Technical guidelines on methodologies and indicators for the estimation of the magnitude and impact of illegal, unreported and unregulated (IUU) fishing

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Acronyms and abbreviations

AIS	Automatic Identification System
ALC	Automatic location communicator
APFIC	Asia-Pacific Fisheries Commission
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CMM	Conservation and management measure
COFI	FAO Committee on Fisheries
EEZ	Exclusive economic zone
EM	Electronic monitoring
EPO	Eastern Pacific Ocean
ETP	Endangered, threatened and protected
FAO	UN Food and Agriculture Organisation
FAD	Fish aggregation device
FFA	Forum Fisheries Agency
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICES	International Council for the Exploration of the Sea
IPOA-IUU	International Plan of Action for IUU
IUU	Illegal, unreported and unregulated fishing
MARPOL	Marine pollution
MCS	Monitoring, control and surveillance
NPOA-IUU	National Plan of Action for IUU
PSMA	FAO Port State Measures Agreement
RFMO	Regional Fisheries Management Organization
RIMF	Regional Information Management Facility
SAR	Synthetic aperture radar
SIDS	Small Island Developing State
TAC	Total allowable catch
VDS	Vessel Days Scheme
VMS	Vessel monitoring system
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western and central Pacific Ocean

1 Preamble

Illegal, unreported and unregulated (IUU) fishing is a recognised global problem which undermines the integrity of responsible fisheries management arrangements, results in lost value to coastal States and can threaten food security (e.g. Agnew et al, 2009). Previous studies have shown that the effects of IUU fishing are often hardest felt in developing coastal States heavily reliant on fishing for income (e.g. MRAG, 2005). Quantifying the nature and extent of IUU fishing is important in gauging potential losses suffered by coastal States, addressing uncertainties in stock assessments and planning effective monitoring, control and surveillance (MCS) investments. However, by its very nature IUU fishing is secretive and difficult to estimate with accuracy (FAO, 2002; Le Gallic and Cox, 2006).

In February 2015, FAO convened a workshop in Rome, Italy, to consider methodologies for estimating IUU fishing at the global level. The workshop suggested that FAO could:

(i) coordinate a 'study of IUU fishing studies' to review the different methodologies being used to estimate IUU fishing;
(ii) lead a process to develop technical guidelines for future studies so they could be conducted in a way that would allow for estimates to be combined to contribute to a global estimate; and
(iii) consider indicators of IUU fishing for inclusion in FAO's bi-annual State of World Fisheries and Aquaculture (SOFIA) publication.

The study of IUU fishing studies (Macfadyen et al, 2016) was finalised in early 2016 and found that:

(i) there are many different methodologies being used to estimate IUU catch but many estimates are not robust and are insufficiently transparent about the sources of information used;
(ii) estimates of 'total removals' made in some studies include catch that is not necessarily 'IUU' in terms of the definitions in the IPOA-IUU;
(iii) developing an updated global estimate of IUU catch may have limited benefit due to wide confidence intervals, a strong reliance on assumptions in the process of scaling up estimates and a lack of clarity in IUU behaviours included;
(iv) efforts are more likely to be usefully focused on generating estimates at sub-national, national or regional levels as a basis for practical targeting of fisheries management and MCS;
(v) indicators to monitor progress in combatting IUU fishing need not necessarily include global estimates of volumes of IUU fish, and could focus on other aspects such as numbers of vessels on IUU fishing vessel lists, the number of countries on the EU IUU 'yellow' and 'red card' lists, and selected regional or local estimates of IUU fish catch based on repeatable and robust methodologies; and
(vi) FAO might play a role in supporting the development of technical guidelines, both on methodologies for estimating IUU catch, and on how to conduct risk-based assessments of IUU fishing.

The outcomes of the study of studies were considered by the FAO Committee on Fisheries (COFI) at its 32nd Session in July 2016. The Committee supported the development of technical guidelines on methodologies and indicators by FAO for the estimation of the magnitude and impact of IUU fishing. It also called for the reliable periodic estimates of IUU fishing, including at the regional level.

In line with the second action agreed during the 2015 workshop and COFI32 guidance, these guidelines, including a toolbox of methodologies, have been developed.

Consistent with the outcomes of the study of studies, the overarching objective of the guidelines is to strengthen the quality and consistency of IUU estimation studies, irrespective of the methodology chosen or the nature and scope of the study. It is not the aim of the guidelines to channel people towards a single 'best practice' methodology – given the wide variability in the objectives of IUU estimation studies, the very different types of IUU that may be estimated and the highly variable availability of information from which to estimate them, all methodologies will need to be bespoke to some extent and innovative approaches are continually being developed. Rather, the guidelines set out a number of 'guiding principles' which should be incorporated into study design and implementation irrespective of the specific methodology used. The guidelines also provide a 'toolbox of methodologies' to estimate IUU, together with advice on their main data needs, relative pros and cons and circumstances in which they might be used.

Following this preamble, section 2 provides a brief background to the concept of IUU and sets out some of the main challenges in defining IUU for the purposes of estimation. The section notes that what is, and isn't considered 'IUU', can have a very big bearing on the magnitude of IUU estimates and sets out a practical pathway for defining IUU at a scale relevant to the study. The section also sets out some of the benefits to be gained from having robust estimates of IUU activity.

Section 3 highlights a range of guiding principles for IUU estimation study design and implementation which have been distilled from the 40+ studies reviewed as part of the study of studies. These guiding principles are not methodology specific and can be applied irrespective of the approach used.

Section 4 sets out the 'toolbox of methodologies'. For each methodology, an overview of the conceptual approach is provided, together with the main data needs, relative pros and cons and examples of key studies. At the conclusion of this section, a basic decision tool is provided to assist researchers chose an appropriate estimation methodology based on the objectives of the study and the nature and extent of information available.

Section 5 provides advice on a number of issues commonly faced by estimation studies, including avoiding and mitigating 'double counting' and estimating the value of IUU fish from estimates of volume and species composition.

(Section 6 – indicators – to be completed)

Finally, Section 7 provides advice on the technical presentation of IUU estimation studies and measures to encourage uptake of results by interested stakeholders.

2 What is IUU and why estimate it?

2.1 IUU – what's in a name?

The notion of 'IUU fishing' first emerged during the 1990s in reaction to perceived inadequacies of the extant international legal and policy framework governing the exploitation of living marine resources (Tsamenyi et al, 2015). At the regional level, efforts to fill the gaps in the 1982 United Nations Convention on the Law of the Sea ('Law of the Sea Convention') were championed by international organisations responsible for high seas management of straddling and highly migratory stocks in an attempt to identify and reduce the impact of fishing by parties that were not subject to or complying with their management measures. One of the first organisations to act, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), developed a suite of measures to address the increasing uncontrolled fishing activities of several non-members and members alike in the Southern Ocean, which were undermining CCAMLR conservation and management measures. At the international level, the term "IUU fishing" was formally adopted by FAO and became a central part of the Organization's international fisheries policy at the 23rd Session of COFI in February 1999, based on a paper submitted by Australia, urging FAO to develop an

international plan of action to combat IUU fishing. Tsamenyi et al (2015) note that a series of rapid developments after the 23rd Session of COFI between 1999 and 2000 'concretised' the IUU fishing notion, which ultimately led to the adoption by the FAO Council of the International Plan of Action to Prevent, Deter, and Eliminate Illegal, Unreported and Unregulated Fishing (IPOA-IUU) at its 120th Session in June 2001.

The text of the IPOA-IUU includes the most commonly accepted working 'definition' of IUU (FAO, 2001), which has subsequently been adopted in a range of instruments including the FAO Port State Measures Agreement (PSMA). Rather than providing a prescriptive definition, the IPOA-IUU describes a number of illustrative activities under each of the IUU components (see Box 1).

BOX 1: IPOA-IUU 'Definition' of IUU fishing

3. In this document:

3.1 Illegal fishing refers to fishing activities:

3.1.1 conducted by national or foreign vessels in waters under the jurisdiction of a State, without the permission of that State, or in contravention of its laws and regulations;

3.1.2 conducted by vessels flying the flag of States that are parties to a relevant regional fisheries management organization but operate in contravention of the conservation and management measures adopted by that organization and by which the States are bound, or relevant provisions of the applicable international law; or

3.1.3 in violation of national laws or international obligations, including those undertaken by cooperating States to a relevant regional fisheries management organization.

3.2 Unreported fishing refers to fishing activities:

3.2.1 which have not been reported, or have been misreported, to the relevant national authority, in contravention of national laws and regulations; or

3.2.2 undertaken in the area of competence of a relevant regional fisheries management organization which have not been reported or have been misreported, in contravention of the reporting procedures of that organization.

3.3 Unregulated fishing refers to fishing activities:

3.3.1 in the area of application of a relevant regional fisheries management organization that are conducted by vessels without nationality, or by those flying the flag of a State not party to that organization, or by a fishing entity, in a manner that is not consistent with or contravenes the conservation and management measures of that organization; or

3.3.2 in areas or for fish stocks in relation to which there are no applicable conservation or management measures and where such fishing activities are conducted in a manner inconsistent with State responsibilities for the conservation of living marine resources under international law.

While the range of national and international instruments directed at combating IUU fishing has evolved considerably since the adoption of the IPOA-IUU, Tsamenyi et al (2015) note that a number of definitional challenges remain. In particular, in the context of attempts to estimate IUU activity, they note that the IUU fishing term is broad and, due to the diversity in governance frameworks, national legislation, fishing operations throughout the globe, there are a number of grey areas and overlapping situations among the three components of IUU fishing (e.g. much of which that is 'unreported' is also 'illegal'). In addition, whilst the IPOA-IUU describes a number of illustrative activities under each of the IUU fishing components, it does not completely cover all possible scenarios and does not address the issue of overlap among the three IUU fishing components.

Perhaps partly because of these uncertainties and overlaps some States have increasing sought to treat 'IUU fishing' as a single concept (for example, the EU IUU regulation simply provides a list of activities that are considered to be 'IUU fishing', without attempting to categorise them into 'I', 'U' and 'U'), or alternatively redefine the concept in national legislation.

In order to resolve some of the uncertainty and provide consistency to interpretation and estimates of IUU activity, Tsamenyi et al (2015) proposed a redefining of the IUU concept to the effect that (1) illegal fishing could cover fishing activities by all vessels (national and foreign) in areas under national jurisdiction, including inland fisheries, in contravention of national laws or RFMO conservation and management measures, (2) unreported fishing should be recast as "non-reporting, underreporting or misreporting of any information related to the fishing activity" and (3) unregulated fishing' should be recast as largely an issue of governance failure which would cover other types of activities that are not regulated, or that are taking place in areas without a fisheries governance framework.

Formal consideration of these changes by COFI and other groups has not yet occurred and the text in Section 3 of the IPOA-IUU remains the most widely accepted 'definition' of IUU fishing internationally. Nevertheless, some of the concepts raised by Tsamenyi et al (2015) – particularly consideration of any non-reporting whether or not it is required by regulation or law – are commonly considered "IUU" in the literature. We include them here because they are subject to the same sorts of considerations for estimation, and may legitimately be included in IUU studies, whether or not they are formally considered to fall into the international (FAO) definition of IUU fishing.

Noting that, as the above discussion shows, it is often difficult to categorise the different activities that are commonly referred to as "IUU" purely in terms of the formal FAO definition, the FAO 2015 workshop identified a number of different types of activity that could be, or have been, commonly identified in IUU studies (FAO, 2015, Annex 7). Table 1 presents these, organised into groups and roughly indicating the IPOA-IUU definition that relates.

Table 1: Example categorisation of common types of IUU activity relevant to estimation studies.

Group	Category	#	Types of activity	Notes
Fishing outside of regulations	**Encroachment (IPOA-IUU definition category 3.1.1, 3.1.3, 3.3.1)**	1	• Fishing in the waters of a country without a valid licence, authorisation or permit by the relevant national authority, where required; • Fishing in the waters of an RFMO without a valid licence, authorisation or permit;	Note if this is within a country or by an RFMO Contracting party flag state it is Illegal, if in an RFMO area by a non-party it is unregulated. Where there is activity within an EEZ that is not required to be licensed this is referred to by IUU analyses as "unregulated" but strictly speaking it is not according to the FAO definition – see below category 3.
	Absence of authentic documentation (3.1.3)	2	• Fishing in the waters of a country or an RFMO with false documentation; • Fishing as a stateless vessel (not registered with a national registry, or registered simultaneously on more than one); • Falsifying or concealing the markings, vessel identity, vessel location.	Note this is really a subset of encroachment.
	Legal non-reporting of activity	3	• Lack of reporting of fishing activities where this is **not** required either by national law or in international waters by RFMO and/or flag state regulations	Examples include fisheries that are often unregulated such as artisanal, subsistence and recreational fisheries. Note as above that this is not *unregulated* according to the IUU definition.

