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Stock assessment report 2019 – Ocean Trawl Fishery

Silver Trevally (*Pseudocaranx georgianus*)

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Acronyms

AFMA	Australian Fisheries Management Authority
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CPUE	Catch per unit effort
CTS	Commonwealth Trawl Sector
DPI	Department of Primary Industries
EAC	East Australian Current
EGF	Estuary General Fishery
MLL	Minimum legal length
NSW	New South Wales
OTF	Ocean Trawl Fishery
OTFN	Ocean Trawl – Fish Northern zone
OTISP	Ocean Trawl – Inshore
OTLF	Ocean Trap and Line Fishery
OTOSP	Ocean Trawl – Offshore Prawn
RAG	Resource Assessment Group
RBC	Recommended biological catch
SAFS	Status of Australian Fish Stocks
SESSF	Southern and Eastern Scalefish and Shark Fishery
SFT	Southern Fish Trawl
TAC	Total allowable catch

Summary

This stock assessment report for Silver Trevally (*Pseudocaranx georgianus*, CAAB 37 337062) provides information to inform the current biological status of the NSW stock and aid the determination of a Total Allowable Catch (TAC) for the NSW Ocean Trawl - Fish Northern Zone (OTFN). It uses the criteria for determining stock status from the Status of Australian Fish Stocks (www.fish.gov.au/).

The aims of the current report are to: 1) define the biology and stock structure of the species within NSW; 2) summarise fishery statistics and additional data sources to inform the assessment; 3) assess and determine the biological status of the NSW stock; 4) outline information and data limitations and uncertainty in the assessment; and 5) indicate future research and assessment directions.

Assessment outcome and justification

The status of the NSW Silver Trevally stock is classified as **depleting**, with strong indication of localised depletion in Ocean Zone 5. The status is based on:

1) Declining but variable standardised catch rates in multiple areas and time periods, particularly during 1998-2009 and in Ocean Zone 5;
2) Decline in lengths in the OTF between 1987 and 1999 that has been maintained between 2005 and 2019;
3) Recent B/B_{msy} estimates from a catch-only Boosted Regression Tree (BRT) model are below 10%, with no improvement when discard estimates were included within catch history;
4) B/B_{msy} estimates from an Optimised Catch-Only Model (OCOM) model below 50% across a range of stock-specific natural mortality estimates. Recent F/F_{msy} estimates were below 1;
5) High but variable F/M values and low Spawning Potential Ratio (SPR) values (~0.2) over 12 sampling years.

Limitations and uncertainties regarding the assessment and stock status include: 1) the stock structure of Silver Trevally is uncertain in the assessment region, 2) the data used to understand the stock status of Silver Trevally in NSW are entirely fishery-dependent, 3) changes in catch reporting through time, particularly for fishing effort, 4) the assessment is constrained to a weight-of-evidence approach including multiple data-limited methods, 5) the potential effects on time-series of protected areas and the introduction of a minimum legal length (MLL), and 6) inconsistency with the Commonwealth stock status determination.

Future assessments would benefit from: 1) an improved understanding of stock structure over time-scales relevant to fishing effects, 2) incorporation of NSW and Commonwealth data, 3) fishery-independent data sources, 4) an understanding of the selectivity of major gear types in NSW, and 5) an estimate of recreational catch that includes non-residents of NSW.

Introduction

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The aims of the current report are to: 1) define the biology and stock structure of the species within NSW; 2) summarise fishery statistics and additional data sources to inform the assessment; 3) assess and determine the biological status of the NSW stock; 4) outline information and data limitations and uncertainty in the assessment; and 5) indicate future research and assessment directions.

Biology and stock structure

Silver Trevally in NSW comprises a single species recently revised as *Pseudocaranx georgianus* (previously considered *P. dentex*; Smith-Vaniz and Jelks 2006, Bearham et al 2019). The species is a medium-bodied bentho-pelagic carnivore inhabiting a broad range of habitats, from shallow estuaries through to the outer continental shelf. Silver Trevally are relatively long-lived and slow growing, attaining a maximum age in excess of 25 years (Rowling and Raines 2000). However, the species is moderately fecund and matures at a relatively early age (2–4 years). The current report updates a previous assessment report on Silver Trevally completed in 2018 (Fowler and Chick, 2018).

The stock structure of Silver Trevally is uncertain, with no investigations of potential genetic structure within NSW. Investigations of population connectivity and post-settlement movement are also limited. Tag-recapture studies in Western Australia and New Zealand indicate restricted post-settlement movement of Silver Trevally despite their fast swimming ability, potentially leading to ecological stock structuring over moderate (100s of km) spatial scales (James 1980; Fairclough et al. 2011). Recent evidence from a large-scale tag-recapture study in NSW suggests restricted movement over the current scale of management in NSW (Fowler et al. 2018a).

The stock structure of Silver Trevally was reviewed during the 2016 and 2018 Status of Australian Fish Stocks (SAFS) processes (Chick et al. 2016, Fowler et al 2018b). Due to the limited information available, and the complex of *Pseudocaranx* species exploited in some states, the SAFS stock status assessments were conducted at the jurisdictional level. Acknowledging these constraints, this assessment is also completed at the NSW jurisdictional level, while providing consideration of the stock status determined for the species in the adjacent Commonwealth Trawl Sector (CTS) of the Southern and Eastern Scalefish and Shark Fishery (SESSF). The CTS is the primary extra-jurisdictional source of mortality for Silver Trevally on Australia's southeast coast.

Fisheries statistics

Data treatment

The time periods of reporting in the following sections are generally structured around commercial catch reporting histories within NSW. Silver Trevally has a long history of commercial harvest in the State (recorded in logbooks back to 1945), yet the trends in fisheries statistics, including both catch and effort, are influenced by inconsistencies in reporting through time and management changes (see Limitations and uncertainty section and Appendix 1). Major reporting changes that affect interpretation of trends are: 1) the exclusion of catches from Commonwealth waters on NSW catch returns following 1997/98, 2) monthly reporting of total catch and effort (in days) for specific fishing methods following 1997/98, with previous data not specific to a particular method, and 3) monthly reporting of daily catch and effort (in hours) from 2009/10. Vertical lines are used to indicate the latter boundary in figures showing standardised catch rates.

To construct longer time-series, i.e. from 1997/98 to present, daily records from 2009/10 have been re-aggregated into monthly catches (kg), with effort in days per month estimated from the number of distinct fishing dates reported in each month. This was only done when the method was used within a month and there was a reported landing of Silver Trevally in that month, irrespective of whether the species was reported on each day, to be consistent with earlier reporting (see Appendix 1). Data presentation and analyses are generally restricted to the period following 1997/98, because data prior to this period can only be linked to a specific method (and therefore fishery) in months where a single method was used by a fisher. However, fishery-specific catch data from 1955 to 1997 has previously been reconstructed using a combination of individual fisher behaviour (1985-1997) and proportional allocation between methods according to knowledge of fishery operations during particular time periods (prior to 1985, Pease and Grinberg 1995).

Information presented in figures and tables below is summarised by fiscal year (July to June). Reference to 'year' refers to the last year of a fiscal year unless otherwise stated. For example, 2010 refers to the fiscal year 2009/10.

Catch

Silver Trevally are predominantly caught in three commercial fisheries within NSW; the Ocean Trawl Fishery (OTF), the Ocean Trap and Line Fishery (OTLF) and the Estuary General Fishery (EGF). Substantial catches are also occasionally taken in the Ocean Hauling Fishery (OH). During the period 1998–2019, the OTF accounted for 63% of catch by weight (inter-annual range: 30–86%), with catches in the OTLF and EGF accounting for 24% (range: 9–50%) and 10% (range: 4–21%), respectively (Table 1, Figure 1).

Within the same period, catches of Silver Trevally in the OTF in NSW have declined, from more than 200 t in 2007 to less than 40 t within the last three years (Table 1, Figure 1). The substantial decline following 2007 coincided with the introduction of a minimum legal length (MLL, 30 cm total length, TL) for the species and the establishment of the Batemans Marine Park and other areas closed to commercial fishing.

Historical commercial catch between 1955 and 2019 showed that trawl catches were initially low (1955-1970) and then increased rapidly to >1100 t during the early 1980's, after which

catches declined to present day (12.5 t in 2019), the lowest level for more than 50 years (Figure 2). Records prior to 1997 include an unknown proportion of catch taken in the Commonwealth.

The fish trawl sector of the OTF has two endorsements that are spatially separated; Ocean Trawl – Fish Northern Zone (OTFN) and Southern Fish Trawl (SFT). During the period 2009/10–2018/19, the OTFN accounted for 33% of Silver Trevally catch by weight (range: 16–61%) while the SFT accounted for 66% of catch (range: 39–84%; Table 2, Figure 3). Total catch in the OTFN was 240.7 t during 2009/10–2018/19, with an average annual catch of 24.2 t (range 7.5-35.9 t) (Table 2, Figure 3). Catch by the prawn trawling endorsements (OTISP and OTOSP) was negligible during the same period (Table 2, Figure 3).

For the purpose of recording spatial distribution of fishing activity, the NSW coast is divided into ocean zones that each span one degree of latitude (Figure A1-1). Catches of Silver Trevally in the OTF varied considerably among ocean zones during 1998-2019, with the greatest number of catches throughout the entire period being taken from Ocean Zones 5, 6, and 7 (Figure 4). Substantial catches were taken from Ocean Zones 8 and 9 prior to 2007/08. Since 2009/10, a consistent level of catch has been reported from Ocean Zone 6, with the exception of the most recent year.

Effort

Fishing effort (days) in the OTF was relatively high and stable during 1998-2007, then declined rapidly until 2010 (Figure 5). Effort has subsequently remained low, with a gradual decline to 370 days in 2019. The trend in number of days fished between 2010 and 2019, derived from summing the number of fishing events recorded within a month (see Data Limitations), was similar to the trend in hours fished (Figure 6). Hours fished is the required reporting metric on catch returns following 2009.

Recreational catch

Three surveys of recreational fishing have been conducted at the statewide level in NSW. Retained landings by recreational fishers resident in NSW have decreased, with landings estimated from off-site telephone/diary surveys declining from approximately 140,000 fish during 2000/01 to around 49,000 individuals during 2013/14 (Henry and Lyle 2003, West et al. 2015) and around 13,000 fish in 2017/18 (NSW DPI, unpublished). This corresponds to a decrease in retained catch weight from approximately 100 t during 2000/01 to around 27 t during 2013/14 and 7 t in 2017/18 (Figure 1), based on body weight for the species (NSW DPI, unpublished). Over half of the retained landings in NSW during 2000/01 were taken by anglers from other states, with an estimated catch of over 250,000 fish when non-NSW anglers were included (Henry and Lyle 2003). An estimate of catch by non-NSW anglers was not available for 2013/14 (West et al. 2015) or 2017/18. The 2017/18 NSW survey sampled individual one- and three-year licence holders present in the NSW Recreational Fishing Fee (RFF) Licence database, whereas the previous NSW survey sampled households from the White Pages (West et al. 2015). The extent to which differences in the sampling frames between the 2013/14 and 2017/18 surveys have influenced catch estimates is unknown.

Mean catch rate (fish.day^{-1}) of recreational fishers also declined from 0.05 (±0.01 SE) to 0.03 (±0.01 SE) between 2000/01 and 2013/14 (West et al. 2015).

Illegal, Unregulated and Unreported (IUU) fishing

The level of Illegal, Unregulated and Unreported (IUU) fishing has not been quantified.

Assessment

Approach

A weight-of-evidence approach has been taken to classify the biological status of the NSW Silver Trevally stock, using the following lines of evidence:

1) Time-series of standardised catch rates;
2) Time-series of length frequency data;
3) catch-only Boosted Regression Tree (BRT) model (Zhou et al. 2017a);
4) Optimised Catch-Only Model (OCOM, Zhou et al. 2017b);
5) Length-Based Spawning Potential Ratio (LB-SPR, Hordyk et al. 2015).

Standardised catch rates

Methods

To account for the change in effort reporting between 2009 and 2010, standardised catch rates (hereafter 'catch rates') for Silver Trevally are provided separately for the periods 1998-2009 and 2010-2019. Catch rates for the entire period (1998-2019) are also provided for comparison, while recognising that these standardisations combine data across the reporting change and are not directly comparable to the catch rates for the periods before and after the reporting change. In addition to catch rates for the OTF, those for the OTLF are included in this section as a complimentary line of evidence for trends over time.

Catch rates ($kg.day^{-1}$) were standardised using general linear models in the R package 'cede' (v. 0.0.4, Haddon 2018). Variables used included month of capture, ocean zone, depth (from 2010 onward), fishing business (as a proxy for 'vessel' in the trawl fishery) and authorised fisher. The combination of standardising variables depended on the dataset used and the spatial area examined. Fishing business was used as a proxy for vessel identification, because as of 2019 vessel identifiers are no longer a reporting requirement of NSW commercial fishers, preventing a direct link between catch and individual vessel. Data were natural log-transformed prior to analysis. Model residuals were visually inspected for adherence to normality and trends in catch rates were compared to those generated using generalised linear models using the gamma distribution with a log link. Minimal differences were observed between the two standardisations methods; therefore, the general linear models were retained.

Standardisation models identified a significant effect of ocean zone; therefore, trends in catch rate were examined separately within the three ocean zones with a relatively high number of catches - Ocean Zones 5, 6 and 7.

Substantial discarding has been observed within the OTF following the introduction of the MLL in 2007 (NSW DPI, unpublished). To examine the potential effect of discarding on trends

in catch rates, discard estimates were added to catch data following 2007 and catch rates were re-standardised. A range of discard adjustments were examined (13%, 40% and 63%), spanning the range of discard rates in the OTF recorded by onboard observers within the Commercial Fisheries Observer Program during 2015 and 2016 (13-63%, NSW DPI, unpublished).

Catch rate trends

Trends in catch rates of Silver Trevally in the OTF varied between time periods and areas examined. When data for all ocean zones were combined, catch rates declined during both the 1998-2009 and 2010-2019 periods (Figures 7a and b). Catch rates across the entire period also showed the initial decline (1998-2009), but then increased after 2008 and remained relatively stable between 2011-2018, followed by a substantial decline in 2019 (Figure 7c).

The declining catch rates observed during 1998-2009 were also observed within Ocean Zone 5 (Figure 8a), but not during 2010-2019 when catch rates were associated with substantial error and a decline was not apparent until after 2016 (Figure 8b). Catch rates across the entire period in Ocean Zone 5 were similar to the trends when all zones were combined; however, the rebound in catch rates during the second period (2010-2019) was less substantial (Figure 8c).

Catch rates in Ocean Zones 6 and 7 were more uniform across the entire period (1998-2019), with relatively broad confidence intervals and limited evidence of the declines apparent in both the combined analysis and Ocean Zone 5 (Figures 9 and 10). A short-term decline was apparent in Ocean Zone 6 between 2008 and 2009 (Figures 9a and c), while an increase in catch rates associated with considerable error was observed in Ocean Zone 7 between 2008 and 2012 (Figures 10b and c).

