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Does unreported catch lead to overfishing?

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Abstract

Catches are commonly misreported in many fisheries worldwide, resulting in inaccurate data that hinder our ability to assess population status and manage fisheries sustainably. Under-reported catch is generally perceived to lead to overfishing, and hence, catch reconstructions are increasingly used to account for sectors that may be unreliably reported, including illegal harvest, recreational and subsistence fisheries, and discards. However, improved monitoring and/or catch reconstructions only aid in the first step of a fisheries management plan: collecting data to make inferences on stock status. Misreported catch impacts estimates of population parameters, which in turn influences management decisions, but the pattern and degree of these impacts are not necessarily intuitive. We conducted a simulation study to test the effect of different patterns of catch misreporting on estimated fishery status and recommended catches. If, for example, 50% of all fishery catches are consistently unreported, estimates of population size and sustainable yield will be 50% lower, but estimates of current exploitation rate and fishery status will be unbiased. As a result, constant under- or over-reporting of catches results in recommended catches that are sustainable. However, when there are trends in catch reporting over time, the estimates of important parameters are inaccurate, generally leading to underutilization when reporting rates improve, and overfishing when reporting rates degrade. Thus, while quantifying total catch is necessary for understanding the impact of fisheries on businesses, communities and ecosystems, detecting trends in reporting rates is more important for estimating fishery status and setting sustainable catches into the future.

Keywords Catch monitoring, catch reconstructions, catch reporting, fisheries management, fisheries stock assessment, illegal fishing

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Introduction

Scientific predictions to inform fisheries management are usually based on stock assessments that rely on catches, survey time series and biological information (Hilborn and Walters 1992). Fishery-independent surveys are the most informative for changes in population size over time (Francis 2011), but catches are also required to assess fishing pressure in relation to population size (Branch *et al.* 2011). The credibility of these fisheries stock assessment models hinges on the quality of data inputs and viability of model assumptions.

Catch data are the most common source of information provided by a fishery, but not always the easiest to obtain. Catches alone cannot be used to assess the status of a fishery, as they are a product of complex human behaviours and not a direct feedback from the ecosystem (Branch *et al.* 2011). In cases where catch data are unreliable or non-existent (as is the case for protected species), it is possible to assess the status of fish populations without catch data, for example using survey data only (Cook 1995), length composition of a sample of the catch (Cope and Punt 2009) or mark–recapture studies (Coggins *et al.* 2006). However, the amount harvested is useful for estimating the productivity of the population, its ability to withstand increased fishing pressure (Hilborn and Sibert 1988) and its importance in providing food, employment and other resources to society (McClanahan *et al.* 2013). When catch is misreported, estimates of total productivity are altered, hindering the ability of managers to balance conservation and food security goals. The most common type of misreported catch is under-reporting, due to the decentralized nature of many fishing sectors, and poor monitoring and enforcement in much of the world (Pitcher *et al.* 2002; Agnew *et al.* 2009; Pauly and Zeller 2016). Illegal harvest, discards, subsistence and other non-commercial fishing sectors are often unreported to management bodies (Pitcher *et al.* 2002), leading to overall under-reported catch for fish populations, which averages 53% globally (Pauly and Zeller 2016). Since 1950, the United Nations Food and Agriculture Organization (FAO) has compiled a fisheries landings database from their member countries (Food and Agriculture Organization 2014). Due to its ease of access and wide geographic scale, the FAO database has been instrumental in global fisheries research, for example in testing data-limited assessment methods (Thorson *et al.* 2012), exploring the status of unassessed fish populations (Costello *et al.* 2012) and examining the impacts of biodiversity loss on ecosystem services (Worm *et al.* 2006). However, the FAO database has been criticized as it often does not include commonly unreported fishery sectors (Pauly and Froese 2012). This is largely due to operational problems with many monitoring programmes, including a lack of quality control, supervision for data collection and insufficient resources (Weyl *et al.* 1999). Due to these logistical issues, the majority of funding for fisheries management in these regions is spent on catch monitoring, without adequate support for assessment of the monitoring data, management of the resource and enforcement of fisheries regulations (Darwall and Allison 2002).