Fishing in contravention of regulations	**Non-compliance with technical measures (3.1.3)**	4	• Vessels may be licensed and have authentic documentation, but are:
			    • fishing in an area and/or season in contravention of management measures;
			    • engaging in directed fishing for a stock or species which is subject to a moratorium or for which fishing is prohibited;
			    • using prohibited or non-compliant fishing gear with applicable laws and conservation and management measures
			• Non-compliance with, or contravention of, technical requirements relating to a fishing access contract/agreement.
			• taking on board or landing fish in contravention of applicable laws and conservation and management measures (e.g. species for which there is no remaining quota, under-sized	

			fish, fish not landed in designated landing centres, landing of shark fins); • Unauthorized transshipment of fish and fishery products without authorization from the coastal or flag state or in contravention of the requirements of an RFMO, and/or without a designated and accredited observer to witness and record the transshipment operation if required.	
	Illegal non- and mis-reporting (3.2.1, 3.2.2)	5	• Lack of reporting of fishing activities where required either by national law or in international waters by RFMO and/or flag state regulations • Lack of reporting of catches, discards, and other incidental impacts of the use of fishing gear, where required by regulations • Over-reporting of catch (for example, to 'load' logbooks in advance of allocations based on catch history)	A distinction is made between legal and illegal non-reporting. Normally IUU studies restrict themselves to estimating discards, but some have gone further to estimate mortality from ghost fishing.
	Legal non-reporting of catches and discards	6	• Lack of reporting of catches and discards where this is **not** required either by national law or in international waters by RFMO and/or flag state regulations	If not required in law reporting discards is not *unreported* according to the IUU definition. Despite not being *sensu stricto* IUU, categories 3 and 6 are often the primary objective of IUU studies, and should be considered in any future IUU studies.

2.2 Why estimate it?

Irrespective of the definitional challenges involved in interpreting the IUU concept and the patchy and incomplete nature of available information, where IUU fishing is likely to be even a moderate problem, there can be very substantial benefits in attempting to quantify the nature and scale of it.

Each fishery and area is likely to have its own unique reasons for wanting to estimate IUU activity, but some of the most common benefits are set out below:

- **Improving stock assessments and scientific/policy advice** – one of the earliest motivations for fisheries researchers to estimate IUU activity was to improve the accuracy of stock assessments. 'Unaccounted for' catch, particularly in fisheries where IUU activity is thought to be a substantial problem, has the potential to bias assessment outcomes. This can lead to scientific recommendations that are unable to maintain the target stock at biologically sustainable levels (Maximum Sustainable Yield or above) and result in overfishing. IUU fishing impacts on habitats, bycatch and the incidental mortality of endangered and threatened species also needs to be understood if managers are to deliver sustainable ecosystem-based fishery management. Lack of knowledge on the level of IUU fishing, and the inaccurate estimates of stock status that result, may also lead to overly conservative assessment outcomes and unnecessary restrictions on legitimate fishery opportunities. To that end, producing credible estimates of IUU activity (or total unaccounted for catch, which may or may not all be 'IUU') are important in strengthening the scientific certainty or stock assessments and the appropriateness of resulting policy advice;
- **Improving socio-economic conditions of legitimate fishers** – understanding the economic impact of different types of IUU activity, either directly through economic impacts on legitimate fishers through the market, or indirectly through damage to stocks and the ability of the ecosystem to provide legitimate users with a full suite of ecosystem services, allows managers to identify the measures necessary to mitigate these economic impacts. However, while it is often the case that "unlicensed" or "pirate" IUU fishing damages local economies and the elimination of such fishing will benefit legitimate fishers, in many cases IUU activities may be also carried out by those same legitimate fishers such that the elimination of all IUU fishing will have initial short term negative impacts on them.
- **Information to allow better targeting of MCS activities –** a key benefit of those studies which aim to assess the full suite of the 'IUU problem' in a particular fishery and/or area is that they provide information on the relative contribution of different types of IUU activity (e.g. unlicensed fishing, under-reporting, illegal transhipping) to overall IUU volume and value. Such information is typically highly valuable, both from an operational and financial point of view, because different types of IUU activity can require vastly different types of MCS responses to detect and mitigate. For example, where the main IUU activity is unlicensed fishing by 'pirate' vessels which are essentially 'dark' from a monitoring point of view, substantial investments in assets and infrastructure (e.g. aerial and surface surveillance, satellite images) may be required to address the problem. However, where the main form of IUU activity is under-reporting by licensed vessels, comparatively modest investments in additional monitoring (e.g. observers, dockside inspection, electronic monitoring, catch documentation schemes) may be all that's required. Understanding the relative importance of each type of IUU activity can help prioritise limited MCS resources and help optimise compliance activity.
- **Monitoring changes in IUU activity in space and time** – Even where the nature and extent of IUU activity has been robustly estimated within a particular fishery, the reality is the picture will change over time. The nature of IUU fishing is highly dynamic, with the extent of activity changing as the mix of incentives, disincentives and regulatory environment evolves. Fishers

are often quick to respond to changes where economic opportunity arises and a squeezing of the regulatory and enforcement 'balloon' in one area may result in bulges in others. To that end, a key benefit of IUU estimation studies which produce 'reproducible' models of activity is the capacity to track changes over time and space as the nature of the operating environment changes. Tracking changes over time allows us to evaluate the effectiveness of previous MCS activity, as well as ensure current MCS plans and approaches are most appropriately targeted at the current configuration of IUU activity.

- **Evaluating MCS cost effectiveness and helping calibrate sanctions** – as with most forms of resource management, the benefits received from addressing a particular challenge should ideally outweigh the investment put into tackling it. Having a robust estimate of the value and costs associated with different forms of IUU activity can help fisheries managers and MCS practitioners evaluate the relative cost effectiveness of MCS investments (i.e. if I invest $5m in a new surveillance asset, how much am I likely to 'save' in income that would otherwise be lost to IUU operators?). Having a good understanding of the volume of IUU, and in particular the economic benefits to IUU fishers, can also help calibrate sanctions to ensure they sufficiently exceed the benefits to act as an effective deterrent.
- **Advocacy** – there's little doubt that actions taken by FAO and others through initiatives such as the IPOA-IUU and more recently the PSMA have considerably raised the profile of the perils of IUU internationally. However, the production of credible estimates of IUU volume and value can still have substantial advocacy benefits in highlighting the issues and mobilising resources. Estimates of 'pirate' fishing are often quick to be picked up by global media, helping to galvanise public support for action, while for policy makers and treasury officials having a credible estimate of 'lost value' to local economies is typically more effective in justifying spending than qualitative information and anecdotes.

BOX 2: Johannesburg sustainability goals and IUU

While there are multiple reasons to carry out IUU studies, in the context of the FAO, IUU activities are considered primarily as activities undermining the achievement of the Johannesburg sustainability goals agreed by the international community. Against this background, COFI would like to be informed, on a regular basis, of the magnitude and impact of IUU activities and progress in combatting IUU fishing globally. With this in mind, COFI requested the inclusion of information on the magnitude and impact of IUU fishing in the biennial SOFIA report.

2.3 Which parts of IUU should I estimate?

In the absence of a formal 'definition' of IUU fishing, stakeholders involved in IUU fishing estimation studies are left to make a judgement about which of the possible components of IUU fishing should be estimated and which, if any, will be excluded. The answer to this question will largely be informed by the objectives of the exercise.

In many cases, stakeholders will simply be interested in estimating the volume and species composition of fish harvested or transferred through the supply chain *illegally* – that is, outside of, or in contravention to, relevant fisheries management frameworks operating in the fishery/area of interest. In this case, *illegal* fishing would include all forms of unlicensed activity, all forms of contravention of fisheries regulations and license conditions and all forms of non- or misreporting of fish where there was a legal requirement to do so. It would also include fishing by Stateless vessels in contravention of international law, and fishing in an RFMO area by vessels flagged to a non-party State. It would not include, for example, other elements raised in the Tsamenyi et al (2015) considerations (above) such as non-reporting of discarded fish where there was no legal requirement to do so, or 'unregulated' fishing to the extent that there was no law in place prohibiting the activity (for example, where a lack of regulation in a particular area allowed fishing to

take place in a manner inconsistent with internationally recognised biodiversity conservation and stock management principles).

In other cases, stakeholders may be interested in estimating the volume and species composition of one particular type of IUU activity only.

In practice, the nature of activities that are 'IUU' will vary from fishery to fishery, State to State and region to region according to which legal framework/s are in place - what is perfectly legal in one area may be considered an egregious offence in another. Accordingly, attempting to provide a prescriptive 'top down' list of IUU activities that should be considered in estimation studies runs the risk of missing important forms of IUU activity at the local level and therefore biasing results.

With that in mind, these guidelines take the view that the nature of IUU activities to be estimated is best defined by interested stakeholders taking into account the objective of the study (e.g. is the objective to estimate 'total' IUU or just a specific component?), the legal frameworks in place and the use that is going to be made of the results (see section 2.4). The advantages of this approach are that stakeholders (e.g. fisheries managers, MCS practitioners, RFMO contracting parties) are able to ensure efforts are focused on the issues considered most important while avoiding devoting limited time and resources to issues of lesser interest. For instance, if the objective is to identify and then act to stop a particular illegal activity affecting a single sensitive species, it may not be necessary to estimate other illegal activities on that or other species in order to identify the scale of the problem and the most appropriate actions that should be taken to prevent it.

It is usually also the case that local stakeholders are well placed to advise both on local laws and their interpretation in practice, and those activities likely to make the largest contribution to the overall IUU problem.

The exception to this approach is where a study is part of a broader coordinated effort to estimate IUU across multiple fisheries/areas – for example, a coordinated effort to produce an updated estimate of global IUU. In this case, coordinators of the study should provide broad policy guidance on some of the key areas of uncertainty (for example, should discards which are not legally required to be reported be included in estimates?) to ensure 'apples vs apples' estimates between regions.

BOX 3: A note on 'unregulated' fishing

Of the three components of IUU fishing, unregulated fishing is perhaps the hardest to define in clear terms and therefore the hardest to estimate with any precision. While there are certainly examples of unregulated fishing which are relatively clear – e.g. fishing by stateless vessels on the high seas; fishing in the area of an RFMO by a vessel flagged to a non-Party in contravention of CMMs; fishing for a high seas resource that has no coordinated international management nor specific flag state regulations – the IPOA-IUU definition also arguably encompasses circumstances which are harder to define (see Tsamenyi et al, 2015 for discussion). These include, for example, fishing activities in areas under national jurisdiction which are not prohibited or regulated by national legislation or conservation and management measures of an RFMO, but which are contrary to the general international obligations of States (e.g. failure to collect relevant scientific data, failure to declare a total allowable catch under Art. 61 of the Law of the Sea Convention). These latter circumstances are largely issues of governance failure and are likely to be opaque, difficult to estimate in practice and potentially sensitive for a range of interested stakeholders. Given the potential for the inclusion of such activities to substantially influence overall estimates of IUU activity, and the potential for controversy surrounding their inclusion to overshadow the benefits for any study, our view is that unless there is a very clear guidance around what is considered 'unregulated' fishing within a national jurisdiction (e.g. through an NPOA-IUU), these more opaque forms of unregulated fishing should not be included in IUU estimates. This is consistent with the historical development of the concept of 'unregulated fishing' which focused largely on indiscriminate fishing activity by vessels flagged to States and fishing entities that were not members of RFMOs.

2.4 Why interpretation matters

In the context of studies estimating the nature and scale of IUU activity, debates around the definition of IUU fishing are more than esoteric legal arguments – what is, and isn't, considered IUU can have a very substantial influence on the overall outcomes. For example, including as 'IUU' estimates of unreported discards even where there is no legal requirement to report could lead to a several-fold increase in overall 'IUU' volume estimates for some fisheries.

Moreover, even where the illegality of the activity is clear, how particular circumstances are interpreted for estimation purposes can have a large bearing on overall estimates. For example:

- If a fishing vessel accurately reported its catch in a compulsory logbook, but submitted the logbook after the legal deadline for submission, should these catches be considered IUU?
- Within a single trip if a vessel fishes within its licensed area for 80% of the time, but 20% of the time in an area for which it has no license, is all of the catch on the trip considered IUU? Or just the catch taken in the unlicensed 20%?
- If a vessel fishes with three lines, but only one uses illegal gear, is all of the catch from that vessel IUU or just the catch taken from the illegal line?
- If a fishing vessel is required to continuously operate a vessel monitoring system (VMS), but the VMS is non-operational for a proportion of the trip and the vessel fails to manually report, should the catch taken during the trip be considered IUU? If so, should all of it be considered IUU or just an amount equivalent to the proportion of the trip for which the VMS was inactive?

The point here is that, in practice, most studies will come across a range of situations in which some form of 'call' needs to be about how illegal activities will be interpreted for the purposes of quantification. These calls can have a substantial influence over final results and should be given careful consideration. Our view is that such 'calls' are best made with the active participation of interested stakeholders in the context of the objectives of the study. Irrespective of the interpretation agreed, all such 'calls' should be carefully documented in study outputs such that readers have a clear picture of how estimates were arrived at.

3 Guiding principles for IUU estimation studies

The different objectives motivating IUU estimation studies and the highly variable nature of data and information sources available mean that all estimation methodologies will be bespoke to some extent. Nevertheless, many of the best studies share a number of features in common that serve to strengthen their overall credibility, defensibility and practical usefulness to interested stakeholders.

This section sets out a number of principles (or features) common to studies which could be considered 'best practice' in IUU estimation. Principles have been categorised as relevant to either 'study design' or 'study implementation' and have been distilled from the review of recent methodologies in the 'study of studies' (Macfadyen et al, 2016), as well as the authors' own experience in IUU estimation.

To that end, while the actual estimation methodology is expected to be tailored to the circumstances of the study in question, the incorporation of the following principles/features into the overall approach is likely to better position the study to produce credible, informative outcomes which will be useful to the intended audience.

3.1 Study design

3.1.1 Clear objectives

Arguably the first step in the design and implementation of an IUU estimation study is to be clear about why you're doing it – what are the objectives of the exercise and what are you hoping to achieve? The answer to these questions can have a substantial influence on the design of the study and the methodology chosen.