Across all zones, trends in catch rates observed during the separate analysis of 2010-2019 were generally not consistent with those for the same years in the analysis of the entire period (1998-2019). The recovering catch rates observed after 2008 in the analyses of the entire period were not often apparent in the analyses restricted to 2010-2019. Catch rates during 2019, in both the separate analyses of the time period 2010-2019 and the entire period, were among the lowest observed within all areas.

Declining catch rates in the OTF during 1998-2009 were also observed in the OTLF. Substantial declines occurred between 1998 and 2005 when all zones were combined (Figures 11a and c), and in Ocean Zone 5 (Figures 12a and c). The trend during the same period in Ocean Zone 6 was less pronounced and associated with substantial error (Figures 13a and c). Catch rates during 2010-2019 were generally stable, except for Ocean Zone 5 where a decline between 2014 and 2017 was apparent (Figure 12b).

The addition of discard estimates to catch after 2007 had little effect on the declining catch rates observed during 1998-2009 (Figure 14a-d). However, the recovery of catch rates observed after 2008 in the analysis of the entire period increased substantially across the range of discard additions (Figure 15a-d). Despite this increase, catch rates during 2019 remained low, even when catches were increased by 63% (Figure 15d).

Length frequencies

Length data for Silver Trevally from the OTF have been investigated in numerous studies between 1987 and 2015/16, including observer-based investigations and fish market sampling of commercial catches. Truncation of larger size-classes was observed in trawl catches made between 1987 and 1999 (Liggins 1996; Rowling and Raines 2000). Size truncation has been maintained since that period, with individuals larger than 30 cm fork length composing a small proportion of trawl catches between 2005 and 2019, according to monitoring of landed catches during fish market sampling (Figure 16).

Catch-only modelling

Methods

Two catch-only models were applied to the catch data available from the OTF, a boosted regression tree (BRT) model (Zhou et al. 2017a) and an Optimised Catch-Only Model (OCOM, Zhou et al. 2017b). Catch data spanned the entire period available (1955-2019). The BRT model uses a decision tree learning approach based on linear regression to infer stock depletion status using only a time-series of catch. OCOM uses a time series of catch and two priors, one for intrinsic population growth rate derived from life history parameters and another for stock depletion based on catch trends, to estimate a range of biological and management quantities including unfished biomass, depletion and exploitation rates. OCOM modelling in the current study was conducted over a range of natural mortality values (0.05, 0.10, and 0.15) that were previously estimated for Silver Trevally in NSW (Rowling and Raines 2000). Both methods assume constant recruitment.

Results

B/B_{msy} estimates from the BRT modelling decreased throughout the assessed period (1955-2019), with a substantial decline in 2016 to their lowest levels (<0.1 in 2019, Figure 17). Estimates were variable and highly uncertain throughout the period, but the upper confidence bound remained below 1 during 2016-2019. The addition of discard estimates to catch data following 2007 had minimal effect on the trend in B/B_{msy} estimates, with 2019 values remaining below 0.1 (Figure 17).

B/B_{msy} estimates from OCOM remained stable and above 1 between 1955 and the mid-1970s, then decreased substantially during the 1980s and 1990s, remaining low (<0.5) and stable from 2000 to 2019 (Figures 18-20). F/F_{msy} estimates remained below 1 until the early 1980s, after which they increased substantially and remained above 1 until the late 2010s. Trends were similar across the range of natural mortality values examined (0.05-0.15, Figures 18-20).

Length frequency and life history-based modelling

Methods

To provide a complimentary assessment that does not rely on commercial catch data, a preliminary Length Based – Spawning Potential Ratio (LB-SPR) was applied (Hordyk et al. 2015). The LB-SPR approach draws on size structure and SPR in harvested populations, being a function of relative fishing pressure (F/M) and life history ratios. A maximum likelihood

approach is used to estimate 'selectivity', F/M and SPR with a smooth function used to reduce noise in multi-year estimates (Hordyk et al. 2015).

The main model used commercial length data sampled from fish markets during 12 years between 2004 and 2018. Due to potential selection for smaller individuals in trawl samples and the need to obtain representative lengths for the population, length data were taken from trawl, trap and line samples and then weighted according to the relative landings from those methods. Life-history input parameters were taken from Rowling and Raines (2000).

The introduction of the MLL (30 cm TL) in 2007 resulted in discarding below that length, altering length frequency distributions after that year. To investigate the potential effect of this on LB-SPR results, additional models were run with and without data below 30 cm TL for the two years of data available prior to MLL introduction (2004, 2005). Assumptions of the LB-SPR approach include a normal distribution of length-at-age, logistic selectivity and adequate description of growth by the von Bertalanffy equation, and that both sexes have the same growth curve and sex ratio of catch at parity.

Results

The main model (all years) shows an early increase in selectivity, likely due to the introduction of the MLL in 2007 (Figure 21). F/M was highly variable throughout the study period (range: 1.6 to 7.4), with values in the last three years ranging between 3.0 and 5.4. SPR was consistently low and stable across years, ranging between 0.14 and 0.26. The greater uncertainty in recent years may be due to the large range of F/M during the equivalent period.

Models with and without length data below the MLL for years 2004 and 2005 differed little in F/M and SPR values (Figures 22a and b).

Assessment outcome

The status of the NSW Silver Trevally stock is classified as **depleting**, with localised depletion evident in Ocean Zone 5. The status is based on:

1) Declining but variable standardised catch rates in multiple areas and time periods, particularly during 1998-2009 and in Ocean Zone 5. Trends vary among zones;
2) Decline in lengths in the OTF between 1987 and 1999 that has been maintained between 2005 and 2019;
3) Recent B/B_{msy} estimates from a catch-only BRT model below 10%, with no improvement when discard estimates were included within catch history;
4) B/B_{msy} estimates from an OCOM model below 50% across a range of stock-specific natural mortality estimates. Recent F/F_{msy} estimates were below 1;
5) High but variable F/M values and low SPR values (~0.2) over 12 sampling years.

While interpretation of catch rate trends is complicated by changes in effort reporting through time and the introduction of the MLL in 2007, declines were observed in the overall analyses for both the OTF and OTFL. The main decline in the OTF occurred numerous years prior to the introduction of the MLL, meaning catch reductions resulting from discards are

not likely to have driven the declining trend in that fishery. Adding discard estimates to catch data did not remove the declining trend observed in the OTF during 1998-2009. The apparent recovery of catch rates during 2010-2019 observed in some analyses of the OTF occurred immediately after the introduction of the new effort reporting process, which adds some uncertainty and may result in underestimates of effort in days given the estimation approach (see Data Limitations). Catch rates in Ocean Zone 5 showed strong and consistent declines in both the OTF and OTLF during 1998-2009 that have not subsequently recovered, with catch rates during 2019 among the lowest reported in the zone.

Although the absolute values of B/B_{msy} differed between the two catch-only assessment methods (BRT and OCOM), both methods identified a decline throughout the assessment period and recent estimates were below 1, suggesting that the current biomass of Silver Trevally is below that required for sustainable harvest. While limitations of the data and these catch-only methods precludes definitive and confident inferences of the current level of biomass relative to generally accepted biomass limits (e.g. B_{20}), the outputs suggest biomass has been depleted. BRT has been demonstrated to perform best in heavily fished fisheries (Zhou et al. 2017a), which is a reasonable assumption for Silver Trevally in NSW. The OCOM approach suggested that current fishing mortality (F) is relatively low despite the reduced biomass and a history of F above F_{msy}.

The LB-SPR modelling provides information on stock status that is independent of commercial catch weight, although length data were derived from commercial catches from the OTF and OTLF. The high F/M and low SPR values suggest depletion and support findings from CPUE trends and catch-only modelling. The sensitivity analysis run on data prior to the MLL introduction indicated results from the main model are likely robust to the absence of data in the smaller size-classes.

Limitations and uncertainty

Data used to understand the stock status of Silver Trevally in NSW are wholly derived from commercial and recreational fisheries, and are therefore potentially biased by the activities of fishers. Such biases may result in data and trends that do not reflect the biology of the stock.

Changes in reporting practices, the establishment of protected areas and the introduction of an MLL may all have affected trends in fishery metrics of Silver Trevally through time. The change in the method of effort reporting during 2009/10 limits the certainty with which conclusions can be made regarding shifts in effort and catch rates around that time. The establishment of the Batemans Bay Marine Park may also have affected trends in fishery metrics, potentially reducing catches and catch rates following 2007, however these are likely to be restricted to that area of the coast. Lastly, the introduction of the MLL likely reduced landings across the state after 2007.

Standardised catch rates are highly uncertain in some zones. This uncertainty limits confidence in conclusions regarding trends in catch rates in those zones and obscures comparisons between zones, although the issue is partially accounted for in the 'all zones' analyses through the inclusion of a 'zone' standardising variable. The status of fisheries within such zones is therefore uncertain and may not reflect the status of the stock in Ocean Zone 5. Recent movement modelling based on angler-tag recapture data suggests restricted movement of Silver Trevally in NSW at the scale of zones (Fowler et al. 2018); therefore,

analyses at the level of zone are warranted, and caution should be used when managing fishing pressure to avoid localised depletions in future.

The aggregating behaviour of Silver Trevally may have influenced catch rate analyses in the current study. Such behaviour may partially explain the elevated error in catch rate standardisations, but likely does not explain the consistent patterns of decline observed in some areas and during some time periods, because aggregation is more likely to drive hyperstability of catch rates. As such, recent declines may infer more substantial concern for the stocks than might otherwise apply.

Results from data-limited assessment methods must be interpreted with caution, given the limited information used to model population parameters and stock status. Catch-only models inherently assume that changes in catch reflect changes in stock biomass, yet catch is also influenced by a number of other factors including fishery operations. Recent (post-2007) declines in fishing effort have likely reduced catch, irrespective of the actual biomass present, and therefore may have biased later estimates from the catch-only models. However, both models showed a longer-term declining trend in $B/B_{msy,}$ with the OCOM model identifying substantial decline prior to the effort decline. Multiple data-limited assessment methods, including one not based on catch weight (LB-SPR), were used to provide greater confidence in stock status and trajectory than any one method alone.

Factors other than fishing, including environmental factors, may affect changes in the abundance and biological functioning of fish stocks through time. Temporal and spatial variations in oceanographic conditions may influence available trophic resources, growth, population connectivity and ultimately recruitment. The East Australian Current (EAC) has a strong and variable influence on oceanographic conditions and productivity along the NSW coast, with potentially substantial yet unknown consequences for the Silver Trevally stock (Suthers et al. 2011). Knowledge of the interaction of these factors with fishing activity will be important for isolating the role of fishing on changes in the abundance of Silver Trevally.

Commonwealth assessment and status

Silver Trevally are fished in the Commonwealth Trawl Sector (CTS) of the Southern and Eastern Scalefish and Shark Fishery (SESSF). Commonwealth trawl catch has historically been higher than NSW, with catches in excess of 300 t until 2014 (Patterson et al. 2019). Similar to catch trends in NSW, recent catches in the CTS have declined considerably, with 8.3 t landed in 2018/19.

The Commonwealth status for Silver Trevally is 'not overfished' and 'not subject to overfishing', based on a tier 4 assessment of CPUE trends relative to reference points derived from a historical reference period (Haddon and Sporcic. 2017). The Commonwealth's classification criteria for stock status differ to those used in SAFS.

The reliability of the Commonwealth assessment of Silver Trevally and its applicability to the NSW OTF is uncertain because:

- The most recent data used in the CPUE analysis and RBC calculation was obtained during 2016.
- The selected reference period (1992–2001) for defining target catch, target CPUE, limit CPUE and the RBC coincides with a period of instability (decline) in catch and CPUE.

- The assessment utilises catch rate data from the Commonwealth trawl fleet operating in Commonwealth Ocean Zones 10 and 20, which differ to NSW ocean zones.
- State commercial catch (landings and discards) and recreational catch from both Commonwealth and state jurisdictions were not included in CPUE analyses.
- Tag-recapture studies in New South Wales, New Zealand and Western Australia indicate restricted post-settlement movement of *P. georgianus*, potentially leading to ecological stock structuring over moderate (hundreds of kilometres) spatial scales (James 1980, Fairclough et al. 2011, Fowler et al. 2018a)

TAC considerations

The OTFN is responsible for a small fraction of Silver Trevally catch taken across the east coast of Australia. The endorsement is responsible for only 33% of the trawl catch of Silver Trevally in NSW, with the SFT taking the remainder of NSW trawl catch. The entire Ocean Trawl Fishery (OTF) is responsible for 63% of the total NSW commercial catch of Silver Trevally, leaving a substantial proportion of catch unrestricted by a TAC. In addition, recent catches in the NSW OTF have been < 40 t (excluding discards), which is less than half of recent catches in the Commonwealth. Trawl catches in both jurisdictions during 2018/19 were also the lowest recorded in the last two decades, at just 8.3t and 12.5 t.

Future assessment and research

Assessment

Silver Trevally would benefit from joint assessment with the Commonwealth jurisdiction. Not only are assessments for each jurisdiction currently completed separately, data from the adjacent jurisdiction are not used within those assessments. A joint assessment using combined fishery data will likely have greater power to resolve temporal trends, which is increasingly important given the decreasing catch and effort in recent years, and will be more representative of the broader stock. Both jurisdictions would also benefit from common reference points and associated decision rules, to ensure unified response to changes in stock status or the persistence of undesirable stock status.

Research

The continued utility of commercial catch and effort time-series requires consideration for Silver Trevally. Fishery-dependent data are relatively cost-effective, yet are often relied upon out of historical legacy rather than considered selection. The changes in commercial catch and effort reporting through time have generated considerable uncertainty around catch rate trends and catch-only model results in the current assessment. The issue is compounded by recent declines in commercial catch within NSW, raising concerns regarding the long-term utility of commercially-derived data. The utility of fishery-independent alternatives (e.g. the daily egg production method) and complimentary datasets from less traditional sources (e.g. the developing time-series of recreational catch in NSW, baited remote underwater video for length frequencies) warrants investigation. A review of existing and potential data sources for future Silver Trevally assessment is necessary to inform research and development in this

area. The review should consider the utility of NSW fishery data for neighbouring jurisdictional assessments and how those assessments could be adopted or modified to improve the performance and value of the NSW OTF.

Knowledge of the size selectivity of the main commercial fishing methods (trawl, trap and line) for Silver Trevally in NSW would assist interpretation of apparent long-term changes in length distributions and may support more nuanced assessment methods. It is likely that fish trawls and traps select for smaller individuals than line fishing, yet this has not been quantified. The relatively small proportion of line-caught individuals in NSW compared to the other methods may yield biased length distributions. Importantly, the decreased probability of intercepting the less common line catches in market sampling programs may increase temporal variability in length distributions, potentially obscuring longer-term trends. The latter issue could potentially affect even the weighted length distributions used in the length-frequency analyses in the current study.