One option to deal with catch misreporting has been the estimation of the total catch to account for the full impact of fishing. Fisheries science and management bodies in developed nations (e.g. the National Marine Fisheries Service in the United States and the International Council on the Exploration of the Seas in Europe) often devote considerable effort to account for catch misreporting issues for commercially or ecologically important fisheries. This accounting is performed on a stock-by-stock basis and cannot be done easily for a whole country. To fill this gap, there have been extensive efforts by the Sea Around Us Project to quantify the world's misreported catch via reconstruction methods to produce a corrected global database of fishery catches (Pauly and Zeller 2016). Catch reconstruction methods involve a search for local clues to missing data, interpolation between data points and an analysis of the sale and consumption of fish products (Zeller *et al.* 2007; Plagányi *et al.* 2011). The general motivation behind these catch reconstructions is that estimating the degree of misreported catch is better than assuming it is zero (Pauly 1998; Pitcher *et al.* 2002; Cressey 2015).

However, monitoring of fisheries ecological, social and economic performance is only one aspect of a management strategy. The data collected from these monitoring programmes or catch reconstructions are then fed into the stock assessment process, and in regions with effective fisheries management processes, becomes the basis for managing fisheries via decision rules. Although much work at the national and global level has aimed to reconstruct catches, this may not be possible for many of the world's decentralized, small-scale fisheries due to the sheer number of species harvested. Another issue is that reconstructions *en masse* may be biased up or down due to assumptions that simplify the complex nature of many fleets (Pauly *et al.* 2014). The resulting incorrect catch records could in turn bias estimates of population status and sustainable yield coming from fisheries stock assessments, although the direction and magnitude of these biases are not obvious. One assumption is that under-reported catch leads scientists and managers to think the fish population is doing better than it truly is, in turn leading to higher recommended harvest limits than would be sustainable (Metuzals *et al.* 2008). Individual assessments on stocks with under-reported catch have estimated both lower total population sizes and lower sustainable harvest limits than assessments using catch reconstructions, although these studies have not teased out the effect of the under-reported catch from other simultaneous changes in data and model structure (Patterson 1998; Groeneveld 2003; Hammond and Trenkel 2005; Zeller *et al.* 2008; Plagányi *et al.* 2011). Thus, there is a need to explore how changes in catch reporting rates over time impact fisheries stock assessment outputs and the resulting catch limits set by management.

The objective of this study was to quantify the direct impact of different scenarios of misreported catch on stock assessment results and proceeding management recommendations.

Methods

Rationale for different catch scenarios

We used simulations to compare the true and estimated values of total biomass, maximum sustainable yield (MSY), exploitation rate (u), carrying capacity (K), intrinsic growth rate (r) and population status (biomass B and exploitation rate u compared to that which would produce MSY; B_{MSY} and u_{MSY}, respectively). These simulations were conducted with the following catch misreporting scenarios: 100% reporting, constant under-reporting, constant over-reporting, increasing reporting rate over time and decreasing reporting rate over time. Constant under-reporting occurs when distinct sectors of the fishery are not reported over time and the size of that sector remains constant, or when catch is underestimated in catch reconstructions. Constant over-reporting occurs when promotions or bonuses are based on output, as in China (Watson and Pauly 2001), or due to assumptions made in catch reconstructions such as overestimates of discard rates (Chaboud *et al.* 2015). Increasing reporting rates in major commercial fisheries in developed countries have resulted from increased observer coverage, better estimates of discards and reduction in illegal harvest for some of the world's most commercially valuable species, such as tuna (Agnew *et al.* 2009) and lobster (Hilborn *et al.* 2005). Declining reporting rates could result from changes in management, such as the adoption of a quota system or increases in the number of artisanal and recreational fisheries over time as coastal population boom and technology improves, as seen in the Gulf of Mexico (Coleman *et al.* 2004). These patterns are demonstrated in the catch reconstructions; most of the FAO areas have fairly constant reporting rates over time, but some increase and some decrease (Pauly and Zeller 2016).

Modelling overview

To test the effect of misreported catches on estimates of stock status, we simulated the stock assessment process (Fig. 1), generating time series of true population biomass and true catch and running stock assessments on observed catch (based on different catch reporting scenarios) and survey indices sampled from the true biomass. We then estimated carrying capacity and maximum sustainable yield (MSY) using the Pella–Tomlinson surplus production model (Fig. 1). We compared the estimated population trajectory, population parameters and management reference points to their true values to better understand the impacts of magnitude and trend of catch reporting over time. We then projected the population forward based on management at estimated MSY reference points to demonstrate the impact of the different catch misreporting scenarios on meeting management targets.

