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Uncertainty in catch and effort data of small- and medium-scale tuna fisheries in Indonesia: Sources, operational causes and magnitude

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ABSTRACT

This study aims to identify the sources and magnitude of uncertainty in the collection and processing of catch and effort data of small- and medium-scale tuna fisheries in Indonesia, as well as the causes of uncertainty on an operational level. We identified possible sources of uncertainty through a literature review and interviews with experts. Next, we surveyed 40 small-scale (< 10 GT) and medium-scale (10–100 GT) pole-and-line, purse-seine, longline and handline fishers in the oceanic fishing port Bitung, which has the largest number of tuna fisheries activities in eastern Indonesia, to estimate the magnitude of unreported catch of juvenile tuna, on-board consumption, home consumption and catch used as bait. We used logbook data from the fisheries submitted to the fishing port authorities to extrapolate survey results to the fishing port level. Uncertainties around unreported catches were due both to non-reporting by fishers to the fishing port authority and to flaws in data management in the data collection institution. After removing flaws in the logbook database we estimated that the catch by small- and medium-scale fishing vessels active in Indonesian waters could be about 33–38% higher than reported. The proportion of unreported catch, as well as the sources and range of uncertainty, varied according to the types of gear used. Finally, we discuss what aspects of data collection and processing should be improved at the fishing port level, including the identified sources of unreported catch and the processes leading to non-reporting. We hence provide a methodology for estimating unreported catches in small and medium-scale fisheries.

1. Introduction

Globally, fisheries catch statistics underestimate actual catch (Pauly and Zeller, 2016; Watson and Pauly, 2001). Pauly and Zeller (2016) estimate that global catch between 1950 and 2010 might be 50% higher than that reported by member countries to the Food and Aquaculture Organisation of the United Nations (FAO). Worldwide, total unaccounted for catches from unregistered illegal and unreported fishing during 1980–2003 were estimated between 11 and 26 million tonnes or about \$10bn–\$23.5bn annually (Agnew et al., 2009). Catch underestimation is a major cause of uncertainty in estimates of fishing mortality, stock size, and ecosystem impacts from fishing (Caddy and Mahon, 1995; Patterson et al., 2001). For example, the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) redefined its management procedure after accounting for the uncertainty associated with its data induced by misreporting and taking account of illegal, unreported and unregulated (IUU) catches (Kurota et al., 2010; Polacheck, 2012).

The reasons for the underestimation of catches include inadequate data collection systems (Belhabib et al., 2014; Crego-Prieto et al., 2012; Lescrauwaet et al., 2013), illegal fishing (Agnew et al., 2009; Pitcher et al., 2002; Polacheck, 2012; Worm et al., 2009), unreported discards (Patterson et al., 2001; Zeller and Pauly, 2005), and unreported landings by fishers (Bailey et al., 2015; Watson and Pauly, 2001). Another cause is that fisheries managers pay limited attention to small-scale fisheries (Béné et al., 2010; Gillet, 2011; Pauly, 2006; Zeller et al., 2014), which are often found in areas that are difficult to access (Pauly, 1997) and require substantial financial, technical and human capabilities and resources to gather data on (Zeller et al., 2014).

The problem of catch and effort underestimation is particularly urgent in Indonesia. Previous studies (Dudley and Harris, 1987; Proctor et al., 2003) found that Indonesia's national fisheries data suffer from inadequacies, many of which have already been identified in an early FAO report by Yamamoto (1980). Despite major changes to the data

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collection system in response to this report, many of the problems of catch underestimation have persisted. In 1995, a logbook system was introduced to a tuna longline fishery in Muara Baru, Jakarta (Proctor et al., 2003). This effort was strengthened in 2002 with the Decision of the Minister of Marine Affairs and Fisheries Number 3 and again in 2010 with the Regulation of the Minister of Marine Affairs and Fisheries Number 18. However, data reconstructions suggest that the Indonesian catch between 1950 and 2010 was 38% higher than what was reported to the FAO.[1]

As in other fishing nations, catch underestimation in Indonesian data is driven by a range of factors. These include illegal and unreported catch, and procedural problems in primary data collection through the use of logbooks (Bailey et al., 2012; Mous et al., 2005; Pramod et al., 2014; Proctor et al., 2003; Varkey et al., 2010). Varkey et al. (2010) estimate that approximately 13,000 t of tuna caught in Raja Ampat in 2006 was not reported, an amount equivalent to 75% of the reported catch from the area in that year. Pramod et al. (2014) estimate that 35% of tuna exported to the USA in 2011 from the Philippines, Vietnam and Indonesia was caught illegally. They also indicate that 25% of the tuna catch exported by Vietnam was caught illegally from the Indonesian Exclusive Economic Zone (EEZ). Misreporting is a rampant source of uncertainty: differences between reported and actual landed catch are often caused by stratification of catch categories not based on species, but rather on what is useful for trade and sale.[2] This leads to misreporting when different species with the same price category are recorded as one species.

These problems are also found in eastern Indonesia where catch reconstructions over the period from 1950 to 2010 estimate that the total catch was around 57% higher than what was reported.[1] This estimate, however, is based at the provincial level for all categories of IUU fishing in nine major taxonomic categories, and does not distinguish among fisheries or drivers of catch underestimation in official statistics. Tuna fisheries in eastern Indonesia are the largest contributor to the total tuna catch of Indonesia. Gillet (2011) finds that one of the drivers of the low quality of national tuna fisheries statistics is the underreporting of tuna catches in eastern Indonesia, particularly by small-scale fisheries. These uncertainties are usually attributed to flaws at the level of primary data collection, i.e., in the first observation of quantities (Dame and Christian, 2006; Punt et al., 2016; Rosenberg and Restrepo, 1994). However, it has not yet been further specified how these flaws originate in the process of data collection at the level of individual fishers and data collectors, and how this relates to their understanding of the systems in place. Limited attention has also been given to uncertainties as a result of flaws in the processing of primary data into databases.

The Indonesian Ministry of Marine Affairs and Fisheries (MMAF) is currently improving its data collection system in view of the demands from the three Regional Fishery Management Organisations (RFMOs): the aforementioned CCSBT, the Indian Ocean Tuna Commission (IOTC), and the Western and Central Pacific Fisheries Commission (WCPFC). The WCPFC collaborates with the MMAF to strengthen Indonesian tuna data collection through such initiatives as the West Pacific East Asia-Oceanic Fisheries Management (WPEA-OFM) program in eastern Indonesia (WCPFC, 2007). In a 2013 catch estimates workshop, the WCPFC recommended that the MMAF identify the causes of uncertainty in catch and effort estimates and find solutions to address the inaccuracies in its data (WCPFC, 2013).

