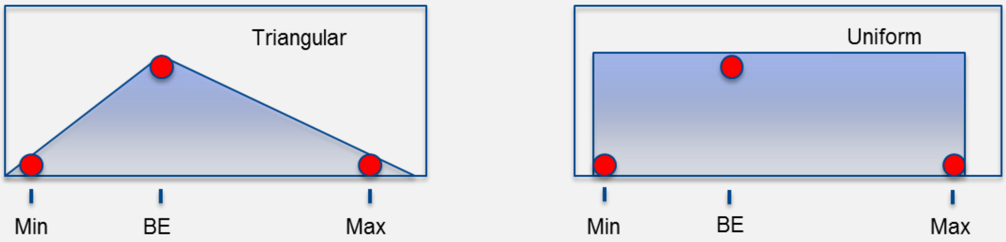
An example of how one study dealt with uncertainty is given in Box 2.

Box 2

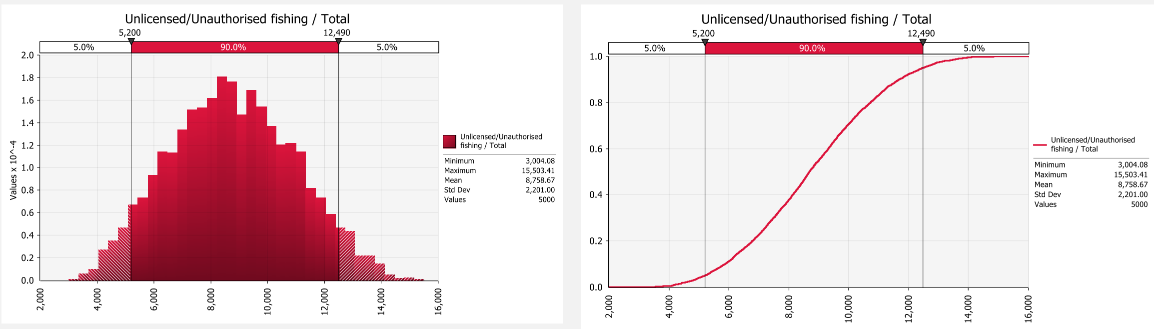
In their study estimating IUU fishing in Western and Central Pacific tuna fisheries, MRAG Asia Pacific (2016) used a bottom up approach which arrived at regional-scale estimates of the volume and value of IUU fishing by first breaking down the "IUU fishing problem" into discrete quantifiable units, and then aggregating these up to produce a regional scale estimate. The process involved five main stages:

1. **Identifying IUU fishing risks.** The first step in the analysis involved identifying the main IUU fishing risks (for example unlicensed fishing, mis- and under-reporting, illegal transhipping, etc.) in each of the main fishing sectors (purse seine, tropical longline, southern longline). These were identified through previous studies in the region and discussions with key stakeholders, and discussed and agreed at the Planning Workshop to commence the project.
2. **Determining best estimate and minimum/maximum ranges**. The next step involved identifying the information available to support estimates of IUU fishing activity, and then using that information to determine a best estimate level of activity and the most plausible minimum and maximum (min/max) values. Given the highly variable nature of the IUU fishing risks, a basic calculation to quantify the likely volume and species composition of catch derived from IUU fishing was tailored to each risk based on the information available. As a general rule, an uncertain quantity (for example the number of days fished by vessels on the FFA Regional Register in EEZs for which they were unlicensed) was multiplied by a known quantity (for example the average catch rate and species composition per day in the relevant sector) to constitute the basic calculation for each risk. Best estimates and minimum and maximum ranges could then be assigned to the uncertain value based on the nature and quality of information available. Minimum and maximum ranges took into account the uncertainty in the available information base (i.e. risks with more certain information has narrower ranges, risks with limited information had larger ranges).

3. **Assigning likely probability distribution.** Once best estimate and min/max values had been assigned, a likely probability distribution of IUU fishing activity within this range was determined. In general, triangular distributions were used where there was a reasonable level of confidence that the actual level of IUU fishing activity was likely to be closer to the best estimate than either the minimum or maximum value. Uniform distributions were used where the information base was highly uncertain, although these should be avoided in general.