Simulations

We used a single true catch time series for all catch misreporting scenarios, which increased to a peak within the first half of the time series, then decreased to very low levels compared to the peak and then increased and stabilized during the

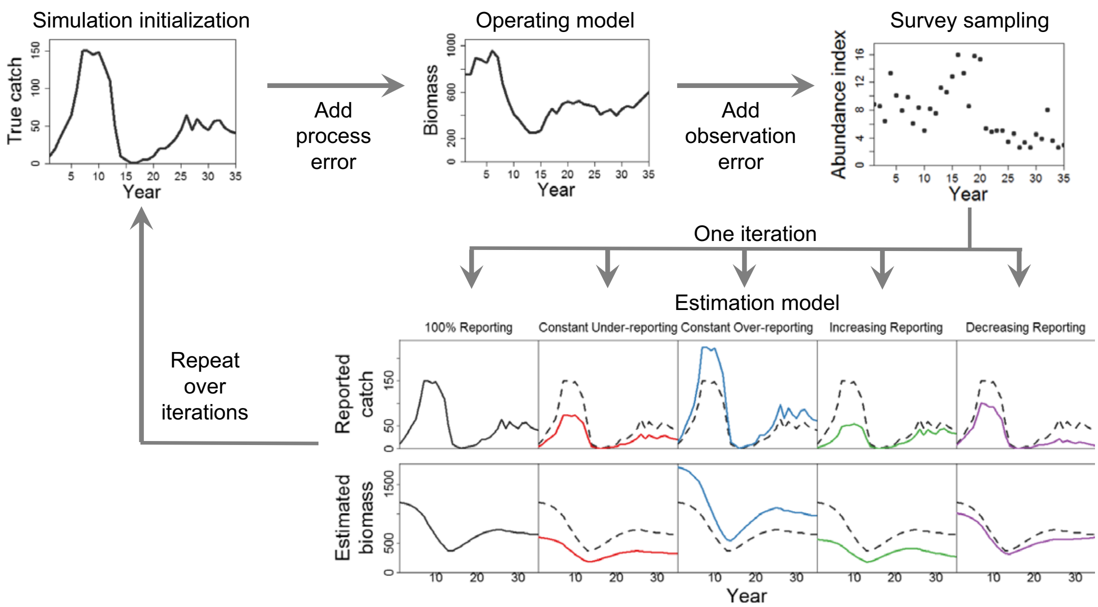

Figure 1 Flow diagram of the main steps in the simulation study. The simulation initialization consists of a deterministic, true catch time series, which is used in the operating model, along with process error, to generate a true population biomass. The survey sampling step then samples an abundance index, which is used as a data input along with reported catch time series in the estimation model. The estimation model estimates the parameters of a biomass dynamic model to derive population biomass and management reference points (dashed lines indicate the true trajectory, and solid lines indicate the reported catch under the respective catch misreporting scenario). [Color figure can be viewed at wileyonlinelibrary.com]

second half of the time series. This two-way scenario has been shown to provide information about population status and growth rates compared to other patterns of catch time series (Magnusson and Hilborn 2007). We also tested a true catch time series that continuously increased over time (a one-way trip) in a sensitivity analysis.

The simulated 'true' population follows a Pella–Tomlinson (discrete logistic) function over 35 years:

$$B_t^{\text{true}} = \left(B_{t-1}^{\text{true}} + \frac{z^{z/(z-1)}}{z-1}\text{MSY}^{\text{true}}\left(\frac{B_{t-1}^{\text{true}}}{K^{\text{true}}} - \left(\frac{B_{t-1}^{\text{true}}}{K^{\text{true}}}\right)^z\right) - C_{t-1}^{\text{true}}\right)\exp(\varepsilon_t - \sigma_B^2/2) \quad (1)$$

where B_t^{true} is the true population biomass in year t, z is the Pella–Tomlinson scaling parameter that determines what biomass level produces maximum sustainable yield (MSY), K is the carrying capacity, C_t^{true} is the true catch in year t, and ε_t is the multiplicative process error in time t. The process error is normally distributed around zero:

$$\varepsilon_t \sim N(0, \sigma_B) \quad (2)$$

where σ_B is the process error standard deviation (set to 0.3 in all scenarios to represent a reasonable level of stochasticity in the population dynamics). In this parameterization of the Pella–Tomlinson model, MSY is a function of the intrinsic rate of growth (r), K and z:

$$\text{MSY}^{\text{true}} = \frac{r^{\text{true}}K^{\text{true}}z}{(z+1)^{1/z+1}} \quad (3)$$

We chose the Pella–Tomlinson over a more complex age-structured model because we wanted to focus on the effect of catch misreporting in the targeted population, rather than including the interaction with age-specific selectivity, fecundity and other dynamics. Understanding how catch misreporting impacts biases in age-structured models would be a logical next step of this analysis (e.g. the discard or harvest of juvenile fish), but is beyond the scope of this study.

