***Illegal, Unreported and Unregulated Catches in tuna Regional Fisheries Management Organizations and quantification of their effects on Assessments***

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**Executive Summary**

The report outlines various methodologies to develop illegal, unreported and unregulated (IUU) estimates for assessments using methods from previous studies, and focuses on the peculiarities of the tuna assessment world. A brief snapshot of current practices in tuna Regional Fisheries Management Organizations (tRFMOs) is provided, and a focus on a recent study conducted in the Western and Central Pacific Fisheries Commission (WCPFC) using bottom-up approaches is discussed. The approach developed substantially different estimates of IUU as compared to previous top-down approaches. Methods described and used in various parts of the world to estimate IUU with their pros and cons are described here, and the implications of underestimated catches in providing stock status advice are examined on assessments in general, and in some particular case studies using a simulation and estimation model framework. Future steps are discussed in detail and these are primarily based on developing consensus based approaches on common issues across the various tRFMO's, applying common methodologies to estimate the magnitude of the issue on providing stock status advice, and quantifying their impacts on assessments using a guiding quantitative framework.

# ACRONYMS

| | |
|---|---|
| BET | Bigeye Tuna |
| CCAMLR | Council for Conservation of Antarctic Marine Living Resources |
| CCSBT | Commission for the Conservation of Southern Bluefin Tuna |
| CPCs | Contracting parties and cooperating non-contracting parties |
| CPUE | Catch per unit of effort |
| EU | European Union |
| EEZ | Exclusive Economic Zone |
| FAD | Fish-aggregating device |
| FAO | Food and Agriculture Organization of the United Nations |
| FFA | Forum Fisheries Agency |
| GPS | Geographical Positioning System |
| IATTC | Inter-American Tropical Tuna Commission |
| ICES | International Council for the Exploration of Seas |
| ICCAT | International Commission for the Conservation of Atlantic Tunas |
| IOTC | Indian Ocean Tuna Commission |
| IUU | Illegal, Unreported and Unregulated |
| IRD | Institut de recherche pour le dévelopement, France |
| LL | Longline |
| MCS | Monitoring Control and Surveillance |
| MSY | Maximum sustainable yield |
| NMFS | National Marine Fisheries Service |
| PL | Pole and Line |
| PS | Purse-seine |
| SBT | Southern Bluefin Tuna |
| SC | Scientific Committee of the IOTC |
| SCRS | Scientific Committee on Review and Statistics of the ICCAT |
| SLL | Southern Longline |
| SPC | Secretariat of the Pacific Community |
| SWO | Swordfish |
| TLL | Tropical Longline |
| tRFMO | tuna Regional Fishery Management Organization |
| VMS | Vessel Monitoring System |
| WCPFC | Western and Central Pacific Fisheries Commission |
| YFT | Yellowfin Tuna |

## A Brief Overview of Illegal, Unregulated and Unreported fisheries Globally

Illegal, unreported and unregulated (IUU) fishing is a major contributor to declining fish stocks and marine habitat destruction (Pauly and Zeller 2016, FAO 2015, Agnew et. al. 2009). Based on studies conducted in 2005 (Agnew et. al. 2009), IUU fishing takes many forms both within nationally-controlled waters and on the high seas. While it is not known for sure how much IUU fishing is taking place, it is estimated that IUU fishing accounts for about 30% of all fishing activity worldwide (Pauly and Zeller 2016, Agnew et. al. 2009). However, for tuna these estimates may be a lot lower as they are managed under the RFMO's.

Strong governance of the high seas through regional fisheries management organizations (RFMOs) is integral to reducing IUU. An increasing number of RFMOs are using port and trade measures to discourage IUU fishing activities (e.g. IOTC 2015, CCSBT 2015a). In addition, from a tRFMO context records of authorized vessels, IUU vessels, regional VMS, transhipment programmes, Catch documentation schemes or statistical document programmes were all developed with the intention to reduce IUU. Other measures include not allowing vessels suspected of fishing illegally to dock or unload in a country's port, developing IUU fishing lists, and scrapping vessels (national actions) found guilty of multiple illegal fishing offences. In the context of this report, the following definitions are introduced:

1) **Illegal fishing** refers to fishing by national or foreign vessels within a country's Exclusive Economic Zone without permission, or, undertaking fishing activities that contravene that country's laws or regulations. This can happen if
    a. Fishing by a vessel flying the flag of a state party to a relevant RFMO that contravenes conservation or management measures adopted by that organization or part of international law, or
    b. Fishing that violates national laws or international obligations.
2) **Unregulated fishing** refers to fishing within the regulatory zone of an RFMO by a vessel without a nationality, or by a vessel flying the flag of a state not party to the organization (flag of convenience), which contravenes the conservation and management measure set out by the RFMO. This could also occur if fishing occurs outside of regulated zones, which is inconsistent with efforts under international law to conserve living marine resources.
3) **Unreported fishing** refers to fishing that has not been reported, or has been misreported, to the relevant national authority or RFMO.

**Objective of this report**

The objectives of this report are three fold; i) examine the methodology used in tuna RFMOs (tRFMOs) and other entities to estimate IUU, describing the pros and cons of these approaches, ii) develop a methodology to use these estimates in assessments and quantifying its impacts, using a case study with some examples, iii) produce guidelines/recommendations for future work.

## Techniques used in Estimating IUU in fisheries

In Appendix II Agnew (FAO 2015) lists a number of approaches used to estimate IUU. The methods varied from an estimation of the error in stock assessment models directly, to using monitoring control and surveillance methods, using remote sensing techniques, or using trade data. The following section summarises each of the approaches suggested and used.

### Stock Assessment Based Methods

These methods are based on comparing a known period of catch that is estimated well versus other years where the data are not as accurate (e.g. North Sea cod catches prior to 1993 and after 1993 due to conservation measure implemented by the EU, ICES 2014). The models examined basically account for observation error in catch estimates and, dependent on the periods chosen, can estimate this to be significant (68% underestimated) as compared to the most recent calibrated values where catches were know with a high degree of precision. The underlying assumption used in these models is that the Fishing mortality (F) does not change dramatically over time (pre and post periods of conservation measures being applied), and as such all the variation seen is attributed to catch changes. Using this assumption underestimated catches can thus be predicted by sector. Similar approaches have been examined in abalone fisheries (Plaganyi et. al. 2011), where the estimated IUU components were tuned to a series of non-compliance indices (IUU catch index estimated external to the model).

### Monitoring Control and Surveillance (MCS) Methods

Direct measures of compliance using observer data, and electronic surveillance systems are used in this approach. While these data can either be collected dockside or with at-sea observer programs, careful attention needs to be paid to the sampling design as inference is derived on the overall population of concern. Examples of these approaches are in much of the rockfish programs implemented under the Magnuson Stevenson ecosystem approach to fisheries on the west coast of the United States of America (NMFS 2011). Dockside and on-board samplers estimate different catch rates across species, and implement real-time management systems that can be controlled as a function of overall landings. In another example on some fishers sampled in the US using MCS techniques, non-compliance or underreporting of catches by US commercial fisheries in federal waters were estimated to be between 10-20% (King et. al. 2009).

### Remote Sensing Methods

These methods incorporate data from numerous sources, but data are primarily collected from satellite imagery using remote-sensing techniques to estimate catches from a variety of sources, either directly estimated by at-sea observations not following inspections or using satellite transponder information (active reporting) along with satellite imagery of fishing activity of vessels (passive reporting). Using an IUU list of vessels and their state of IUU activity serves as a basis, but then estimating what the vessels were doing in areas they shouldn't be in or fishing with illegal gear and quantifying the magnitude of their effects is difficult to do without any direct samples (i.e. observers on these vessels, Agnew 2015 FAO Report 2015, Appendix II). Extrapolation from vessels of similar magnitude operating legally needs to be made where observer data are available. An example of this approach is from the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) estimates (CCAMLR 2013) where anecdotal information was used to estimate the catches of vessels fishing illegally in the Antarctic.

## Trade Based Methods

Trade based estimates use export and import records on a species of value against government records of catches. Using market data and various catch documentation schemes employed by various RFMOs, estimates of IUU can be made based on discrepancies between what is reported and what is exported by a country. This approach, used on the Russian sockeye salmon to estimate IUU catches, was made by examining the differences in global trade data from Russia (Clarke et. al. 2009), and similar approaches were used by Clarke et. al. (2006) to estimate IUU on sharks. Other examples are trade data from toothfish from CCAMLR (Lack and Sant 2001), and abalone (Plaganyi et. al. 2011).

## Pros and cons of approaches used for estimation

The approaches presented above each have their utility dependent on the situation being assessed. A table in Appendix 2 (FAO Report 2015) by Agnew is presented here (with some modifications).