Silver Trevally is an important species for recreational anglers, yet the recreational catch in NSW is infrequently determined and poorly resolved. The most recent survey (2017/18) estimated that recreational harvest (retained catch) was 17% of the commercial sector, but the survey only included one- and three-year recreational licence holders residing in NSW (West et al. 2015). A substantial proportion of recreational catch in NSW is however taken by non-residents (Henry and Lyle 2003). More regular and comprehensive surveys of recreational fishing for Silver Trevally are required to obtain sound estimates of recreational catch, to better understand fishing mortality in the State. Ideally, data would be obtained sufficiently frequently and in a format suitable for inclusion in formal analyses to inform assessments of the stock and fishery.

Stock structure remains a source of uncertainty in determining the status of the NSW Silver Trevally stock, both in NSW and more broadly on the east coast of Australia. Although genetic homogeneity of the species is expected along the south-eastern coast, due to the pelagic larval stage and strong poleward-flowing EAC during the summer spawning period, there is potential for stock structuring over biological time-scales within this region, including in the NSW jurisdiction. Tag-recapture studies in NSW and other regions have found restricted adult movement over a scale of 100s of km (James 1980; Fairclough et al. 2011, Fowler et al. 2018a). Differing trends in catch rates among ocean zones within NSW also suggest sub-structuring of the NSW stock; however, this conclusion must be made cautiously given the minimal data available for some zones and the large uncertainty surrounding estimates of catch rate. If stock structure exists within NSW, there is a risk of localised depletion, particularly given that catch quotas will be applied to large areas of the coast that encompass multiple ocean zones. Research into the stock structure of Silver Trevally is therefore required to understand the level of risk associated with current and future fishing activities, and their association with total allowable commercial catch determinations.

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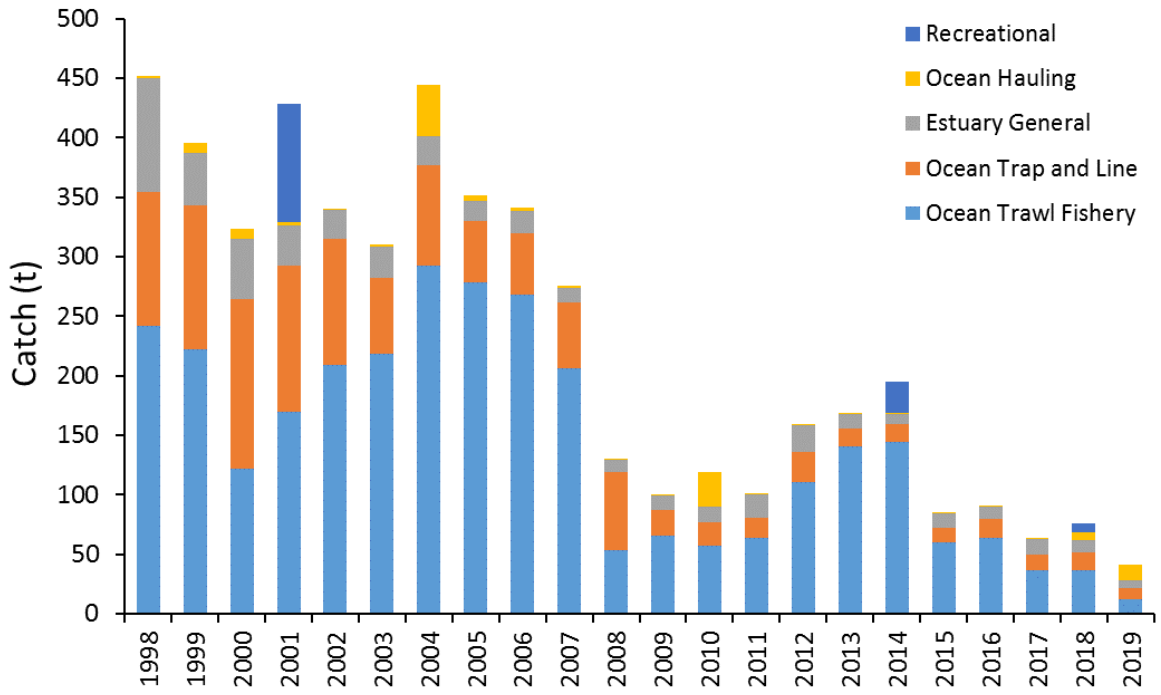

Figure 1 Annual catch (t) of Silver Trevally from NSW Ocean Trawl, Ocean Trap and Line, Estuary General, Ocean Hauling and Recreational fisheries from 1998 to 2019.

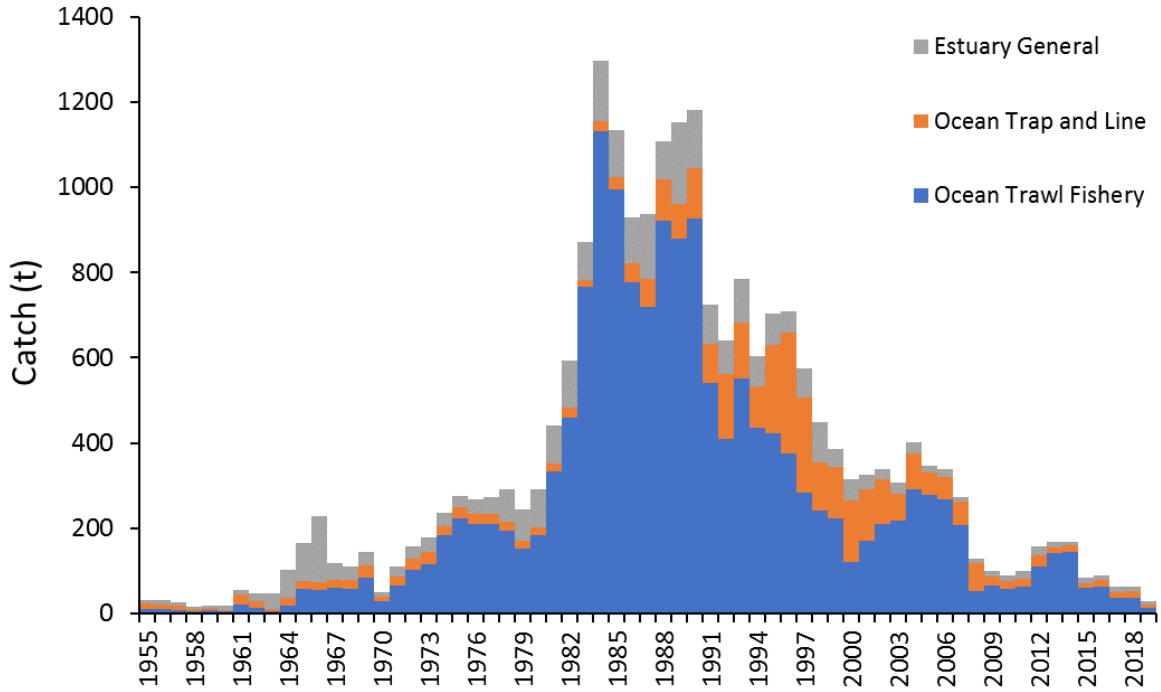

Figure 2 Historical annual catch (t) of Silver Trevally from NSW Ocean Trawl, Ocean Trap and Line, and Estuary General from 1955 to 2019. Catches from 1955 – 1984 were estimated by proportional split of 'ocean' catches reported in Pease and Grinberg (1995). Catches from 1985-1997 were allocated to specific fisheries using knowledge of the fishing behaviour of individual fishers. Data from 1985-1997 are based on calendar year, while other data are fiscal year.

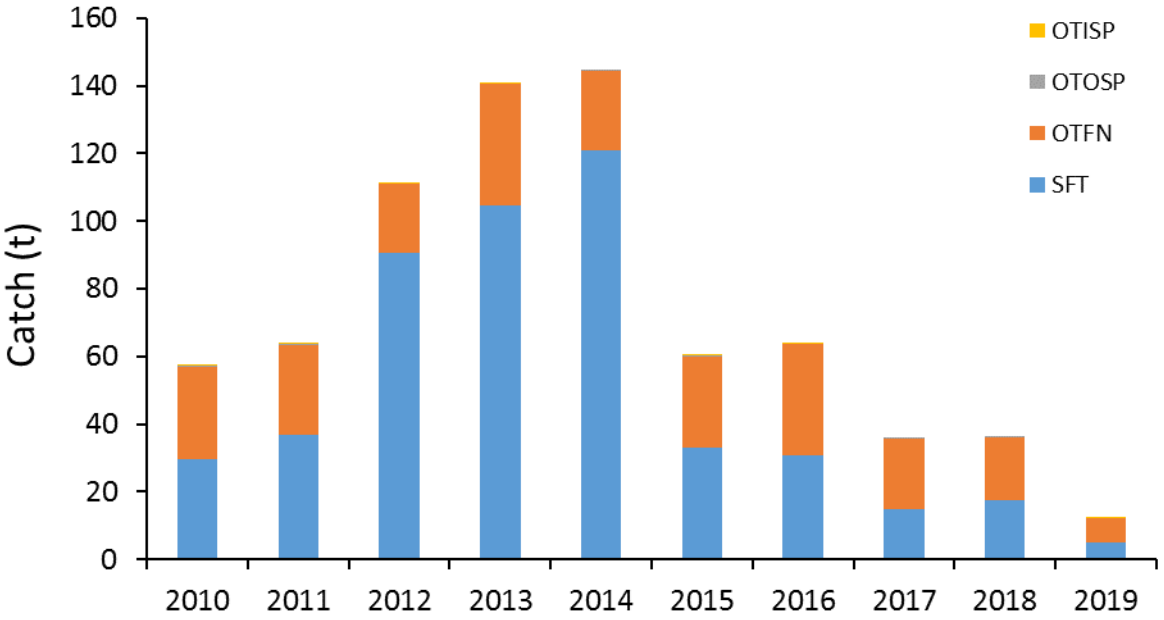

Figure 3 Annual catch (t) of Silver Trevally by trawl fishing endorsement in NSW from 2010 to 2019. Ocean Fish Trawl – North (OTFN), Ocean Prawn Trawl – Inshore (OTISP), Ocean Prawn Trawl – Offshore (OTOSP) and Southern Fish Trawl (SFT).

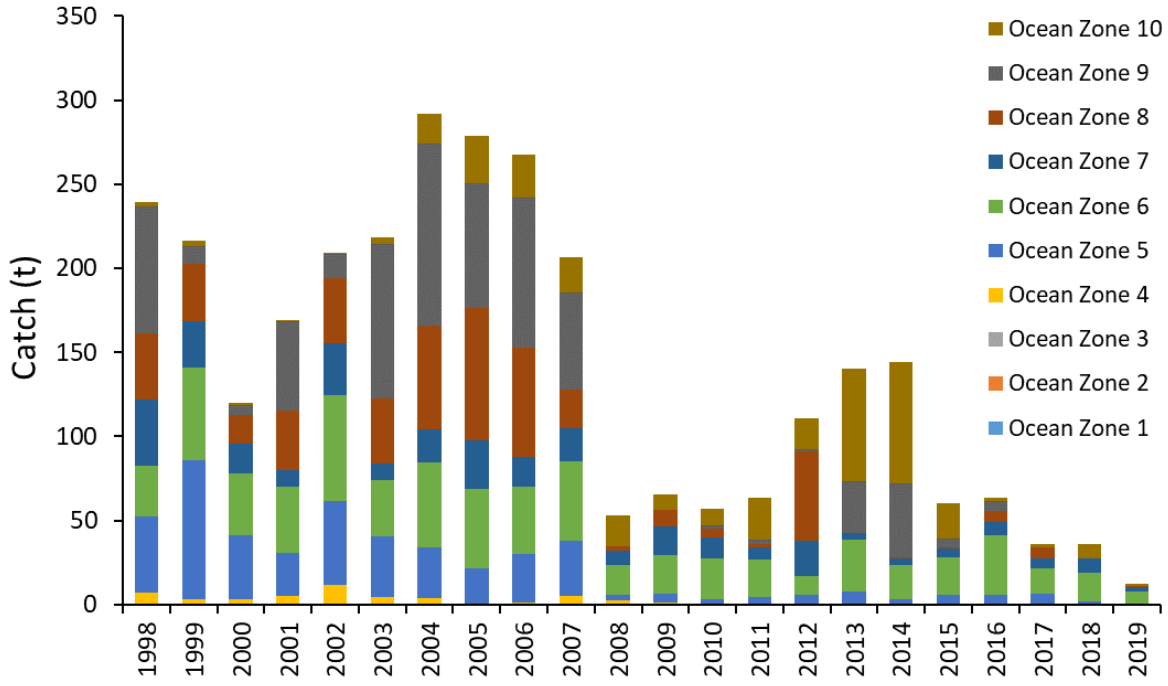

Figure 4 Annual catch (t) of Silver Trevally by Ocean Zone in NSW from 1998 to 2019.

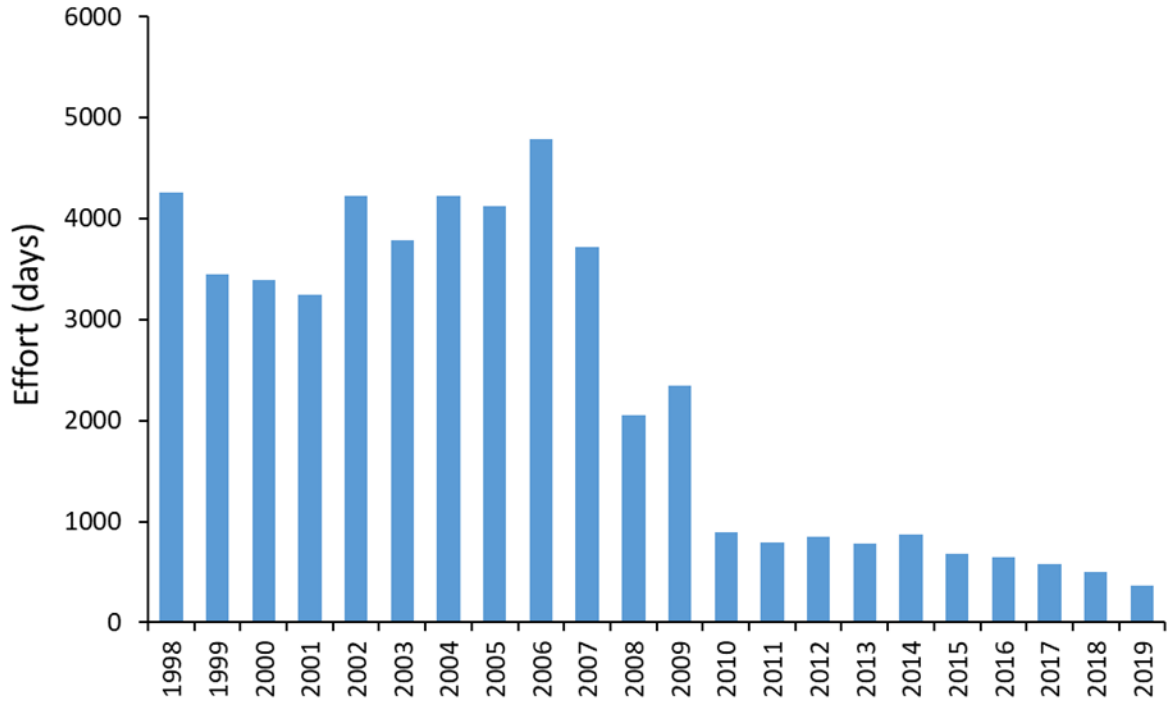

Figure 5 Annual trawl effort (days) for Silver Trevally from 1998-2019. Note: days of effort for the period 2010-2019 were estimated from the number of distinct fishing dates in each month.