We assumed true values of K = 1,000, r = 0.2 and z = 1.188. The value of z is fixed such that the biomass at maximum sustainable yield, B_{MSY}, is equal to 40% of K, which is the average for exploited marine fisheries based on a global meta-analysis of stock assessments (Thorson *et al.* 2012). All population simulations started with a biomass at 75% of the carrying capacity in the first year, thus explicitly assuming that exploitation started before the first year in the model. Starting at carrying capacity did not influence the overall findings. Other simulation studies have varied the population dynamics parameters within the simulation model (Hammond and Trenkel 2005; Ono *et al.* 2014), but we kept these variations to a minimum to demonstrate the impacts of misreported catch on stock assessment output.

From the true population generated by the operating model, including a true value of survey catchability, q, of 0.01, we generated a survey index I_t subject to multiplicative lognormal observation error δ_t with standard deviation σ_I (set to 0.3):

$$\begin{gathered} I_t^{\text{obs}} = q^{\text{true}} B_t^{\text{true}} \exp(\delta_t - \sigma_I^2/2) \\ \delta_t \sim N(0, \sigma_I) \end{gathered} \tag{4}$$

We assumed that survey data were available for every year for which catch data were available. By assuming a good quality survey index, we were able to tease out biases in stock assessment output associated with misreported catch, without the confounding effect of biases and uncertainty resulting from a poor survey time series. The generated survey index and the 'reported' catch time series were then used as data inputs in the estimation model. The reported catch time series C_t^{reported} was a function of the true catch time series C_t^{true} and the annual reporting rate R_t:

$$C_t^{\text{reported}} = C_t^{\text{true}} R_t \tag{5}$$

We considered five scenarios of catch misreporting: 100% reported in all years, constant under-reporting of R_t = 50%, constant over-reporting of R_t = 150%, linearly increasing R_t from 40% to 90% and linearly decreasing R_t from 90% to 40%. The only changing variables across these scenarios were the magnitude and trend in catch reporting (Fig. 1).

To estimate the expected bias from the catch misreporting scenarios on stock assessment output of interest, we ran a deterministic version of the operating model, with process and observation error set negligibly low (0.001), and we also ran stochastic simulations, where the operating model was run with standard deviation values for both process and observation error of 0.3. To visualize the variation expected in estimated parameter values given process and observation error, we iterated each catch misreporting scenario 1,000 times, generating different true populations (from process error) and survey time series (from observation error) (Fig. 1).

Estimation

The estimation model takes the reported catch time series and survey index as data inputs and is also based on the Pella–Tomlinson surplus production model with z fixed at 1.188.

$$\begin{aligned} &B_t = KP_0 && \text{if } t = 1 \\ &B_t = B_{t-1} + \frac{z^{z/z+1}}{z-1} \mathrm{MSY}\left(\frac{B_{t-1}}{K} - \left(\frac{B_{t-1}}{K}\right)^z\right) - C_{t-1}^{\text{reported}} && \text{if } t < 1 \end{aligned} \tag{6}$$

The estimated parameters include MSY, K and P_O (the proportion of carrying capacity in the first year). The survey catchability constant q can be derived analytically from the ratio of the survey index data and predicted biomass:

$$\hat{q} = \exp\left(\frac{1}{n}\sum \ln\left(\frac{I_t^{\text{obs}}}{B_t}\right)\right) \tag{7}$$

where n is the number of years of data. The derived value of q is used to derive a predicted value of the survey index:

$$I_t = \hat{q} B_t \tag{8}$$

The observation error, $\hat{\sigma}$, can also be derived analytically from the deviations between the predicted and observed survey index and the number of years of survey index data:

$$\hat{\sigma} = \sqrt{\frac{\sum \left(\ln(I_t^{\text{obs}}) - \ln(I_t)\right)^2}{n-1}} \tag{9}$$

The K parameter was bounded between the maximum catch and five times the true K, that is 150–5000 with true K at 1000. MSY was given an upper bound of five times the true value of MSY, that is 1–280 with true MSY at 56. P_O was bounded between 0.01 and 1. The parameters K and MSY were estimated in log space. The estimation of these parameters involved minimizing a negative log likelihood function that assumes the indices are log-normally distributed, after removing constant terms:

$$\mathrm{NLL} = n \ln(\hat{\sigma}) + \sum_t \frac{\left(\ln(I_t^{\text{obs}}) - \ln(I_t)\right)^2}{2\hat{\sigma}^2} \tag{10}$$

The estimation model and minimization were performed in AD Model Builder (Fournier *et al.*

2012). The posfun function was used to ensure that biomass could not fall below zero to ensure differentiability. To guarantee that the model converged on the maximum likelihood estimate, for each simulation (iteration of population given catch time series, process error of true population, and catch misreporting scenario), we ran the model ten times with different randomly chosen starting values within 25% of the true parameter values, retaining the estimated parameter values that resulted in the lowest negative log likelihood.