4. **Monte Carlo simulations.** Monte Carlo simulation was then used (using "@RISK" software) to define the relative probability that IUU fishing volumes were within certain ranges, based on the best estimate and min/max values as well as the probability distribution assigned. Where a triangular distribution was assigned, randomly selected simulations involving values around the best estimate would be assigned a higher probability than simulations involving either the minimum or maximum values. In this way, the best estimate value would be given higher weight in the ultimate probability distribution.



(a) *(b)*

To that end, uncertainty was factored into the estimates in three ways:

- The width of the min/max range – in most cases, the narrower the min/max range around the best estimate, the more certain the inputs;
- The probability distribution chosen for the Monte Carlo simulations – for risks in which the best estimate was relatively strong, triangular distributions around the best estimate were chosen (i.e. the probability of the actual level of IUU fishing being close to the best estimate was assumed to be higher than that it being closer to the minimum of maximum value); and
- The probability distribution produced by the Monte Carlo simulation – this gives an estimate of the likelihood that the actual IUU fishing estimate will be above or below chosen benchmarks.

5. **Quantifying ex-vessel value**. Based on the likely volumes and species compositions associated with each risk, ex-vessel value of IUU fishing activity were calculated by assuming likely markets (sashimi grade for longline yellowfin; canning grade for purse seine yellowfin) and market values based on known trade and market data. The likely ex-vessel value of IUU caught fish was calculated across each main sector and collectively.

Phase 2: Study execution

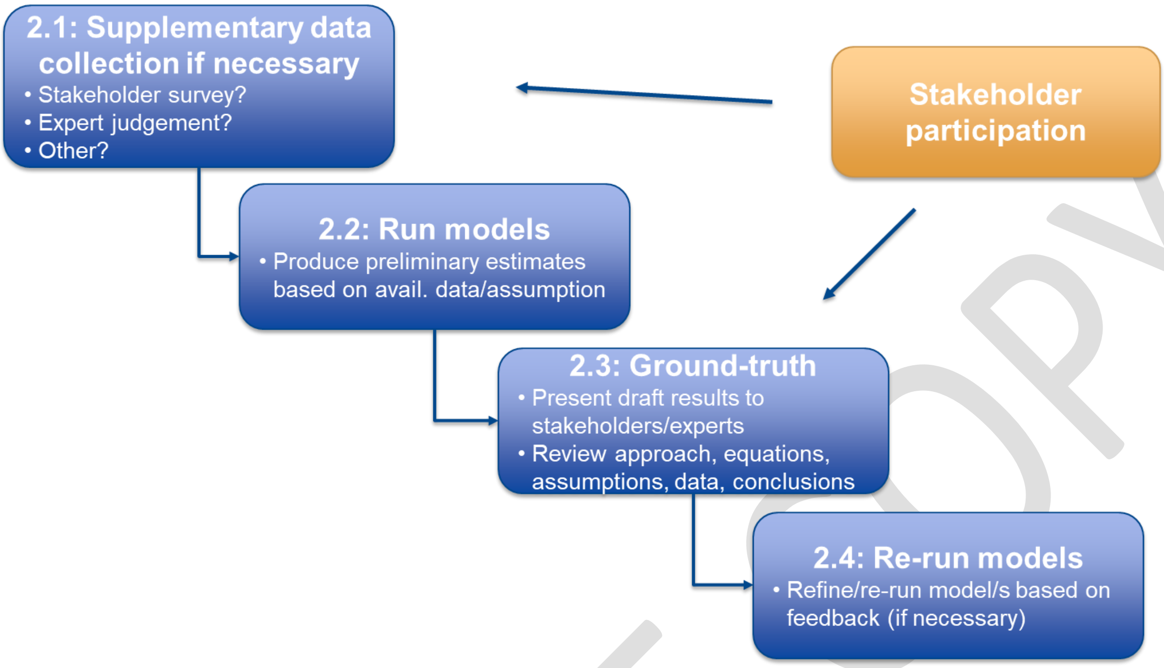


Figure 5: Overview of the study execution phase.