This article aims to identify and quantify the sources of uncertainty in catch and effort data of the small and medium-scale tuna fisheries in Indonesia, exemplified by the oceanic fishing port (OFP) Bitung in North Sulawesi. Small-scale fishers are those who work without a vessel, or with a vessel of maximum 10 gross tonnage (GT) (Law of Indonesia No. 7/2016). Medium-scale fishers are commercially oriented, and use vessels between 11 and 100 GT. We aim to 1) identify the causes of errors in the process of data reporting by small-scale and medium-scale fishers to the authority in OFP Bitung; and 2) to quantify the major sources of catch underreporting besides illegal fishing. In addition we report on problems we encountered in the data processing phase of our study. Our research questions for this study are: 1) What are the main sources of uncertainty in catch and effort data of the tuna fisheries in Indonesia?; 2) What are the causes of these uncertainties at the operational level?; and 3) What is the impact of the main sources of uncertainty on the catch reporting of the small and medium fisheries in the OFP Bitung? We addressed these questions through interviews with fisheries data collection and assessment experts, a survey among fishers in the OFP Bitung, and by extrapolating our findings to the level of the fishing port by means of logbook data. Although it is not the explicit focus of our research, we also report on and discuss problems that we encountered during the data processing phase of our research.

2. Materials and methods

2.1. Study site

In 2012 and 2013, tuna production in the province of North Sulawesi amounted to 22% of the estimated total catch of yellowfin tuna (*Thunnus albacares*) and 14–23% of bigeye tuna (*Thunnus obesus*) in Indonesia (DGCF-MMAF, 2013, 2014). The largest producer is the OFP Bitung which, in addition to a large-scale fishery, harbours numerous small-scale and medium-scale tuna fisheries, and is therefore a sensible location to investigate uncertainty in catch and effort data of fisheries of this size.

2.2. Data collection

Fig. 1 shows the flowchart of data collection, data harmonisation, and data analysis. We collected data through a literature review, expert interviews, a field survey among fishers, and database analysis of logbook and permit issuance data provided by the OFP Bitung. Fishing vessels need a permit every time they leave OFP Bitung, the issuance of which involves a registration of the previous return to the port and the vessel's date of departure. This database also includes such attributes as gross tonnage and gear used for every reported trip. The aim of the field survey was to estimate the magnitude of the main sources of uncertainty in catch estimates, and the logbook data were used to extrapolate the survey results to port level. The permit issuance data were used to complement missing effort information in the logbook data.

2.2.1. Literature review and interviews

Sources for our literature review include primary publications as well as reports from tuna RFMOs and relevant fisheries research institutions. We focused our review on articles and reports that identify sources of uncertainty in recorded catch data. Interviews were conducted with fisheries officers of the MMAF in Jakarta and Bitung and with fishers, data collectors, observers, and surveillance officers in Bitung (see Supplementary Appendix 1 in the online version at DOI: http://dx.doi.org/10.1016/j.fishres.2017.04.009 for a list of respondents). Respondents were selected who had a role in the data collection process and/or were knowledgeable about catch and effort data collection problems in Indonesia. The selection of respondents was a combination of purposive and snow-ball methods, as we were interested to interview respondents with a particular expertise and to gain richer insights into the sources of uncertainty identified in the

[1] Pauly, D., Budimartono, V. (2015) Marine Fisheries Catches of Western, Central and Eastern Indonesia, 1950–2010. Fisheries Centre Working Paper #2015-61. http://www.seaaroundus.org/doc/publications/wp/2015/Pauly-and-Budimartono-Indonesia.pdf

[2] Pet-Soede, C. and Ingles, J. (2008) Getting Off the Hook: Reforming the Tuna Fisheries of Indonesia & Considerations for Ecosystem-based Management. Worldwide Fund for Nature. http://wwf.panda.org/?150401%2FGetting-Off-the-Hook-Reforming-the-Tuna-Fisheries-of-Indonesia-Considerations-for-Ecosystem-based-Management

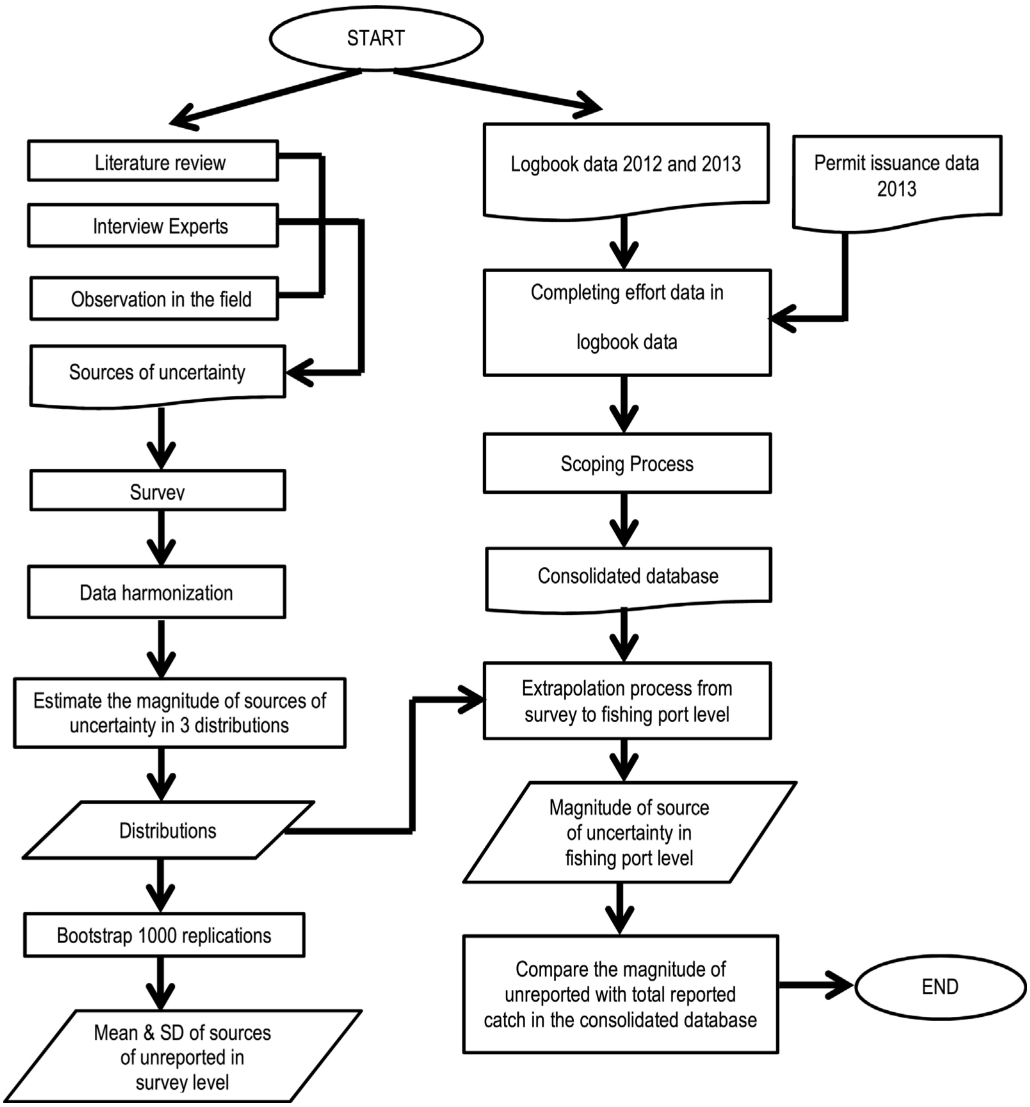

Fig. 1. Flowchart of the data collection, data harmonisation, and data analysis in this study.

survey and from initial interviews. Based on information obtained from initial responses during interviews with experts, e.g. the National Tuna Coordinator WPEA of Indonesia, as well as our own knowledge of the competency of relevant institutions, we identified other experts such as the Directorate of Fisheries Resources, the Directorate General of Capture Fisheries of the MMAF (DGCF-MMAF), and the Directorate General of Marine and Fisheries Resources Surveillance of the MMAF (DGMFRS-MMAF). In the interviews we discussed our findings from the literature review as well as the information obtained through subsequent interviews to obtain more detailed information on the sources of uncertainty as well as the reasons for their occurrence. Additionally, observations on the data collection process were made by joining the fishing port authority in the process of data collection in the OFP Bitung. The list of the sources of uncertainty resulting from the literature review and the interviews served as a basis for the survey questions.