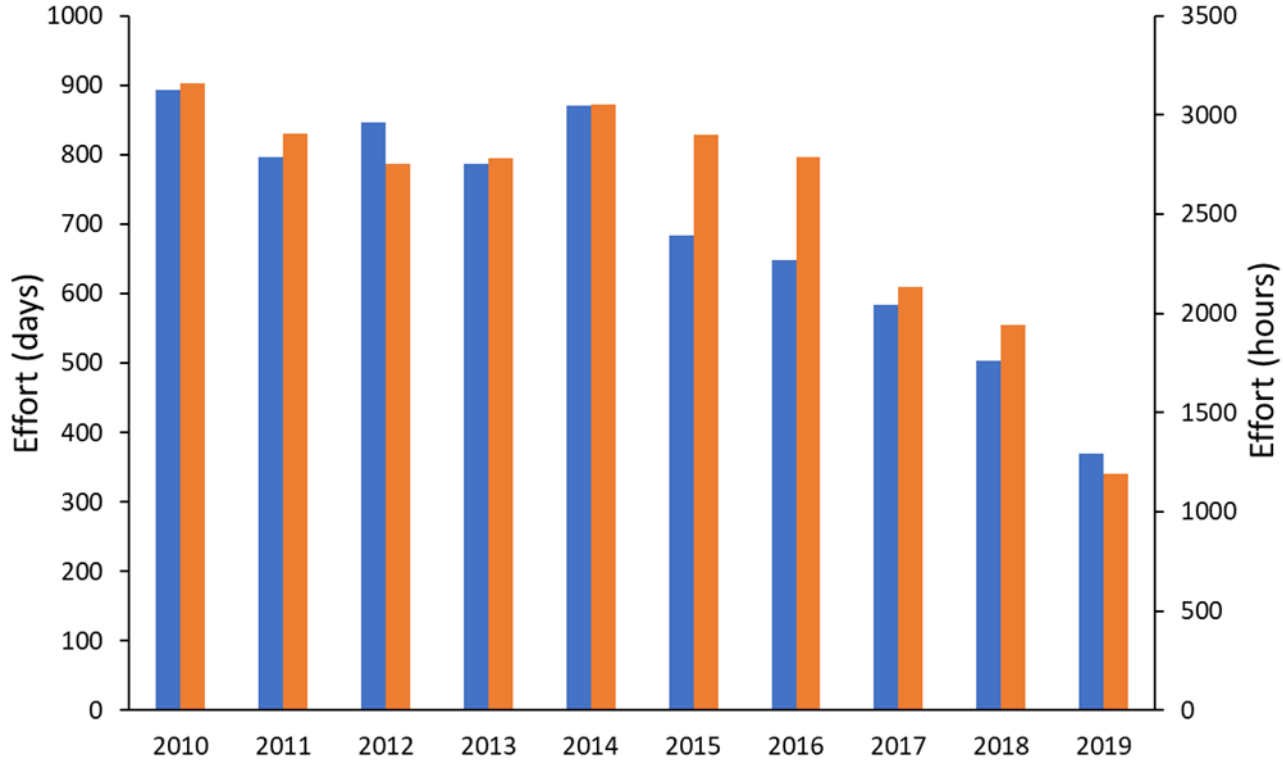

Figure 6 Annual trawl effort for Silver Trevally during 2010-2019 comparing the effort metric on catch return forms (hours, orange) with the estimates of days fished (blue) derived from the number of fishing events within each month.

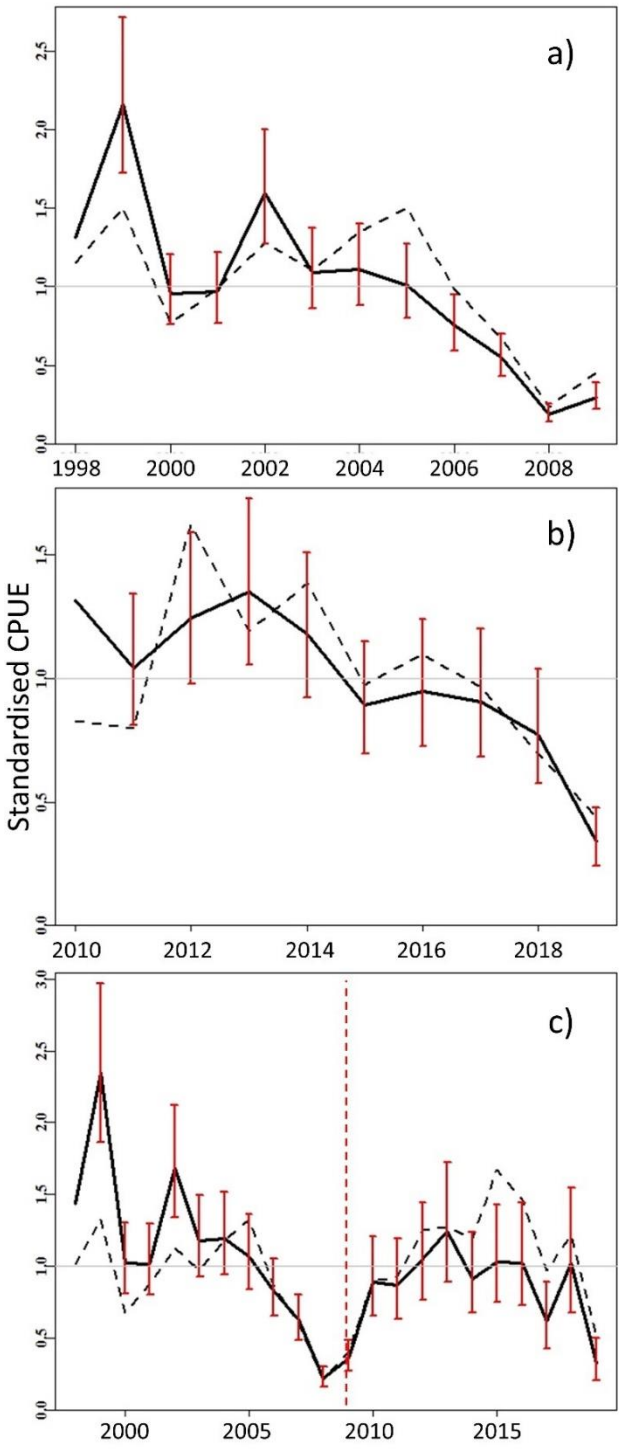

Figure 7 OTF – All ocean zones – Standardised catch rate (t, solid line) of Silver Trevally by trawling within all ocean zones during: a) 1998 - 2009, b) 2010 - 2019 and c) 1998 - 2019. The dashed black line indicates the geometric mean catch rate. Red bars indicate 95% confidence intervals. The dashed red line indicates the reporting discontinuity.

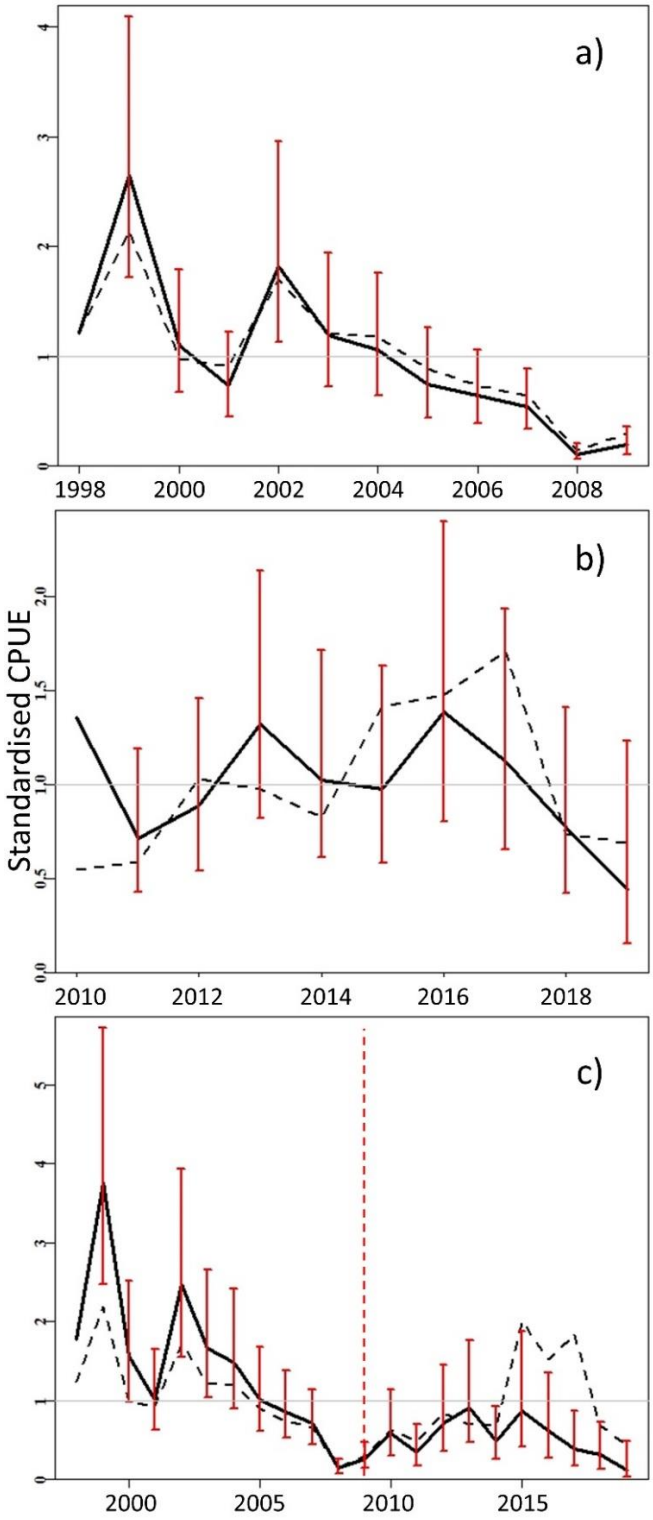

Figure 8 OTF - Ocean Zone 5 – Standardised catch rate (t, solid line) of Silver Trevally by trawling within Ocean Zone 5 during: a) 1998 - 2009, b) 2010 - 2019 and c) 1998 - 2019. The dashed black line indicates the geometric mean catch rate. Red bars indicate 95% confidence intervals. The dashed red line indicates the reporting discontinuity.

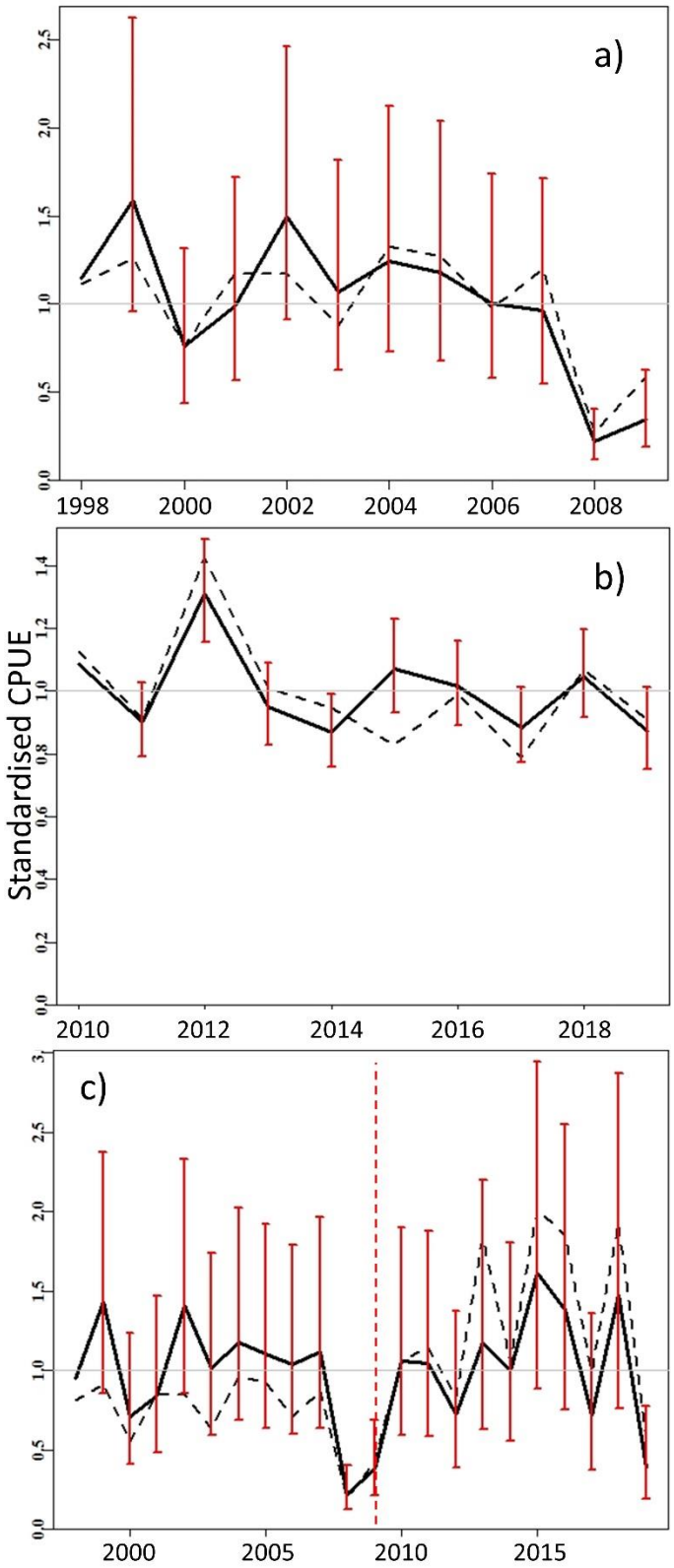

Figure 9 OTF - Ocean Zone 6 – Standardised catch rate (t, solid line) of Silver Trevally by trawling within Ocean Zone 6 during: a) 1998 - 2009, b) 2010 - 2019 and c) 1998 - 2019. The dashed black line indicates the geometric mean catch rate. Red bars indicate 95% confidence intervals. The dashed red line indicates the reporting discontinuity.