Task 2.1: Supplementary data collection

Where the analysis in Task 1.3.3 determines that additional data collection is required (or desirable), study coordinators should make arrangements for the necessary data to be collected before running estimation models. Efforts around additional data collection should involve people with statistical expertise (to ensure maximum robustness in the data collected) and stakeholders (to facilitate ease of collection and to point out possible sources of data) as required. All additional sources of data and methods of collection should be well-documented.

Task 2.2: Run models (and cross-checks)

Once model algorithms have been developed and data entered, models should be run to produce preliminary results.

Where possible, multiple iterations of the model should be run to test sensitivity to different data inputs and alternative plausible assumptions.

Model cross-checks should also be run to allow the plausibility of preliminary model outputs to be tested.

Task 2.3: Ground truth

Following the production of preliminary results, model outcomes (and cross-checks) should be presented to key stakeholders/experts for ground-truthing. This could happen either in written form or, ideally, through a more interactive process such as a Steering Committee or workshop. Where stakeholders have not previously been shown through the model structure, data inputs and assumptions, these should be outlined in detail to ensure familiarity with the approach taken and "how the model works" such that all are able to provide constructive input.

Whether feedback is sought in written form or orally, study coordinators should seek feedback that is practical with clear justification. Where stakeholders believe an assumption or outcome is implausible for some reason, a clear rationale should be provided ideally with a more plausible alternative.

All outcomes from ground-truthing should be recorded to allow study coordinators to demonstrate how the model inputs, outputs and assumptions used have been refined in response to feedback.

Task 2.4: Re-run models (and cross-checks)

Following feedback from key stakeholders/experts, models and cross checks should be re-run incorporating any suggested refinements to model structure, inputs and assumptions. Changes should be well-documented and outputs compared with the original version to demonstrate the impact of changes.

Importantly, this process of ground-truthing and refining of model inputs and assumptions may be repeated multiple times before a final version of the model, inputs and assumptions are achieved.

Task 2.5: Estimate value (if required)

Once final estimates have been produced of volume and species composition of catch derived from IUU fishing, estimates of IUU catch value can be produced using the approaches outlined in section 5.3 in Volume 2 on estimating economic consequences. Researchers should clearly specify whether they are producing estimates of *ex-vessel* or *market* value, their data sources and the justification for each. Where the economic consequences of IUU fishing is discussed in the context of the results, care should be taken not to confuse the *value* of IUU catch with *losses* to interested parties including coastal States.