2.2.2. Survey

The initial questionnaire was tested in the OFP Bitung in October 2013 and adjusted accordingly. The adjustments led to the identification of four categories of sources of uncertainty to be further investigated: unreported catch of juvenile tuna; on-board consumption; catch used as bait; and catch for home consumption. The survey in OFP Bitung was conducted between October and November 2013. Survey targets were obtained through accidental sampling: fishers available at the fishing port were asked to answer the questionnaire. Pure random sampling was not possible in this fishery because of problems in obtaining an overview of the total number of vessels operating from the port, as well as the potentially long time necessary to wait for randomly chosen vessels to return to the port within the limited time available for conducting the survey. Survey targets were captains and vice-captains of pole-and-line, longline, purse-seine and handline fisheries, and numbered 40 in total.

The questionnaire started with a set of general questions related to effort, such as the overall length of the vessel (LOA), number of crewmembers per vessel, number of fishing trips in a year, and number of fishing days per trip by fishing season, which is indicated by month, as well as the amount of time spent not fishing. Fishers indicated three seasons in catch sizes: high, intermediate and low season, which occur over successive months with associated peaks and troughs in catch numbers of tuna. The total number of fishing trips per year and fishing days per year were estimated by considering the number of fishing trips and days in the peak season and the low season.

Next, respondents were asked to report on three categories of sources of uncertainty in catch estimates: on-board consumption of the catch by crewmembers (“on-board consumption” measured in kg per fishing day); catch brought for family or home consumption (“home consumption” measured in kg per trip); and unreported catch of juvenile tuna ("unreported juvenile tunas" measured in kg per trip). For the handline fishery we added the use of catch as bait ("bait" measured in kg per trip). For each category, respondents were asked the minimum, maximum and normal values. Respondents were also asked whether they brought logbooks on their fishing trips, and whether they recorded catches personally, or if the logbooks were filled in by others, such as agents of the companies where they deliver their catch. If respondents were not able to answer these questions in units of weight, they could answer in numbers of fish. Respondents were also asked to give a minimum and maximum size in weight for fish used for on-board consumption, home consumption and for unreported catch of juvenile tuna. These weights were later used to convert numbers to kg. All interviews were anonymised and signed for approval.

2.2.3. Logbook data and permit issuance data

Logbook and permit issuance data were obtained from the port authorities of OFP Bitung. The logbook data used in this study include departure and arrival dates of vessels into the port, gross tonnage (GT), LOA, number of crew, and catch of pole-and-line, longline, purse-seine and handline vessels for every reported trip in 2012 and 2013. The permit issuance data include variables such as GT, LOA, and departure and arrival dates of vessels into the port for every reported trip in 2013. Departure and arrival dates give an indication of the number of days-at-sea for vessels that use Bitung as their home port. Whenever departure and/or arrival dates were missing from the logbook data, these dates were taken from the permit issuance data. The logbook data were used to identify uncertainties in information on effort allocation and calculate an aggregated estimate of the magnitude of the uncertainty around the reported catch for the small- and medium-scale fisheries at port level for 2012 and 2013 in OFP Bitung. Since, for unknown reasons, data for longline and handline vessels were not available for June 2012, we excluded the reports of pole-and-line and purse-seine for this time period.

2.3. Data harmonisation

2.3.1. Survey data

Questions related to fishing effort, particularly on the number of fishing days, were answered in either days or months per trip; all answers were standardized to days per trip. For fishers who conduct monthly fishing trips, we assume that there were four days between successive fishing trips to allow for unloading and bunkering logistics to prepare for the next trip. Answers related to the categories of sources of uncertainty were standardized to kg by multiplying the number of fish by the weight per fish as stated in the questionnaire. For both the number of fish in different types of unreported catch and the weight per fish, the data contain minimum and maximum values; therefore, minimum, normal, and maximum values for total weight were obtained by multiplying the minimum number of fish by the minimum weight per fish, normal number by average weight of minimum and maximum weight, and maximum number by maximum weight, respectively. Incomplete answers were dealt with as follows: for fishers who reported only minimum and maximum values we assume the normal values to be an average of the reported minimum and maximum, and for fishers who answered only a normal value we assume the minimum and maximum values are equal to the normal value.

The magnitude of the four investigated sources of uncertainty were likely related to the number of crewmembers, number of fishing-days and gear type. However, we could not find any significant relationship between these factors and the magnitude of the sources of uncertainty, probably due in part to the low number of respondents (40 fishers). Nevertheless, it is reasonable to assume, for the categories unreported catch of juvenile tuna, on-board consumption, and catch used as bait, that the magnitude of the sources of uncertainty is proportional to the number of crew and the number of fishing days. For the category home consumption, it is assumed that the magnitude is proportional to the number of crew and number of fishing trips. Moreover, exploratory statistical analysis (Supplementary Appendix 2 in the online version at DOI: http://dx.doi.org/10.1016/j.fishres.2017.04.009) suggests that fishing gear is an influencing factor for on-board consumption and unreported catch of juvenile tuna. Although fishing gear is not a significant factor for estimating home consumption, assuming this factor as an influencing factor is plausible because revenues per crewmember vary between gears and crew are sometimes allowed to take fish for home consumption as part of their salary. Therefore, we estimated the magnitude of these sources of uncertainty for each gear type separately.

2.3.2. Logbook and permit issuance data

Analyses of logbook data required preparation through the following steps: 1) estimating missing entries with respect to effort by means of permit issuance data; 2) selection of logbook data; 3) estimation of trip length; and 4) correction of unrealistically long fishing trips. Occasionally entries were missing from the logbook with regard to port departure and/or arrival dates, GT, and LOA. Logbook data entries to be used for the total catch estimates were limited to gear types (pole-and-line, purse-seine, longline and handline) and vessel sizes that were present in our survey. We limited the GT in each gear type to 1 GT smaller than the smallest GT and 1 GT larger than the largest GT in our survey. Fishers that ventured outside the Indonesian EEZ were excluded because we focused our study on the vessels that had fishing licences within the Indonesian EEZ and archipelagic waters.