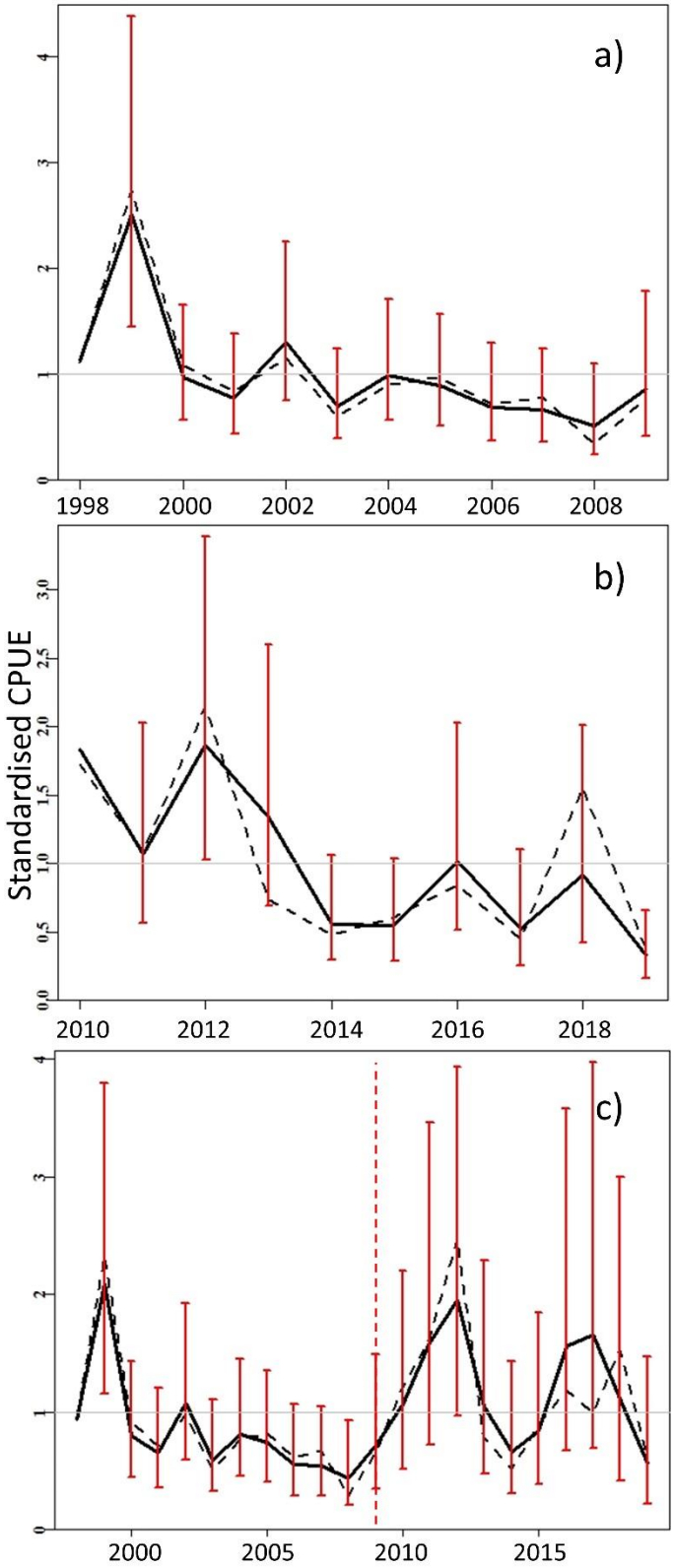

Figure 10 OTF - Ocean Zone 7 – Standardised catch rate (t, solid line) of Silver Trevally by trawling within Ocean Zone 7 during: a) 1998 - 2009, b) 2010 - 2019 and c) the full period (1998 – 2019). The dashed black line indicates the geometric mean catch rate. Red bars indicate 95% confidence intervals. The dashed red line indicates the reporting discontinuity.

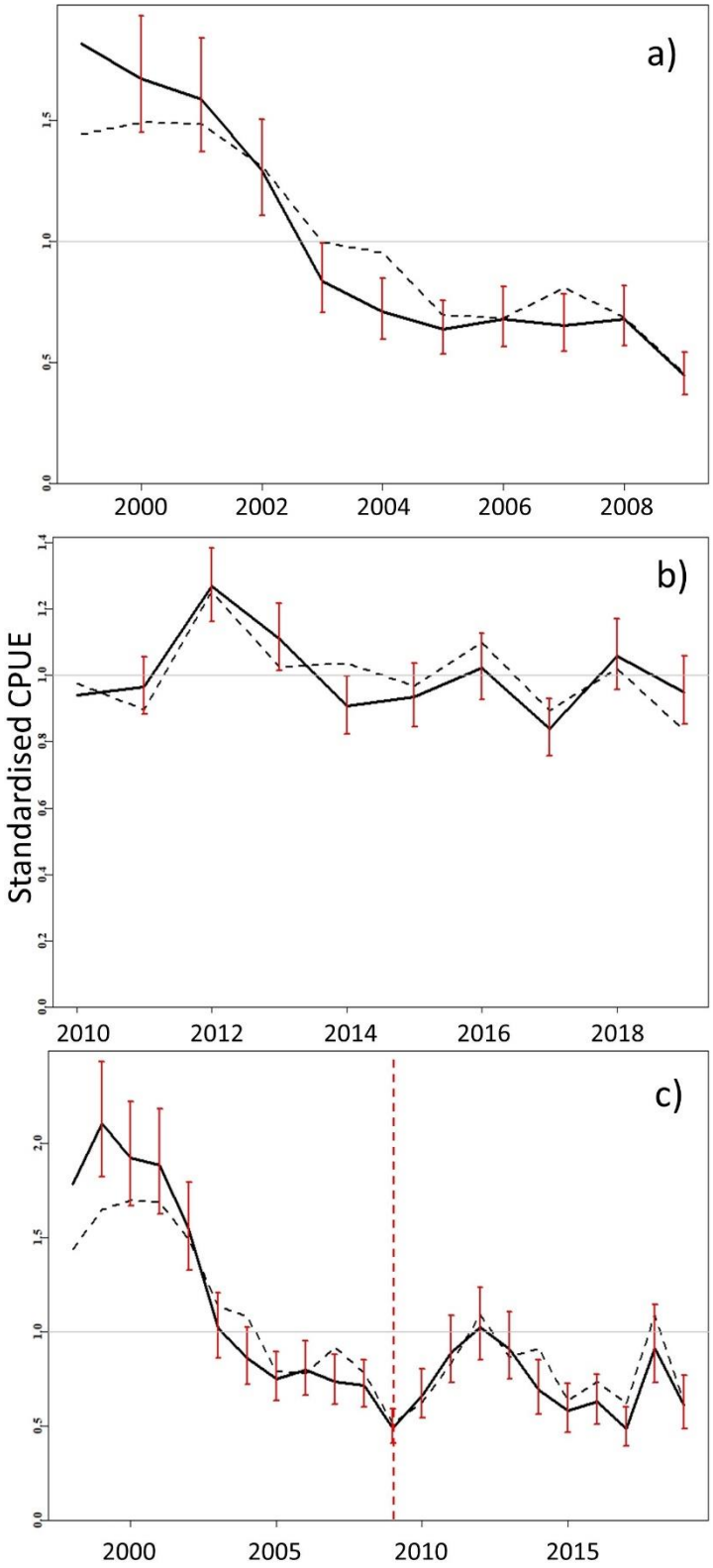

Figure 11 OTLF – All ocean zones – Standardised catch rate (t, solid line) of Silver Trevally from demersal fish trap within all ocean zones during: a) 1998 - 2009, b) 2010 - 2019 and c) 1998 - 2019. The dashed black line indicates the geometric mean catch rate. Red bars indicate 95% confidence intervals. The dashed red line indicates the reporting discontinuity.

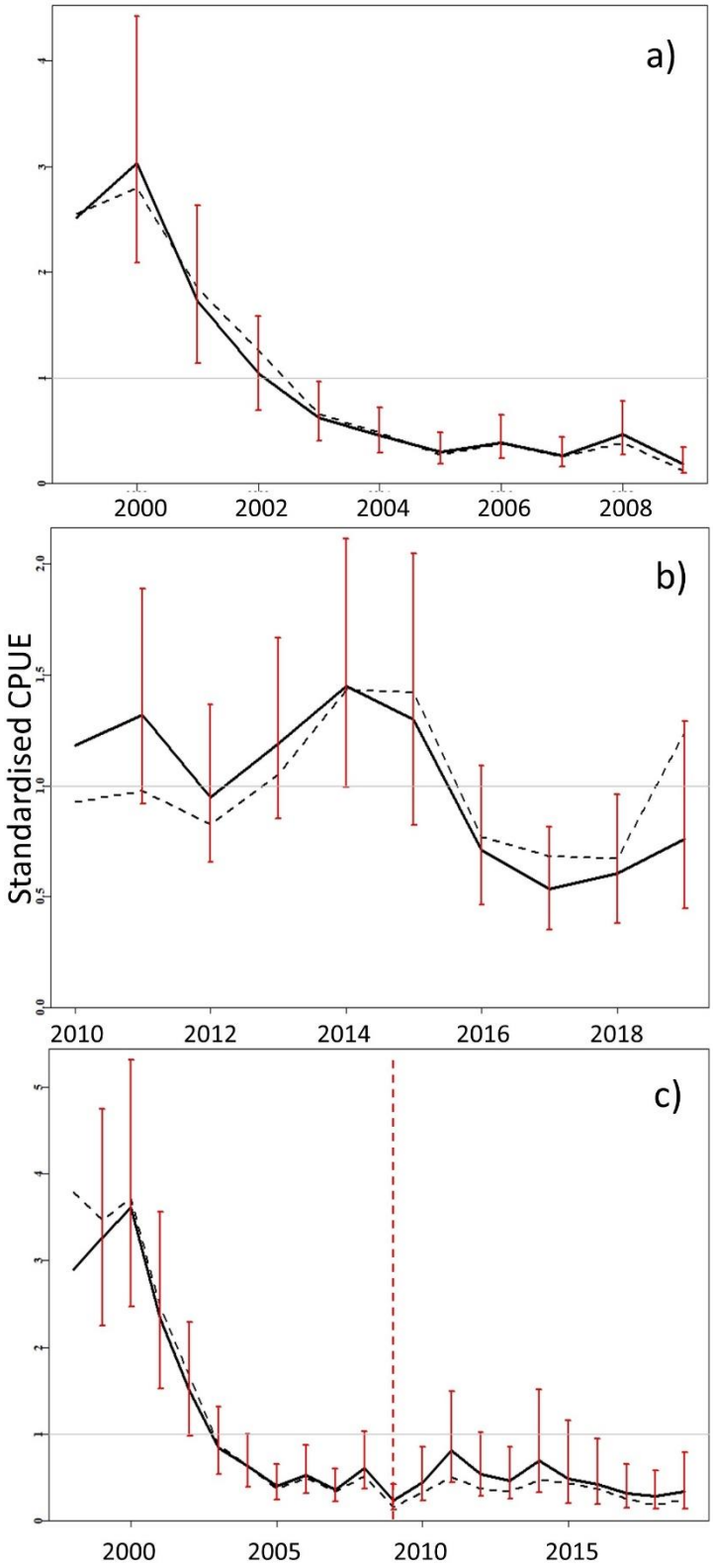

Figure 12 OTLF – Ocean Zone 5 – Standardised catch rate (t, solid line) of Silver Trevally from demersal fish trap in Ocean Zone 5 during: a) 1998 - 2009, b) 2010 - 2019 and c) 1998 - 2019. The dashed black line indicates the geometric mean catch rate. Red bars indicate 95% confidence intervals. The dashed red line indicates the reporting discontinuity.

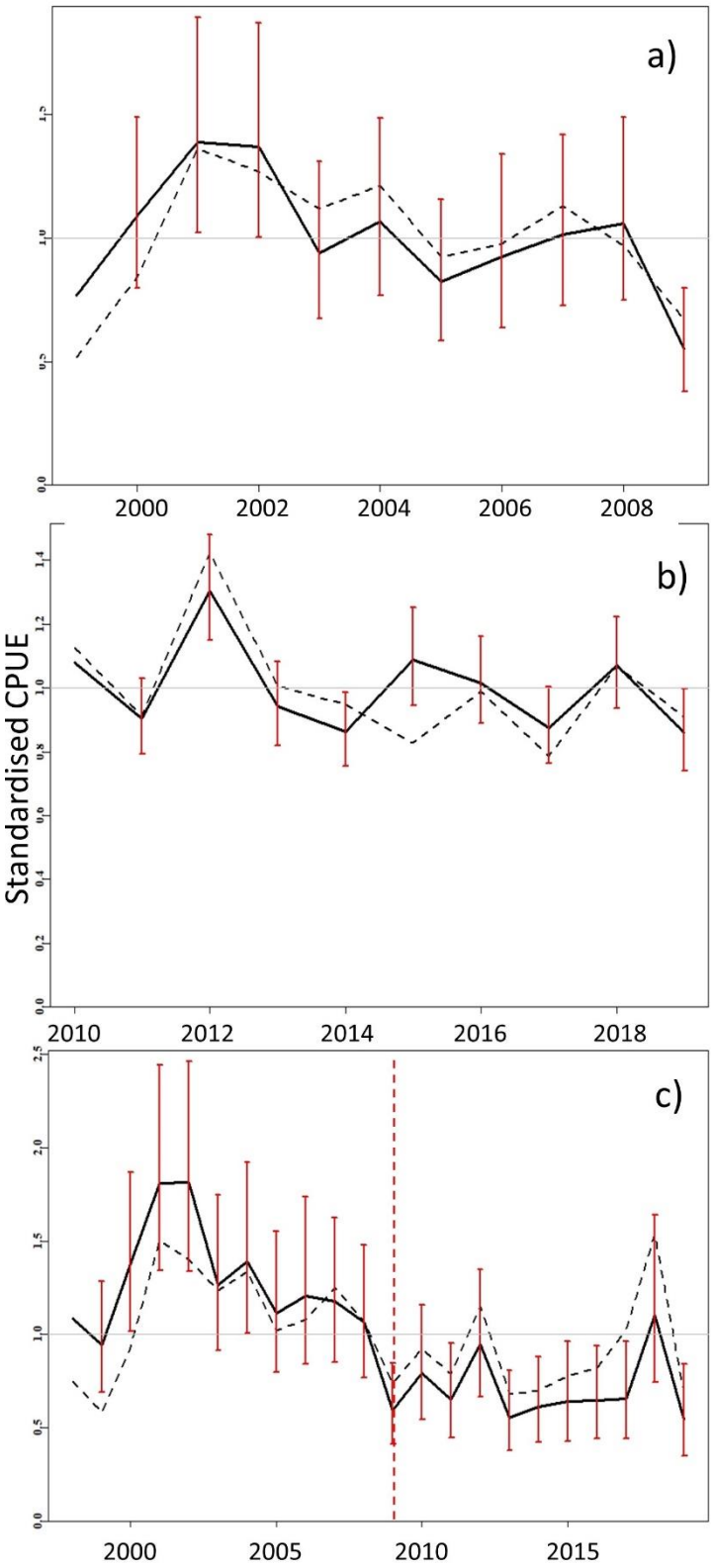

Figure 13 OTLF – Ocean Zone 6 – Standardised catch rate (t, solid line) of Silver Trevally from demersal fish trap in Ocean Zone 6 during: a) 1998 - 2009, b) 2010 - 2019 and c) 1998 - 2019. The dashed black line indicates the geometric mean catch rate. Red bars indicate 95% confidence intervals. The dashed red line indicates the reporting discontinuity.