For example, where the objective is simply to get an understanding of total IUU activity or unaccounted for catch to reduce uncertainty in stock assessments, or to produce a total estimate for advocacy purposes, a top down approach (see section 4.1) which doesn't discriminate between the relative contribution of different types of IUU activity may be appropriate. However, if the objective is to get a more 'granular' analysis of the relative contributions of the different types of IUU activity to the overall IUU problem (for example, for MCS planning purposes or to address specific elements of impact on stakeholder/fisher livelihoods), a more detailed, bottom up approach may be required.

Wherever possible, the objectives of the study should be developed with the active participation of interested stakeholders (e.g. fisheries managers, MCS practitioners, senior policy makers).

As well as helping to ensure the methodology chosen is 'fit for purpose', ensuring clarity around the objectives of the exercise at the outset can also help save costs. For example, if all that's required from an operational point of view is a picture of the relative level of risk between different IUU activities (for example, to help prioritise deployment of MCS resources), a relatively simple qualitative or semi-quantitative risk assessment may cost effectively provide the level of information required. However, if more detailed information on likely volumes, species compositions and economic costs associated with IUU activity is required (for example, to assess the cost effectiveness of new MCS investments, or calibrate sanctions), a more detailed and costly quantitative assessment may be required.

3.1.2 Clear scope

Once the objectives have been agreed, arguably the next main step is to define the scope of the study. As a general rule, this will be a combination of answers to the following questions, many of which are inter-related to some extent:

- Which fisheries/sectors?
- Which species?
- Which area/region?
- Which timeframe?
- Which parts of IUU?

These questions should be answered in the context of the objectives agreed, and with a clear eye towards practicality, feasibility and the resources available. Given the intention to quantify IUU activity with as much precision as possible, every attempt to should be made to limit ambiguity. The 'boundaries' around each component of the scope should be clearly defined ('we are including these species, but not these species'; 'the geographical boundaries of the study will be X/Y/Z') and structured to minimise the potential for overlaps and 'double counting', or alternatively to exclude key areas of IUU activity.

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

Some of the key considerations in choosing an appropriate scope are set out below:

Fisheries/sectors – the choice of which fisheries to include in a study will be driven by the objectives and in most cases will involve decisions that can have a substantial impact on the overall outcomes. For example, if the objective is to estimate total IUU activity within an geographic/geopolitical region (e.g. EEZ, RFMO area), are all sectors – e.g. industrial, artisanal, subsistence, recreational – included? If only industrial fishing is included within scope, are all fleets included or just foreign fleets? Are all gear types included, or just some?

Even where the choice of fishery is relatively clear, some components may be considered more important to include than others based on risk and practicality. For example, in their study of Western Pacific tuna fisheries, MRAG Asia Pacific (2016) included the purse seine and longline sectors within scope, but excluded the pole and line sector on the basis that overall IUU activity in this sector was likely to be small in comparison to the other two.

Often the choice of fisheries/sectors will be a judgement call taking into account the extent to which the sector is likely to contribute to overall IUU activity and the nature and type of information available.

Species/stocks – the choice of target species (or stock) to include in the study should be relatively straightforward based on the focus of the study, although there may be decisions to be made about whether to include other lesser value byproduct and bycatch species in scope. These decisions may be influenced to some extent by the types of IUU activity to be estimated (for example, whether unreported discarding of bycatch species is considered 'unreported' and therefore within scope). The choice of species may also be influenced by the legal frameworks in place at the local level (for example, in one area a species may be subject to a moratorium and included within scope, whereas in other areas the species is not regulated and therefore out of scope).

A clear decision should also be made about whether to include endangered, threatened and protected (ETP), or otherwise potentially vulnerable species (e.g. shark bycatch). Where ETP species are included within scope and overall estimates of 'IUU value' are provided, a clear rationale will be needed for how these species have been valued (e.g. market value, non-market value).

Area/region – the choice of area/region should again be relatively straightforward based on the focus of the study (e.g. RFMO area, EEZ, inland lake) and the interests of stakeholders. Irrespective of the geographic boundaries chosen, these should be described clearly to avoid ambiguity. Where independent estimates from multiple regions are to be combined into an overall IUU estimate, care should be taken to avoid the potential for overlap and double counting.

Timeframe – as with other components of scope, the choice of timeframe will be influenced by the study objectives. For the many studies wanting to estimate 'current' IUU activity (say for the purposes of MCS planning), the most recent period for which sufficient data are available should be used (recognising that in most fisheries, data – e.g. logbook records – takes some time to filter into official sources). Other studies (say those wanting to estimate IUU activity within an uncertain period in a stock assessment model) may limit analysis to a defined period. The results of IUU estimation studies may be expressed in terms of the total volume of IUU activity within the relevant period, or averaged to form a 'typical' annual estimate of IUU fishing.

Which parts of IUU? – as described above, defining which parts of IUU are to be included in estimates is one of the most important choices to be made in defining a scope and can have a very substantial impact on overall outcomes. Decisions are necessary around which activities are considered 'IUU' for the purposes of the study and, for each of those activities, how they will be interpreted for estimation purposes.

The nature of activities considered in scope will be influenced by the objectives of the study – e.g. are we attempting to estimate only one form of IUU – say illegal foreign fishing – or all forms of IUU within a fishery/area – and by the legal frameworks in place in the study area. Ideally, the nature of IUU activities considered in scope, and how they're interpreted for the purposes of estimation,

should be discussed and agreed with interested stakeholders and experts. Where multiple IUU activities are estimated within a particular fishery/area, clear definitions of each IUU activity should be provided to limit ambiguity and opportunities for double counting.

Irrespective of how the above questions are answered, the details of the final scope should be set out in sufficient detail to leave the reader in no doubt about exactly what is being estimated.

3.1.3 Clear, reproducible methodology

As discussed above, the substantial variation in the objectives of IUU estimation studies and the nature of information available means that all methodologies will be bespoke to some extent. Nevertheless, irrespective of the methodology adopted, it is essential that it be described in sufficient detail to ensure the reader has a clear understanding about how the estimates were arrived at and can make an informed judgement as to its appropriateness. As with all scientific studies, the description of the methodology should be sufficient to allow an independent group to carry out the methodology in the same way using the same inputs and achieve the same results.

The other key benefit to ensuring 'reproducibility' is to allow for changes in the nature and extent of IUU fishing to be tracked over time. Being able to repeat the same basic methodology at periodic intervals allows us to track the evolution of IUU within the study area, continually optimise and refine MCS targeting and assess the effectiveness of previous MCS investments and activities. A robust, repeatable basic methodology also allows us to continually improve estimates of IUU activity as better information and monitoring becomes available.

3.1.4 Data-driven and transparent

While the nature of IUU activity means that information is frequently patchy and uncertain, the best IUU estimation studies will prioritise the use of empirical data sources where available. Although they can be subject to their own uncertainties and biases which need to be accounted for, the use of empirical data (i.e. that derived from observation or experiment) offers a more objective starting point than other forms of evidence (e.g. logical argument, expert judgement) which can be subject to a range of conscious and unconscious biases.

Where empirical data are not available or incomplete, the use of expert judgement and other more subjective sources of information may be required to 'fill in the blanks'. Where expert judgement is used, every effort should be made to standardise the process of collection to maximise objectivity. This is particularly the case where estimates are expected to be repeated over time and reproducibility of the methodology is essential.

Irrespective of the final configuration of data and information used, all sources of data and information should be set out in sufficient detail to allow the reader to make an informed judgement of their credibility and reasonableness. The implications of any important data gaps should be discussed.

Three particular types of data sources often used in IUU studies need special mention:

- The use of **confidential MCS data** - these data can rarely be scrutinised by a third party, so the level of trust in the correct collation and analysis of data needs to be high. We would recommend that in order to deliver this level of confidence, studies using such data should include participation by relevant government MCS professionals responsible for the data (e.g. as a member of the study team or on a study steering committee);
- The use of **confidential informants** (which are different from named expert judgement) - these sources can never be effectively verified by a third party. Where possible, these sources should be used sparingly and only for the purposes of corroboration/triangulation (i.e. that they are not the primary sources of information used to estimate IUU activity).

- The use of **grey literature** - without access to the literature a third party cannot verify them, nor identify whether the methods used in those studies were robust (or even whether the specific estimates cited in those studies were actually made by the authors themselves, or were also simply cited from non-robust sources). We recommend that either all grey literature is made publicly available or it is only used for the purposes of corroboration/triangulation.

3.1.5 Use of multiple data sources/triangulation

The nature of IUU activity means that most sources of data and lines of evidence will be patchy, uncertain and incomplete. With that in mind, the best IUU estimation studies will use multiple data sources to 'triangulate' estimates in order to reduce the impacts of uncertainties inherent within individual datasets or approaches. For example, Plaganyi et al (2011) used stock assessment, police/surveillance and trade data to estimate illegal catches of abalone in South Africa, while MRAG Asia Pacific (2016) used VMS, licensing, aerial and surface surveillance data and expert judgement to inform estimates of unlicensed fishing in Western Pacific tuna fisheries.

While the use of triangulation is encouraged, multiple independent sources of data or information may not always available. In these cases, it is essential that any increase in uncertainty associated with the use of a single data source (and any data gaps) be reflected in estimates of statistical confidence, and the implications discussed.

3.1.6 Clarity around assumptions

The uncertain nature of estimating IUU activity means that most studies will need to make a number of assumptions. The nature of the assumptions used can often have a substantial influence on the overall estimates. For example, in their study of south east Asian IUU hotspots Funge Smith et al (2016) assumed that all catch taken by all fleets implicated in IUU fishing hotspots was taken illegally. This is neither 'right' nor 'wrong', but an alternate set of assumptions – for example, that only catch from vessels from the proportion of the fleet for which there was direct evidence of IUU activity was counted in estimates – would have yielded an alternative result.

While the use of assumptions is largely unavoidable even in comparatively 'data rich' circumstances, the important thing is that all assumptions are clearly spelled out in sufficient detail to allow the reader to make an informed judgement about their reasonableness and the extent to which they may have influenced the overall results.

Ideally, all assumptions (but particularly those that are likely to have substantial bearing on outcomes) should be ground-truthed and refined where necessary with informed stakeholders during the course of the study to provide some confidence in their reasonableness.

For all assumptions likely to have a substantial bearing on overall results, the implications of alternative assumptions should be discussed. Where practical, this should be done in quantitative terms (e.g. 'our results assume X. If we assumed Y, our results would be different by Z', with Z being some quantitative figure) and ideally through some form of appropriate statistical sensitivity testing.

3.1.7 Mechanisms to account for uncertainty, estimates of confidence

The estimation of IUU fishing activity is, except in the most isolated of circumstances, an inherently uncertain enterprise. Information is often weak and patchy, sometimes of uncertain provenance and frequently hard to ground-truth except in the most anecdotal manner. To that end, the best IUU estimation studies will incorporate mechanisms to account for uncertainty in the information base and provide the reader with an estimate of confidence in the outcomes, sufficient to allow an informed judgement as to their credibility.

At their most simple, mechanisms may be as straightforward as providing a minimum and maximum range to estimates, with a discussion of the main sources of uncertainty and a justification of the upper and lower bounds of estimates. More sophisticated studies will make use of quantitative analytical techniques to account for uncertainty such as Bayesian analysis, bootstrapping and Monte Carlo simulation. These approaches typically produce probabilistic estimates of IUU activity (e.g. there is a 90% chance that the actual level of IUU activity is within the range X to Y) or 'best estimates' with a range of statistical confidence.

As a general rule, the more uncertain the underlying information the wider the estimated range of IUU fishing should be or alternatively the wider the estimates of statistical confidence. IUU estimation studies which produce single point estimates with no statistically based confidence intervals, or very narrow ranges without a clear justification, should be viewed with extreme scepticism.

All studies should be clear about the sources of data they use, be explicit about any weaknesses and uncertainties and discuss the implications in the context of the results.

3.1.8 Statistical rigour

Most IUU estimation studies will require some form of statistical analysis to account for uncertainty in the underlying information and to provide quantitative estimates of confidence in the final results. Depending on the nature of study, a range of statistical challenges may be encountered including the need to combine estimates of IUU activities with varying levels of confidence or the need to account for non-randomness and bias within available datasets (e.g. the need to account for non-randomness in aerial surveillance targeting where sightings data are used to estimate the extent of unlicensed fishing).

Given the variability in IUU estimation approaches and datasets, there is no one 'best practice' statistical approach to dealing with uncertainty. Nevertheless, the best studies will ensure that mechanisms are in place to ensure statistical rigour in project design and outcomes. This could be including a person with relevant high level statistical training on the study team or seeking advice from an external statistical expert on project design and the interpretation of results.