Trip length was estimated in number of fishing days by departure and arrival dates of vessels. Some purse-seine vessels, however, transfer their catch to a carrier vessel that brings the catch ashore. For those vessels we estimate the number of fishing days by counting the days between the departure date and the arrival date of the catcher vessel. If the arrival date of the catcher vessel is not available, the days between the departure date of the catcher and the arrival date of its carrier vessel as recorded in the logbook data.

Finally, the logbook data contained several handline vessels smaller than 30 GT with fishing trips lasting longer than one month. Such trip lengths, however, are unrealistic considering that these vessels preserve their catch by chilling the fish on ice. Therefore, we assume that the maximum number of days a small vessel can preserve the catch is one month (Shawyer and Pizzali, 2003). We suspect that these fishers landed their catch, or a portion of it, outside Bitung. This was verified in the interviews with handline fishers who reported that they fished in Indonesian waters and landed their catch in a port in General Santos, the Philippines without reporting to legal authorities in Indonesia. Therefore, their reported catch should be attributed to fewer fishing days than suggested by the arrival and departure dates in the logbook data.

Instead of excluding vessels with unrealistically long fishing trips from our data, we estimated the trip length for these handline vessels by considering the average relation between the length of a vessel, LOA, and fishing effort, where the latter is defined as the number of crewmembers times the number of fishing days. We used the following model to estimate the crew-days for handline entries that had trip-durations of more than 30 days:

$$\frac{1}{\sqrt{CD_i}} = b_0 + b_1 LOA_i + \varepsilon_i \quad (1)$$

where CD_i is crew-days in trip i (crew-days), and LOA_i is the length of the vessel in trip i (meters).

2.4. Data analysis

The standardized minimum, maximum and normal values of unreported catch of juvenile tuna, on-board consumption, and catch used as bait in the survey data were used to estimate the distribution of sources of uncertainty of unreported catch of juvenile tuna, on-board consumption and catch used as bait over the number of fishing days reported by the survey respondents. As we did not obtain frequencies of values for these categories of uncertainty, we distributed our estimates over the number of fishing days of each respondent according to three probability distributions of likely values: a uniform, a split-uniform and a triangular distribution. In the uniform distribution, every value between the minimum and maximum values is assumed to have an equal probability of occurrence. In the split-uniform distribution we assumed that 50% of fishing days in a year showed values between the minimum and normal values, and 50% between the normal and maximum values. In the triangular distribution we assumed that the mode of the distribution occurred at the normal values, whereas the minimum and maximum values were assumed to have had zero probability. We followed the same procedure for home consumption by distributing our estimates over the number of fishing trips in a year.

We estimated the average and standard error from the resulting three distributions by employing a bootstrap with 1000 draws. To upscale survey data to fishing port level, random samples from the distributions were taken for home consumption per crewmember and for unreported catch of juvenile tuna, on-board consumption and catch used as bait per crew-day per trip as reported in the logbook database. The sum of draws over all trips is an estimate of the total magnitude of the source of uncertainty in the fishing port level. We repeated this procedure 1000 times and estimated the mean, standard deviation and 5%, 50% and 95% quantiles.

3. Results

3.1. Sources of uncertainty

The sources of uncertainty found in the literature review, field observations, and expert interviews can be divided into two main types: illegal fishing and unreported fishing (Table 1). In this article we abide by the definitions of illegal and unreported fishing established in the International Plan of Action to Prevent, Deter and Eliminate IUU Fishing, particularly because Indonesia has ratified the agreement on Port State Measures to Prevent, Deter and Eliminate IUU Fishing and implemented it in a National Plan of Action.

The most important causes of illegal fishing in Indonesian waters affecting reported catch data were landings outside Indonesia, illegal transhipments, and poaching. In one personal communication, the Head of Station of Surveillance for Marine and Fisheries Resources in Bitung declared that some disobedient companies in Indonesia have an agreement with organisations in other countries to deploy foreign crew on the Indonesian–flagged vessels. This is done so that the vessels can then enter the territory of, and land the catch to, the intended country. In the survey, some Indonesian fishers reported having previously sold and transhipped catches on the sea to Philippine vessels that waited near the border, and failed to report this transhipment in the logbook. This too was confirmed by the Head of Station of Surveillance for Marine and Fisheries Resources in Bitung during a personal communication. The fishers reasoned that they obtained more profit by selling catch at sea to foreign vessels. According to the same Head of Station of Surveillance, poaching in Indonesian waters was conducted by foreign fishers who use double-flagging to be recognized as a registered vessel while travelling and fishing. During their stay in Indonesian waters, the Indonesian flag is raised in violation of the permit to fish in Indonesian waters. After poaching in Indonesian waters, these vessels land their catch in their home country.

During the interviews and field observations, fishers and companies indicated a strong distrust towards the government. Fishers and companies do not want to share information such as the amount of catch or the position of their fishing ground, because some taxes depend on the reported catch, and captains and companies worry that information on their fishing locations will be discovered by their competitors (Head of Sub-directorate of Surveillance and Utilization of Fisheries Resources, Directorate of Surveillance for Marine and Fisheries Resources, DGMFRS-MMAF, personal communication).

It often happens that instead of being filled in directly by the captain, logbooks are filled in after the fishing trip by agents of the company, or by other persons who did not participate in the fishing trip (Proctor et al., 2003). This results in a failure to obtain information directly from the fishers. The implementation of the self-reporting system, or fishing logbook report, is considered to be not yet successful (National Tuna Coordinator WPEA, Research Centre for Fisheries Management and Conservation (RCFMC), Indonesia, personal communication) since underreporting still occurs. This also means, as we were able to confirm during the field survey, that some portion of catch is utilised during the trip and therefore is not recorded in logbooks. Moreover, during the survey some handline fishers reported that agents record only the catch that goes to the processing company and do not take note of catch sold to local markets. Not all fish in a catch fulfil a company's requirements on size and quality, and the rejected part of the catch is usually sold to the local market without being recorded in the logbook. Another cause of underreporting in small-scale fisheries is the exception for vessels below 5 GT to report their catch in a logbook. These fishers need to declare only the amount of fish sold to traders for export. Quantities of fish landed to local markets by these fishers are therefore not recorded. Catch used for on-board consumption, or allocated to crew to take home, is also not reported in the logbook. Fishers claimed that this includes only fish with low economic value

Table 1
Sources of uncertainty in tuna catch and effort data in Indonesia based on a literature review, interviews with experts and field observations in Bitung, Indonesia in 2013.

Source of Uncertainty	Source of information
1) Illegal fishing	
•Landing catch outside Indonesia	Head of Sub-directorate of Surveillance and Utilization of Fisheries Resources-MMAF, Head of Station of Surveillance of Marine and Fisheries Resources in Bitung-MMAF
•Illegal transhipment	Head of Station of Surveillance of Marine and Fisheries Resources in Bitung-MMAF
•Poaching in Indonesian waters	Sodik (2009), Béné et al. (2010), Pramod et al. (2014), Pauly and Budimartono[1] (2015), Head of Station of Surveillance of Marine and Fisheries Resources in Bitung –MMAF
2) Unreported Fishing	
•Failure to comply filling logbook	National Tuna Coordinator WPEA-MMAF, Head of Sub-directorate of Surveillance and Utilization of Fisheries Resources-MMAF,
•Logbook filled by agent or someone who did not participated in the fishing trip	Proctor et al. (2003), Field observation in Bitung in 2013
•On-board consumption and fish distributed to vessel crew and/or bring fish for home consumption	Buchary et al. (2011), Pauly and Budimartono[1] (2015), Field observation in Bitung in 2013
•Catch used as bait	Field observation in Bitung in 2013
•Misidentification and aggregation of species	Field observation in Bitung in 2013, Sub-directorate of data and statistics of capture fisheries-MMAF, Pet-Soede and Ingles[2] (2008), Ismayanti (2014)

and/or non-target catch such as eastern little tuna (*Euthynnus* sp.), juvenile tunas, or other small pelagic fish for which the price is lower than that of adult tunas.