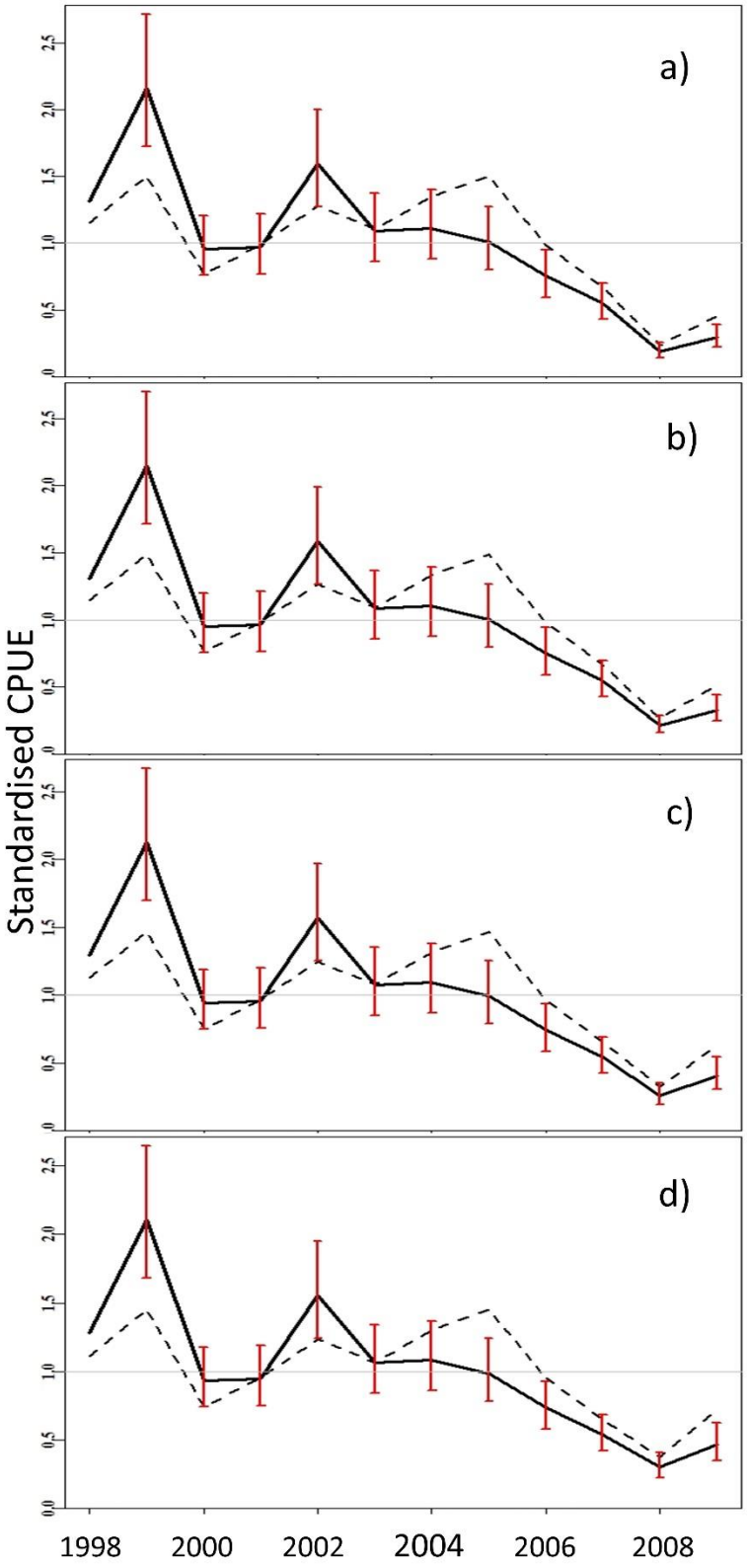

Figure 14 Discard additions, 1998-2009 – Standardised catch rate (t, solid line) of Silver Trevally from trawling within all ocean zones during 1998-2009, with a range of discard proportions added to catch from 2008 onward: a) no discards, b) 13% discards c) 40% discards, and d) 63% discards. The dashed black line indicates the geometric mean catch rate. Red bars indicate 95% confidence intervals.

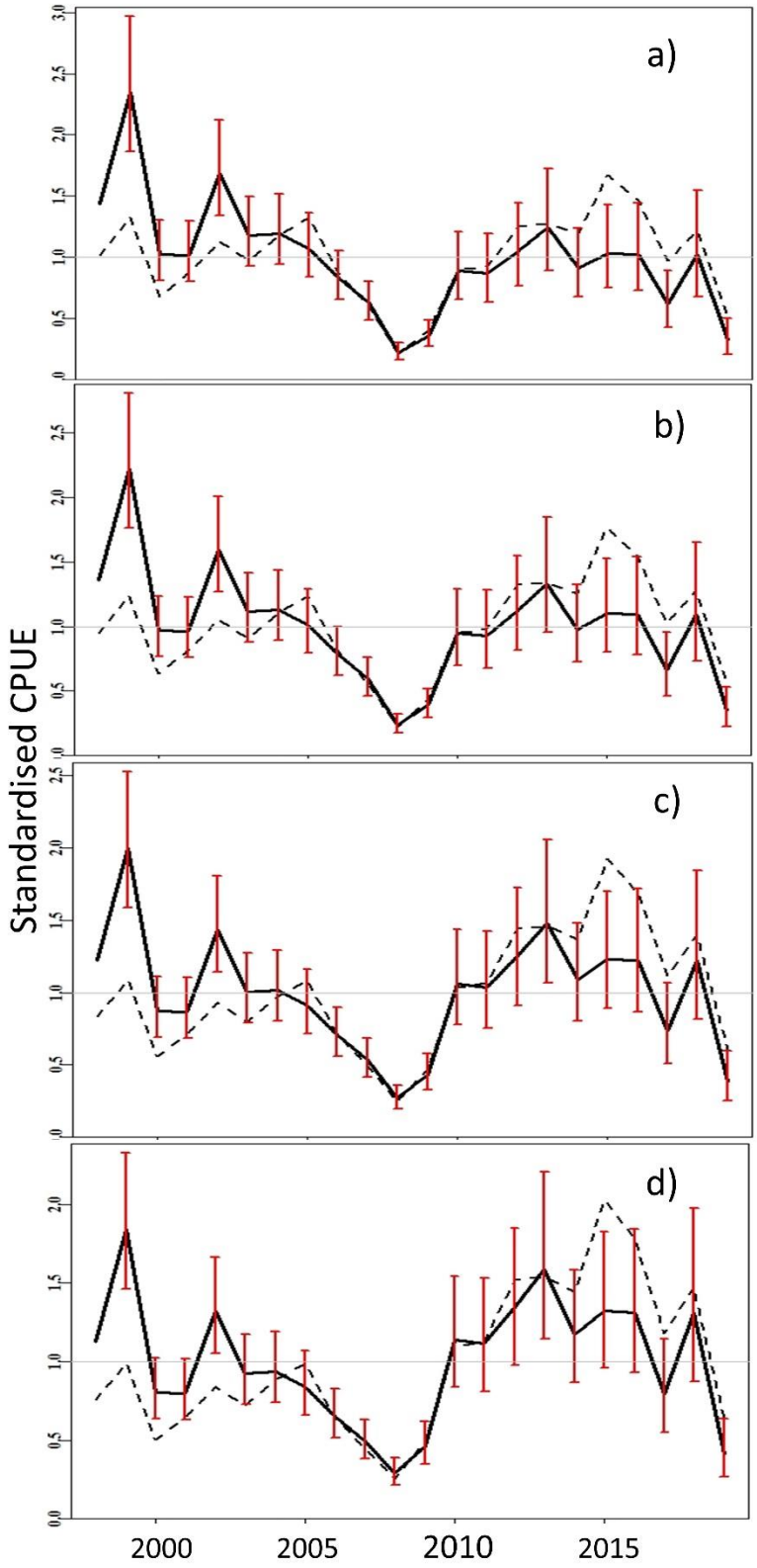

Figure 15 Discard additions, 1998-2019 – Standardised catch rate (t, solid line) of Silver Trevally from trawling within all ocean zones during 1998-2019, with a range of discard proportions added to catch from 2008 onward: a) no discards, b) 13% discards c) 40% discards, and d) 63% discards. The dashed black line indicates the geometric mean catch rate. Red bars indicate 95% confidence intervals around catch rate estimates.

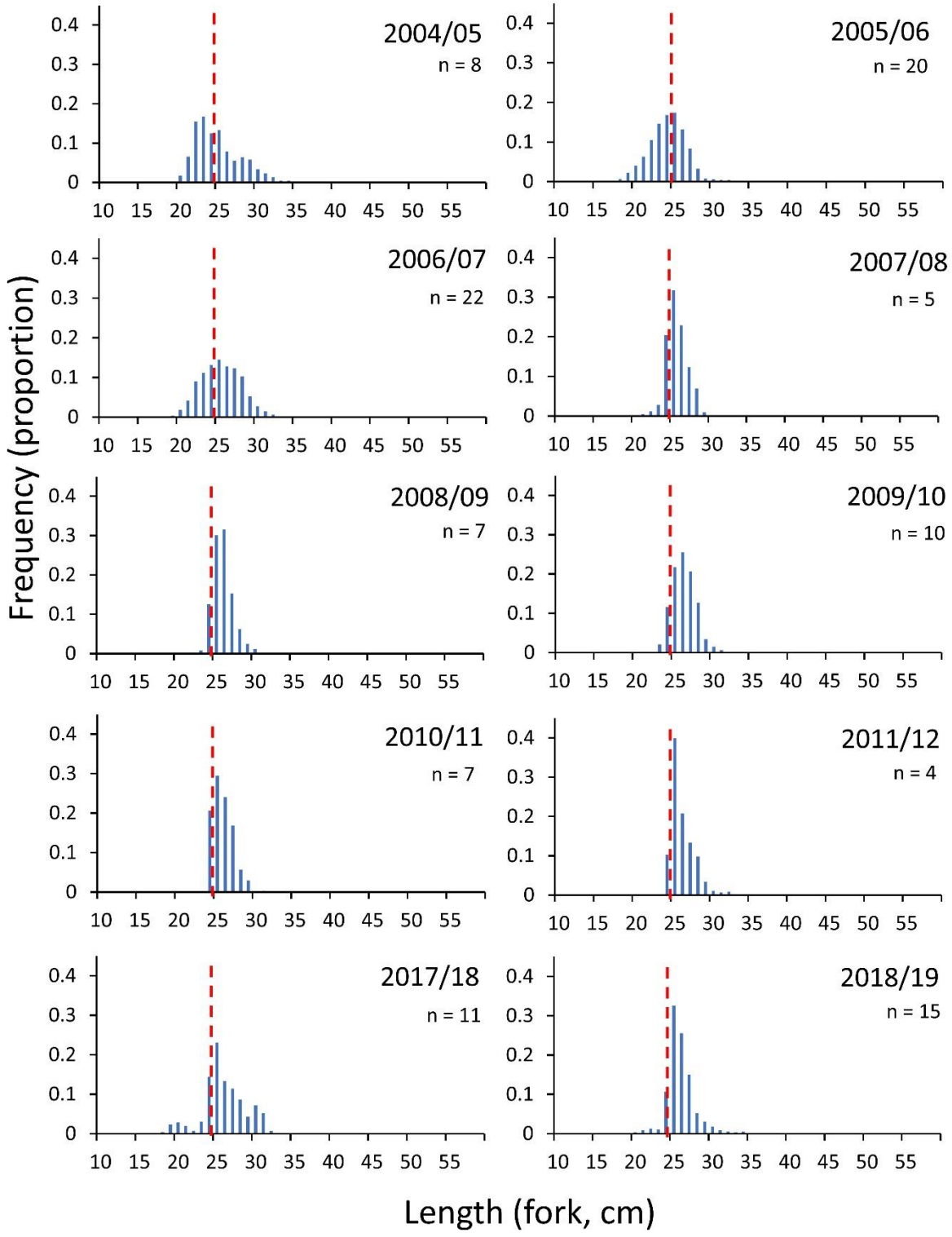

Figure 16 **Length frequencies of Silver Trevally from the Ocean Trawl Fishery between 2005 and 2019. Data are weighted proportional frequencies calculated by weighting length data sampled from fish markets according to relative landings by month and area. The red line indicates the fork length corresponding to the minimum legal length of 30 cm total length. 'n' refers to the number of catches contributing to each histogram.**

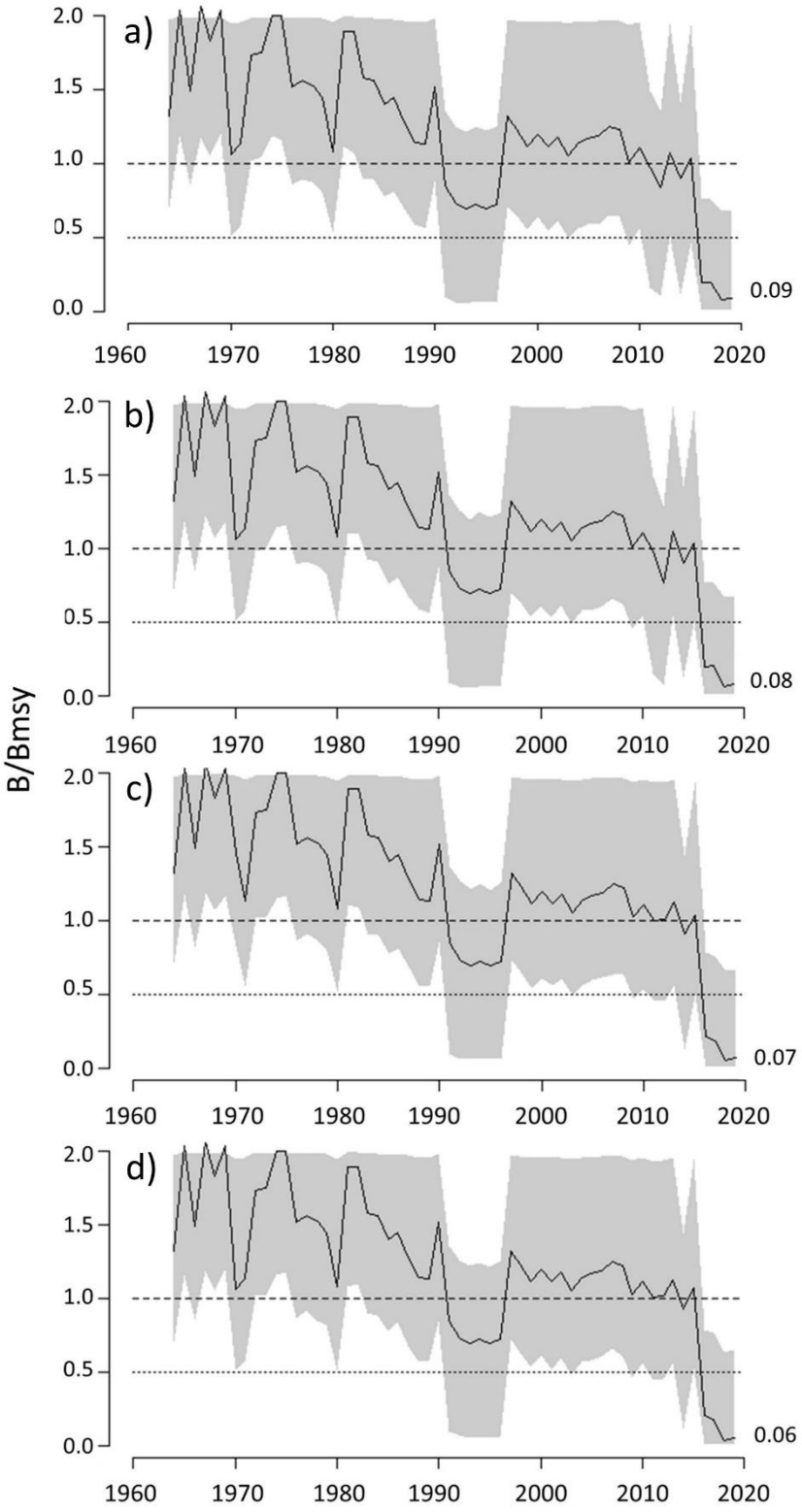

Figure 17 **Estimates of B/B_{msy} using a catch-only boosted regression tree (BRT) model (Zhou et al. 2017a) on NSW trawl catch data (t) from 1955-2019. A range of discard scenarios are explored, where discard proportions have been added to catch following the implementation of an MLL (2007): a) no discards, b) 13% discards c) 40% discards, and d) 63% discards. Error bars represent 95% confidence intervals.**