3.2 Study methods

3.2.1 Stakeholder participation

The active participation of stakeholders in the design and conduct of IUU estimation studies can be highly valuable for a number of reasons. These include:

- **Defining objectives and scope** – Particularly where the outcomes of the study are intended to be used in practice by interested stakeholders (e.g. in prioritising future MCS activities/investments), the involvement of stakeholders in the definition of study objectives and scope can help ensure the study is focused on 'the right things'. The 'ownership' engendered by giving stakeholders a say in study design will also, in most cases, mean the outcomes have a better chance of being 'picked up';
- **Identifying risks** – within the objectives and scope agreed, informed stakeholders will often be a valuable source of advice on the types of IUU activities operating in the area of interest (based on their knowledge of local legal frameworks and the operation of relevant fisheries), as well as their likely relative importance to the overall IUU problem;
- **Provision of information/data** – stakeholders who have worked in and around the relevant fishery/area being studied will often be well placed to advise on the types of information and data that exists to help support IUU estimation. Those holding official positions may also be well placed to facilitate access to information that would otherwise not be publicly

available. Industry and MCS practitioners may also be able to provide advice on some of the key input parameters underlying estimation (e.g. average hold size for IUU fleets; average trip length and fishing strategy for IUU vessels based on previous prosecutions, etc);

- **Use of expert judgement** – given the frequently patchy nature of information available on IUU, the judgement of persons considered experts in the issue at hand can often be used to 'fill in the blanks' in available information. Expert judgement can also be used to provide a secondary or tertiary source of data to help triangulate IUU estimates;

- **Ground-truthing of draft outputs** – the presentation and discussion of draft outputs with informed stakeholders, and refinement of inputs and outputs where necessary, can be a valuable 'ground-truthing' exercise, leading to more accurate and plausible estimates. In addition to involving stakeholders in study design, the process of ground-truthing can help build stakeholder confidence in the outcomes and better position the results to be picked up in practice.

With that in mind, the best IUU estimation studies will incorporate mechanisms to allow for meaningful stakeholder participation. This could be arranged, for example, through a series of workshops, the establishment of a study steering committee or advisory committee, the involvement of stakeholders on study teams where appropriate or formal processes to ground-truth draft outcomes to ensure practicality.

Studies completed in isolation from interested stakeholders run the risk of focusing on 'the wrong things', missing important IUU activity and arriving at conclusions that may not be plausible. There is also a higher chance that project outputs will be viewed with suspicion and provoke a negative response upon publication.

3.2.2 Risk identification/assessment

Risk identification

Where the objective of the study is to assess total IUU within a defined fishery unit, a formal process of IUU risk identification and/or risk assessment can assist in ensuring the full scope of IUU activities are captured and appropriate distinctions/definitions are made between each. Although the two terms are sometimes used interchangeably, it is worth noting they are not the same thing. As the name suggests, in the context of IUU estimation risk identification is the process of identifying and defining IUU risks within a fishery unit (e.g. unlicensed fishing, under-reporting target species, non-reporting of bycatch, illegal transhipping, etc). The nature of risks will be influenced by the legal frameworks in place for the relevant area. The process of clearly defining IUU risks/activities through a formal risk identification exercise can help ensure comprehensiveness as well as well as minimise opportunities for double counting.

Risk assessment

By contrast, risk assessment builds on risk identification by applying some form of qualitative or quantitative judgement as to the relative importance of each risk to the overall IUU problem based on the information available. The process of risk assessment can help IUU estimation studies focus on activities likely to make the greatest contribution to overall IUU and thereby make best use of limited resources. Nevertheless, it should be recognised that studies which only incorporate IUU activities considered highest risk may lose the quantitative picture of relativity between higher and lower risks which can be important in MCS planning.

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.

3.2.3 Ground-truthing/peer review

Ground truthing

As described above, the process of ground-truthing preliminary study outputs with informed stakeholders/experts can add significant value to overall study outcomes. Ground-truthing can provide an important 'filter' to ensure relevance and credibility to study outputs and any conclusions drawn, can help detect and correct at an early stage implausible outputs which would otherwise undermine the overall credibility of the study and can help build stakeholder support and improve the chances of the outcomes of the study being used in practice. Depending on the nature of the study, ground-truthing could be undertaken through a formal workshop, or alternatively by allowing stakeholders and independent experts to review draft reports prior to publication.

Peer review

Formal peer review is arguably a slightly different process involving critical examination of study methodology and the reasonableness of the interpretation of results by a relevant expert/s not involved in the study team. A formal process of peer-review may not be required for many studies (particularly those not published in the scientific literature), however the exercise can help strengthen robustness and defensibility of outcomes. The best studies may undertake both ground-truthing and peer-review, however where some form of ground-truthing is not carried out every effort should be made to ensure at least one peer-reviewer has a strong familiarity with the fisheries in question.

4 Toolbox of methodologies

4.1 Overall approaches to IUU estimation – 'top down' and 'bottom up'

Broadly, the different methodologies used to estimate IUU fishing volume and value can be categorised into two types: "top down" and "bottom up" (see for example, MRAG, 2005).

Top down approaches typically estimate a fixed proportion (or range) of the catch which is likely to be IUU to arrive at an overall estimate of IUU catch volume and value, or alternatively use biologically-based stock assessment models or trade data to estimate an overall level of 'missing catch'. Top down approaches are convenient in that they can often be applied cost effectively to produce global or regional estimates of IUU catch, but should be applied with caution given the nature and extent of IUU fishing may vary substantially from country to country, region to region and fishery to fishery. Approaches which produce a single total estimate of unaccounted for catch also leave open the possibility of including catch that may not be IUU (e.g. catch discarded at sea which is not required to be reported, subsistence catches), and tell us little about the relative contributions of the different types of IUU activity to the overall IUU problem. In some cases, top down estimates may be quite precise (for instance those using stock assessments to estimate unseen catch) but in most the estimates are quite imprecise. Nevertheless, they have value in identifying large IUU problems (e.g. Lack and Sant, 2001).

Bottom up approaches typically involve detailed analysis of information at a more 'granular' scale in an effort to build a more accurate picture of IUU fishing activity. Bottom up approaches can be used to estimate the nature and extent of individual IUU risks (e.g. unlicensed fishing in an EEZ or RFMO area), or across multiple different types of IUU activity to estimate overall levels of IUU in a fishery or area. The challenge with this approach is that it is time consuming and information is often very patchy and hard to collect. There are therefore many gaps to fill that require analytical methodologies of varying degrees of complexity. Even when these are used, it is still possible that some types of IUU catches will be missed, and also that some may be 'double-counted'. Nevertheless, depending on the nature and level of information available, bottom-up approaches

arguably have the potential to provide more accurate estimates of IUU activity. Moreover, they also have the very significant benefit of providing information on the relative contribution of individual IUU activities to the overall IUU problem. This is particularly useful in MCS planning because different types of IUU activity require different approaches to mitigate, some of which are more expensive than others. To that end, the more 'granular' level of analysis provided by bottom up approaches may be more expensive in the short term, but provide good return on investment and better MCS outcomes through smarter deployment of limited resources in the longer term.

4.2 Categorisation of methodologies

As discussed above, the different mix of study objectives, types of IUU activities and the nature and extent of information and data available mean that all IUU estimation methodologies will be bespoke to some extent (often heavily so). Nevertheless, most can be generally grouped according to their basic design.

The following section sets out a range of different methodologies which have been used to quantify the extent of one or more types of IUU activity in past studies (for a comprehensive review of past IUU studies see Macfadyen et al, 2016). Methodologies are broadly grouped according to 'top down' and 'bottom up' categorisation described above.

The methodologies included are those that attempt to estimate current (or recent) levels of IUU activity using primary data. 'Meta' type methodologies which rely on secondary data and external studies for which it is often difficult to establish the quality of the original analysis have not been included. Likewise, consistent with the outcomes of Macfadyen et al (2016), methodologies which focus solely on estimating 'total removals' which may include some catch which is not IUU have not been included. The different methodologies have been compiled from Macfadyen et al (2016) as well as previous reviews of IUU estimation methodologies (e.g. Agnew, 2015).

Within the broad 'top down' and 'bottom up' categorisation, it should be noted that there are a number of possible ways to group individual methodologies – for example, by study objective, by data type used or by type/s of IUU activity estimated. Here we have attempted to keep the categorisation fairly simple. For the top down approaches, we have grouped methodologies into the two main types used: stock assessment based and trade data based methodologies. For the bottom up approaches (for which IUU activity and data type can vary markedly), we have categorised methodologies according to the type of questions being answered. Initially, the key distinction is whether the methodology is focused on a single type of IUU activity (e.g. unlicensed fishing within an EEZ) or multiple IUU activities (e.g. all IUU activity within an EEZ). Within the single issue approaches, a further distinction is drawn based on whether the activity being estimated is associated with known (usually licensed) vessels (e.g. under-reporting by licensed vessels) or unseen (usually unlicensed) vessels (e.g. 'border hopping' by vessels licensed in neighbouring EEZs).

For each methodology, an overview is provided of the conceptual approach, together with the main data needs. Examples of key studies which have used the methodology are provided, as well as specific examples to highlight how the methodology has been applied. Finally, a summary of the relative pros and cons of each methodology is provided.

Methodologies are broadly discussed in the context of their capacity to estimate the types of IUU activities set out in Table 1. This is not intended to be an exhaustive list, rather a series of comparatively common types of IUU activity for illustrative purposes. Actual IUU activities for which estimation is required will vary based on the legal frameworks in place and the objectives of stakeholders.

At the conclusion of the section a basic decision tool is provided to help people choose the 'best' methodology based on the objectives of the study and the nature and extent of data available.

4.3 Top down methodologies

These methods take the entirety of the "missing catch" that often arises from IUU and try to estimate it without aiming to specifically attribute this to any one of the categories listed in Table 1. There are two primary methods that have been used.

4.3.1 Stock Assessment methods

Stock assessment models can sometimes be used to estimate the total catch of a species, which when compared with declared catch provides an estimate of unrecorded catch. This unknown catch may be unreported, misreported or discarded; and depending upon relevant legislation it may be legal or illegal.

Stock assessments generally assume perfect knowledge of catches, and use either trends in fishery dependent indicators (such as catch per unit effort, mark-recapture studies) or fishery-independent indicators (such as survey density estimates) to generate plausible estimates of the current and past state of the stock. They can incorporate observation and process error in these indicators but rarely do so for catches. However, if there is external knowledge of unreported data this can be estimated by stock assessment models. This usually works best if at least there are some periods of assumed accurate recording of catches, such that the IUU estimated period is constrained. In these circumstances the model uses information from the "good" bits of the assessment – for instance knowledge about variability in natural mortality or fishing mortality – to help it estimate the catches in the uncertain period.

Examples:

- ICES has used the technique to estimate unreported catches during the early 2000s (ICES, 2014). Facing a rapid decline in cod stock size in the North Sea, in the 2000s the European Commission implemented a number of measures which aimed to recover stocks, including area closures, restrictions in effort and reductions in total allowable catch (Mardle et al, 2008). The substantial reduction in TACs in the early 2000s are judged likely to have led to significant under-reporting, whether illegal (landings) or not illegal (discarding). Scottish compliance authorities tracked illegal landings, and through a series of measures were able to reduce them to the extent that in 2006 they were thought to have been eliminated; real fishing mortality dropped rapidly and the stock has been recovering from about that time. The ICES working group in 2014 used a model called SAM. Instead of assuming catches to be known without error and simply subtracting those, SAM assumes that catches include observation noise. This has the consequence that estimated F-at-age paths display less inter-annual variability with SAM than with deterministic assessment models, because part of the observed fluctuations in catch-at-age are arising from observation noise instead of from changes in F. Application of the model assuming unknown catch observation noise for a very long period of time (1993 to the present) did not lead to satisfactory results, but constraining the "uncertain" time to 1993 – 2005 allowed ICES to estimate that during the period of most rapid management action, the early 2000s, real catches were up to 68% higher than the combined declared catches (including discards).
- Plaganyi et al (2011) used a different approach. While ICES (2014) assumed no actual knowledge of the magnitude of unreported catch except that it probably happened, Plaganyi et al (2011) took an index of illegal activity, from compliance/inspection records (confiscations per unit policing effort), and used this to tune the estimated catch in each year, again within the framework of a population dynamics model. The results were cross-checked against estimates of illegal catches/exports generated through a review of trade data.

- Payne et al (2005) used a production model to estimate IUU catch of toothfish over a 2 year period in the SW Atlantic. The years of unreported catches were quite well known, and the model was able to estimate the size of them quite accurately.

Pros and cons:

Using stock assessments to estimate illegal or unreported catch have the advantage that they can be accurate when the illegal activity is known to have happened but unknown in magnitude, and they are able to provide an estimate of variance (confidence intervals). They benefit from being a statistical method framed within a model of the dynamics of fish populations, and so cannot estimate biologically unreasonable levels of illegal catch. However, they are computationally intensive, rely on there being a stock assessment approach that can be used, and cannot distinguish between illegal activities and legal activities.

4.3.2 Trade Data

Trade statistics analysis examines the level of trade in a species, matching exports and imports against government records of catches. Because international trade statistics are often publicly available, particularly for high profile species, these methods can have some power, and in addition to publishing a number of such studies[1] Traffic International have developed a guide to sourcing and analysing fisheries trade data[2]. Methodologies can be quite complex, requiring identification of specific target export and import markets, some of which may not have customs codes for the species of concern; taking account of the import or export product type and conversion factors to whole fish; taking care not to introduce double counting, for instance trade in both bodies and heads or roe of the same fish. These elements of the analysis can be controlled, but there are others such as the fact that some countries may import and reexport fish (transactions which are not identified in trade data) and that some products may spend several years in the supply chain. Moreover, many species may be traded under generic names which are also used for other species, leaving open the possibility of misclassification. In order to control supply chains better specific catch documentation schemes have been introduced for some species (toothfish; bluefin tuna) and FAO has developed a guide to the design of such schemes (FAO, 2017).