The handline fishery uses artificial bait and live bait for fishing big tuna. Live bait is caught by using small hooks. According to the interviewees, bait species to catch large tunas include other pelagic fish such as mahi–mahi (*Coryphaena hippurus*), malalugis (*Decapterus* sp.), squid, eastern little tuna (*Euthynnus* sp.), or mackerel. Despite the large size of some bait species, fishers do not record these in logbooks since they reportedly assumed that only the targeted species and landed fish should be recorded. This is despite an explicit statement in the logbook that all fish caught should be recorded in the logbooks.

During the survey, fishers reported that they logged catches of juvenile tuna with those of skipjack because both earned the same price from the first buyer. Interviewees additionally reported selling juvenile tunas mixed with skipjack tuna to the first buyer or middleman in the local market. However, during field observations we also found that the species were sold separately to consumers in the retail market. Apparently, in the transfer of the catch of juvenile tuna mixed with skipjack from the fisher to the first buyer, from the first buyer to the middleman, and eventually to the retail market, the catch is eventually separated by species and quality.

Another cause of misreporting is rooted in the process of data collection and digitisation conducted by enumerators and data operators of the local government. Despite annual training by the MMAF, the local governments' commitment to keep the data collectors on their job for an extended period of time is very low (Ismayanti, 2014) (also confirmed by the Sub-directorate of Data and Statistics of Capture Fisheries, DGCF-MMAF, personal communication) and data collectors often retain this position for less than one year. Data quality deteriorates because of the high turnover of state-employed enumerators, for instance in the reporting of catch by using local names of species that do not fit with the standardized survey form of the MMAF. A lack of highly qualified enumerators and data entry operators available for hire at the OFP Bitung was confirmed during the interviews (Head of OFP Bitung, personal communication). Additionally, the fishing port authority claims that there are insufficient numbers of enumerators, and that since the working hours of the fishing port authority is limited to day time, unsupervised landings of fishing vessels frequently occur.

3.2. Quantitative results

3.2.1. Primary data

We collected quantitative data from 40 respondents from four fishing gears in OFP Bitung (Table 2). We standardized respondents' answers for the minimum, normal and maximum value of the catch of juvenile tunas to kg per trip; on-board consumption to kg per fishing day; home consumption to kg per crew^{-}trip and bait to kg per trip.

Unreported catch of juvenile tuna consisted exclusively of yellowfin (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*). The reported approximate weight of juvenile tunas varies depending on the gear type. Handline fishers report that they usually catch between 1 and 10 kg, purse-seine fishers between 1 and 2 kg, and pole-and-line fishers between 0.5 and 5 kg. Longline fishers claimed to catch juveniles only rarely and that the smallest tuna caught was around 10 kg. The biological definition of juvenile tunas, however, is based on length, so that any length below length at first maturity is considered juvenile. This occurs around 103 cm (~18 kg) for yellowfin tuna (Wild, 1994), and around 100–125 cm (16–32 kg) for bigeye tuna (Froese and Pauly, 2016), indicating that fishers may have a different view on what constitutes juvenile tunas. Standardised unreported catch of juvenile tuna were estimated at 0.6–6.2 kg per crew-day, 4.1–7.2 kg per crew-day, and 17.4–29.2 kg per crew-day for handline, pole-and-line and purse-seine respectively (Table 3). Juvenile tunas are used to compensate for labour in the fishing port, to sell at local markets, or for other uses during and after the fishing trip, including use for bait, home consumption and on-board consumption. However, on-board consumption, home consumption and bait also includes other species such as eastern little tuna (*Euthynnus* sp.), mahi–mahi (*Coryphaena hippurus*), malalugis (*Decapterus* sp.) and small pelagic species.

Table 2
Descriptive statistics of the samples based on an interview survey conducted between October and November 2013 in the OFP Bitung, Indonesia.

	Pole-and-line	Longline	Purse-seine	Handline
Range of GT	49–91	26–69	20–34	2–30
Sample	9	3	6	22
Scale	medium	medium	medium	small(n = 18) medium (n = 4)
Average crew (people per vessel)	44 ± 13.5	15 ± 1.2	28 ± 1.3	7 ± 2.1
Fishing days per trip (days per trip)	5 ± 1.8	137 ± 35.2	5 ± 1.9	11 ± 2.8

On-board consumption in the handline fishery was between 1.1 and 3.0 kg per crew-day. This is based on an estimate of 180–500 g of fish meat per meal, assuming that 40–50% of the weight of the fish is head and bones, and that fishers eat three times a day. Assuming this number of meals per day, on-board consumption levels were between 100–140 g and 50–150 g of fish per crew in each meal for the longline and pole-and-line fisheries respectively. We did not estimate the magnitude of on-board consumption for purse-seines due to limited responses during the interview survey. In the survey, home consumption for pole-and-line, longline and purse-seine appeared to be mostly similar between gears, while handline fisheries had the highest number of catch per crew-trip for home consumption (Table 3). The amount of bait used in the handline fishery was in the range of 0.7–2.4 kg per crew-day. These results indicate that the range of answers obtained from the fishers interviewed were not highly variable. Therefore, we believe that the results are sufficiently reliable to be extrapolated to fishing port level by limiting the range of vessel sizes from the logbook data to the range in sizes from our survey.

3.2.2. Secondary data

The logbook data contained information on 8650 trips, which includes 1057 pole-and-line, 2985 purse-seine, 166 longline and 4442 handline trips. Selection of the range of GT of small- and medium-scale fishers resulted in the deletion of 1802 trips, including 12 handline, 26 longline, 1620 purse-seine and 144 pole-and-line trips. Limiting the analysis to fisheries operating within the Indonesian EEZ resulted in the deletion of an additional 49 longline trips. Purse-seine, handline and pole-and-line vessels with fishing grounds beyond the Indonesian EEZ were already removed when we excluded vessel types outside the scope of the study. We used 4127 trips of handline fishers to estimate a corrected number of crew-days for the 303 handline entries with trips that lasted longer than 30 days. The regression of the inverse square-root of crew-days against LOA (model 1) is statistically significant ($F_{1,4125} = 797.2$, $p < 0.001$, $r^2 = 0.16$, slope = -0.00495, intercept = 0.178). These actions led to a 25% reduction of the now consolidated database, resulting in 6496 trips.