**Table 1: Adapted summary table of various methods to estimate IUU catches and distinguish different components (From Appendix II, FAO 2015)**

| ***Method*** | ***Quantity estimated*** | ***Pros*** | ***Cons*** |
|---|---|---|---|
| Stock assessment data | Estimates of total unreported catches of fish | • Estimated within the model so free from assumption other than fitting to a series or keeping F relatively stable over time to generate Catches<br>• Statistically robust. | • Cannot distinguish IUU components.<br>• Works best with fitting an index of IUU. |
| MCS inspection data | Accurate recording of individual violations (IUU or non-IUU) in practice on land and sea | • Data collected through VMS are high resolution and detailed<br>• Large samples if done correctly over the fleet, insuring unbiased samples<br>• Information gathered on bycatch species as well | • Representativeness of the samples<br>• Difficult to attribute different activities to IUU estimates<br>• Use of VMS would refer to authorized vessels that go to areas where fishing is not permitted and catch there illegally. However, once again, VMS is not regional for all RFMO and tracking depends on Flag States. There have been many events of illegal activities identified on vessels that were never penalized by their flag states meaning that monitoring is poor in most cases in some flag countries. |
| Remote sensing | Estimates of number of vessels fishing without licences or in areas that are prohibited | • Ability to track vessels with remote sensing using high level resolution data<br>• Ability to define activities legal and illegal<br>• Ability to estimate IUU with anecdotal and observer data<br>• Ability to have repeatability and give snapshots over time | • Needs inference from other vessels<br>• Lacks the ability to define other activities as it is tracked through satellites (e.g. gear violations).<br>• Expensive and time consuming |

| | | | |
|---|---|---|---|
| Trade Based | Estimates of total unreported catches of fish | • Easy to compute based on government records<br>• Direct access to global market data available and can be used | • Accuracy of trade data questionable.<br>• Need to be calibrated to market data (e.g. auctions at fish markets)<br>• Data may not normally account for all catches (e.g. bycatch and discards are ignored) |

## Current status of IUU Estimation on tuna RFMO's

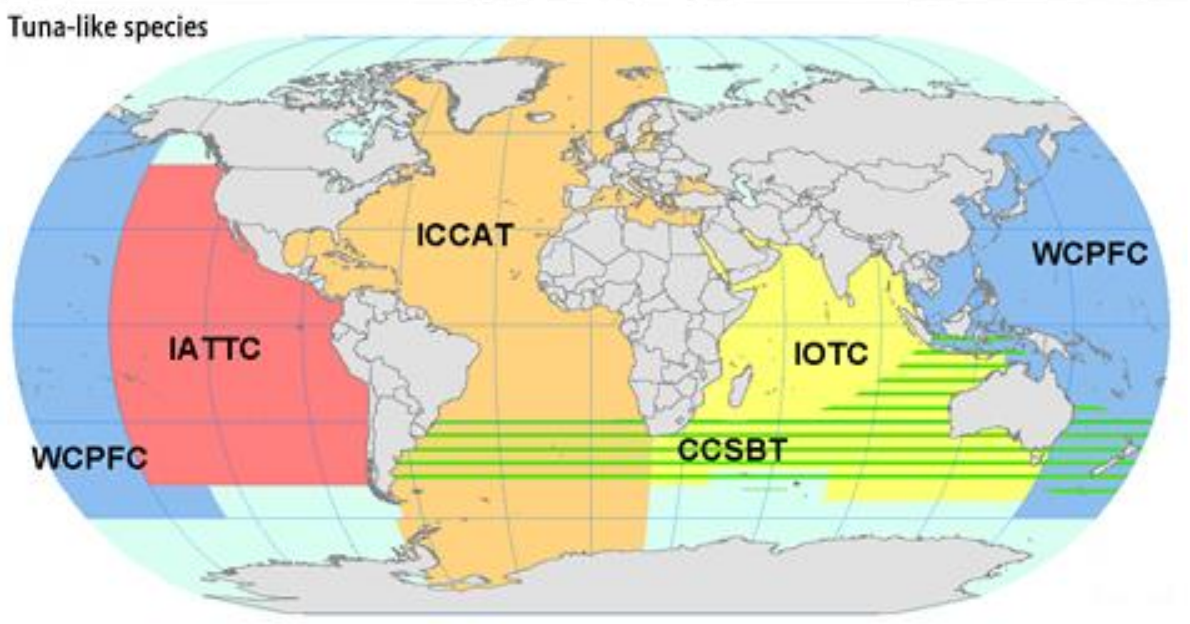



***Figure 1: Area covered by the 5 global tRFMO's***

While the purview of the five global tRFMO's is to promote conservation and optimum utilization of tuna stocks (primarily in the high seas and coastal EEZs), balanced with the sustainable development of fisheries; it is evident that the five tRFMO's operate using different mechanisms, and have different levels of knowledge, infrastructure, and ability to account for IUU within their jurisdiction. It is attempted here to cover where things stand currently with respect to methodology to estimate IUU, and what is being done in that respect.

### Convention for the Conservation of Southern Bluefin Tuna (CCSBT)

Due to large infractions identified in reported and estimated catches (through trade/market data) it was reported that the catch being reported through much of the 1990's was underestimated (by a factor of two, Polachek and Davies 2008, Figure 2 below). On the basis of this report, and other violations identified through much of the 1990's and early 2000's, the Kobe process was initiated across tRFMO's. CCSBT has a detailed observer program as a consequence of this, and coverage of 10% is targeted across all vessels operating across all countries and fleets (CCSBT 2015b). Catch data are now thought to be much more reliable and IUU levels are low or non-existent (though some Chinese large scale driftnet vessels have been caught operating illegally in the south Indian Ocean (2016) by Sea Shepherd and could have an impact on SBT stocks) for this Commission in recent years (CCSBT 2015b).

*__Note, CCSBT implicitly accounts for all sources of uncertainty of catches in the assessment based on both landed and IUU catches.__*

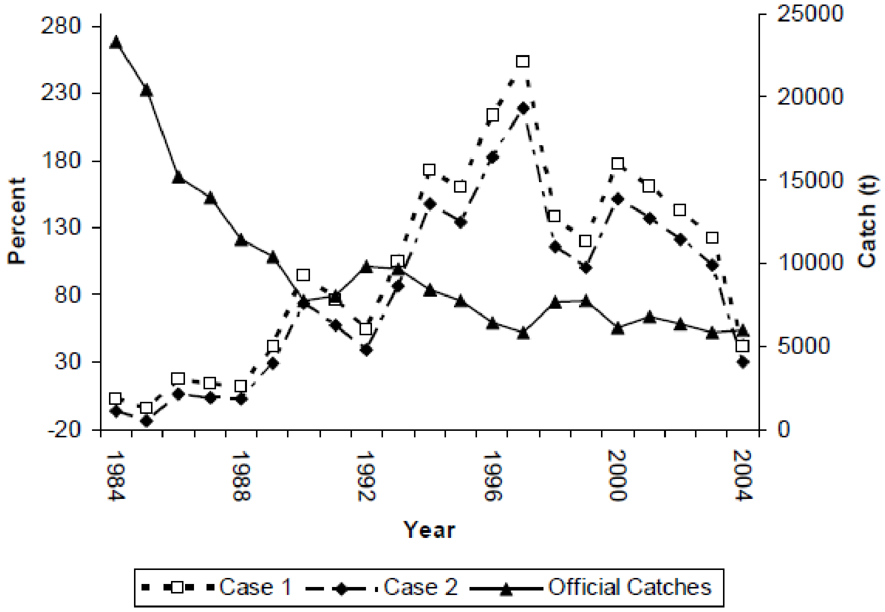



***Figure 2 (from Polachek and Davies 2008): The figure shows the discrepancy in reported catches, and what was estimated using market and trade data at sashimi markets, using different approaches.***

### Inter-American Tropical Tuna Commission

Longline vessels have low observer coverage in this RFMO, but purse seine vessels have 100% coverage and use protocols  similar to NAFO and CCAMLR to estimate catches by region and area. However, this coverage is primarily for vessels 300Gt, and for smaller vessels this component may not be known very well, and is probably being under-reported. IUU estimates from Purse Seines is thought to be low, and no external estimates are made on reported catches, at the current time based on our current knowledge and understanding with respect to this RFMO. The only available source used on this tRFMO was  from Agnew et. al. (2009) which estimated 129.7Kt to 278.45 Kt as the amount of IUU biomass extracted from the eastern Pacific.

However, this estimate is across all species and does not only account for tunas. FAO (Gillet 2011) had made an estimate of the artisanal component of bycatch (Unreported catch) for the artisanal fleet in this tRFMO. Gillett (2011) noted that about 25% of catches from small scale fleets in the eastern Pacific was tuna (9000 t out of a total of 39000t tuna bycatch).

*__Note, implicitly IUU are not incorporated in assessments at IATTC. It is unknown whether they will do so in the future.__*

### International Convention for the Conservation of Atlantic Tunas (ICCAT)

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 (estimates of total catch based on capacity and fishing power of the fleet, for instance). Based on current knowledge of fisheries and through the species group meetings, catches which are thought to be low are estimated externally and corrected based on observer or anecdotal data on similar vessels catches/catchability that are applied to vessels underreporting/not reporting catches (an example of this was catches reported by Ghana in the bigeye tuna assessment meeting, were reanalysed and larger estimates were reported based on similar vessel activity in the Ghana EEZ, ICCAT 2015).

Another primary example of how things have changed over time, based on the review of catches, is shown below (Figure 3, take from Fromentin et. al. 2014). Initially, as regulations became stronger and enforcement was lacking, IUU was quite substantial (reported catches were off by a factor of two. However, as observer and at sea recovery and sampling programs were initiated (2008 onwards) these estimates reduced drastically, and are now negligible or zero, based on recent years.