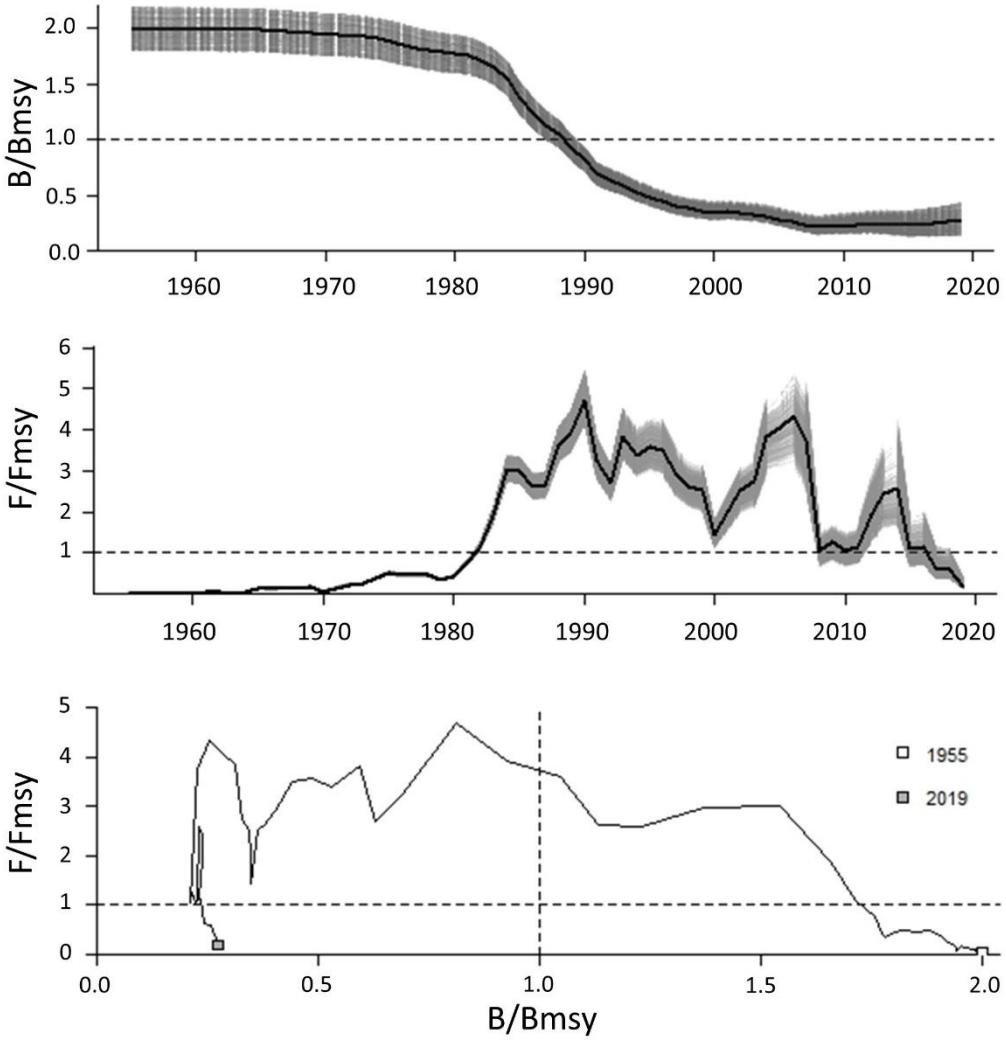

Figure 18 **Estimates of B/B_{msy} and F/F_{msy} using an optimised catch-only model (OCOM, Zhou et al. 2017b) on historical NSW trawl catch data (t) from 1955-2019, assuming natural mortality of 0.05 (Rowling and Raines 2000). Error bars represent 95% confidence intervals.**

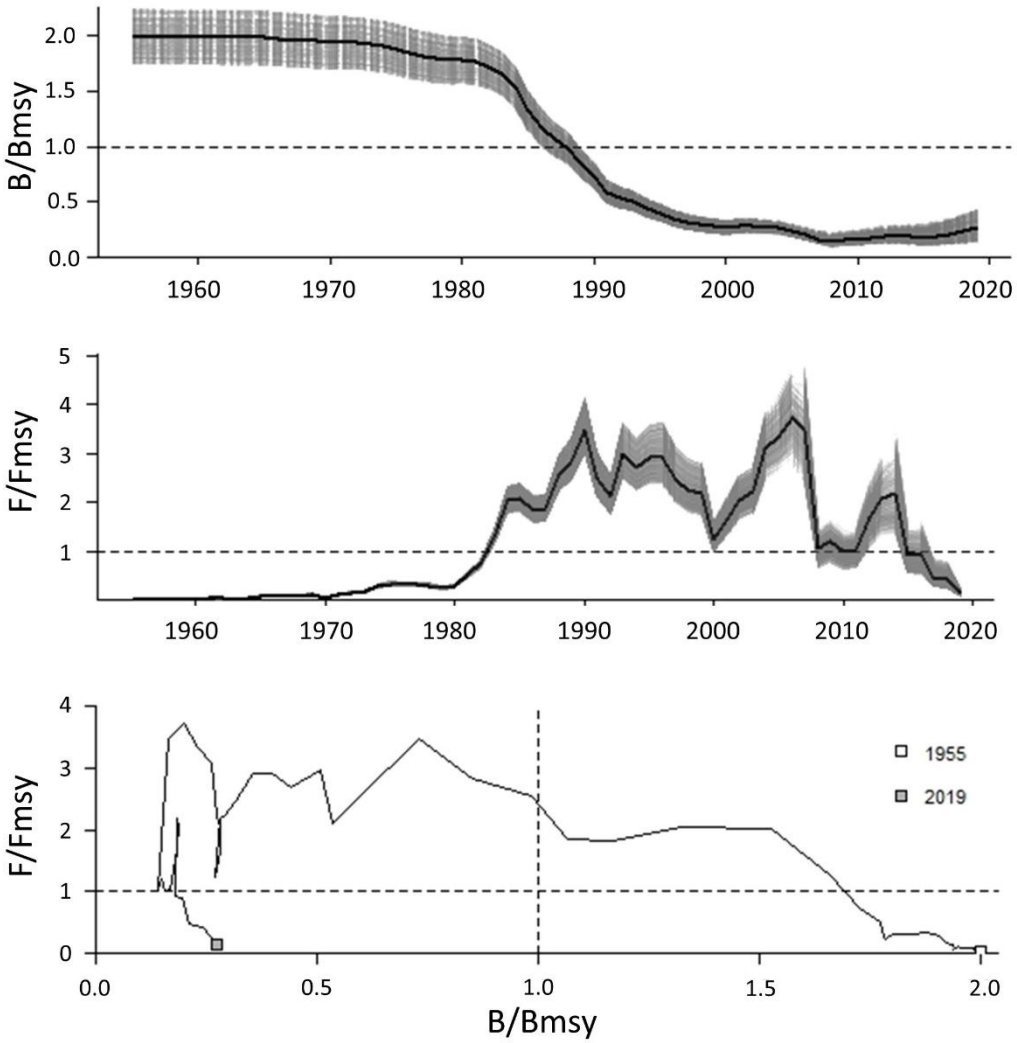

Figure 19 **Estimates of B/B_{msy} and F/F_{msy} using an optimised catch-only model (OCOM, Zhou et al. 2017b) on historical NSW trawl catch data (t) from 1955-2019, assuming natural mortality of 0.10 (Rowling and Raines 2000). Error bars represent 95% confidence intervals.**

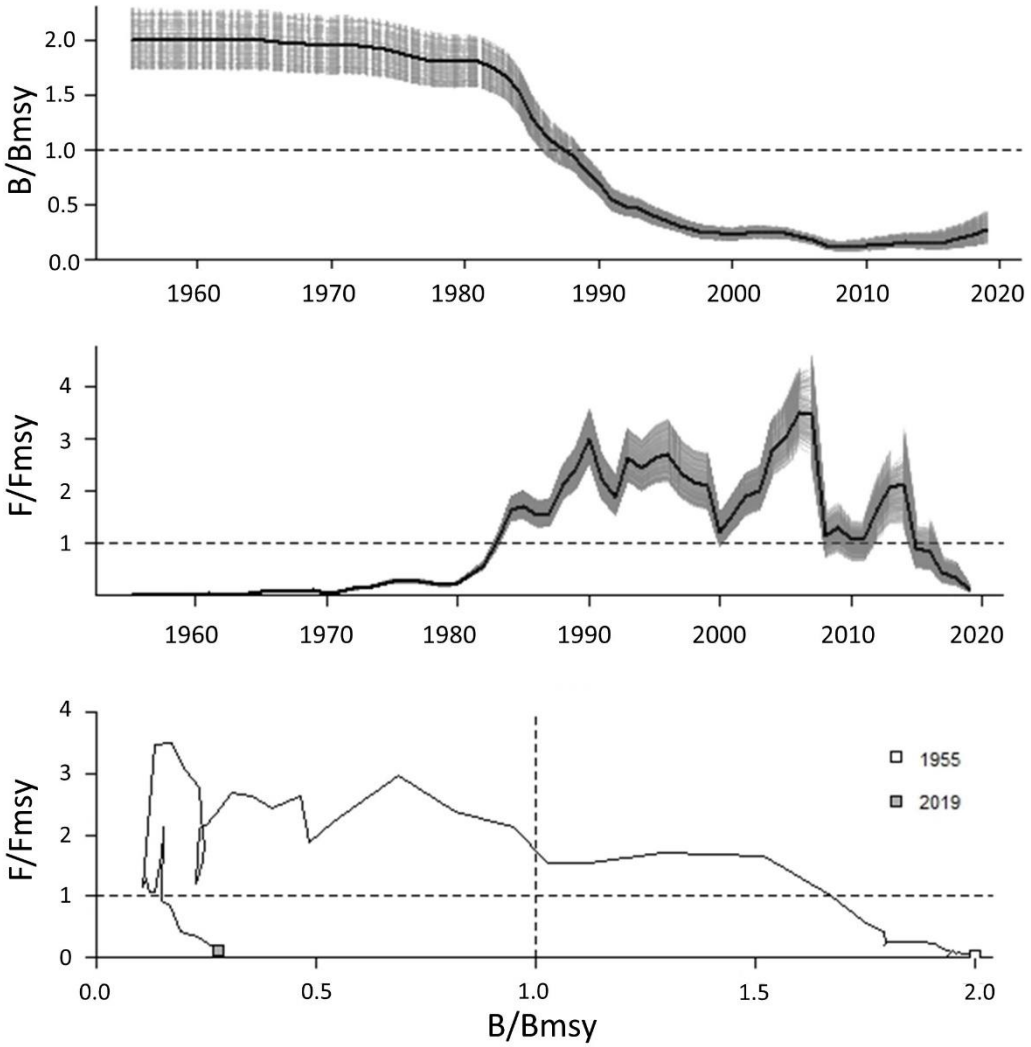

Figure 20 Estimates of B/B_{msy} and F/F_{msy} using an optimised catch-only model (OCOM, Zhou et al. 2017b) on historical NSW trawl catch data (t) from 1955-2019, assuming natural mortality of 0.15 (Rowling and Raines 2000). Error bars represent 95% confidence intervals.