Phase 3: Study presentation

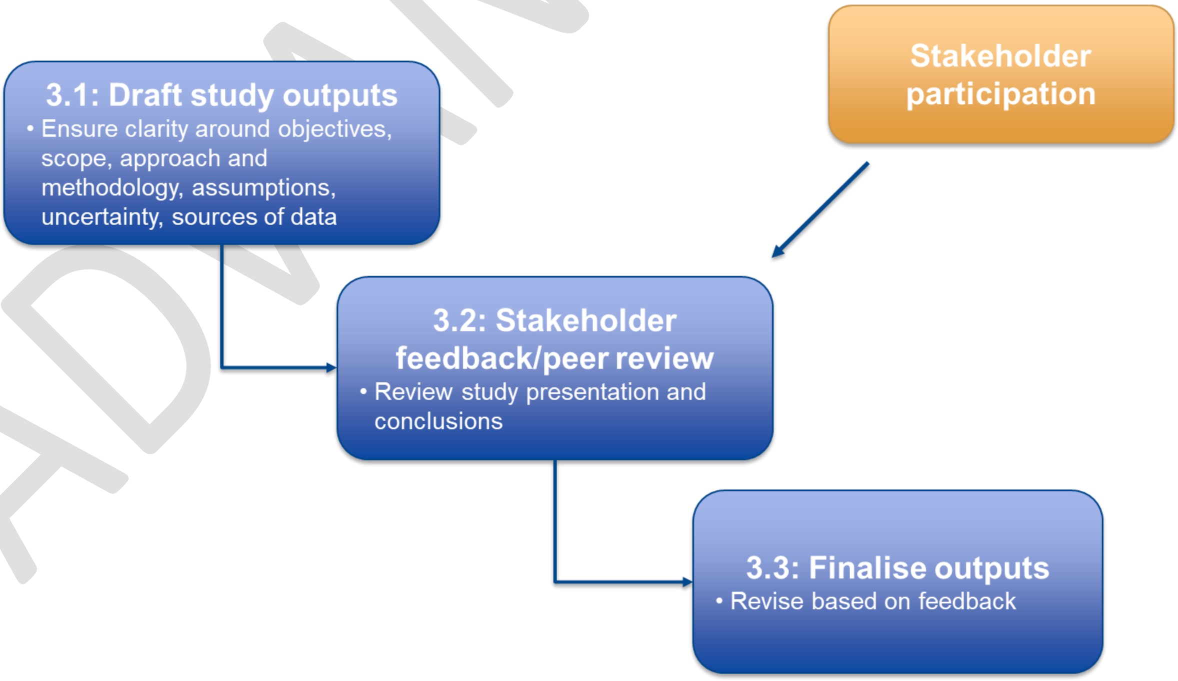


Figure 6: Overview of the study presentation phase.

Task 3.1: Draft study outputs

Once final estimates have been produced, study coordinators should begin the process of drafting the main study outputs. Please refer to section 7 in the Volume 2.

A key observation from the *Study of Studies* was that many previous IUU fishing estimation reports lacked clarity around key features of the approach and methodology used, the net result being that readers were not in a position to make an informed judgement about the reasonableness of the outcomes (or their potential implications).

The checklist in Table 3 in Volume 2 should be used to ensure that all key elements necessary to understand the basis for a study, its results and the estimates of confidence around those results. All studies on the estimation of the magnitude and impact of IUU fishing should fully document the decisions taken during study planning (items 1.1.1 to 1.1.3 above) and the methodologies and assumptions that were used to estimate IUU fishing, relevant triangulation studies and the approach to handling uncertainty and bias (items 1.2.1 to 1.2.5)

The presentation of model outputs will be dependent on the approach and methodology used, although it should provide the reader with a clear sense of relative certainty in the outcomes (for example by providing a best estimate and statistically-derived probability distribution of likely results).

The implications of any key assumptions, data weaknesses and interpretations of IUU fishing activity for the purposes of estimation should be discussed.

Task 3.2: Stakeholder feedback/peer review

Once the main study outputs have been drafted, feedback should be sought from key stakeholders/experts or peer-reviewers as required. The key task here is to ensure the approach and methodology has been presented with clarity, there are no obvious errors or omissions and any conclusions or interpretations drawn are reasonable and justified.

Task 3.3: Finalise outputs

Following the receipt of comments by stakeholders or peer-reviewers, study outputs should be finalised taking into account this feedback.

Preview to Volume 3.2

The field guide

This practical guide (volume 3.1) presenting a stepwise and broad procedure from a theoretical and logical point of view to estimate IUU fishing for any given fishery or region is complemented by a field guide (Volume 3.2) providing further detailed/specific guidance on a range of concrete scenarios. These scenarios, representative of the most common situations where an estimation might be required, illustrate a variety of situations with specific aspects and characteristics that will influence decisions at the level of the design and execution of the study.

No single methodology will fit every estimate. Consequently, these scenarios include a variety of fisheries, geographical ranges, species composition, data availability, exploitation status, management regime and timeframe to exemplify the selection of approaches and methodologies suitable for each study.

Examples cover industrial fisheries for different species, artisanal fisheries and inland fisheries, and include highly managed fisheries and new fisheries with the aim of addressing a wide array of situations. Examples of studies estimating the three different components of IUU fishing collectively or individually are also considered. This will increase the likelihood of practitioners finding a comparable study, as they look through this guide, to the study they wish to conduct.

At the time of publishing this Volume 3.1, work on the field guide (Volume 3.2) is ongoing and will aim to cover as many relevant scenarios as possible, as well as the full process for a complete estimation. The field guide will go beyond the design of the approach and selection of the methodologies, and include a number of defined steps in planning a study, illustrating these with practical examples of the scenarios and leading to the appropriate selection of a model for the respective case study to be undertaken.

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