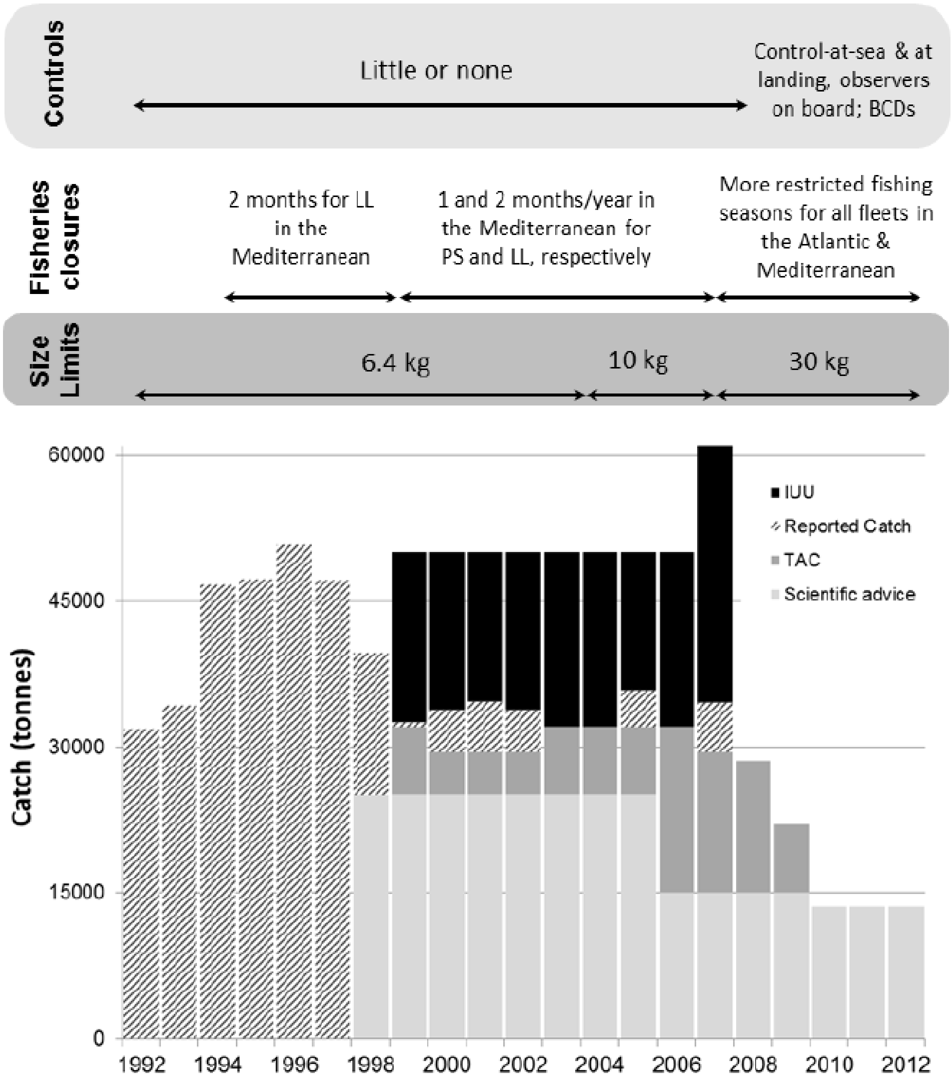



***Figure 3: Atlantic Bluefin catches (From Fromentin et. al. 2014).***

Overall yearly catches (biomass removals), essentially called Task 1 activities, are reported directly from the member countries/CPC's (these are catches not only landed but also include drop off and incidental mortalities, Carlos Palma pers. comm. data administrator at ICCAT). It was noted that <u>only</u>

the Scientific Committee on Review and Statistics (SCRS, ICCAT) can change official statistics with corrections, data gap completeness, etc. based on several rules (e.g.: carry overs, SCRS documents "faux poisson" estimations, historical revisions/corrections]) of other ICCAT studies/programmes (GBYP, etc.). This would include unreported/under estimated catch (and in some years IUU catches). These are recorded under special codes ("NEI" prefix in Fleet codes, "QualInfoCode" field) to identify those catches in Task I. Data can be obtained here ( **http://www.iccat.int/Data/t1nc_20151102.rar**) for ICCAT with these fields.

Some other larger issues were the reporting of catches from one ocean into another. In the mid and late 2000's, there was a big problem with fish laundering by Taiwanese fleets with catches of BET from the Atlantic reported as from the Indian Ocean. This had consequences on both RFMO: as underreporting occurred in ICCAT and over reporting in IOTC. Catches were corrected to address this, but it is not sure to what degree these issues were resolved (ICCAT 2005, IOTC 2005). In ICCAT, the use of driftnets by some CPC's (e.g. Morocco) and no reporting of catch data from this sector is still and issue in ICCAT despite the recommendation to ban the use of driftnets and the UN Resolution that states the same.

*Implicitly, catches are corrected for IUU/unaccounted mortality outside the stock assessment models, and then used in the assessment. However, the components of the I,U and U are not accounted for or reported in a separate category in any report.*

### Indian Ocean Tuna Commission (IOTC)

IOTC used similar approaches to the remote sensing approaches, to generate yearly estimates of IUU (unreported) catches in the Indian Ocean by combining knowledge of active vessels whose catch was known not to be reported to the Commission with estimates of the likely catch of those vessels during the year (while not strictly being a "remote sensing" methodology, having some close links to the port inspection data described above, the basic philosophy behind the approach was similar to Remote Sensing). Other examples of how IOTC verifies and corrects estimates are the following:

1) Using numbers of vessels not reporting catch and average catches from proxy vessels to estimate catches of the non-reporting vessels. Other studies in IOTC verify reports by on the ground sampling and changing the assumed species composition based on direct observational studies.
2) Using information on frozen tropical (e.g.BET) exports to identify underreporting from some countries and has corrected catch reports using this information in the past.

Based on recent data (IOTC 2015, Figure 4), it is apparent for some species external estimates can account for almost 50% of the catches used in assessments. While these are not strictly called IUU within the IOTC context, these are estimates made by the secretariat where reported catches seem unlikely or too low based on external knowledge of the fisheries and observer programs. Within IOTC, the species Working Groups and the Scientific Committee endorse these estimates annually.

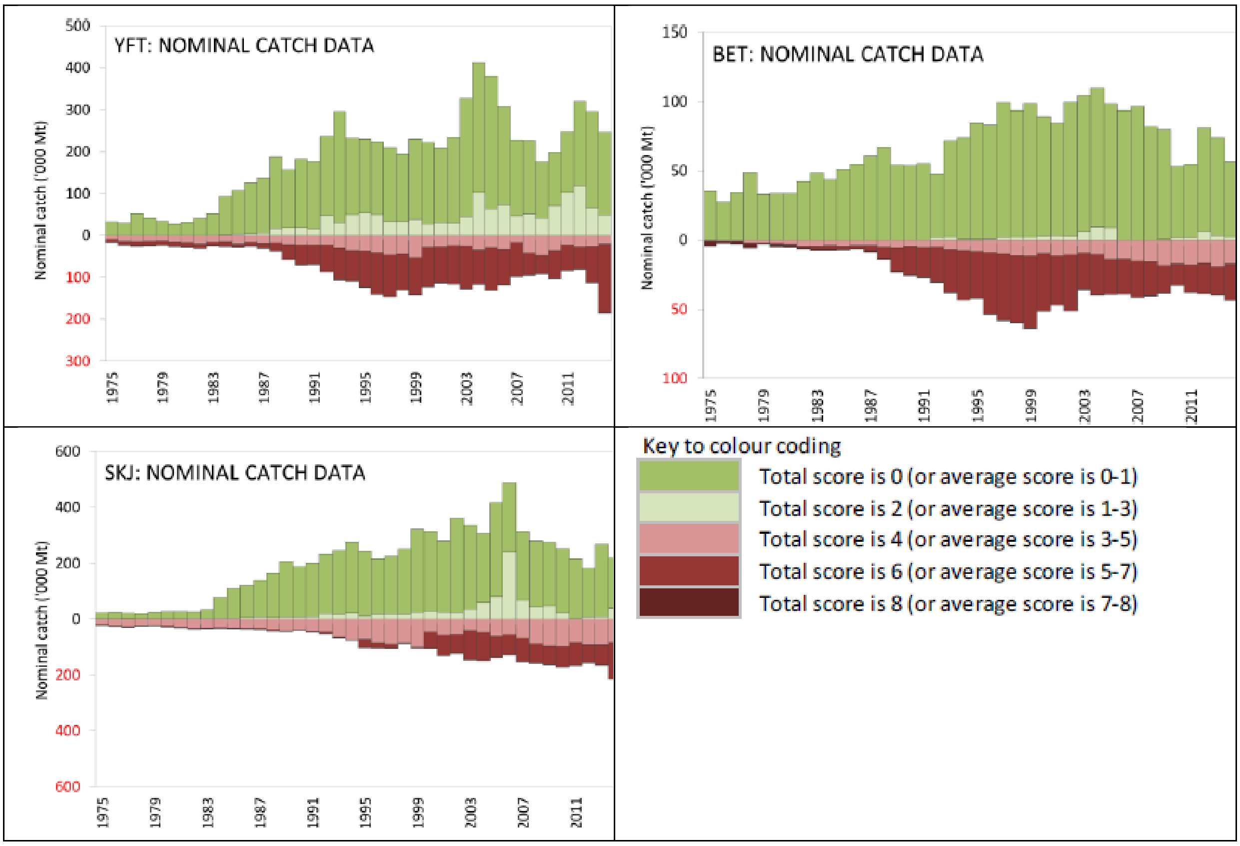



***Figure 4: Tropical tuna data quality used in the IOTC assessment in 2015. Catches on the positive axis indicate good quality (green) intermediate quality (light green). Catches on the negative axis indicate estimated catches (red indicate large assumptions made, whereas light red indicate lesser assumption used). The higher the number the more the assumptions used to estimate data, and poorer the quality.***