A comparison between the number of vessels in the survey in Table 2 and the number of vessels in the consolidated database in Table 4 suggests that our sample covers 3.4% of handline vessels, 29% of the pole-and-line vessels, 13% of the longline vessels, and 12% of the purse-seine vessels known from the port authority data. The number of crewmembers per vessel and the distribution of the number of fishing days for pole-and-line, purse-seine and handline vessels in the survey both fall within the distribution of those in the consolidated database. The exception is the average number of fishing days per trip for the longline fishery, where the survey values (mean = 137, sd = 35.2) differed from the consolidated database (mean = 27, sd = 18.9). The

Table 3
Average standardized normal (minimum-maximum) values of sources of unreported catch by gear type calculated from the interview survey carried out in OFP Bitung between October and November 2013. (NI) Not investigated; (ND) not determined.

	Unreported catch of juvenile tuna (kg per crew-day)	On-board consumption (kg per crew-day)	Home consumption (kg per crew-trip)	Bait (kg per crew-day)
Pole and Line				
Normal(Min–Max)	5.2(4.1–7.2)	0.5(0.3–0.9)	1.4(0.5–2.3)	NI
Longline				
Normal (Min–Max)	NI	0.8(0.7–0.8)	1(1–2)	NI
Purse-seine				
Normal (Min–Max)	20.3(17.4–29.2)	ND	1.7(1.4–2)	NI
Handline				
Normal (Min–Max)	2.6(0.6–6.2)	1.7(1.1–3.0)	4.6(1.9–7.2)	1.5(0.7–2.4)

reason for this difference may be that most longliners land their catch in private company harbours instead of the main public harbour, which made them difficult to access for interviews. Therefore, with respect to longliners, our sample may be biased toward fishers that had longer trip durations. Total production of OFP Bitung in 2012 and 2013 was 103,045 t. Our catch estimate for the small- and medium-scale fisheries covers about 24.4% of total catch in OFP Bitung for period 2012 and 2013 (Table 4), with high coverage of the handline (81%) and pole-and-line (56%) and relatively low coverage of the longline (16%) and purse-seine (11%) that are dominated by large-scale operations.

3.3. The magnitude of sources of unreported catch in the survey

The estimates of unreported catch per fishing trip (kg per trip) do not vary strongly between the assumed probability distributions (Table 5). Comparison between gear types shows that purse-seine has the largest total unreported catch per trip, followed by longline, pole-and-line and handline. Unreported catch of juvenile tuna is the greatest source of uncertainty in total catch estimates for all fisheries. For the purse-seine fishery we estimate that around 3100–3400 kg per trip is categorized as unreported. On-board consumption per trip is the highest in longline fisheries and was the largest source of uncertainty in catch estimates for this fishery type. The high values are caused by the long duration of trips, which average 27 days (Table 4). Catch for home consumption was the highest for the pole-and-line fishery, because this fishery employs a large number of crewmembers. Lastly, handline fisheries used about 100 kg bait per trip.

3.4. The magnitude of sources of uncertainty in fishing port level

The estimated total magnitude of unreported catch by gear type and by source of uncertainty in OFP Bitung for 2012 and 2013 is shown in Table 6. A comparison between total unreported catch per category from all gear types and total reported catch in the consolidated database is found in Table 7.

There is no clear relation between the assumed type of distribution and the coefficient of variation of the estimates of the sources of uncertainty extrapolated to the port level. Therefore, our results appear to be fairly robust to the assumed probability distribution.

3.5. Database problems

During the process of estimating crew-days of handline fisheries with trips lasting longer than 30 days, we identified a range of errors in the documentation of the logbooks of 2012 and 2013, resulting in uncertainties in the basis for catch and effort estimation. We provide the main problems in the database, which include typos, inappropriate data-types and missing data, in Supplementary Appendix 3 in the online version at DOI: http://dx.doi.org/10.1016/j.fishres.2017.04.009. Unlike catch data, effort data were also available in the permit issuance database, which made verification of effort data between logbook and permit issuance possible. Therefore, effort data at the fishing port level are potentially well-covered.

4. Discussion

The official catch statistics for tuna fisheries in eastern Indonesia and Indonesia as a whole, including its small- and medium-scale fisheries, are known to underestimate actual catch (Gillet, 2011).[1] In this article we identified and quantified the sources of uncertainty in the catch data of the small- and medium-scale tuna fishers in OFP Bitung, Indonesia. While doing so, we also identified problems in the

Table 4
Descriptive statistics of the consolidated logbook database based on data from the port authority of OFP Bitung representing the small and medium-scale fisheries. Total catch is uncorrected by the length of the trip and is aggregated over the period from 2012 to 2013.

	Pole-and-line	Longline	Purse-seine	Handline
Range of GT	48–92	25–70	19–35	1–31
Scale	Medium	medium	medium	small (n = 3621trips) medium (n = 809 trips)
Average crew (people per vessel)	42 ± 13.6	12 ± 3.8	25 ± 4.6	7 ± 3.3
Fishing days per trip (days per trip)	7 ± 8.7	27 ± 18.9	6 ± 12.4	14 ± 5.0
Total catch (mean(-sd, +sd))	9879.4 (3635.2, 26846.1)	2049.9 (618.1, 6798.7)	3413.7 (1123.2, 10375.3)	457.7 (173.0, 1211.1)
Proportion of consolidated catch (%)*	53.7	1.4	30.5	14.4
Proportion of consolidated catch per gear to total catch per gear in OFP Bitung (%)**	56.4	16.0	11.0	81.2
Number of observations (trips)	913	91	1365	4430
Number of vessels	31	22	49	647

* Total catch of consolidated database = 25160 t.
** Total catch per gear in OFP Bitung in 2012 and 2013 are 23926 t for pole-and-line, 2210.86 t for longline, 70000.07 t for purse-seine, and 4471.96 t for handline (DGCF-MMAF, 2015).

Table 5
Estimated bootstrap mean and standard deviation of the mean of the magnitude of sources of unreported catch by gear type based on interview surveys conducted between October and November 2013 in OFP Bitung. Units are in kg per trip. (N) Number; (NI) not investigated; (ND) not determined.

	Unreported catch of juvenile tuna	On-board consumption	Home consumption	Bait
Pole-and-Line	N vessel = 4	N vessel = 6	N vessel = 7	
	N trip = 286	N trip = 406	N trip = 434	
•Uniform	629 ± 310.4	102 ± 37.6	61 ± 16.6	NI
•Split-uniform	796 ± 294.3	120 ± 43.4	70 ± 20.4	NI
•Triangular	782 ± 168.8	113 ± 33.8	63 ± 12.5	NI
Longline		N vessel = 3	N vessel = 3	
		N trip = 6	N trip = 6	
•Uniform	NI	1524 ± 265.5	19 ± 3.5	NI
•Split-uniform	NI	1520 ± 334.1	20 ± 4.9	NI
•Triangular	NI	1568 ± 275.5	20 ± 0.3	NI
Purse-seine	N vessel=3	N vessel = 1	N vessel=5	
	N trip = 193	N trip = 66	N trip=318	
•Uniform	3182 ± 1231.7	ND	45 ± 22.7	NI
•Split-uniform	3180 ± 1647.8	ND	47 ± 20.2	NI
•Triangular	3351 ± 1848.4	ND	46 ± 19.5	NI
Handline	N vessel = 20	N vessel = 15	N vessel = 13	N vessel = 15
	N trip = 490	N trip = 345	N trip = 288	N trip = 350
•Uniform	220 ± 45.2	153 ± 41.9	31 ± 5.1	100 ± 27.8
•Split-uniform	234 ± 57.3	141 ± 22.8	30 ± 3.3	108 ± 36.3
•Triangular	211 ± 51.3	153 ± 47.8	29 ± 4.8	98 ± 37.0