Examples:

- Global trade analyses were used to estimate the mismatch between declared (legal) and traded toothfish by Lack and Sant (2001) and abalone (Plaganyi et al, 2011). Clarke (2006, 2009) has applied trade analysis to sharks and Russian sockeye salmon. The TRAFFIC approach has been successfully applied to squid and abalone in South Africa (Burgener, 2010).
- Where specific statistical document schemes exist, they are used to derive trade-based estimates of illegal/unreported catches, or to augment other estimates. For instance, in ICCAT the statistical document scheme was used to identify underreporting of catches in the mid-2000s (Restrepo, 2004) and it is still used by the ICCAT statistical committee in conjunction with other data (Sharma, 2015).

Pros and cons:

Like the stock assessment methodology, trade data methodologies are unable to identify the type of IUU fishing involved, although additional information (such as the surveillance, arrests etc that might be detected under a deductive approach see 4.1.1) may suggest the likely sources. Trade data are

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[1] See http://www.traffic.org/fish/

[2] http://www.fisheries-trade-data.org/menu_guide.html?guide

increasingly easy to access electronically, making desktop studies easy, particularly with the electronic guide produced by TRAFFIC. However, there are limitations to the methodology: the method requires that there are recognised customs codes for the species in question, and for some this may be “miscellaneous”; misdeclared products are not captured; and assumptions must be made about conversion rates (unless whole fish are traded) and the time periods represented by capture and import data. Finally, catch document schemes can work well to capture the global trade in a particular commodity only where most or all of the product is imported by countries requiring use of the document. Collectively, these limitations mean that trade based approaches to estimate IUU activity will only be available in a relatively narrow set of circumstances.

4.4 Bottom up methodologies

The most common approaches to estimating IUU fishing take a detailed, bottom up view. Starting off with identifying a particular type of IUU that is of concern or interest, these methods attempt to estimate the prevalence of that type of IUU, and its impact, most usually in terms of catch tonnage of target species or bycatch species.

4.4.1 Unseen activity

Activities 1-3 in Table 1 are essentially ***activity on unseen or unknown vessels*** and require a rather different approach to estimation from activities 4-7. In the former we need to estimate both the size and activity of an unknown population of unlicensed fishers; for the latter we need only to estimate the frequency and size of an activity within a known population of licensed fishers.

The methodology adopted by most IUU studies is fundamentally the same:

1. Estimate the quantity of the activity. This is often the number of units (e.g. vessels) and the time that they are active (e.g. months in a year), or simply the total estimated units (e.g. unlicensed fishing days).
2. Estimate the impact of that activity. This is normally the catch or catch rate but could also be monetary value. For endangered species this would be mortality, but this could be modified by an estimate of release survivorship if such estimates are available from the IUU activity.
3. Estimate the statistical confidence in estimates 1 and 2.
4. Multiply quantity x impact = total impact, expressed as a “best estimate” and confidence intervals around it.

There are two core approaches to estimating the quantity of activity (item 1), although often it is necessary or beneficial to use both.

a) **Deductive approaches**. These are probably the most commonly used, and universally applicable. Often the core methodologies are interviews with MCS professionals, supported using alternative sources of information such as industry investigations, press reports, port visit information, arrests and court cases. Derived data are often in the form of “it is likely or known that 20 vessels of around 15m LOA are fishing with gillnets regularly (all year) in the waters of an adjacent EEZ without licences, catching mostly xxx species”. They rely on good interview techniques and triangulation between sources. Sometimes there is direct intelligence on the activity of specific vessels which allows estimation of when and where they are likely to be fishing.

b) **Objective survey approaches**. In these studies, specific observation data are used to support estimates of the number of vessels fishing and the type of activity. Typically, the observations are derived from surveillance data, and techniques include overflights; passive satellite data such as visual or SAR imagery; active satellite data such as monitoring AIS transmissions. Remotely sensed detections of unlicensed vessels may be used as simple

counts, and then used in what is otherwise a deductive approach as described in (a). However, they also offer the possibility of statistically designed surveys, such that a stratified surveys of parts of an area or fishing ground may provide estimates, with statistical confidence limits, of the number of unlicensed vessels per area or per licensed fleet. Survey techniques are regularly used to estimate the activity of artisanal and recreational fishers.

Deductive approaches may often also yield an estimate of vessel catch, or ways to estimate it. An example is the use of information on hold capacity of fishing vessels or reefers, which combined with assumptions about trip length, allows some estimate of illegal/unregulated catch to be made. Often the direct catch of vessels is also unknown and the best estimate is usually derived from the legal licensed fleet. Using these data has the additional advantage of often providing an estimate of variance in likely catch or catch rates.

Estimated catch per vessel or fisher or gear unit is often assumed to be the same as legal fishing with like gear, target, area, and may include bycatch rates of endangered, threatened and protected (ETP) species; however, if these values are determined from observer data on legal vessels, the likelihood that unlicensed vessels are applying all the bycatch mitigation requirements that legal vessels are required to apply should be taken into account. Sometimes estimates are made based on the number of likely trips, hold capacity, and catch rates of vessels, again based on legal vessels, or if there are no legal vessels operating in the area, expert judgement or knowledge of the specific characteristics of the fleet.

Often it is necessary to use a combination of techniques and data sources, together with the above basic principles, to estimate unseen activity. The most useful studies triangulate from a number of different sources and using a number of different methods to obtain increased confidence in the estimates.

Examples:

- For a number of years CCAMLR calculated estimated IUU fishing based on knowledge of specific vessels known to be fishing in the Antarctic, the potential number and duration of their trips, days fished and catch per day based on licensed vessel data (Sabourenkov & Miller, 2004). Estimates of bird bycatch by these vessels was only possible because CCAMLR possessed comparable data from legal vessels from the years before they were required to implement mitigation measures. CCAMLR recently stopped making these estimates due to the IUU activity making use of gear (gillnets) that licensed vessels were not allowed to use, so removing the possibility of understanding catch rates and behaviour from licensed vessels.
- Kleiven et al. (2012) estimated recreational catch by combining estimates of recreational fishing effort from at-sea random strip transect surveys, with estimates of recreational CPUE derived from catch diary and telephone interviews. Combined, these estimated total recreational unreported catch with statistical variance. National authorities often carry out surveys of recreational fishers in order to determine their likely catch even if full reporting is not demanded by legislation. Free et al (2015) and Williamson et al (2014) conducted surveys of lost or abandoned fishing gear as a way of estimating the extent of illegal recreational fishing in a Mongolian lake and Great Barrier Reef Marine Park.
- Free et al (2015) supported their surveys of lost gear with structured interviews of local people. Ermolin and Svolkinas (2018) combined semi-structured interviews, direct observations and triangulation with buyers to estimate, with statistical confidence intervals, illegal catches of sturgeon and bycatch of seals in the Volga river delta.
- Oozeki et al (2018) have used satellite imagery to estimate the numbers of light-emitting vessels fishing in the high seas waters of the northwest pacific. The raw satellite data

required processing to reliably identify fishing vessels, whose activity was corroborated through examination of vessel tracks derived from AIS data. Estimates of catch were generated using estimates of fishing vessel capacity, supported by interviews, and triangulated and compared with estimates of total catch based on fish carrier capacity. Waluda et al (2008) also used visual satellite imagery to estimate unregulated squid jig activity in the southwest Atlantic.

- MRAG (2005) and MRAG Asia Pacific (2016) have used overflight data in west Africa and in the western Pacific. Licensed vessels have known registrations and/or positions that are confirmed using VMS data; any vessels that cannot be confirmed as licensed are potentially unlicensed. Catches can be estimated from the catch rates of licensed vessels.
- Agnew & Kirkwood (2005) and Ball (2005) developed a statistical simulation model to estimate likely unlicensed fishing activity from surveillance vessel sightings of unlicensed vessels and abandoned gear. The model was used to estimate IUU catch of toothfish in the Antarctic, and provided model-based confidence limits for its estimates.
- Funge-Smith et al (2015) estimated the number of vessels crossing borders and illegally fishing within neighbouring EEZ waters (encroachment), or in high seas waters adjacent to EEZs, for a variety of species in APFIC countries. They used a variety of different techniques and data sources to estimate the number of vessels undertaking the specific types of activity. Estimates of the quantity and species caught by encroaching vessels were made using a variety of means including comparison with licensed vessels and expert judgement.
- Skytruth used an AIS/SAR approach to monitor the waters around Easter Island in 2013, detecting more than 40 possible vessels fishing without a licence [3], and Daniels et al (2016) used a combination of data including AIS data on reefers to estimate IUU fishing in West Africa.

Pros and cons of using different detection means

Most of the techniques listed in the deductive methodology – interviews, expert opinion, etc – are difficult to validate, or are very specific to a particular circumstance. Nevertheless, they are often the only available data sources, and so long as IUU studies use many alternative sources and approaches to triangulate they can be reliable.

Surveys by inspection vessels are the most limited in geographical coverage, are expensive and therefore usually need to maximise their effectiveness by targeted searches, and are likely the easiest for unlicensed vessels to evade. On the other hand they are the only assets able to board fishing vessels and make estimates of catch rates, composition, the presence of illegal gear, etc. Information from inspection vessels is therefore most likely useful in informing deductive approaches.

Remote sensing offers the ability to survey large areas efficiently. Air surveys are most limited in extent, but frustrate evasion and offer the possibility of detailed vessel identification, including the possibility of detecting the use of illegal gear.

Passive satellite visual images generally have high resolution but low coverage of offshore marine areas, and analyses of visual images need to take into account cloud coverage. SAR suffers from an inability to detect small vessels or those with a very low radar image (eg wood, glass fibre), and to be confused by some sea states and by icebergs and bergy bits with the same reflectance and size properties as vessels, but is not hindered by clouds. Vessels cannot evade visual and SAR imagery,

[3] See http://skytruth.org/wordpress/wp-content/uploads/2013/07/SkyTruth.About_.IUU_.2013.FINAL_.pdf

but it cannot be used to detect fishing activity and so the possibility that vessels are simply on innocent passage through an area cannot be discounted.

AIS data can be described as partially active in that vessels transmit AIS positions but not with the objective of being tracked. They may switch off AIS at will and therefore can evade detection. However, the advantage over passive remote sensing is that vessel activity can often be detected using algorithms which detect patterns of movement characteristic of fishing. AIS data are increasingly used and several commercial organisations routinely process such data (Gutierrez et al, 2018). However, AIS transmissions are much less likely to be turned off by large vessels such as reefers, enabling their meetings with fishing vessels to be observed reliably (Daniels et al 2016).

4.4.2 Unseen behaviour of known vessels or activities

Activities 4-6 in Table 1 are essentially misbehaviour of known vessels. Being known, the estimation problem is easier, or at least likely to be more accurate, because at least the size of the potential fleet or activity is known. However, the means of making these estimates will depend on the type of transgression.

As with section 4.4.1, the process involved in estimation is similar amongst studies:

1. Estimate the proportion of the licensed fleet that is engaged in the activity
2. Estimate the impact of that activity in terms of catch tonnage by species
3. Estimate the statistical confidence in estimates 1 and 2.
4. Multiplying (1) by (2) provides an estimate of the total catch due to the activity

The estimated number or proportion of vessels or fishers (1) expected to be undertaking transgressions may be estimated directly or indirectly. Several different approaches are applicable:

a. For issues such as fishing in a prohibited area and transhipment violations VMS, AIS, satellite or visual surveillance data will usually provide both the number of vessels and their identity of the licensed vessels violating the regulations. Fishing at prohibited day- or season- times may also be detected by these means. In common with using remote surveillance survey techniques to estimate unseen activity (section 1.3.1) it may be possible to acquire comprehensive counts or sample based estimates, with confidence intervals.

b. For issues such as fishing with illegal gear, discarding (whether illegal or not) and retaining illegal sizes/species, inspection data are usually required. Observer data are used for this purpose in many cases and there is the growing possibility of using on-board cameras and remote monitoring. Observers are rarely present on the entire fleet or are able to observe every haul, so general should be considered as samplers of fleet activity, and pro-rating the data to get an estimate of the prevailance of the activity across the fleet will require some statistical treatment, taking into account stratification by activity, species, etc.

c. Interviews with fishers or MCS professionals can provide anecdotal information on quantities and trends of illegal activity, corroborating other data.

Some of the violations in these IUU categories do not lead to misreporting or underreporting of catches, so there may be no estimated catch to multiply by the number of violations.

Unreported catches may be both illegal (if required by legislation) or legal, and most studies at this level are able to distinguish between the two, although some older studies on discarding fail to make the distinction between our categories 6 and 7 above.

Estimated unreported or misreported catch is usually obtained by comparing logbook (declared) data with observer data (or some other form of independent record of catch – e.g. from dockside inspections). Because observer coverage is only rarely 100%, techniques exist to estimate unreported catch on unobserved vessels by comparing data from vessels that are observed and those that are unobserved. The simplest treatment is to assume that the observed activity occurs in

the same way – the same frequency and the same amount – on unobserved vessels as it does on observed vessels. More sophisticated statistical modelling is needed to take account of stratification within a fleet's activity, for instance to avoid applying a discard rate estimated on a bottom trawler to longline operations.

All such models assume that observations are random across the fleet (observations are not targeted at one particular sector rather than another) and that behaviour is unchanged by the presence of an observer, which is not always the case. For instance, an illegal cod end liner may only be used when an observer is not present (including when they are asleep on an observed trip). Camera technology is now advancing to the point where cameras may replace observers, with the opportunity to sample larger parts of the fleet, and reduce some of these sampling biases.