In IOTC, transhipment issues and illegal fishing in some counties EEZs can account for a large amount of catch which may never be reported (Greenpeace 2012). Some of these estimates are between 16-20 Kt in India's EEZ alone, based on average catch per vessel and the number of vessels employed through some licensing schemes employed by foreign fleets in national waters. The estimated economic ex-vessel value can be estimated between 10-30 million USD for one country alone based primarily on tuna catches here (Greenpeace 2012). There is a large disagreement whether these data are reliable as the flag country refuses to acknowledge this discrepancy, and IOTC is sceptical that the magnitude is as large as reported by Greenpeace.

As noted by the previous data coordinator at IOTC (Miguel Herrera Pers. Comm.), estimates of IUU are made internally based on knowledge and activities within the area of compliance. While these are not basically categorized as IUU, these are estimated catches (largely underreported) based on numerous approaches (see above description of approaches used to estimate underreported catches) and the quality of the data used in the assessment is not as good as the direct estimates made (e.g. for yellowfin tuna in the assessment used in 2015, close to 40% is estimated in between 1995-2013 and is shown in Figure 4), but in the assessment context these catch data are used as known without error, and possibly other methods accounting for observation errors in catches in the assessments could be proposed in subsequent years.

*Implicitly, catches are corrected for IUU/unaccounted mortality outside the stock assessment models, and then used in the assessment. However, the components of the I,U and U are not accounted for or* *reported in a separate category in any report, though these are largely Underreported (U) or not reported components of the catch.*

### Western and Central Pacific Fisheries Commission (WCPFC)

Most catch estimates are made by the Secretariat of the Pacific Community (SPC, Ocean Fisheries Program), as all science and assessment matters are outsourced directly to them for the Western Central Pacific Convention area. Species catch composition estimates, in particular those for the purse seine fishery, are adjusted for logsheet species reporting bias using observer species sampling data (see Hampton and Williams, 2015).

In addition, previous studies conducted by **MRAG** (Agnew et. al. 2009) estimated a large volume of IUU catches in the Western and Central Pacific 785.9 Kt to 1.73 Mt (these estimates are across all species and would extend to more than just tunas in the region), estimated at USD**$750m – USD$1.5b annually**. As a proportion of reported catches this is approximately 21%-46% of reported catch. These, like previous studies/methodologies used (e.g. Agnew et. al. 2009 and Pitcher et. al. 2002), were top down approaches based on reported catches and some variant of estimated IUU of various components of the reported landed catch.

In a recent study commissioned by the Forum Fisheries Agency (FFA), with inputs from WCPFC and SPC, MRAG used a bottom up approach to quantify IUU in the WCPFC region. Methods developed were associated with differential risk factors across four categories of risks, namely based on unlicensed/unauthorized fishing, misreporting, non-compliance with regard to license conditions and post-harvest risks (*MRAG 2016 unpublished document, Hugh Walton pers. comm.*). Estimates were made for three categories, tropical longline, purse seine and southern longline fisheries, based on information from 2011-2014.

Our simulations suggest the best estimate **total volume of product either harvested or transhipped involving IUU activity in Pacific tuna fisheries is 306,440t, with 90% confidence that the actual figure lies within a range of 276,546t to 338,475t. Based on the expected species composition and markets, the ex-vessel value of the best estimate figure is $616.11m. The 90% confidence range is between $517.91m and $740.17m.** That is, there is a 95% chance the figure is greater than $517.91m and a 5% chance the figure is greater than $740.17m.

Of the three main sectors assessed, estimated volume of IUU product was highest in the purse seine fishery, accounting for 70% of overall volume. Estimated IUU volumes in this sector were largely driven by reporting violations and illegal FAD fishing during the closure period. The Tropical Longline (TLL) and southern longline (SLL) sectors accounted for 19% and 11% of the overall volume respectively. In the TLL sector, IUU volumes were largely driven by misreporting (49% of total TLL volume) and post-harvest risks (39%), principally illegal transhipping. Estimates of both misreporting and illegal transhipping were, in turn, influenced by high levels of uncertainty. Similar results were achieved in the SLL sector, with misreporting and post-harvest risks accounting for 57% and 36% of overall estimated IUU volume respectively.

By contrast, the TLL sector accounted for the highest ex-vessel value of IUU product ($272.55m) given the higher market value of its target species. This sector accounted for around 44% of overall estimated IUU value, while the purse seine sector accounted for 37%. The SLL sector had the lowest overall estimates of IUU product value (19%).

Of the four main IUU risk categories assessed, reporting violations and non-compliance with other license conditions (e.g. illegal FAD fishing; use of non-prescribed gear) accounted for 54% and 29% of the total estimated IUU volume respectively. Post-harvest risks (mainly illegal transhipping) accounted for 13% of the estimated volume but 27% of the estimated value. This was driven by higher estimates of illegal transhipping in the longline sectors which receive proportionally higher prices for product. Unlicensed fishing accounted for only 4% of the estimated overall volume.

Amongst the main target species, skipjack accounted for the largest proportion of total estimated IUU volume (33%), but a lesser proportion of the total estimated ex-vessel value (18%). The total estimated IUU volume of SKJ (100,730t) equated to around 5.1% of estimated total SKJ catch in the WCP-CA in 2014. Yellowfin accounted for the next highest volume (96,126t), making up 31% of the total estimated IUU volume, and 27% of the ex-vessel value. The total estimated IUU volume of YFT equated to around 15.8% of the estimated total catch of YFT in the WCP-CA during 2014. Much of this is driven by estimates of misreporting in the purse seine fishery which is subject to 100% observer coverage, and therefore may result in little unaccounted for catch. Bigeye also accounted for 19% of the overall estimated IUU volume, but 28% of the ex-vessel value. The total estimated IUU volume of BET equates to around 35% of the estimated total catch of BET in the WCP-CA in 2014. Importantly, this does not necessarily mean that 35% of additional BET have been taken in addition to reported figures. For example, a substantial proportion of the overall IUU BET estimates come from estimates of illegal transhipping, the product for which may still be reported in logsheets. ALB accounted for 4% of the overall estimated IUU volume and 6% of the total ex-vessel IUU value. The total estimated ALB IUU volume equates to around 9.4% of the estimated total ALB catch in the WCP-CA in 2014, although a substantial proportion of this related to post-harvest offences for which information was uncertain.

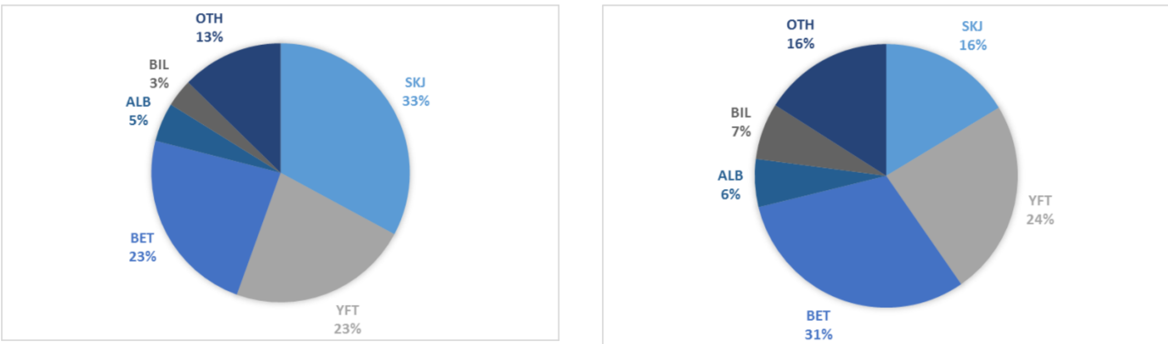



***Figure 5: WCPFC IUU amounts based on species (left panel, volume 306 Kt) and value (right panel, USD$616.11 M), but is not broken by sector (taken from MRAG 2016).***

A number of recommendations are made in the report to reduce the IUU components as they are primarily related to licensed vessels operating in the region and to a large extent can be dealt with and drastically reduced by MCS techniques like electronic vessel monitoring systems (e-VMS) on all licensed vessels with mandatory electronic surveillance/observers and remote-sensing capability to track vessels. More details can be obtained from the report (MRAG 2016).