first-stage processing phase in the OFP Bitung fisheries data. It appears from the interviews that experts and operators are well aware of the shortcomings of the data collection systems and the sources of uncertainty of catch and effort estimates. Our work highlights in detail what these shortcomings mean on an operational level. We identify the sources that contribute to the high uncertainties in catch and effort data on two levels: 1) uncertainty at the operational level of reporting by fishers to the fishing port authority, which includes perceptions on what constitutes a catch to be reported, who does the actual reporting, distrust of fishers in reporting actual catches to government officials, and fishing activities that are considered to be illegal; and 2) uncertainty at the operational level of data management in the data collection institution, which includes a lack of capacity and capabilities of available personnel associated with a high turnover of data enumerators, difficulties and mistakes in data handling and digitising, lack of error detection facilities during digitising, and databases constructed in formats that are inaccessible to direct analysis. In the following sections we first discuss our estimates in the light of other estimates of unreported catches and then focus on these two levels as well as their implications for the catch and effort estimates of the small- and medium-scale tuna fisheries.

Our results suggest that the actual catch of the fishing trips in the consolidated database for vessels below 100 GT is about 33%–38% higher than the reported catch due to non- or misreporting of juvenile tunas catch, on-board and home consumption, and use as bait. In interpreting the total uncertainty of unreported catch, one should be aware that unreported catch of juvenile tuna may also be used for on-board consumption, home consumption and bait, implying that our estimate could be an overestimate. Nevertheless, our estimate is lower than the 57% suggested for the industrial and artisanal marine fisheries of eastern Indonesia in 1950–2010 in an earlier study by Pauly and Budimartono.[1] That estimation includes sources of uncertainty that are beyond the scope of our study, such as large-scale vessels, illegal fishing and marine recreational fishing. Our result is also lower than the estimate by Varkey et al. (2010), who estimated the unreported tuna in Raja Ampat at about 75% of reported tuna. This estimation included large-scale tuna companies in Sorong, which are outside the scope of our study. Because the estimates in these two studies are not categorized by type of fishery and source of uncertainty, we could not further examine possible causes for our considerably lower estimates. Neither study provides information on pole-and-line and handline fisheries, which are dominant in the tuna fishery in our study area. The study by Pauly and Budimartono[1] assumed consumption rates to be around 400 g per crew-day. Compared to that number, if we assume that about 50–60% of the weight of a fresh fish is eaten, our results are similar for the longline fishery, higher for the handline fishery (1,000 g per crew-day), and lower for the pole-and-line fishery (250 g per crew-day). However, the range of consumption in our results are within the range found by Labrosse et al. (2006) that suggests meals of up to 400 g. Pole-and-line and longline vessels are larger and therefore may have a more extensive and more varied food supply on-board, while the smaller handline vessels have less space for food supplies and may be more dependent on fish catches. Lastly, the extrapolation process used in previous studies Varkey et al. (2010) and Pauly and Budimartono[1] used time series in provincial data, while our analysis uses recent trip data from the fishing port of a specific fishery which has recently received attention for improving data collection procedures (Sunoko and Huang, 2014).

Our results demonstrate that the problems with catch underreporting appear to be particularly serious for catches of juvenile tuna. We estimate that the total catch from the trips recorded in the consolidated database for fisheries < 100 GT is likely to be about 26–28% higher than the reported catch due to unreported juvenile tunas, not considering illegal catches. Fishing juveniles impacts economic efficiency, as juveniles are part of future income for the fishers (Najmudeen and Sathiadhas, 2008). On-board consumption and home consumption of catch amounted to about 5–6% of recorded catch. Fish brought for home consumption is an important source of animal protein for households directly dependent on these fisheries, and it could be part of the subsistence strategy of fishers with limited access to other jobs. However, the proportion of consumption varies greatly between gears and between small- and medium-scale fisheries. Our estimate shows that small-scale fisheries, such as handlines, have a wide range of uncertainty. This is due to our own survey estimates, but may also be caused by higher uncertainties in logbook reporting, as indicated by the relatively high proportion of unlikely values of trip durations that we found. Because the logbook reporting of trip catches of these fisheries are also more variable than those of the larger scale fisheries, uncertainties are high on all three levels of our analysis. Around 14% of the reported total catches of the Bitung fishery is from handline, indicating that more attention should be paid to catch and effort reporting of these small-scale fisheries (Bush et al., 2017; Duggan and Kochen, 2016).

Uncertainties at the operational level of reporting by fishers to the

Table 6
Estimated 90% central range interval of magnitude of sources of uncertainty (in ton), coefficient of variation (CV) of the estimated unreported catch (in%) and proportion of estimated magnitude of sources of uncertainty with total catch per gear (in %) of vessels < 100 GT. Data taken from the consolidated logbook database of OFP Bitung over the period 2012–2013. (U) Uniform distribution; (S) Split-uniform distribution; (T) Triangular distribution.

	Unreported catch of juvenile tuna		On-board consumption		Home consumption		Bait	
	Estimated magnitude (ton)	Proportion to total catch per gear (%)	Estimated magnitude (ton)	Proportion to total catch per gear (%)	Estimated magnitude (ton)	Proportion to total catch per gear (%)	Estimated magnitude (ton)	Proportion to total catch per gear (%)
Pole and Line								
●U	1345–1348 (CV = 0.09%)		161–162 (CV = 0.16%)		52–53 (CV = 0.24%)		NI	
●S	1303–1306 (CV = 0.09%)	9–10	146–147 (CV = 0.17%)	1–2	52–53 (CV = 0.27%)	1	NI	NI
●T	1317–1321 (CV = 0.09%)		151–152 (CV = 0.15%)		52–53 (CV = 0.20%)		NI	
Longline								
●U	NI		23–24 (CV = 0.05%)		1–2 (CV = 0.99%)		NI	
●S	NI	NI	23–24 (CV = 0.05%)	6–7	1–2 (CV = 1.02%)	1	NI	NI
●T	NI		23–24 (CV = 0.04%)		1–2 (CV = 0.27%)		NI	
Purse-seine								
●U	4318–4340 (CV = 0.15%)		ND		58–59 (CV = 0.55%)		NI	
●S	4043–4063 (CV = 0.16%)	52–57	ND	ND	58–59 (CV = 0.54%)	1	NI	NI
●T	4144–4154 (CV = 0.15%)		ND		58–59 (CV = 0.53%)			NI
Handline								
●U	1566–1570 (CV = 0.17%)		1026–1029 (CV = 0.17%)		144–145 (CV = 0.31%)		753–757 (CV = 0.19%)	
●S	1370–1373 (CV = 0.17%)	37–44	910–912 (CV = 0.16%)	25–29	144–145 (CV = 0.31%)	3–4	735–740 (CV = 0.20%)	20–21
●T	1433–1436 (CV = 0.15%)		948–951 (CV = 0.15%)		144–145 (CV = 0.23%)		741–746 (CV = 0.19%)	

Table 7
Proportion of the magnitude of the sources of uncertainty over all gear types with vessels < 100 GT compared to their total reported catch based on the consolidated logbook database of OFP Bitung over the period 2012–2013.