We then compared the outputs of the estimation model, estimates of MSY, K, r, population biomass and B_{MSY} to the true values from the operating model. We were particularly interested in the estimates of these key population and management parameters in the terminal year of data, which is the key information about population status that is available to a manager blind to catch misreporting after collecting 35 years of data.

Projections

Typically, stock assessments would be used by managers to recommend sustainable harvest rates, as exemplified by fishing at u_{MSY} into the future. This would be enacted by multiplying the estimated u_{MSY} by the estimated current population biomass to set a catch limit. We simulate the effects of this kind of control rule for 5 years into the future, assuming the same conditions of catch misreporting as in the terminal year of data. We then compared the expected equilibrium population size and overfished status (B/B_{MSY}) based on this harvest strategy for each scenario of catch misreporting.

Results

We found that constant under-reported catch leads to a more conservative view of the productivity of the resource, with total population size, MSY and exploitation rate underestimated on average compared to the simulated truth (Fig. 2l). The degree to which these parameters were underestimated is proportional to the reporting rate: a 50% reporting rate results in estimated population size, MSY and exploitation rate that is 50% of the truth. Conversely, constant over-reported catch by 50% leads to estimates of the population size, MSY and exploitation rate that are 50% higher than the actual values (Fig. 2m). Thus, catch data are important in scaling the estimated population size and MSY: when reported catches are lower than the truth, the population is perceived to be less productive.

However, when reporting rates were constant over time, neither under-reporting nor over-reporting biased estimates of population status (Fig. 3l, m,q,r). For these two scenarios, biomass and exploitation rate relative to those that would produce MSY (i.e. B/B_{MSY} and u/u_{MSY}) were correctly estimated (Fig. 2l,m). The reason these are correctly estimated is that the identical, proportional biases in biomass estimates and in MSY cancel out when calculating the ratios B/B_{MSY} and u/u_{MSY}. In other words, given a reliable index of abundance, only a proportional index of catch (which need not be absolute) is needed to obtain reliable estimates of population status relative to reference points.

The biases in population parameter estimates were not as straightforward when catch reporting rates changed over time. When the reporting rate improved over time, estimates of population size were 20% of the truth, MSY was 60% of the truth, and carrying capacity was 75% of the truth (Fig. 2n). Population status relative to reference points was also poorly estimated, with B/B_{MSY} being far below and u/u_{MSY} being far above the true values (Fig. 2n). As our perception under this scenario is that the population is overfished, this results in precautionary management. Thus, under the scenario of increasing reporting rates over time, applying an estimated exploitation rate into the future that is thought to lead to biomass at B_{MSY} and catches at MSY will in reality result in catches below MSY, biomass above B_{MSY} (Fig. 3n) and exploitation rates well below u_{MSY} (Fig. 3s).

The opposite result occurs when reporting rate decreases over time. Here, exploitation rate is estimated to be 20% of the true value (Fig. 2o), and the population size is estimated to be 90% of the truth. Similar to when the reporting rate improves over time, these non-proportional biases prevent unbiased estimates of population status. Now, though, we are in the danger zone where we have an overly optimistic perception of the population, analysts would erroneously perceive the population to be lightly fished, and future catches would be set too high, resulting in overfishing. Thus, future projections that involve deteriorating reporting rates demonstrate that if exploitation rate is estimated to be far below u_{MSY}, managers