However, a larger issue in this tRFMO maybe the extent of coverage and reporting from smaller CPC's like Indonesia and Philippines. This component covered here maybe lesser than underreporting which may occur in these CPC's (Williams 2011).

*Currently, it is unknown how this information will be fed into an assessment, but it is likely that the impact of IUU will be assessed in the future by this tRFMO.*

## Comparisons across tRFMOs for estimating IUU

Based on the comparisons across the various RFMO's the quantity and methodology varies quite substantially based on the tRFMO. Table 2 below summarizes comparisons across the various tRFMOs in terms of methodology used and what the historic/current estimates range of IUU in the various tRFMOs based on the best available data.

**Table 2: Status of IUU estimation across tRFMO's***

| *Parameter* | *CCSBT* | *IATTC* | *ICCAT* | *IOTC* | *WCPFC* |
|---|---|---|---|---|---|
| Estimation technique | Market/Trade based | Unknown but 100% coverage on PS. Assumed no IUU | Case by case based on external knowledge approved by SCRS | Case by case basis done internally by secretariat and approved by SC | Bottom up approach based on field and remote-sensing data |
| Volume | 10K t -25Kt (mid 1990's- 2005). (Polacheck and Davies 2008). Currently negligible | 129.7Kt to 278.45 Kt (Agnew et .al. 2009) | 596Kt-1.43 Mt (Agnew et .al. 2009) | 697.1Kt-1.53 Mt (Agnew et .al. 2009) | **of 276,546t to 338,475t** (MRAG 2016 draft) |
| Value USD (ex-vessel) | $ 200- $500 Million | $117-$251M | $538M-$1.29B | $627M-1.38B | **$517.91m and $740.17m** |

* Based on all species estimate of which tuna is approximately 30-40% based on WCPFC, 10-20% IATTC based on Gillett (2011). IOTC and ICCAT are likely in the range of WCPFC.

Based on the above table, CCSBT may not be missing much catch currently, after resolving all the issues from the past. After 2008, the IUU issue may be largely resolved by CCSBT. For other RFMO's the situation varies. ICCAT has adopted measures to penalize countries not reporting catch, and this may have increased misreporting/underreporting in recent years. IOTC on the other hand has identified problems with some countries for which catches are highly uncertain, and tries to make estimates independent of the countries reports in those cases. For WCPFC and IATTC, this is largely unknown.

## Current Status of IUU as used in tRFMO Stock Assessments

Currently, there is no standardized approach for tRFMO's to use IUU in assessments. While some tRFMO (ICCAT, IOTC) make estimates outside of the model, and use this directly in assessments, the implicit assumption is that these are observed catch and the same quality as those sampled and reported in assessments. We know that is not the case, and, we suggest using approaches from other areas (eg. CCAMLR, and S. Africa).

**Table 3 below displays the current approaches used in assessments across tRFMO's. It is apparent that the tRFMO's do not have any particular recommended approach to use these estimates, and a strong recommendation should be made to apply these approaches in the future.**

Table 3: Current state of IUU in tRFMO Stock Assessments

| ***Parameter*** | ***CCSBT*** | ***IATTC*** | ***ICCAT*** | ***IOTC*** | ***WCPFC*** |
|---|---|---|---|---|---|
| IUU Estimated | yes | Unknown | Yes: Case by case basis | Yes: Case by case basis | Yes |
| Assessments use IUU | Yes. Part of the model and advice. | Unknown. Probably not. | Used in cases where its estimated | Used in cases where its estimated | Unknown currently |
| Catch/IUU used with error | Assumed known without error | Unknown currently | known without error | known without error | Unknown currently |

As is evident from the above table, the methods of using IUU in assessments is limited currently. In the next 2 cases described, the assessment could either directly incorporate estimates of IUU along with legal catch estimates, or estimate it directly in the assessment. The two cases are probably the two extremes of what could be done with IUU's in tRFMO context and are described in detail below.

### CCAMLR Patagonia Toothfish example (Hillary 2009)

Based on external estimates of legal and IUU catches, a biomass dynamics model was analysed to examine effects of fishing on a sub-area of CCAMLR. The model is fairly simplistic, and used an index of abundance along with tagging data to estimate overall underlying population abundance, and fishing mortality accounting for tag shedding and over-dispersion. Implicit in the analysis was the assumption that all tags are fully mixed in the area, so the basis of inference of the entire population is valid.

Even though the model is fairly simplistic, the paper presented a framework for performing a prototype-stock assessment for exploratory fisheries and a framework for adapting an ongoing tagging program to better achieve strategic management goals. The assessment model itself is capable of incorporating IUU as well as legal catches, CPUE and mark–recapture data. The model developed accounted for key stock-specific productivity parameters, and explicitly accounted for the uncertainty in the stock dynamics either using Bayesian techniques or standard frequentist approaches using the tagging data. Depending on the precision of the catches, different catch limits would be targeted that would meet the objectives of management.

The approach presented here would need to estimate externally the IUU component and then account for that component in the model developed, using both reported and IUU catches. This approach is similar to what was pursued in IOTC (Rice and Sharma 2015) and relies on the following steps:

1) Estimate IUU from external methods
2) Incorporate IUU into the catch that I used in model fitting with uncertainty
3) Use estimated F's from tagging and catch+IUU data to use in model dynamics
4) Report biomass dynamics and estimated F with IUU in Assessment.

### S. Africa Abalone Example (Plagyani et. al. 2011)

An alternative approach to estimate IUU catches is to estimate it within the model itself. As shown in Plagyani et. al. (2011) independent data from export findings and Illegal catch per unit of monitoring effort are used in the model as an external CPUE indicator for the illegal component of the catch.

Since that component is not reported, the model internally estimates these components and then fits to the reported Illegal component of the index of IUU abundance. This approach is calibrated or verified with external trade data, and uncertainty in the estimate of illegal catch are made in the model, as well as the overall F computed has the illegal component as part of it.

In this approach the following would be needed:

1) An index of abundance of IUU would need to be developed based on external methods
2) This IUU index would be added to the likelihood component of the model for landings.
3) Estimated IUU would be computed to best fit the index of IUU.

This approach is quite different from the one shown above for CCAMLR Patagonian toothfish as in that approach IUU estimates are made and then used in the assessment, whereas here it is done simultaneously and is part of the assessment. This approach is probably a more straightforward robust approach, though external estimates of an IUU index of abundance is needed to develop this approach (which is quite difficult to generate).

# Effects of IUU on Assessments

## Other methods to quantify effects

While the impacts of IUU are quite uncertain in different tRFMO's and the magnitude of the error in time is unknown, a simulation approach is developed here to assess what the effects of different scenarios of IUU levels might be on assessment over time. In essence, the yield curves would be underestimated as a function of IUU, and as such the scaling parameter would be off by a factor in the assessments as both $R_0$ (virgin recruitment estimates) and virgin Biomass ($B_0$) would be biased low. An attempt to quantify these impacts using a simple age structured model is developed in the next section.

A second affect that maybe detectable is a temporal effect where the quality of the catch data substantially declines over time due to some key Conservation and Management Measure (CMM) that was initiated in a year following large catches (e.g. the case of the North Sea cod in ICES after 1993). We can quantify these effects over time, by running the model with and without the estimates of IUU, and quantify the effect on a stock trajectory with regard to reference points, using the Kobe plot framework adopted by tRFMO's in the subsequent sections (a contrary examination may also account for underreported catches in the past as quality of information improves as is the case in many tRFMO's, but was not pursued here).

## Simulation demonstrating effects

**Simulation Model Used**

The standard age-structured model used was

$$N_{a+1,t+1} = N_{a,t}(1-u_t v_a)s_a \quad \text{for } a>1,\ a<n \qquad \text{eq. 1}$$

$$N_{n,t+1} = \left(N_{n,t} + N_{n-1,t}\right)(1-u_t v_n)s_n \quad \text{for } a = n \qquad \text{eq. 2}$$

$$E_t = \sum_a N_{a,t} f_a \qquad \text{eq. 3}$$

$$N_{1,t+1} = g(E_t) \qquad \text{eq. 4}$$

Where the functional forms are given in eq. 8, 9 and 10 below. The only difference is that process error is used, and has some auto-correlation built in it, so equation 4 is modified to

$$N_{1,t+1} = g(E_t)e^{\varepsilon} \quad \text{where } \varepsilon \sim \sigma^2 N(0,1) \qquad \text{eq. 5}$$

Auto-correlation in the process error term is defined as

$$\varepsilon_t = \phi\varepsilon_{t-1} + (\sqrt{1-\phi^2})\varepsilon_t \text{ where } \varepsilon_t \sim \sigma^2 N(0,\sigma^2) \qquad \text{eq.6}$$

$$C_t = \sum_a u_t v_a N_{a,t} w_a \qquad \text{eq. 7}$$

Where

$N_{a,t}$ number of individuals age a time t

$u_t$ fraction harvested time t

$v_a$ vulnerability to fishing age a

$n$ oldest age considered

$s_a$ survival from natural mortality

$E_t$ spawning biomass time t

$f_a$ egg production age a

$g$ recruitment function (B/H, Ricker etc)

$C_t$ biomass of catch

$w_a$ mass at age a

$\phi$ is the autocorrelation term, and can be between 0 and 1.