	Unreported catch of juvenile tuna	On-board consumption	Home consumption	Bait
Uniform	28–29	4–5	1	2–3
Split-uniform	26–27	4–5	1	2–3
Triangular	27–28	4–5	1	2–3

fishing port authority persist due to limited incentives to report all catch, and to deficiencies in capabilities of actors providing data (Herrera and Kapur, 2007). Suggested incentives that could actively encourage data collection from the fishers include direct payment, additional quota and more days at sea (Mangi et al., 2013). In Indonesia incentives to report have been created through the implementation of catch certificate regulations for legal, reported and regulated catches exported to the EU and the US. Although this catch certificate declares only the amount of exported catch, regulations require the use of a logbook in the certificate issuing process. However, vessels below 5 GT need only to declare the amount of exported catch to receive the catch certificate, which means that the exported catch, despite itself being legal, reported, as well as regulated, can still be associated with unreported fishing. Additionally, we found that the current system of data collection through logbooks is still associated with unreported catch, and therefore does not fulfil the requirement of the Ministerial Regulation No. 48/2014. Despite our findings regarding problems with the capabilities of port staff, enumerators and operators, these are not the only actors whose capabilities in reporting need to be enhanced. Fishers also have a responsibility to report fishing activities and catch data in the logbook, and should become accustomed to reporting their actual catch in the logbook, including catch used for purposes other than trade and export. If logbooks are actually brought during the fishing trip, information on catch and fishing ground, in principle, can be recorded immediately and more accurately. Still, the larger problem exists that recording the catch weight is an obstacle for at-sea reporting. Training for and supervision of the documentation of data in the logbook should be provided by competent educators to improve data accuracy. Depth of understanding of terminology used in the logbooks should be the same for all actors providing and processing data.

Solutions to problems in catch and effort reporting and in first stage data processing may also be found in data verification procedures used to certify the accuracy of reported catch and effort (FAO, 1999). Verifying the reported logbooks against landing data could address the problem of uncertainty in the level of reporting from fishers to the fishing port authority. In the technical guidelines of fish landing verification by the MMAF of Indonesia, indicating species and total weight are part of the verification procedure. However, these procedures will not solve the problems of unreported catch utilised for the purposes of home consumption, on-board consumption and as bait as described in this paper. Moreover, in practice, current validation processes are intended only to check whether gear types land the expected species of catch, and ensure an appropriate correlation between reported catch and the length of fishing trip. The process is thus aimed at detecting illegal fishing and not to validate catch or effort data.

Errors in first stage data processing lead to uncertainties at the operational level of data management in the data collection institution. Error-checking systems meant to prevent or identify mistakes in data digitisation, which are commonly built-in features of databases in other systems, are not present in the current system used by port authorities to digitise logbook data and permit issuance data. Therefore, data input errors such as missing entries, and mistyping of catch size, species, or vessel name, cannot be addressed. Without direct access to the original data, data cleaning remains very difficult, and will remain partly based on assumptions about ranges of acceptable values for catch and effort variables. Research for this paper required approximately two months of cleaning and verifying the data to arrive at the effort estimates on which we based our calculations of uncertainty levels in catch reporting.

During the research and analysis of this study, it became clear how difficult it is to quantify the sources of uncertainties in the catch and effort reports of tuna fisheries in Indonesia. Our results are subject to the following shortcomings: First, our estimates depended on fishers' memories of their catches, consumption practices and other considered variables. Second, although numerous enough to achieve reasonable coverage of the fishery, the amount of respondents is rather small. We believe that the values reported by fishers adequately represent the volumes of catch used for on-board and home consumption as well as for bait use as these are all part of normal daily routine activities. Juvenile catches are not illegal so there is no reason for fishers to give false reports on these catches. By asking maximum, minimum and mode values we believe that we also sufficiently captured variability. Although there are cases where fishers report high variation, such high variation is not unlikely in tuna fisheries and fisheries on small pelagics (Dagorn et al., 2012; van Oostenbrugge et al., 2002). Larger sample sizes probably would not have changed the ranges of observations used to calculate the uncertainties. Some sources of unreported catch could not be determined, such as on-board consumption of the purse-seine crew. This may have been caused by a flaw in our questionnaire where we did not sufficiently take into account the mode of operation of purse seines that also work with carrier vessels with a separate crew. The actual unreported catch at fishing port level of around 18–20 t for small- and medium-scale fisheries is likely to be higher if it would also include the consumption in the purse-seine fishery. Lastly, we have not been able to obtain an estimate of the uncertainty in tuna catches on a species-by-species level in the survey, as fishers do not recall such distinctions when recalling the utilisation of catch over their various activities. This is especially problematic in the case of juvenile tunas where, during our interviews, fishers reported difficulties distinguishing between bigeye and yellowfin tuna.

Estimates of unreported catch can improve stock assessments and related information relevant for decision makers. Moreover, improved monitoring programmes can benefit the assessment of efficient harvest strategies through improved estimates of Maximum Sustainable Yield (MSY), biomass and carrying capacity of the fishery (Rudd and Branch, 2017). The MMAF acknowledges the existence of unreported catch, which it assumes to be around 11% higher than the reported landings (Sub-directorate of Data and Statistics of Capture Fisheries, DGCF-MMAF, personal communication). This proportion has no clear basis and is probably an oversimplification if applied to vessels and gears irrespective of scale. Our results show that the proportion of unreported catch varies between categories of unreported catch, gears and the scale of the fisheries. We suggest that the MMAF should consider the type and scale of the fisheries in their assumed unreported catch. As the MMAF has a plan to implement fishing quota as stated in the Regulation of Minister of Marine and Affairs No. 25/2015, full documentation of total catch and all fishing operations is required (Kindt-Larsen et al., 2011). Therefore, not only better procedures for catch reporting are required, but also estimates of non-reporting should have a clear methodological basis. Our paper presents a step in the direction of providing such a basis. We have presented a practical method to quantify unreported catch, as well as in scaling up survey estimates to the port level. In our survey, we found that fishers are willing to declare information related to catch utilisation during and after fishing activities. Fishers do show reluctance, however, to talk about illegal fishing practices. Proposals to discuss this, even in the absence of recording, affected their willingness to participate in the survey, suggesting that estimates of illegal fishing should be obtained by other means. By taking into account the size of the vessels, we made a conservative extrapolation to the port level as the database covers a wider population than the survey. Sources of uncertainty such as consumption, sales to local markets, and bait are likely to be found in other Indonesian fisheries. In using the method, we suggest to consider the scale of the fishery and to have a good understanding of how a fishery operates before devising a survey.

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