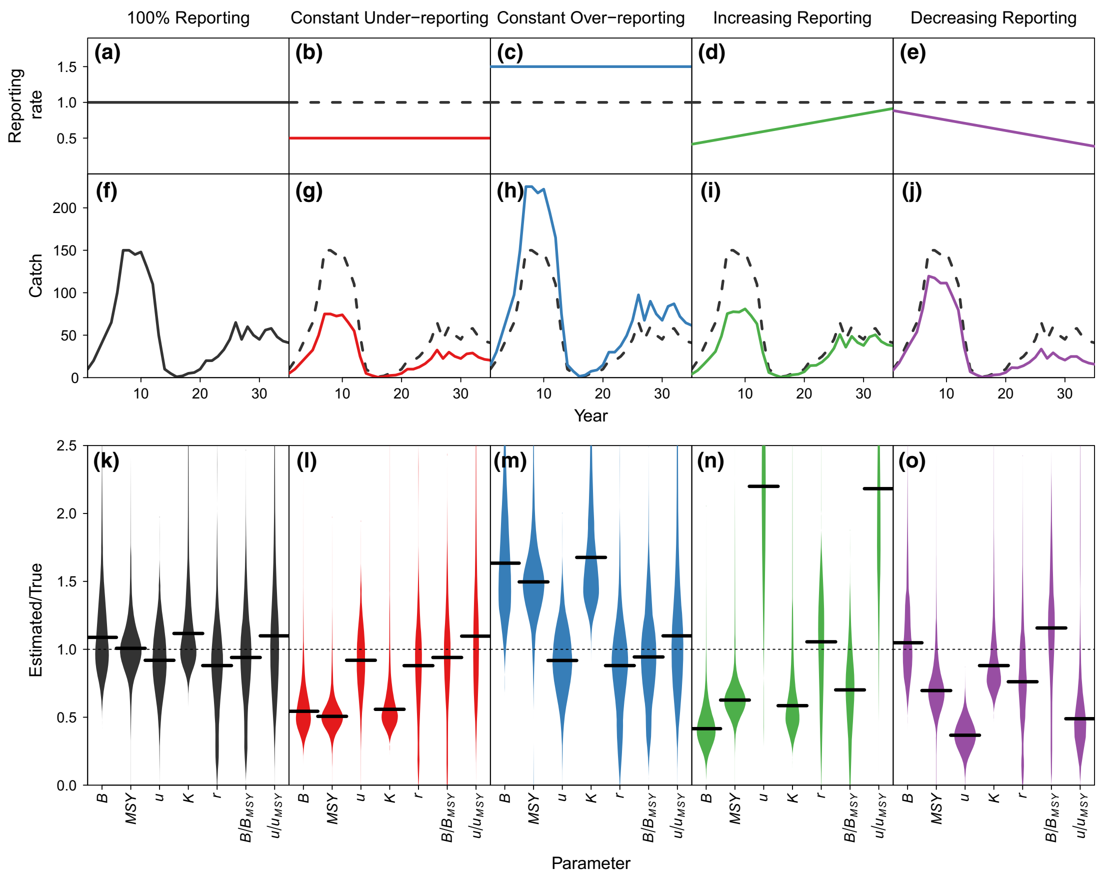

Figure 2 Effect of different patterns of catch reporting on estimates of population parameters. The reporting rate (a-e), time series of catches (f-j) and the distribution of estimated:true parameter values for 1000 simulation runs (k-o) are displayed in each row, respectively. The catch scenarios by column are (a) 100% reporting, (b) constant under-reporting, (c) constant over-reporting, (d) increasing trend in reporting, (e) decreasing trend in reporting. The ratio of estimated:true is given for the following parameters: biomass at the end of the time series (B), maximum sustainable yield (MSY), exploitation rate (u), carrying capacity (K), intrinsic rate of growth (r), biomass relative to that yielding MSY (B/B_{MSY}) and exploitation rate relative to that yielding MSY (u/u_{MSY}). Dashed grey traces in panels b-e and g-j represent the 100% reporting rate and catch, respectively. The thinner, dashed line in panels k-o represents where the estimated and true values of each parameter are equal, and the short black lines represent the median of the distribution for the 1000 simulation runs. Where the parameter estimates are unbiased, the short black lines lie at the dashed line. [Color figure can be viewed at wileyonlinelibrary.com]

aiming to fish at the u_{MSY} target will rapidly increase catches and cause swift population collapse (Fig. 3e,j,o,t). Thus, from a conservation perspective, it is far worse to have declining reporting rates over time than increasing reporting rates over time.

Sensitivity tests examining the influence of different values of K and r revealed that these variables did not influence the overall patterns found. The only exception in this sensitivity analysis was estimates of status relative to MSY reference points when r was low (e.g. r = 0.05) and there were trends in misreported catch over time. These differences were likely due to the lack of response in the population to the changing population due to slow growth rates, and the decreased contrast in the catch time series with trends in misreporting. Use of the one-way catch time series decreased the ability to estimate population parameters reliably even with no observation or process error, thus adding uncertainty in parameter estimates and direction of biases given catch misreporting. Therefore, the biases reported in this study may be less applicable to very slow-growing fish, or with less informative catch time series, but the overall message remains consistent:

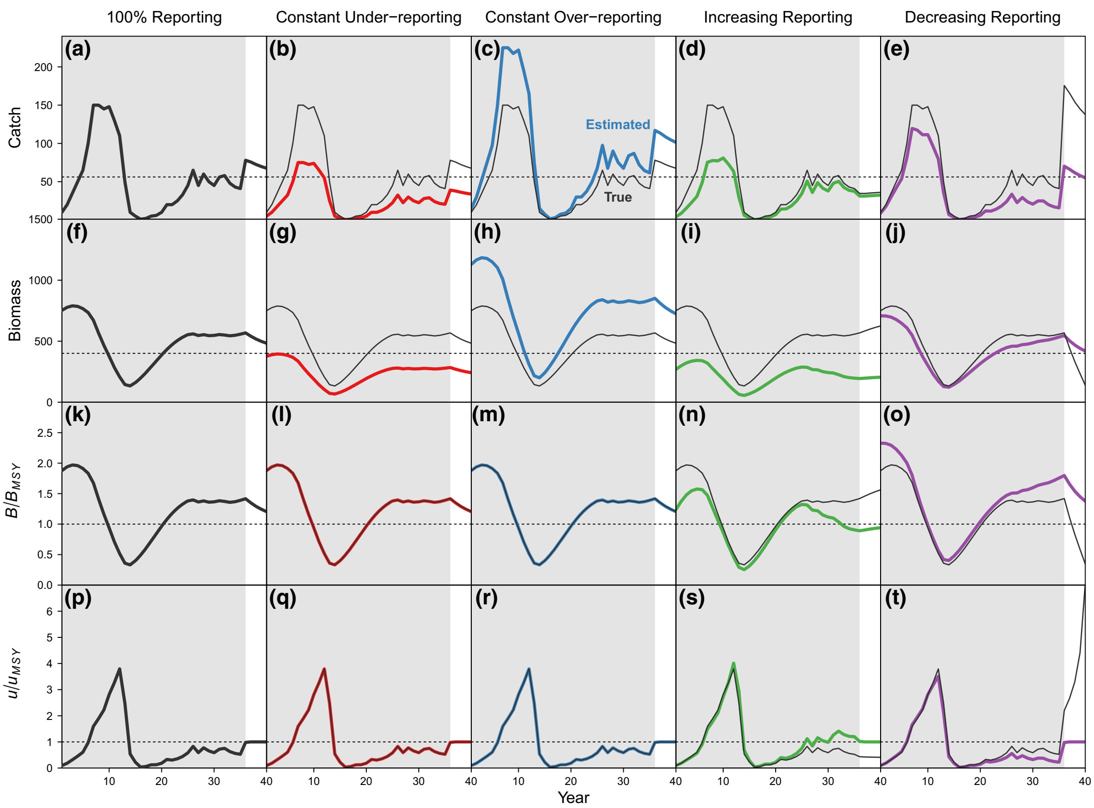

Figure 3 Time series of estimated (thick lines) and true (thin lines) status, and future projections. These are deterministic trajectories of (a-e) catch, (f-j) biomass, (k-o) B/B_{MSY} and (p-t) u/u_{MSY} under each scenario for catch reporting (thick lines). Shaded background areas designate the time period with catch and survey data available, and white areas indicate the 5-year projections where harvest rate is set at u_{MSY}. All three scenarios with constant reporting rates lead to sustainable management, but trends in catch misreporting lead to biomass that is higher than MSY levels for increasing reporting rates (i), and lower than MSY levels for declining reporting rates (j). The dashed line indicates true MSY (a-e), true B_{MSY} (f-j), target B/B_{MSY} (k-o) and target u/u_{MSY} (p-t). [Color figure can be viewed at wileyonlinelibrary.com]

exploitation rate may be overestimated with increasing reporting, underestimated with decreasing reporting, but unbiased with constant misreporting, and unintuitive biases in estimates of stock status relative to reference points may occur with trends in misreporting, but not with constant misreporting.

Discussion

Our results demonstrate how misreported catch at a constant rate can still lead to unbiased estimates of stock status and sustainable management. The biases in this case are simply in the estimates of the scale of population size, but do not affect the estimates of relative values such as exploitation rate and estimated biomass to B_{MSY} ratios. Trends in catch reporting can, however, lead to unintuitive biases in estimates of stock status. The biases in estimates of population parameters are not proportional to the reporting rates, nor are they identical. When trends in catch misreporting have occurred or are occurring, improved catch data can only help to estimate sustainable reference points and stock status.