For the 1st age, i.e. recruitment I use the equation

$$N_{1,t} = \frac{\alpha S_{t-1}}{\beta + S_{t-1}} \qquad \text{eq. 8}$$

where

$$\alpha = \frac{4hR_0}{5h-1} \qquad \text{eq. 9}$$

and $\beta = \dfrac{B_0(1-h)}{5h-1}$ eq.10

where h is steepness (base case h=0.8 was used in the simulations), $R_0$ and $B_0$ are recruitment at Virgin Biomass and Virgin Biomass respectively, $\alpha$ and $\beta$ are parameters related to the density independent and dependent terms in the Beverton Holt relationship.

Thus

$\alpha' = \frac{\kappa(4hR_0)}{5h-1}$ is used in simulations instead of $\alpha$, as it will indirectly be effected as if we account for IUU, the value of $R_0$ is likely to be scaled up. For illustrative purposes I used 15% change in $R_0$ as I failed to account for that in the catches, so $\kappa$ =1.15 in the equation above.

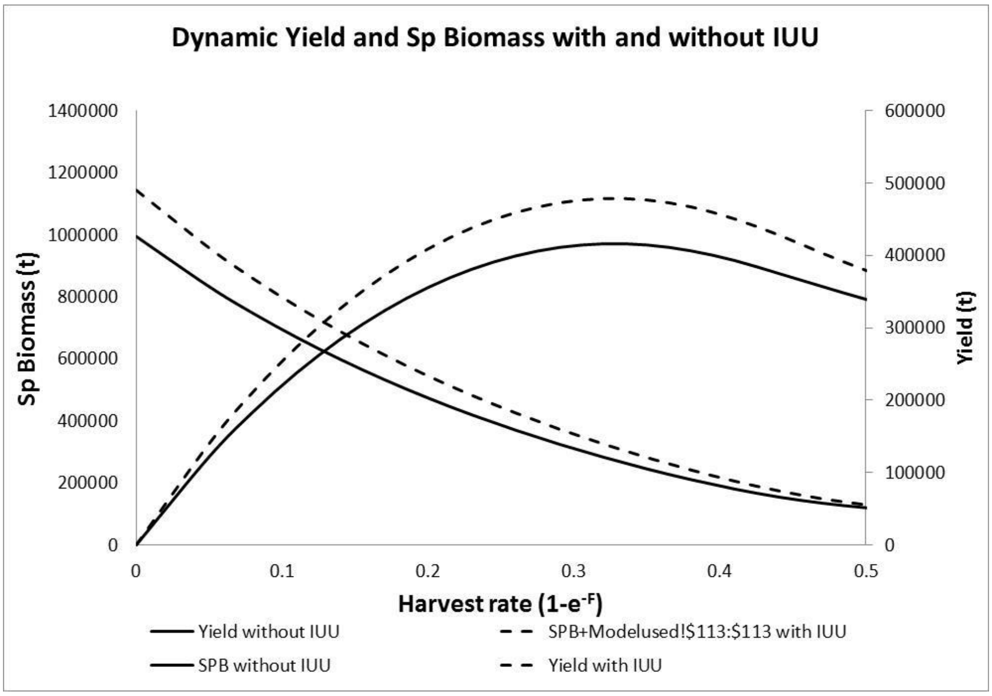



***Figure 6: Effects of IUU on Assessments (A simple simulation-based approach).***

In the figure above (Figure 6), parameters were taken from the Indian Ocean skipjack (*Katsuwonus pelamis*) assessment (Table 4 and Figure 7) and a theoretical underestimate of $R_0$ of 15% can create an underestimate of overall potential yield on the stock. Note, this was done as a simulation based exercise with certain assumptions (see equations above). In reality, we would rerun the assessment based on the new catch estimates (IUU+Reported Catch), re-estimate $R_0$ and quantify these effects.

**Table 4: Biological data for skipjack tuna (*Katsuwonus pelamis*)**

| Parameter | Values |
|---|---|
| **Gender group** | **1: Sex Ratio (1:1)** |
| **Age Class** | **0-8 (8 ages)** |
| **M at age** | **0.8/yr across all ages (survival=0.45/yr)** |
| **Growth** | **L(inf)=70, K=0.37, t(0)=0** |

| | |
|---|---|
| **Weight** | **α= 0.00000532, β = 3.35** |
| **Proportion Mature** | **0 to age 3, 0.25 (age 4), 0.5 (age 5), 0.75 (age 6), (age 7 and 8)** |
| **Fecundity** | **Proportional to Weight** |
| **Recruitment** | **h=0.8 (Sigma R= 0.55)** |

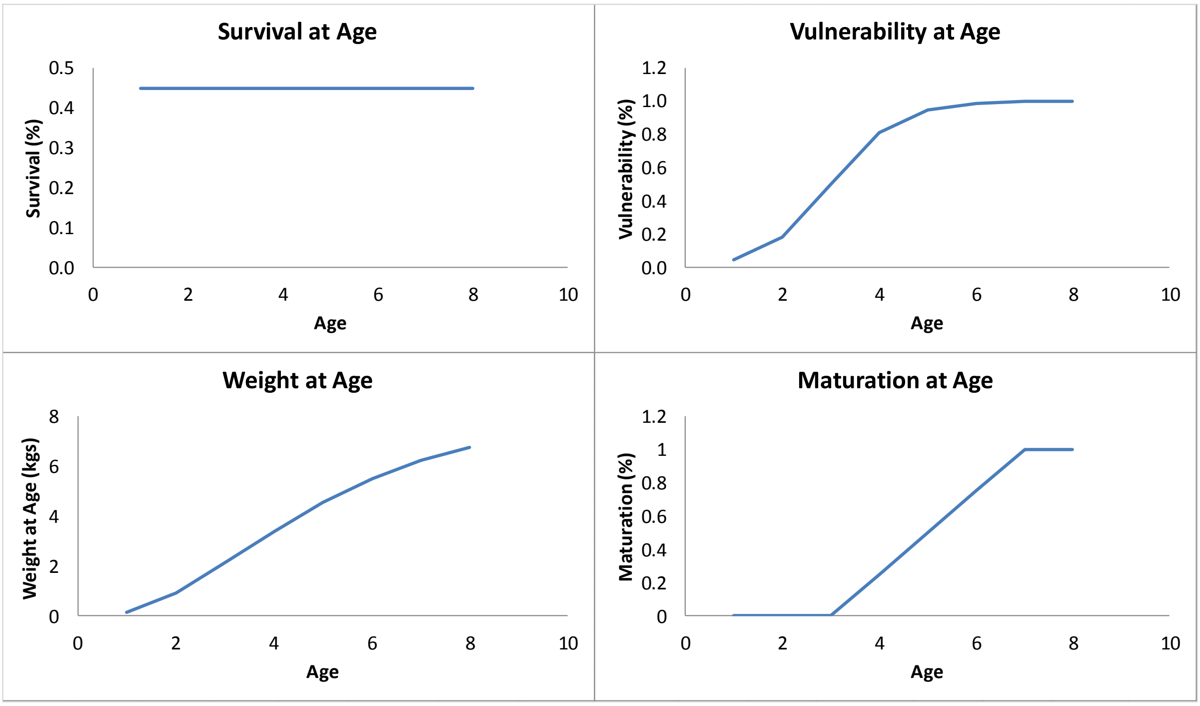



*Figure 7: Key parameter values used for the skipjack simulation*

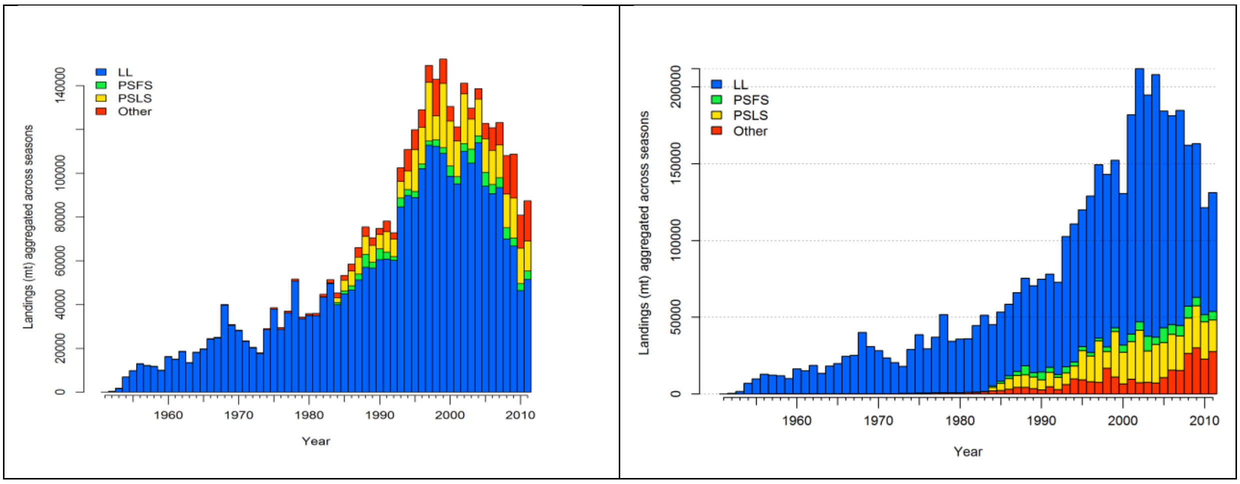



*Figure 8: Catch trajectories without (left) and with IUU (right accounting for a hypothetical 50% increase in reported catches for bigeye tuna (Thunnus obesus) in the Indian Ocean), if it occurred in the last 10 years of a fishery and was not accounted for.*