Estimated violations of other regulations – fishing in closed areas, or with prohibited gear – can be recorded by observers or inspectors. If working from observer data, the same statistical sampling theory outlined above for estimating the occurrence the illegal behaviour can be used. However, physical inspection data are more difficult to deal with, because inspections are typically targeted at high risk sectors of the fleet, and are rarely truly random samples.

Examples:

- Aanes et al (2011), in a methodology approved by ICES, used VMS and AIS data to estimate the total fishing and transhipment effort in the Norwegian EEZ. They then raised known data from documented and inspected trips to estimate the total catch of the fleet, taking into account vessel storage capacity. This methodology is consistent with standard statistical sampling theory, enabling them to calculate statistically robust confidence intervals for their estimate.
- Bremner et al (2009) compared the declared logbook catches of vessels having scientific observers on board with unobserved vessels to estimate unreported catch. A statistical model was constructed using the observed vessel data to determine factors influencing bycatch rates, including gear type, time of day, time of season and depth, and this model was used to predict the true catch in unobserved trips. Unreported catch may have been discarded or just unreported.
- Kariuki (2012) used the data from frame surveys to quantify the use and impact of illegal gillnets in Lake Victoria.

Pros and cons

The pros and cons of using observer or inspection data have been previously outlined, but broadly observer data are often assumed to be unbiased and comprehensive samplers of a part of the fishing fleet, but are expensive and are often only present on some vessels. The bias associated with partial coverage needs to be taken into account in the analysis. True 100% sampling generally requires the presence of two observers to allow for rest periods. Observers are most useful for recording objective scientific data, and the more they are used for compliance recording the higher the likelihood that fisher behaviour will change and the higher the danger that observers will suffer threats, bribes or personal danger. At sea inspection data are generally much less comprehensive in coverage than observer data, and cannot record behaviours that are easy to avoid when a patrol vessel is seen.

The use of cameras may avoid many of these cons of using observers, but camera placement needs to be carefully considered and recordings forwarded through expensive communication links to shore-based monitoring stations. However, comprehensive 24-7 camera footage can be sampled effectively at different rates depending upon the specific IUU element of interest – for instance, sampling only setting and hauling if illegal gear is suspected, or sampling the haul if misreporting of bycatch of ETP species is suspected.

Since all the methods identified in this section are used to detect illegal or unreported activity on known licensed vessels, sampling theory should often allow statistical estimates of confidence intervals.

4.4.3 Multi IUU activity bottom up approaches

A small number of studies have used bottom up approaches across multiple IUU activities to estimate the full nature and extent of IUU activity in particular fisheries or geographic regions. These studies tend to first break the IUU problem down into discrete quantifiable units based on known IUU activities, taking care to limit opportunities for overlap and double counting. Bottom up estimates of each of the IUU activities are then made according to the general approach described for unseen activities and unseen behaviour by known vessels described above. Given the variability in IUU activities and data available, tailored estimation equations are typically required for each activity. Once estimations of the volume and species composition associated with each IUU activity have been developed, these can be aggregated to form an estimate of total IUU activity. Depending on the nature of the data available, analytical techniques such as bootstrapping and Monte Carlo simulation may be used to estimates of statistical confidence both at the individual activity and overall levels.

Examples:

- MRAG Asia Pacific (2016) used a granular bottom up approach across multiple IUU activities to estimate the total volume, species composition and value of IUU activity in Western Pacific tuna fisheries. A variety of different information and sampling methods were used to generate estimates of activity across different risks:
    - For unlicensed fishing: aerial and surface surveillance, licensing information, VMS, compliance analysis data, previous risk assessments and expert judgement
    - For mis-reporting: comparisons of observer reports and dockside inspections vs logsheet reports
    - For fishing on FADs: recent independent analysis of mis-reporting of set type based on catch composition (Hare et al, 2005)
    - For fishing inside closed waters: VMS data, observer reports and expert judgement
    - For shark finning: regional observer data
    - For use of wire traces in the longline sector: isolated boarding and inspection reports, dockside monitoring reports and observer reports
    - For illegal transhipping: aerial and surface surveillance, and expert judgement

Pros and cons

The pros and cons of using a bottom up approach to estimate overall IUU activity across a full fishery or geographic unit are similar to those outlined in section 4.1. Where the objective of a study is to quantify the nature and extent of IUU activity across a full fishery/geographic unit, bottom up approaches arguably allow scope to produce more accurate estimates than top down approaches by encouraging detailed analysis of each individual IUU activity. Bottom up approaches also offer the key advantage of providing information on the relative contribution of each IUU activity to the overall IUU problem, which can then be used to optimally plan MCS investments and deployments, while reproducible bottom up models can also track the changing nature of IUU activity over time. Nevertheless, bottom up approaches tend to be time consuming and the level of information available to support quantification may vary markedly between risks. Accordingly, multi-IUU bottom up studies will require effective mechanisms to account for differing levels of uncertainty in individual IUU activity estimates when combining to produce total estimates.

4.4.4 Estimating statistical confidence for bottom up approaches

Deriving accurate, objective statistical confidence around estimates of IUU fishing is very difficult. Where a single point estimate is available, it may be possible to characterise this as being of high accuracy or low accuracy, and assign small or large confidence intervals respectively. Often where the only information is from expert interviews, all estimates should be considered equally plausible. Authors often assume uniform, uneven triangular and statistically defined distributions for their estimates.

Combining data from different sources many of which are not adequately characterised by classical statistical distributions is difficult, and often authors simply bootstrap from all available estimates. A more statistically appropriate methodology is to bootstrap weighted by the accuracy of the estimate; for instance an estimate with that is very uncertain but has guessed bounds 2-8 t/day catch rate should not have the same weight as a very confident estimate derived from sampling that the catch rate is 6 t/day with statistically determined 95% confidence intervals of 1 – 10 t/day.

- Ainsworth and Pitcher (2005) and MRAG Asia Pacific (2016) and most other studies make use of two types of estimated distribution:

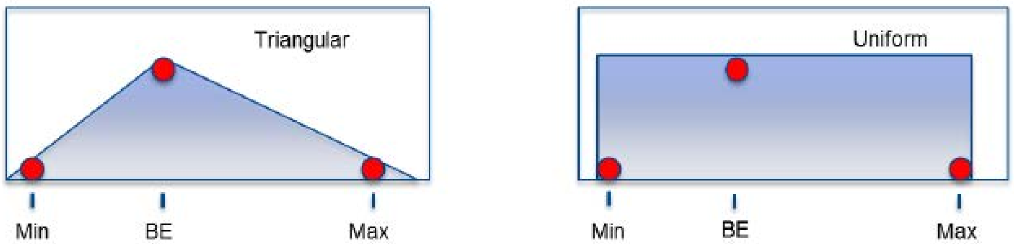

Figure 1: Example distributions of probability assigned to IUU activity. Triangular distributions were used where it was more likely the actual level of IUU activity was closer to the best estimate than either the minimum or maximum values. Uniform distributions were used where the information base was highly uncertain.

- Pirrodi et al (2015) following Mastrandrea (2010) used an approach which determines statistical confidence intervals around an estimated mean based on perceived confidence in the estimate, ranging from mean-10% to mean+20% when there are multiple, consistent independent lines of high-quality robust evidence, to mean-50% to mean+90% when there are few or inconsistent lines of low quality evidence.

4.5 Combined approaches

Many of the most successful IUU studies use a combination of approaches, both to estimate single quantities (for example, the estimates of unreported high seas light boat fishing by Oozeki et al [2018]; Plaganyi et al's [2011] estimate of south African illegal abalone catches) and to estimate multiple quantities (MRAG Asia Pacific's [2016] regional estimate of IUU in Western Pacific tuna fisheries). This generates more confidence that the estimates from the multiple sources are reasonably accurate (although the individual estimates using different approaches may differ quite widely – see Oozeki et al, 2018). The first two examples cited above (Oozeki, Plaganyi) were of single IUU issues, and generated confidence intervals around the estimates appropriate to the methodologies used. Many other methods identified above (for instance estimation of bycatch/discard rates) are also able to generate statistically robust confidence intervals.

These studies also benefit from a coincidence in time – the different elements of IUU are all estimated using temporally concurrent or near-concurrent data, and therefore are at least attempting to measure the same thing.

4.6 Which methodology should I use?

The 'best' approach for each estimation exercise will ultimately be determined by the objectives of the study, the nature of the information available and to some extent by the expertise available to the study team. For example, if the objective of the study is simply to produce a credible overall estimate of total IUU activity in a particular fishery and/or region for the purposes of advocacy and mobilising resources, a top down approach may be cost effective (although the ability to use either trade data or stock assessment approaches may be infeasible, depending on the particular species and circumstances of the study – see sections above). However, if a key aim of the study is to examine the relative contributions of different types of IUU activity to the overall IUU problem and a reasonable level of information is available, a bottom up approach is likely to be more valuable.

As a general rule, bottom up approaches are more likely to be the most appropriate methodology at smaller scales; top down approaches are more likely to be appropriate at larger scales.

Table 2 provides a basic decision support tool to assist people interested in IUU estimation identify a methodology which best suits their circumstances. Approaches are initially categorised into top down and bottom up approaches based on the level of granularity required in estimates. For each of the methodologies within these categories, advice is provided on the circumstances under which when the approach is most appropriate to use and the main pre-requisites and data needs. From there the main pros and cons to each approach are highlighted, together with some examples of key studies which have used the methodology for people seeking more detailed information.

Table 2: Basic decision support tool to assist in choosing an IUU estimation methodology.

Approach	When would you use it?	Methodology	When would you use it?	Pre-requisites/ Main data needs	Pros	Cons	Example studies
Top down	Where only the total amount of IUU volume or 'missing catch' is required	**Stock assessment based**	Where illegal activity in known to have occurred but the magnitude is unknown	• Pre-existing stock assessment model • High level computational power • Advanced statistical expertise	• Strongly data-driven – offers a potentially more precise and credible estimate of missing catch than more subjective approaches • Estimates cannot be 'biologically unreasonable' • Provides statistical estimates of confidence	• Typically requires high level stock assessment expertise and computational power • Provides single estimate of unaccounted for catch – does not distinguish between different types of IUU activity • Limited value for MCS planning unless underlying IUU activities are well known	Payne et al, 2005; Plaganyi et al, 2011; ICES, 2014
		Trade based	Where illegal activity in known to have occurred but the magnitude is unknown	• Species subject to trade, ideally to a limited number of markets • Ability to match reported catches against exports and imports (e.g. through customs codes) • Good information on post-harvest supply chains (e.g. proportion	• Strongly data-driven – offers a potentially more precise and credible estimate of missing catch than more subjective approaches • Provides statistical estimates of confidence	• Customs codes may not be available for all products • Can be temporal mismatches between catch and trade • May not distinguish between illegal and legal catches • Provides single estimate of unaccounted for catch – does not distinguish between	Clarke et al, 2006; Clarke et al, 2009; Plaganyi et al, 2011;

Approach	When would you use it?	Methodology	When would you use it?	Pre-requisites/ Main data needs	Pros	Cons	Example studies
				exported vs domestic sale) • Good information on wet-weight conversion rates for imported product forms		different types of IUU activity • Limited value for MCS planning unless underlying IUU activities are well known	
Bottom up	Where more 'granular' information on the relative contribution of one or more IUU activities to the overall IUU problem is required	**Single issue – unseen activity**	Where an estimate of activity (volume, species composition, value) is required for an unseen type of IUU activity (e.g. fishing by unlicensed vessels)	• Some information to estimate the quantity of the activity (e.g. number of days fishing by unlicensed vessels) and the quantity of the impact (e.g. average catch rate/species composition for that vessel/gear type in that area) • Some mechanism to estimate the statistical confidence in estimates	• Can be strongly data-driven if information available • Estimates can be tailored to each IUU activity • Provides estimate of the relative contribution of individual IUU activities to overall IUU problem	• Information often very limited for 'unseen' activities – assumptions and more subjective info sources (e.g. expert judgement) often required	Sabourenkov & Miller, 2004; Agnew & Kirkwood, 2005; Ball, 2005; Kleiven et al., 2012; Free et al, 2015; MRAG Asia Pacific, 2016; Oozeki et al, 2018
		Single issue – known vessels	Where an estimate of activity (volume, species composition, value) is required	• Some information to estimate the extent of the activity (e.g. proportion of the fleet under-reporting) and the	• Can be strongly data-driven if information available • Estimates can be tailored to each IUU activity	• Information often very limited for 'unseen' activities – assumptions and more subjective info sources (e.g. expert	Bremner et al, 2009; Aanes et al, 2011

Approach	When would you use it?	Methodology	When would you use it?	Pre-requisites/ Main data needs	Pros	Cons	Example studies
			for an unseen behaviour for a known group of vessels (e.g. under-reporting by licensed vessels)	quantity of the impact (e.g. average volume/species composition of under-reporting) • Some understanding of how available information sources (e.g. observers) have sampled population of known vessels (random? targeted?) • Some mechanism to estimate the statistical confidence in estimates	• Provides estimate of the relative contribution of individual IUU activities to overall IUU problem	judgement) often required	
		Multiple issues	Where the objective is to estimate total IUU activity across a fishery/stock/area and information is desired on the relative contribution of each activity	• As above • Mechanism/s to account for differing levels of statistical confidence in estimates across different IUU activities	• Potentially provides more accurate estimate of overall activity than some top down approaches • Can be strongly data-driven if information available	• Can be time consuming • Data may be limited for some risks	MRAG Asia Pacific, 2016

Approach	When would you use it?	Methodology	When would you use it?	Pre-requisites/ Main data needs	Pros	Cons	Example studies
					• Provides estimate of the relative contribution of individual IUU activities to overall IUU problem • Reproducible methodologies allow changing nature of IUU to be tracked over time		
Combined approaches	Where information and resources are available to support independent estimates using multiple methodologies	Multiple	Triangulation across multiple methodologies	• As above, for individual methodologies	• Allows for triangulation of estimates • Reduces impact of uncertainty in single methodologies	• Data to support estimates using distinctly different approaches may not be available • May be time consuming	Plaganyi et al, 2011; Oozeki et al, 2018

5 Other key issues

In addition to the guiding principles and toolbox of methodologies provided above, this section highlights a number of issues commonly faced by IUU estimation studies and provides guidance to encourage consistency across studies.