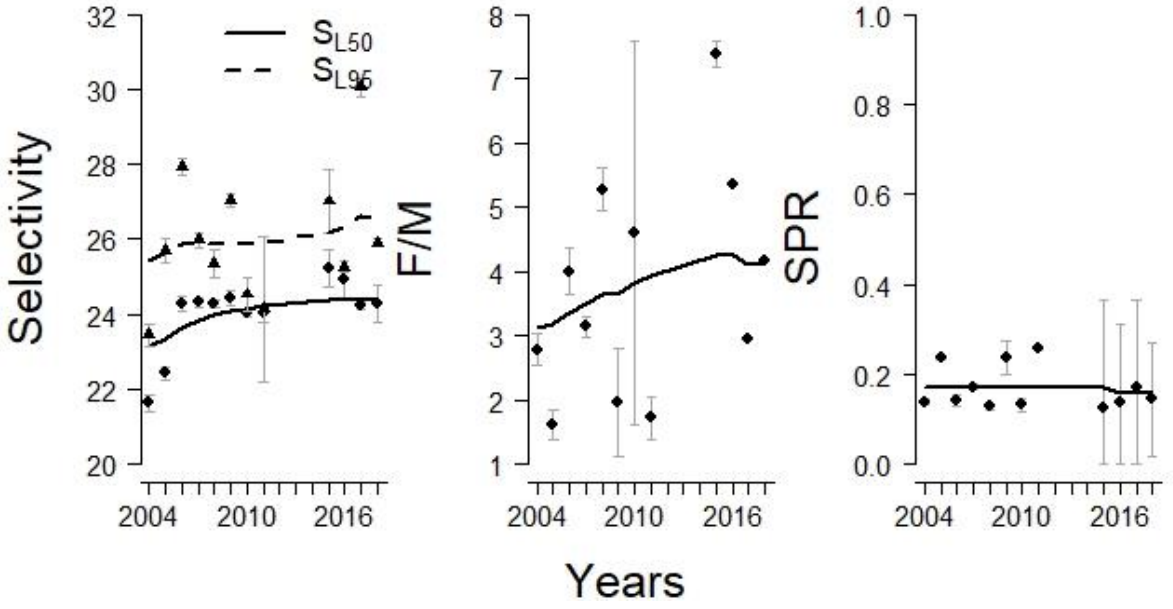

Figure 21 **Outputs from the LB-SPR model applied to commercial length-frequency data of Silver Trevally for 12 years between 2004 and 2018. Error bars represent 95% confidence intervals.**

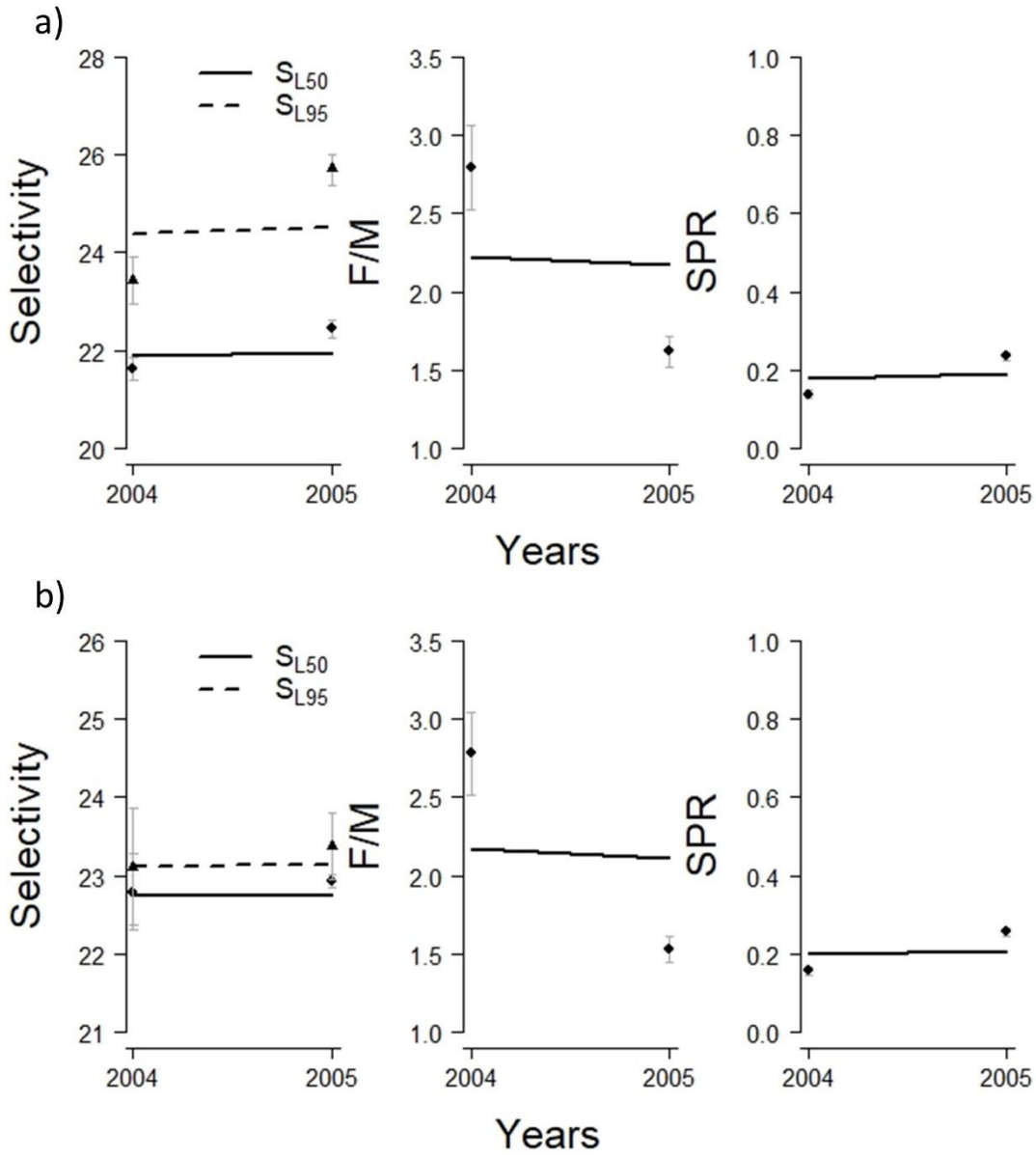

Figure 22 **Outputs from the LB-SPR models (a) with and (b) without length data below the MLL (30 cm TL) for the years 2004 and 2005. Error bars represent 95% confidence intervals.**

Table 1 **Annual catch (t) of Silver Trevally from NSW Ocean Trawl (OTF), Ocean Trap and Line (OTL), Ocean Haul (OH) and Estuary General (EG) Fisheries from 1997/98 to 2018/19.**

	EG	OTF	OH	OTL	Total
1997/98	95.8	241.4	2.4	112.5	452.1
1998/99	43.8	222.1	8.5	121.2	395.6
1999/00	50.6	121.6	7.9	142.9	323.0
2000/01	33.7	169.4	2.7	122.8	328.6
2001/02	24.7	209.1	0.9	105.5	340.2
2002/03	25.9	218.2	2.4	63.9	310.4
2003/04	24.7	292.1	43.0	84.4	444.2
2004/05	17.1	278.6	4.2	51.4	351.3
2005/06	18.9	267.8	2.8	51.8	341.3
2006/07	12.0	206.2	2.1	55.5	275.8
2007/08	10.9	53.3	1.1	65.3	130.6
2008/09	11.7	65.3	0.4	21.9	99.3
2009/10	12.7	57.1	29.5	19.7	119.0
2010/11	19.6	63.4	0.1	17.2	100.3
2011/12	22.3	110.9	1.0	25.2	159.4
2012/13	11.5	140.5	0.5	15.3	167.8
2013/14	8.0	144.5	0.5	15.2	168.2
2014/15	12.7	60.0	0.4	11.6	84.7
2015/16	9.6	63.7	0.4	16.2	89.9
2016/17	13.1	36.2	0.3	13.0	62.6
2017/18	10.4	36.0	6.2	15.8	68.4
2018/19	7.0	12.5	13.0	8.8	41.3
Total	496.7	3069.9	130.3	1157.1	

Table 2 **Annual catch (t) of Silver Trevally from NSW Ocean Fish Trawl – North (OTFN), Ocean Prawn Trawl – Inshore (OTISP), Ocean Prawn Trawl – Offshore (OTOSP) and Southern Fish Trawl (SFT) from 2009/10 to 2018/19.**

	OTFN	OTISP	OTOSP	SFT	Total
2010	27.5	0.0	0.0	29.6	57.1
2011	26.5	0.1	0.2	37.0	63.6
2012	20.3	0.1	0.2	90.6	111.2
2013	35.9	0.1	0.0	104.6	140.7
2014	23.4	0.0	0.0	121.1	144.5
2015	27.2	0.0	0.2	32.9	60.3
2016	33.0	0.2	0.0	30.6	63.8
2017	20.9	0.0	0.0	15.0	35.8
2018	18.6	0.0	0.0	17.4	36.0
2019	7.5	0.0	0.0	4.9	12.4
Total	240.7	0.4	0.7	483.6	

Appendix 1 – NSW data sources

Commercial logbook reporting changes

NSW catch and effort logbook data vary spatially and temporally across different eras, delineated by changes in catch reporting requirements and management. This section briefly summarises the catch and effort data available for each era and associated limitations and caveats (Table A1 - 1).

(1) Historical data (pre-1984) – annual catches (kg) reported by port of landing or individual estuaries, which can be aggregated into the ten broad ocean zones and seven estuary regions used in later eras (Figure A1 - 1). No information on fisher, vessels or effort is available, and catch could only be assigned to individual methods if a single method was used by a fisher in any given month. Given the lack of appropriate effort data for this era, it is not possible to compile a CPUE series for any species in NSW state waters prior to July 1984.

(2) Historical data (July 1984 to June 1997) – monthly catches (kg) reported by ten broad ocean zones or individual estuaries (Figure A1 - 1). Details on fishers, boats and effort by gear type (in days fished per month) are available. Catch could only be assigned to individual methods if a single method was used by a fisher in any given month. Therefore, CPUE data for this period include only a subset of catch records for each species. No depth information is available. Trawl catches taken in offshore Commonwealth waters south of Barrenjoey Point and landed at a NSW port were included on NSW log sheets.

(3) Recent data (July 1997 to June 2009) – monthly catches (kg) reported by ten broad ocean zones or individual estuaries (Figure A1 - 1). Details on fishers, boats and effort by gear type (in days fished per month) are available. Method was assigned to all catches. No depth information is available. Trawl catches taken in offshore Commonwealth waters south of Barrenjoey Point and landed at a NSW port were no longer included on NSW reporting. Catch, effort and CPUE data (in kg per fisher day) are available for this era.

(4) Recent data (July 2009 to June 2016) – daily catches (kg) reported to individual estuaries and a finer spatial scale (0.1° x 0.1° C-square grid) for ocean waters. Many species complexes were split and catches reported by individual species. Details on fishers, boats and effort by gear type (by a single effort unit, e.g. hours fished, number of hooks or traps, or net length). Depth information is not reported by fishers but could be interpolated from location data (from the mean depth of the reported C-square). To construct a longer time series of data (from 1984/85 or 1997/98 to present), these daily records are re-aggregated into monthly catches (kg) by fisher and gear type, with effort in days per month estimated from the number of distinct fishing dates in each month where the method was used, irrespective of whether the species was reported on those days, to be consistent with earlier reporting. Catch, effort and CPUE data (in kg per effort unit or kg per fisher day, using re-aggregated data) are available for this era. Significant reductions in effort (and consequently spikes in CPUE) are evident in some species' data following these logbook changes in July 2009; long time series of CPUE that cross this period need to be interpreted with caution.

NB: Mixed zone reporting – prior to July 2009, some catches were reported against mixed ocean zones (e.g. OZ1 and OZ2 combined). To report by zones, these catch and effort data are divided and reallocated evenly to each of the zones involved. Most of the mixed zone

records were for just two zones and less than 3% involved three or more zones. After June 2009, all catches were reported according to the finer-scale C-squares.

Table A1 - 1 Data sources of commercial fishery records and changes to fisher reporting requirements through time.

Fishery	Time period	Data source	Reporting requirements
Ocean Trawl (OTF)			
	Pre-1984	HCatch	Catch unit – kg per month No fisher, vessel or effort information available Spatial scale – port of landing
	July 1984 – June 1997	ComCatch	Catch unit – kg per month Effort unit – days fished per month Catch data not linked to individual methods, therefore, effort only assigned to catches when a single method was used in a given month. Spatial scale – 10 broad ocean zones
	July 1997 – June 2009	ComCatch	Catch unit – kg per month Effort unit – days fished per month Catch data provided for each method used Spatial scale – 10 broad ocean zones
	July 2009 - present	FishOnline	Catch unit – kg per fishing event (within each day) Effort unit – hours trawled per day (days fished per month can be extracted from re-aggregated daily data). Catch data provided for each method used Spatial scale – 0.1º x 0.1º C-square grid Voluntary E-reporting of catch records since 2011

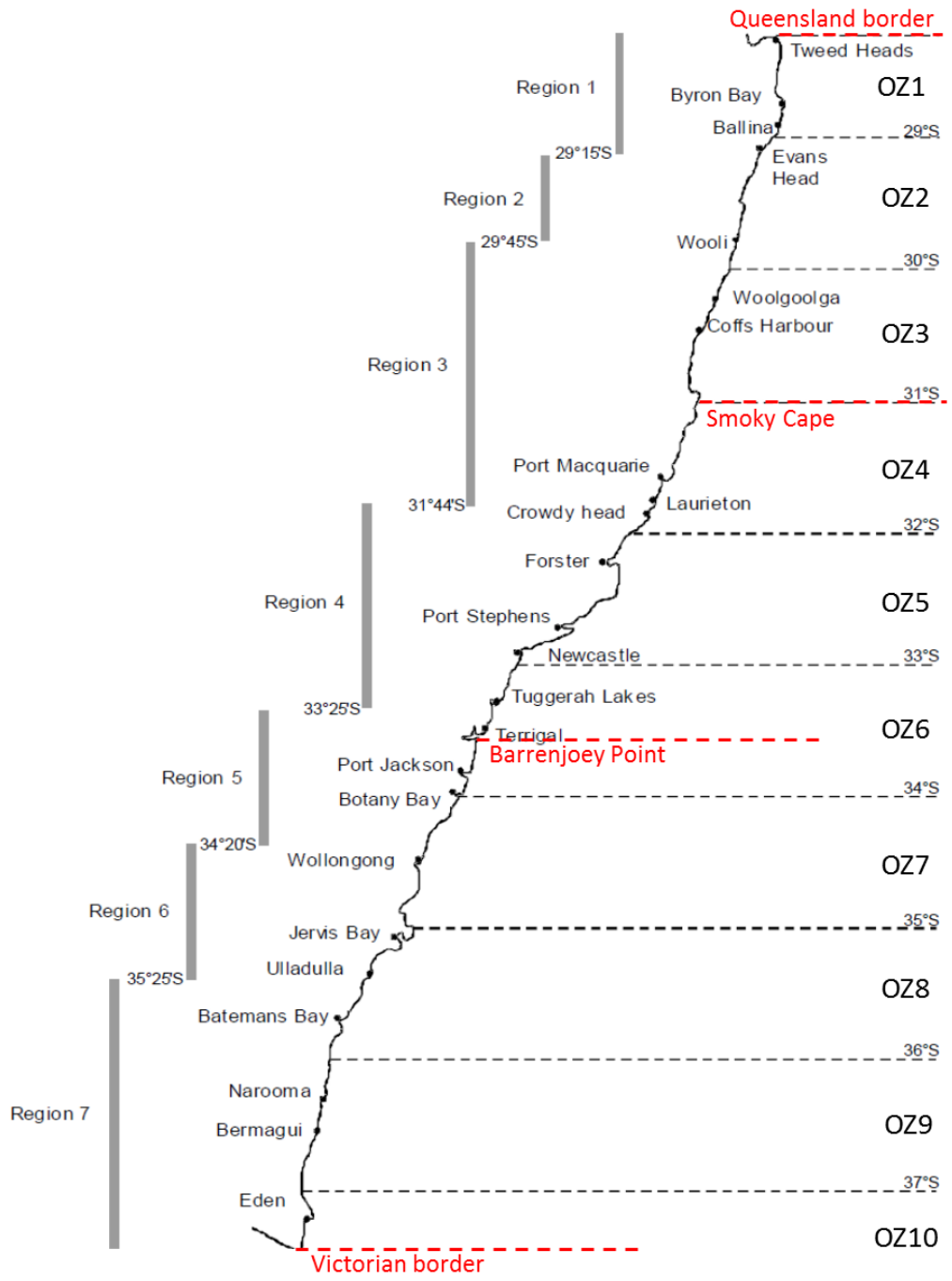

Figure A1 - 1 **Map of NSW coastline indicating the main ports of landing, broad ocean fishing zones (OZ1 to OZ10) and estuary fishing regions (Regions 1 to 7) for catch and effort reporting. Important management landmarks, including Smoky Cape, Barrenjoey Point and the Queensland and Victorian borders are also indicated by dashed red lines.**