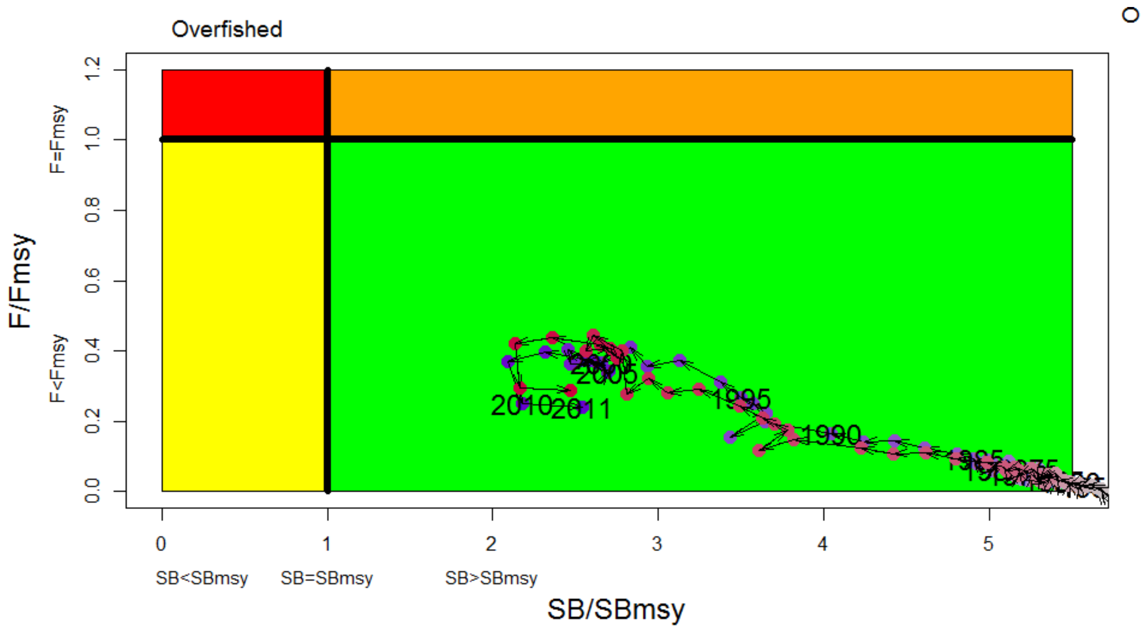



***Figure 9: Effects of IUU in assessments using the Kobe framework running the models with and without IUU estimates (a hypothetical example using bigeye tuna assessment from the Indian Ocean from parameters and the model from Kolody et. al. 2010). Red dots show assessment results with IUU and blue dots without IUU estimates.***

If we do not account for IUU after a certain period (prior to say a certain year our accounting was fine, in the above case 2001), and then a hypothetical CMM caused certain restrictions in a fishery after that year, we would need to rerun the assessment with the IUU estimates after that period. In that case, our estimates of F will be low (underestimated) if we don't incorporate IUU, and as such the health of stocks will be poor as compared to what we had. We demonstrate this with a simplified bigeye tuna assessment in the Indian Ocean (Figures 8 and 9) with and without IUU. When the full assessment is run with tagging data, the effects are marginal as in the case shown above as the tagging data drives the assessment. However, if we had no tagging data the effects would be much larger as catches (right panel Figure 8) are 50% larger after 2010 on all fleets. In addition, although the effects seem marginal, they are not as, the realized F's are 15-20% more in the latter years relative to the scenario with no IUU (Figure 10).

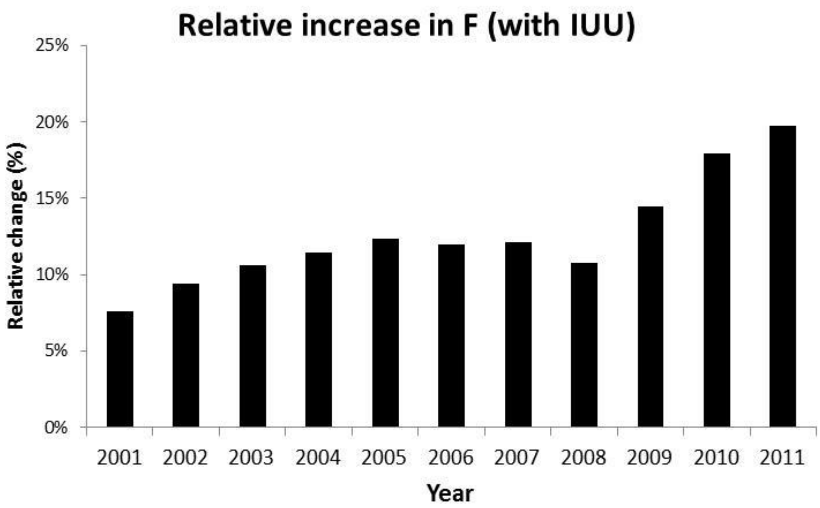



***Figure 10: IUU effects relative to base F values in assessment without IUU using bigeye tuna from the Indian Ocean as an example***

A possible set of rules to assess the impacts of the IUU on assessments would be the following:

1) Run the assessment without IUU
2) Estimate IUU outside the model
3) Update catch estimates to account for IUU
4) Re-run the assessment
5) Assess differences in F with and without IUU.

Again, in the case shown above it is marginal as it is driven by tagging data in those periods, but if that were not available it is likely that F changes would be more than the amount shown in Figure 9 and 10.

## Other consequences of IUU on assessments

Most tRFMO's rely on commercial fishery based indicators for abundance. If IUU is substantial (as it was for CCSBT, Polachek 2012) there would be a large bias in what the standardized CPUE indicates, as catches would be unreported, thereby creating a biased information basis for the CPUE being estimated and used in assessments. In addition, catch estimates by region (spatial assessments would be biased) would be inaccurate if data were not being recorded correctly or missing. In almost all tRFMO's, the reliance on fishery based indicators is large (Polachek 2012) and less reliance on fishery dependent indicators and more reliance on fishery independent indicators in an important factor to consider in future years.

## Effects on blue shark (*Prionace glauca*) in the Indian Ocean (2015 assessment IOTC)

Although strictly not a target species in tRFMO's blue shark are caught in large numbers in the Pacific, the Indian and the Atlantic Oceans. In 2015, in IOTC in the ecosystems and bycatch working party, two series of data were examined in the 2015 assessment. One set was based on the IOTC Secretariat's database which appeared to severely underestimate the overall catches, whereas another dataset produced by Shelley Clarke (pers. comm.) based on trade-based datasets and methodology used in Clarke (et. al. 2006), produced an alternative picture of the blue shark estimate in the Indian Ocean. The trade-based estimates are the overall estimate including IUU, whereas the Secretariat's dataset is reported catch which is off by a factor of six in the case of bycatch species.