5.1 Double counting

'Double counting' occurs when a single unit of IUU activity – e.g. a tonne of unaccounted for fish – is counted twice or more in estimates and is a particular challenge when estimating IUU across multiple IUU activities, fisheries or areas.

For example, a single tonne of IUU fish that is harvested in a closed area, not reported in logbooks and then transhipped illegally may be counted up to three times in overall estimates of IUU activity if each of these values are estimated independently. To that end, if not identified and accounted for double counting has the potential to bias overall outcomes.

The opportunities for double counting will be largely dependent on the scope of the study and the nature of the IUU activities being estimated. Broadly, the opportunities are of two types:

- In the context of a single IUU study, double counting may occur if individual units of IUU fish are included in estimates of multiple IUU activities. For example, MRAG Asia Pacific (2016) identified the potential for double counting in their study of Pacific tuna fisheries which estimated the volume and value of IUU activities across different parts of the 'supply chain' (e.g. catching, reporting, transhipping). In this case, there was potential for double counting if the same 'IUU fish' were involved in multiple activities (e.g. fish taken in EEZ to which the vessel had no license, not reported in logbooks and then illegally transhipped). The potential for double counting is arguably highest in 'bottom up' approaches which estimate IUU across multiple IUU activities separately, although scope for double counting also exists in top down methodologies (e.g. Lack and Sant, 2001);
- In the context of attempting to combine estimates of IUU activity from multiple studies into a single overall estimate for a fishery or region, potential for double counting exists where there is overlap in the scope of different studies (e.g. where estimates of IUU activity are made for the same fishery/geographic area across multiple studies). Recognising and accounting for this type of double counting is a particularly important consideration in any attempt to produce an updated global/regional estimate of IUU activity from multiple pre-existing studies, or alternatively in the design of any new coordinated effort to estimate global IUU from multiple discrete fishery units.

While the potential for double counting remains a common challenge for all studies attempting to estimate IUU volume and value across multiple IUU activity types and/or geographic regions, its impacts can be minimised through a series of hierarchical steps:

- **Eliminate the potential for double counting in study design** - first and foremost, potential areas of double counting should be identified and eliminated where possible in the design phase of the study. This could be through a series of justified assumptions where multiple forms of IUU activity are being estimated (e.g. all catch taken by unlicensed vessels is also likely to be unreported, therefore catches from these vessels are only included in unlicensed catch estimates), or by carefully designing the scope of 'discrete' units to avoid overlap where IUU activity is being estimated across multiple fisheries and/or geographic areas.
- **Provide quantitative estimates of double counting if possible** - where the potential for double counting cannot be entirely eliminated in the study design but capacity exist to quantify the extent of double counting (e.g. where there is evidence of the proportion of

overlap in IUU estimates between two studies or individual IUU activities for which estimates are being combined), quantitative estimates should be provided with justification and overall figures adjusted as required.

- **Where quantification is not possible, explicitly recognise the possibility of double counting and discuss the implications** - Where potential for double counting cannot be eliminated at the design stage, and the extent cannot be accurately quantified, the potential for double counting should be explicitly recognised and its implications on overall estimates discussed. For example, is residual double counting likely to substantially bias results? If so, how? Across which activities/fisheries/areas is it likely to be most prevalent? If it's not likely to bias results, why not? This discussion should be provided in sufficient detail to allow the reader to make an informed judgement about the reasonableness of the conclusions reached.

5.2 Combining estimates from different studies

Within a single study, where the project team has a good understanding of how each individual IUU estimates was derived, their likely statistical properties and their limitations, estimates of multiple activities may be combined with some confidence.

Regional studies usually attempt to combine such estimates to derive estimates of total IUU (e.g. total unreported catch of species X = estimated unlicensed vessel catch of species X + estimated unreported retained quantity of species by licensed vessels + estimated unreported discarded quantity of species X by licensed vessels). Generally, confidence intervals estimated for the different types of IUU are of quite different forms and robustness, and the only practical way of deriving combined estimates of confidence around the total is through analytical techniques such as bootstrapping or Monte Carlo simulation.

It is more difficult to combine estimates from different studies, although there may be an interest and need to do this. For instance, there may be some interest in combining an estimate of unreported catch of species Y with a separate estimate of unlicensed fishing on the same stock to achieve an estimate of overall unreported mortality. In some circumstances this would be possible, particularly where the general principles outlined in this paper have been followed, such that the statistical properties of the various estimates are known.

Global estimates have, in the past, been based on combining studies from the literature. These suffer from rarely being able to use studies that are temporally coincident and which are fully transparent in their methodology and statistical properties. We would advise against IUU projects that attempt to combine data/sources from widely differing studies; and that if large scale combined estimates are attempted, wherever possible reference be made to original authors, and that data be limited to a narrow temporal window. In any case, these approaches will likely only produce a reliable top down estimate with quite wide confidence intervals, although they may also be able to make use of metadata relationships (such as the relationship between IUU and governance identified by Agnew et al, 2009).

5.3 Estimating economic consequences

Once the volume and species composition of IUU fishing activity have been estimated, many studies will seek to provide an indication of the economic consequences of the problem. This has most frequently been done through an estimate of the value of the IUU product (e.g. Agnew et al, 2009), or sometimes through an estimate of the loss to coastal States (e.g. MRAG Asia Pacific, 2016). Having an accurate picture of economic impacts arising from IUU activity can be valuable for advocacy purposes, as well as in evaluating the cost effectiveness of potential MCS solutions.

This section provides some high level advice on the most common approaches for estimating value from volume and introduces some of the differences between *value* and *loss*. The intent is not to provide a detailed economic treatise on economic valuation methods, but to encourage consistency in the presentation and discussion of economic consequences in IUU estimation studies.

5.3.1 Estimating value from volume

Once IUU volume and species composition have been estimated, assigning a value to the IUU catch is usually undertaken through a relatively straightforward multiplication of volume and the associated price, according to the following formula:

1) $$TR = Q \times P$$

Where TR is the total revenue (or value) of IUU catch, Q is the estimated IUU volume and P is the associated value per unit volume. For example, if it was estimated that 5,000MT of catch was illegally taken and it was determined the value per MT was US$3,500, then the total value of IUU product would be 5,000MT x US$3,500 = US$17.5 million.

There are two options most commonly used for assigning a price per unit volume: ex-vessel price and market price.

Ex-vessel price is the price per unit a vessel operator receives when selling product to the next point in the supply chain (e.g. a seafood trader). Ex-vessel price is also sometimes referred to as the 'free on board' (FOB) price. Unless the vessel operator is part of a vertically integrated company, the ex-vessel price can be assumed to be a reasonable reflection of the value of IUU product received by the fisher.

By contrast, 'market value' is typically estimated based on a market price found at a commonly accepted marketplace for a given fishery (albeit 'market' value is often ill-defined and technically could be the price at any point in the supply chain where goods are traded). For example, sashimi grade tuna will often use Japanese auction markets as a price guide and canning grade tuna would use Thai customs import prices.

Given fisheries products often pass through multiple links in the supply chain, each with their own overhead, market value will almost always be higher than ex-vessel value.

There is no 'standard' metric to assign value to estimated IUU volumes and each of the two approaches have pros and cons. For example, MRAG (2015) used market prices to calculate estimated values of IUU product in their study of IUU in the Bay of Bengal Large Marine Ecosystem, while MRAG Asia Pacific (2016) used ex-values to calculate the value of IUU product in Western Pacific tuna fisheries.

Ex-vessel value is arguably a better reflection of the price (and therefore a component of the incentives) available to fishers from IUU fishing, however such figures may not always be readily available. To calculate ex-vessel value from market price, the analyst will need to discount all supply chain costs up to the point of vessel landing. However, this information is not typically not available to the public so obtaining it usually requires industry access, knowledge, and/or experience. The use of ex-vessel value will also produce a lower overall estimate of 'IUU value' than market value, so may dilute the value of studies whose aim is to produce 'a big number' for advocacy purposes.

Market values are often easier to obtain than ex-vessel price (for example, through trade data services such as UN Comtrade[4] or Globefish), although differences in value adding along the supply chain may obscure incentives for IUU at the fisher level. Nevertheless, the consistent and widespread availability of market values means they are relatively easy to apply across multiple

[4] https://comtrade.un.org/

species and product types and allows for straightforward 'apples vs apples' comparisons of impact across different fisheries/jurisdictions.

Irrespective of which value is ultimately chosen, it is essential that the approach and data sources are set out explicitly such that studies can be repeated over time and meaningful comparisons can be made.

5.3.2 Accounting for multiple species and IUU activities

The discussion above provides a very basic formula for estimating total revenue (TR) for a single species of fish taken through IUU means. However, in many cases IUU activity will result in several species being taken, all of which may be sold. Moreover, if the objective of a study is to estimate the total value of IUU activity in a particular fishery/area, the estimated value of multiple IUU activities may need to be calculated.

If the IUU catch estimate includes multiple species, the different species will almost certainly have different quantities (Q) and prices (P). This can be accounted for with a slight amendment to Equation 1)) which is:

2) $$TR = \sum_s (Q_s \times P_s)$$

where Q_s is a value of IUU catch for each species and P_s is the associated price for each of those species. The products of quantity and price for each species is calculated and each are then added together to make the total revenue estimate.

Where multiple IUU activities occur within a fishery, it is possible that both catch composition and the value per unit volume will vary between activities. For example, an unlicensed free school purse seine set could result in 20MT of skipjack tuna only, while a set on a FAD during a moratorium period could result in 20MT of catch that consists of 15MT of skipjack, 4MT of yellowfin tuna, and 1MT of bigeye tuna. While these two examples result in the same overall IUU volume (20MT), the catch composition and therefore value of IUU product is different. Moreover, it is possible that some forms of IUU activity will target the same fish species at different stages in their life cycle, resulting in different values (for example, one IUU activity may harvest juveniles, whereas another IUU activity may target higher priced adults).

Factoring in differences in prices received across different IUU activities can be achieved with a further amendment to the total revenue equation which is:

3) $$TR = \sum_a \sum_s (Q_{sa} \times P_{sa})$$

where Q_{sa} is the IUU catch quantity of a species through a certain activity and P_{sa} is the price of that species in that activity. The product of quantity and price is calculated for each species under one IUU activity and is then summed up. This step is repeated for each of the different activities and then these are all summed to provide a total revenue estimate.

Where double counting is likely across different IUU activities, a value of zero can be assigned to P_{sa} for each instance in which the estimate is likely to be a repeat of the original quantity of fish.

5.3.3 Value versus loss

A key concern of many IUU studies is to estimate the 'losses' to various stakeholders from IUU fishing, and in particular to coastal States. Where only the ex-vessel or market values of IUU fishing are presented, there is often an implicit assumption that these values represent the revenue lost to coastal States. However, *value* doesn't equal *loss* in most cases, largely because the full value of fishing revenue doesn't flow to coastal States under normal circumstances.

Consider the following fairly common scenario in which a developing coastal State collects revenue by licensing foreign fishing vessels to access its waters: In the relevant fishery, the average annual

revenue per vessel (i.e. the total ex-vessel value of the catch) is US$1m. If the coastal State set the access fees at the full ex-vessel value of the catch (US$1m), the fishing vessel would be unviable because there would be no money to pay for the costs of fishing (e.g. capital, fuel, crew wages etc) (note if the access fees were set the market value, the vessel would be even more unviable!). To that end, assuming the coastal State wants licensed fishers to remain viable, they can only ever expect to recover a proportion of the value of the catch. While the nature of access fee arrangements varies markedly around the world, many States aim to set fees at a level roughly equivalent to 'rent' from the catch. In economic terms, 'rent' is the residual left over after production costs, capital provisions and normal profits are deducted from the revenue generated from the sale of the fish. In this scenario, if we assume a rent value of 5%, the revenue that would flow to the coastal State through access fees would be US$50,000.

Using the same logic, the coastal State could not expect to receive the full value of any catch taken through IUU activity. Looking at it another way, if MCS was strengthened such that IUU fishing was reduced by $1m and the coastal State could sustainably license one additional foreign vessel, the revenue received would not be the full US$1m – it would be $50,000.

This distinction between *value* and *loss* is more than an academic argument around economic terminology – it has very practical implications. For example, in the above scenario if a $500,000 investment in MCS was made by the coastal State on the mistaken assumption that it could return $1m in revenue, the investment is unlikely to prove cost effective.