Thus, our results demonstrate that monitoring programmes and catch reconstructions should be geared towards understanding the trend in catch reporting over time when data collection and research capacities are limited in management strategy development. These findings have far-reaching implications for assessments with misreported catch, fisheries for which assessments could be conducted based on new catch reconstruction data and the development of future monitoring and assessment programmes. The trend in reporting rates is likely cheaper to estimate than the accurate magnitude of catches. These trends in misreporting can then be accounted for in stock assessments, leading to more sustainable catch-based harvest control rules. While catch reporting rates are likely increasing for many fisheries with either improved accounting or decreasing of discard rates (Kelleher 2005; Davies *et al.* 2009), it is likely that reporting rates for other fisheries may be decreasing as demand for seafood increases and more people participate in commonly unreported artisanal fleets (Salas *et al.* 2007). However, many of the catch reconstructions from FAO areas appear to demonstrate fairly constant misreporting rates over time (Pauly and Zeller 2016). Thus, the catch misreporting scenarios of the world's fisheries are likely as varied as the world's fisheries themselves.

While understanding the total catch is critical in understanding overall ecosystem impacts and the economic value of fisheries, total catch alone is insufficient to conduct stock assessments and choose sustainable harvest control rules. When survey data are not available or precise, catch data are increasingly used alongside biological information in catch-based, data-limited assessment methods (Carruthers *et al.* 2014). With minimal information to account for age-structure, these methods often use biomass dynamic models similar to the one used in this study (Dick and MacCall 2011). With constant misreporting, we would expect these data-limited assessment methods to estimate population size and MSY scaled to the level of misreporting, without biased trends. However, without well-informed estimates of current population depletion, these methods would likely perform poorly in estimating population status when catch reporting rate changes over time. Approximately 78% of global reported fishery catch has undergone some form of stock assessment, with 34% of global reported catch accounted for within the RAM Legacy Stock Assessment Database (Ricard *et al.* 2012; Costello *et al.* 2016). However, the remaining 22% of global reported catch remains unassessed, and nestled in this category are the small-scale and non-commercial fishery sectors that are often unreported. These same fisheries provide crucial nutrition to densely populated coastal peoples with otherwise low protein diets (Food and Agriculture Organization 2014), adding even more weight to the critical need to estimate trends in catch and improve catch reporting.

Catch reconstructions show great potential for finding efficient outcomes in the trade-off between resource utilization and conservation when paired with the stock assessment and decision rule aspects of management strategy development. For example, when the Hawaiian bottomfish resource was assessed with a catch time series that included both reported commercial and reconstructed recreational catch, the estimated MSY increased compared to that which was estimated when only reported commercial catch was considered (Zeller *et al.* 2008). Accounting for the unreported sector provides more confidence to scientists and managers that the assessment has improved and the advantage of a potentially increased harvest limit for fishermen due to the higher estimated MSY. However, the benefit of this reconstruction is its resolution to catch at the population level, as opposed to the country level.

As has been previously experienced by FAO, catch monitoring and reconstructions are expensive to conduct on a stock-by-stock basis, and unrealistic to keep up to date at a time scale relevant for management (Darwall and Allison 2002). Many published reconstructions, such as that for small-scale fisheries in the U.S. flag-associated island nations, are at the country level (Zeller *et al.* 2007). Our results show that in terms of setting sustainable harvest limits, understanding this general trend at the population level may be more important than the overall catch trend in the country. This is increasingly important as catch reconstructions replace previously misreported catch time series in fisheries stock assessments. As catch reconstructions involve making assumptions based on limited data on unreported catches (Belhabib *et al.* 2014, 2015; Chaboud *et al.* 2015), reconstructed catch time series could conceivably be lower, higher or have different trends than true catches. Given these scenarios, our results provide substantive advice for making management decisions in the face of uncertainty.

Our study shows that improved catch reconstructions and catch monitoring programmes are valuable in terms of assessing the scale of harvest, as they result in better estimates of total food produced and income earned from fishing. Accurate catches are also necessary to estimate true MSY, biomass and carrying capacity of a particular fishery and hence the relative importance of that population as predator or prey within food webs.

However, catch reconstructions and monitoring would need to be conducted stock by stock, which is time-consuming and expensive. While the time and money spent to undergo catch reconstructions or improve monitoring programmes have their advantages, moving forward in the fisheries management process will likely require management strategies robust to limited data and capacity for most of the world's fisheries. Some of the key components to catch reconstructions, such as information from local experts, could help to identify trends in catch reporting over time. Catch time series could then be adjusted accordingly, or this expert information would be useful for various other assessment methods and harvest control rules. While expert information may not account for all harvest from the system, it could still be used to help set sustainable harvest rates into the future. Under-reported catch itself does not lead to overfishing unless reporting rates deteriorate over time, suggesting a key area of focus for catch reconstruction efforts, resource management strategies and data collection.

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