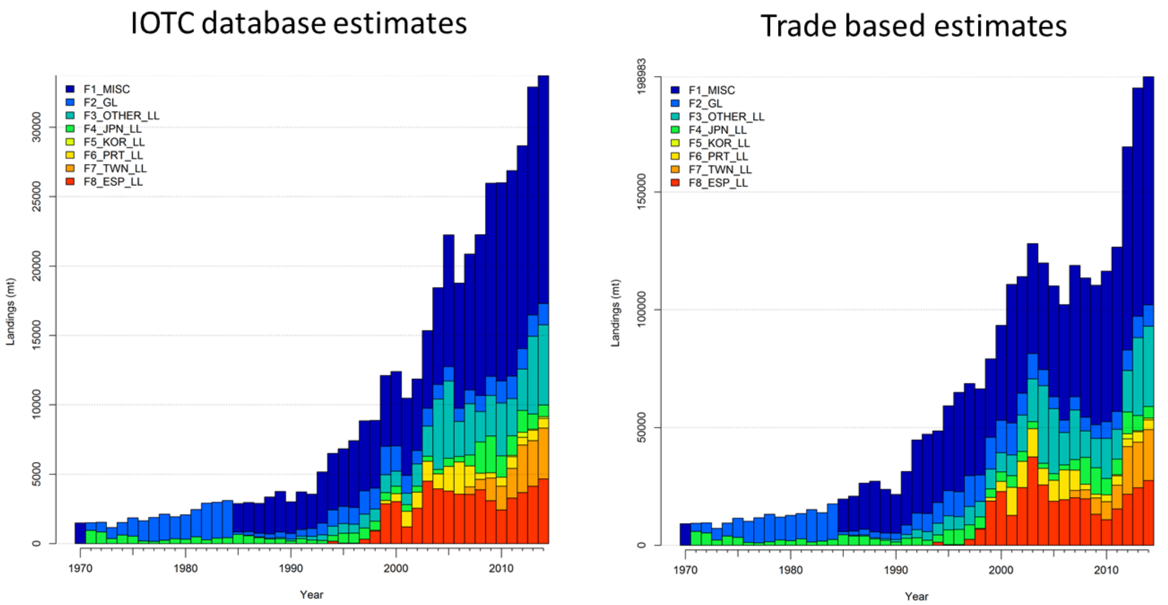


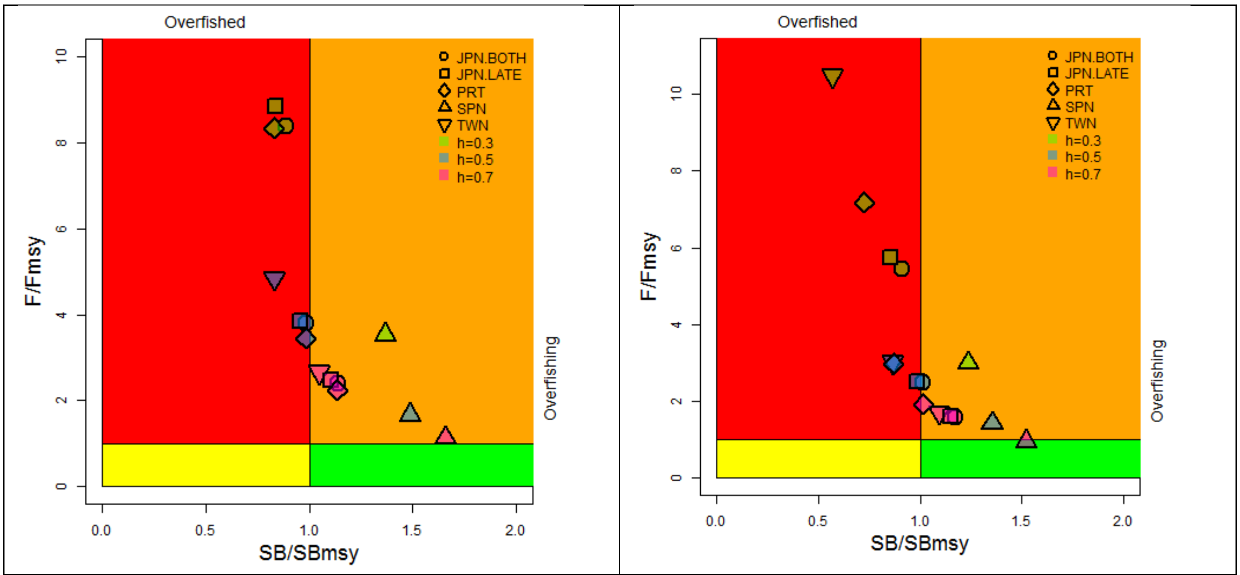

***Figure 11: Indian Ocean blue shark (Prionace glauca) datasets used in 2015 assessment with (right panel???) and without IUU (left panel)***

The assessment was run with both data series (Figure 11) and gave similar results, as the stock trajectories (slopes) were similar in both cases giving a result which is similar to Figure 6 which indicates a scaling effect on the virgin biomass parameters. Results of all runs and different datasets with regard to stock status are shown in Figure 12, Table 5 (from Rice and Sharma 2015). While direct measures of reference points change the overall stock status trajectories remain similar based on the assumptions used for the last point used in the assessment (Figure 11).

**Table 5: Key reference points and derived management quantities for blue shark stock status advice on the Indian Ocean (from Rice and Sharma 2015)**

| Management Quantity | Aggregate Indian Ocean (IOTC Catch) | Aggregate Indian Ocean (Trade Catch) |
|---|---|---|
| 2014 catch estimate (t) | 33714 | 141571 |
| Mean catch from 2010–2014 (t) | 29628.41 | 129199.2 |
| MSY (1000 t) (range) | 9.53 | 56.8881 |
| | (4.611-15.640) | (28.241-84,860) |
| Data period (catch) | 1971-2014 | 1971-2014 |
| $F_{MSY}$ (range) | 0.143059 | 0.144 |
| | (0.055-0.225) | (0.055 - 0.228) |
| $SB_{MSY}$ or $*B_{MSY}$ (1,000 t) (range) | 16.497 | 92.642 |
| | (13.344-27.023) | (77.690 -147.039) |
| $F_{2014}/F_{MSY}$ (range) | 3.52523 | 2.521 |

| | | |
|---|---|---|
| | (1.131-15.684) | (0.960-10.478) |
| $B_{2014}/B_{MSY}$ (range) | n.a. | n.a. |
| $SB_{2014}/SB_{MSY}$ (range) | 0.983875856 | 1.014 |
| | (0,584-1.658) | (0.568-1.522) |
| $B_{2014}/B_{1950}$ (range) | n.a. | n.a. |
| $SB_{2014}/SB_{1971}$ (range) | 0.424 | 0.425 |
| | (0.28-0.65) | (0.272-0.591) |
| $B_{2014}/B_{1971,\ F=0}$ (range) | n.a. | n.a. |
| $SB_{2014}/SB_{1971,\ F=0}$ (range) | Na | n.a. |
| | | |




| IOTC secretariat (no IUU) | Trade based datasets (IUU) |
|---|---|

***Figure 12: Estimated stock status for blue shark (Prionace glauca) in the Indian Ocean using different datasets based on different assumptions for the assessment and using a Kobe plot for the diagnostics.***

The method here essentially follows the five point steps above identified for accounting for IUU in assessments, and could serve as a general guideline of how the assessments could be run with and without IUU as was shown in Rice and Sharma (2015).

## Conclusions

While numerous methodologies exist on how to estimate IUU, it is difficult to quantify the Illegal (I) component in these estimates and to a large extent these are largely focussed on Unregulated (U) & Unreported (U).The Unreported component is the largest issue (at least in the context of tRFMO's) and much better sampling requirements and observer coverage may improve this piece. However, past data will be inaccurate and some examination of imprecision in the past data should be examined on the assessments. Data reporting regimes are the key to improving this component and at the present time, most tRFMO's are spending significant time to improve this component.

In the Western Pacific some attempts have been made to quantify illegal activity by using VMS and remote-sensing data, but the accuracy of those approaches are not currently known (Agnew 2009, MRAG 2016). The pros and cons of alternative methodologies are discussed, and an attempt is made to assess what the current state of these techniques and estimates of IUU are in global tRFMO's.

It is apparent that with the exception of CCSBT (and in some cases IOTC and ICCAT) some attempt of incorporating IUU in assessments is made. However, this is not done systematically across all tRFMO's and some attempt of dealing with this issue across all tRFMO's should be made. It may not be a high priority issue in some cases, but based on the magnitude of the catches in WCPFC (MRAG 2016), one cannot discount it either, as it would have some consequences on stock status advice.

The state of observer coverage, the methods used to estimate IUU in various fisheries, the species, and fleets vary substantially in the various RFMOs. An attempt was made to quantify and synthesize these approaches with the estimated values of what the IUU may be currently in each RFMO based on best available data in this report. Finally, the report produced here makes an attempt to quantify the impacts of IUU for tRFMO's using a simulation framework and lays out a possible step by step approach (heuristic/flow process) to use once the estimates are generated by examining the effect on key reference points produced in an assessment. The process could be repeated using a bootstrap for many series of catch data based on uncertainty in these estimates, and the results could then be compared across a variety of structural (model) uncertainties and data uncertainties in assessing stock status. While this is by no means comprehensive, the approach developed here could be a starting point. There is obviously a lot more work that can be done on this topic, but due to time constraints this was all that was attainable.

## Recommendations for future work

While the approach presented here has an iterative independent feedback to first estimate the catches and then examine the effects on assessments, an approach doing both simultaneously like North Sea cod (ICES 2014) or abalone (Plagyani and Buttwerworth 2011) could be examined, and compared with the process outlined here. In addition, replicating/expanding the results of the WCPFC to other tRFMO's should be conducted in subsequent years.

Other simple exercises like presenting how many IUU vessels are listed by ocean, and verify if the IUU estimates made are plausible by area. Using a simple back of the envelope calculation on what is plausible based on vessel characteristics in the list and what proportion of the IUU estimate could hypothetically come from the Illegal vessel activity, and estimated accordingly

There are a number of recommendations that may be sent to tRFMO's to better account for catches and for the scientific committees (SC) from each tRFMO to abandon the best catch series without error approach, and account for uncertainty in the catch when running assessments, and developing stock status advice based on IUU and reported catch estimates. In addition, data standards could also be changed and harmonized to facilitate independent auditing of data reports by tRFMO Secretariats or independent panels set up to verify the catches being reported in particular areas.

Once these are addressed/developed a series of workshops could be held. The first workshop should be developed to revise data reporting requirements and status of databases at tRFMOs. This workshop should develop methods/sources in order to obtain additional information to generate estimates of IUU catches in each case, through procedures that are as harmonized as much as possible across tRFMO's, depending on the amount of data sources identified.

Following this, further workshops could be developed to assess their impacts on assessments. , Two additional workshops should be conducted on this subject; i) the first workshop convene a team of experts to examine how robust these estimates of IUU are by jurisdiction, and ii) a second workshop convene a stock assessment working group to examine alternative approaches of which some issues identified here could be answered (i.e. how these could be used in the assessments or directly estimated from the assessments, rather than the heuristic methodology outlined here).

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