It is also worth noting the types of mechanisms in place to collect revenue from the fishery can have a substantial influence over the extent of actual losses in a fishery. Consider the following two fisheries – Fishery A is charged a flat fee of 5% of the value of its catch as an access fee and has no observers or other measures in place to independently validate catch. Fishery B is subject to a competitive process in which fishing companies bid for access to the fishery (in terms of fishing effort or quota) annually and is also subject to 100% observer coverage, cost-recovered from industry. In Fishery A, under-reporting of catch is likely to result in direct losses in revenue because arrangements to collect rent are inefficient and there are no mechanisms to detect under-reporting. In Fishery B, under-reporting can be picked up and corrected by observers and the competitive nature of the bidding process will mean that fishing companies will take into account both reported and unreported catches in their calculations of how much to bid for access. To that end, efficient mechanisms to collect rent from licensed vessels together with strong MCS arrangements can limit the extent of losses from IUU in practice.

Calculating the actual losses to coastal States (and other stakeholders) from IUU fishing will in most case be a complex exercise and require a detailed understanding of the economics of the sector, the mechanisms available to collect rent and the potential direct (e.g. lost rents, MCS costs) and indirect (e.g. reduced stock productivity, foregone taxes, opportunity costs) costs involved. In the context of these guidelines, the important point is the *value* doesn't necessarily equate to *loss* and care should be taken by the authors of IUU estimation studies to avoid conflating the two in the discussion of study outcomes.

5.4 Other IUU impacts

In addition to estimating volume and value of IUU fishing, study authors should discuss the main consequential impacts arising from such fishing. These should be considered in the context of fishery/management system/economy being assessed, although may include:

- **Broader ecosystem impacts** – IUU fishing is often undertaken with fishing gears that are destructive to the aquatic environment. Impacts may be felt by endangered, threatened and protected (ETP) species (e.g. through the non-use of impact mitigating gear types), habitats (e.g. through the illegal use of bottom trawl apparatus) and the broader ecosystem (e.g.

through trophic cascades associated with the illegal harvest of keystone species or unsustainable volumes of biomass from a particular trophic level);

- **Socio-economic impacts** – the impacts of IUU fishing on communities and economies dependent on fish stocks can be myriad and complex. Although there may be some short term benefit to some stakeholders (the IUU fishers and associated supply chains), experience indicates that the impacts are, particularly in the long term, overwhelmingly negative. Impacts may be felt on local employment (e.g. where IUU fishers are competing for catches with legitimate fishers) as well as on local supply chains (e.g. where IUU fish is diverted away from local supply chains into export supply chains). Impacts may also be felt disproportionately by women (e.g. where the supply of legal fish to post harvest processing facilities is reduced) and may mean a deterioration of labour standards (e.g. where IUU vessels are associated with slavery and other labour and human rights abuses). Considerable impacts may also be felt at the coastal State government level through loss of foreign or domestic fishing access revenues and the need to fund additional MCS resources (or reallocate limited resources to MCS which could otherwise be invested in productive sectors of the economy).
- **Food security** – IUU fishing can have an impact on food security at the local level through the depletion of key food fish stocks by IUU fishers and the redirection of IUU caught fish to alternative markets. Where food security is likely to be impacted by IUU fishing, studies should identify the stakeholders and sectors most affected;
- **Data integrity/management capacity** – given its largely hidden nature, a key impact of IUU activity is the undermining of official data sets used for stock assessment and other fisheries management purposes. Weakening the integrity of official datasets in turn weakens the capacity of fisheries agencies to manage stocks and impacts effectively. Where available data is likely to be compromised by IUU fishing (bearing in mind that 'unaccounted for' catch may be either positive or negative - in some cases there may be incentives to over-report catch in the lead up to allocation exercises), the main impacts and implications should be discussed;
- **Geopolitical impacts** – IUU fishing, particularly that undertaken by vessels flagged to one country fishing in another's waters, can result in heightened geopolitical tensions between countries and regions. While this is perhaps most obvious in the case of unlicensed foreign fishing, there are numerous examples of sensitive political situations arising from licensed foreign fishers breaching license conditions. Moreover, where stocks are shared, illegal, unreported or unregulated domestic fishing in one state may have impacts on other states, leading to political tensions; and
- **Food safety** – Although much of the fish taken through IUU means may ultimately find its way into 'legal' supply chains, there is a risk that fish taken illegally may not be subject to the same food safety standards and inspection regime as legally produced fish.

Studies should identify and discuss other key impacts where appropriate.

When considering impacts from IUU fishing, both direct impacts and indirect 'externalities' should be taken into account. In economic terms, an externality is a positive or negative impact of an activity felt by an unrelated third party (who doesn't choose to have the impact occur). Externalities are generally not reflected in the market price for goods or services. In the context of IUU, costs to legitimate fishers associated with stock depletion by IUU fishers would be an example of a negative externality.

Impacts should be discussed at least qualitatively, or quantitatively if data is available to support estimates.

6 Indicators of IUU fishing

As with all indicators, indicators of IUU fishing should be as simple as practical, quantifiable and monitorable over time, and tell us something informative about the issue of interest (many international organisations adopt a SMART framework - specific, measurable/ meaningful, assignable/attainable, realistic, and time-related).

There are a number of possible approaches to indicators of IUU fishing, ranging from indirect 'proxy' measures of status, trend and preparedness of combat IUU (e.g. # countries signing/implementing international instruments designed to combat IUU; # of vessels of RFMO IUU lists) to more direct measures which rely on robust estimates of IUU (e.g. proportion of IUU product as a proportion of total legal catch; proportion of total IUU attributable to different infringement categories, etc).

The main advantage of the first type is that they can be monitored cost effectively, although considerable care is required in selecting indicators that provide a meaningful insight into the issues at hand (e.g. # of vessels on RFMO IUU lists may be a poor indicator of IUU activity if political dynamics mean that listing vessels is a difficult process). The advantages of the second type of indicator are that it provides a direct measure of IUU activity and a consistent reporting framework can facilitate comparisons within and between fisheries over time, but generating the information to inform the indicator may be expensive.

The London workshop noted that developing effective, informative indictors of IUU fishing is a challenging exercise and may require a separate dedicated exercise. In the meantime, the guidance included in these guidelines will focus on what makes a good indicator in the context of IUU fishing and the types of indicators that may be used by different jurisdictions.

7 Presentation of results

7.1 Technical considerations

The 'best' format for the presentation of study outcomes will be influenced to some extent by the nature and objectives of the exercise, the target audience and the medium in which the results are presented (e.g. academic paper, technical report, policy brief). Space restrictions for academic journals will mean there is less latitude to go into detail around the methodology and key results, while policy briefs will want to get 'straight to the point'.

Nevertheless, there are common elements of presenting the methodology and outcomes of IUU estimation studies which will help improve 'understandability' and allow the reader to make an informed judgement about the reasonableness of the methodology used and the credibility of the outcomes. Many of these are discussed in some length in the Section 3. Rather than repeat these here, Table 3 provides a brief 'checklist' which study authors may wish to use as a guide to ensure key content and formatting considerations are incorporated into study outputs.

Table 3: Checklist of key considerations in the presentation of IUU estimation studies.

Yes/No?	Presentation element
	Are the objectives of the study clearly stated?
	Is the scope of the study clearly outlined – i.e. which fisheries, which species, which geographic area, which timeframe and which components of IUU?
	Are all important interpretations of IUU at the level relevant to the study explicitly stated? Are the implications of alternative interpretations discussed?

	Is the methodology set out in sufficient detail to allow a reader to make a judgement as to its reasonableness, and allow and independent group to reproduce the methodology if required?
	Is the reasoning for choosing the methodology used made clear?
	Are all data sources used clearly set out, together with any information gaps? Are the main implications of any data gaps discussed?
	Are all key assumptions explicitly spelled out in sufficient detail to allow a reader to make a judgement as to their reasonableness, with the implications of alternative plausible assumptions spelled out?
	Are estimates of statistical confidence provided around all estimates?
	Where economic value has been estimated from volume and species composition, is the approach to valuation (e.g. ex-vessel Vs market price) clearly spelled out, together with data sources? Where loss to coastal States or other stakeholders has been estimated, is it clear how the estimates were arrived at?
	Are the main implications of the study outcomes (e.g. extent and types of IUU fishing, estimated volumes, species composition and value of IUU product) discussed in the context of fisheries management, science and compliance?

7.2 Encouraging uptake

For IUU estimation studies to have more than academic value, the outcomes need to be picked up and applied by relevant stakeholders. This could be politicians considering future spending priorities, MCS practitioners planning deployment of resources or scientists refining stock assessment models, amongst others.

While encouraging uptake is often thought of as something that happens *after* a study is completed, the reality is that much of the 'heavy lifting' to ensure adoption of outcomes needs to be completed well before then, in the study design and early implementation phases.

This section sets out a (non-exhaustive) range of practical measures that study authors and funders can take to improve uptake of study results. Broadly, these are broken down into actions able to be taken before the study commences ('before study'), while the study is being undertaken ('during study') and after the study is completed ('post study').

Before study

Arguably the most important period for encouraging uptake of an IUU estimation study is not after the study is completed, but before its commenced. Involving the key stakeholders at the early stages of study design will mean the questions being asked are the ones of most relevance, while allowing them to contribute to and refine the methodology where necessary means the study is more likely to proceed in a way that gives them confidence in the outcomes.

The rapport established in these early stages, through collaboratively setting the direction of the study and dealing with any methodological challenges, can often be invaluable in laying the groundwork for uptake of study outcomes during later stages.

The process of involving stakeholders in study design and the definition of objectives can take a number of forms including study design workshops or one-on-one meetings with key stakeholders.

During study

As discussed in Section 3.2, there are a range of mechanisms that can be used to encourage a participatory study process, and therefore better ensure credibility and relevance of outcomes and

ultimately uptake of results. These include the use of stakeholder-inclusive project Steering Committees to help guide study implementation, assist with interpretation and facilitate access to information, and the 'ground-truthing' of results with stakeholders to ensure project outcomes are plausible based on collective experience.

For longer running studies, written study updates or presentations on progress to key stakeholders may be undertaken.

Post study

Following the completion of the study, there are a range of mechanisms available to raise awareness and encourage uptake which can be tailored the target audience. These include:

- **Media event/study launch** – Media events to launch project reports have been used successfully to promote awareness for a range of different IUU studies. The issue of illegal fishing often attracts media attention – particularly where 'big numbers' are involved – and widespread media coverage can play a strong role in influencing public decision makers to take action to address IUU. While there is often limited control over how the outcomes of reports are presented by media outlets, care should be taken in written materials to ensure all results are presented accurately and in context. Press releases should be drafted by trained media professionals where possible, but with the involvement of the study authors to ensure accuracy in the presentation of outcomes. Media launches tend to work best when interested stakeholders are involved and are supportive of the outcomes of the study – this is more likely where stakeholders have been actively engaged at all stages (rather than simply asked to turn up at the concluding media event);
- **Meetings with key decision makers/influencers** – where the objective of a study is to influence government (or other) decision making (e.g. to invest in new MCS assets; to establish new bilateral/multi-lateral instruments to tackle IUU fishing), there can be considerable value in arranging for face-to-face meetings with key decision makers (e.g. senior politicians) and influencers (other parties with capacity to influence decision makers – e.g. NGOs, public thought leaders). Arranging for in person meetings allows for the key results and implications of the study outcomes to be transmitted directly to the key decision makers and allows them to ask questions and receive answers that would assist them in directing future policy;
- **Policy briefings** – policy briefings summarise the main outcomes of the study and focus mainly on what those results mean (e.g. in the context of fisheries management, MCS planning, science or economics). Policy briefings can be concise written summaries highlighting the key issues or delivered in person to groups of key stakeholders (e.g. to a relevant Government Standing Committee);
- **Social media/web presence** – The increasing use of social media in recent years and the widespread access to the internet amongst most countries offers study authors a range of novel means to raise awareness of study outcomes. In particular, the 'viral' nature of social media networking means that key study outcomes can be distributed amongst large numbers of people virtually instantaneously. Social media strategies can be tailored to particular audiences, with information available through a central website for those seeking further details. While social media users may not be decision makers in their own right, politicians and others with the capacity to influence the operating environment for IUU fishers are increasingly attuned to social media activity. To that end, a strong social media reaction to study outcomes can play an important role in creating the right conditions for positive change.

8 Concluding remarks

Almost two decades after the adoption of the IPOA-IUU, IUU fishing in its various guises remains one of the most important challenges facing world fisheries. Despite the impressive progress made in combatting the problem by FAO and its members, IUU fishing continues to undermine responsible fisheries management regimes with varying degrees of severity in many parts of the world. Moreover, there is evidence that as our efforts to combat existing forms of IUU fishing have borne fruit, new forms of IUU activity have developed. To that end, the need for an accurate contemporary picture of IUU activity remains as important as ever, both to understand its ecological and socio-economic consequences and best target future mitigation efforts.

Methodologies to estimate IUU activity have evolved considerably over the past 20 years and are likely to continue to develop as new information and technologies become available and new groups of smart people apply innovative thinking to the problem. In particular, continuing advances in data analytics and the increasing availability of information from remote sensing technologies appear to offer exciting possibilities in the detection and estimation of some forms of IUU fishing. As a result, the toolbox of methodologies provided here should be seen as a starting point only, with the development of innovative new approaches both welcomed and encouraged.

Nevertheless, while the specific techniques used to estimate IUU fishing may change over time, the general approaches to ensuring quality and consistency in estimation studies should remain relatively constant. To that end, the framework of 'best practices' set out in these guidelines should serve as a useful frame of reference for all groups involved in undertaking, commissioning or evaluating IUU estimation studies. Incorporation of these approaches into study design and implementation will help strengthen the credibility and robustness of estimates, as well as ensuring outputs are both relevant and informative for stakeholders.

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