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Australian Herring and West Australian Salmon Scientific Workshop Report, October 2017

Brent Wise and Brett Molony (Editors)

July 2018

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Executive Summary

A scientific workshop was held on 25th – 29th September 2017 to review available data for Australian herring (*Arripis georgianus*) and determine current stock status using the Department of Primary Industries and Regional Development's (DPIRD) Risk-based Weight of Evidence Approach (Appendix 1). Recommendations for future monitoring and assessments required to reduce uncertainties and establish sustainable catch levels were also made. Similar discussions were undertaken to establish monitoring and assessment approaches for establishing sustainable catch levels for West Australian salmon (*Arripis truttaceus)*. The workshop was attended by DPIRD and non-DPIRD scientists, fishery managers from DPIRD and South Australia, commercial fishers, representatives of WAFIC and Recfishwest (Table 1).

The objectives of the workshop were;

1. Review available Australian herring information.
2. Complete a new Australian herring stock assessment based on the recent available data using a Weight of Evidence approach.
3. Determine current Australian herring stock status including scientific advice to management.
4. Recommend monitoring programs or assessment methodologies that could be adopted that would reduce uncertainties in future Australian herring stock status and sustainable catch levels.
5. Develop recommendations for monitoring and assessment approaches suitable to determine sustainable catch levels for West Australian salmon.

Workshop outputs which will be made publicly available with the release of this report were;

- Australian herring Weight of Evidence assessment and risk assessment
- Updated Australian herring stock status and scientific advice to management
- Australian herring future monitoring and assessment recommendations
- West Australian salmon future monitoring and assessment recommendations.

For Australian herring, available data were presented and reviewed (Appendices 2, 3 and 4) and all lines of evidence explored by workshop attendees. This included working groups undertaking analyses based on information presented at the workshop. Outcomes of analyses were presented in a Weight of Evidence approach (Table 2). Workshop attendees discussed each line of evidence before undertaking a risk assessment and determining likely stock status over a five-year period (2016 – 2020). Workshop attendees then discussed future monitoring and assessment approaches to further reduce identified uncertainties and a schedule of assessments.

Overall the current risk status over the next five years of the Australian herring stock was estimated to be MEDIUM generated by the combination of C2 (moderate level of stock depletion) and L4 (greater than 50% likelihood level). This risk level reflects the productivity

of the species. In addition, the declining commercial catches since early 2000s following changes in fisher behaviour (e.g. reductions in market demand), later combined with the cessation of G-trap fishing and reductions in recreational bag limits since 2015, has likely allowed the stock biomass to increase. It is likely that stock biomass will continue to increase under current management arrangements. New sampling is proposed to commence in 2018 with a new assessment proposed to be undertaken in 2021.

Table 1. Herring and Salmon Scientific Workshop Attendance list

Name	Affiliation	Attendance dates
Dr Brent Wise (Chair)	DPIRD	25 -29/9/2017
Mr Nick Soulos	Commercial Fisher	25 -29/9/2017
Dr Jeremy Prince (funded by DPIRD to participate)	Biospherics P/L	25 -29/9/2017
Mr Tony Westerberg	Commercial Fisher	25 -27/9/2017
Dr Matt Pember	WAFIC	25 -29/9/2017
Dr Emily Fisher	DPIRD	25 -29/9/2017
Ms Alissa Tate	DPIRD	25 -29/9/2017
Dr Norm Hall	DPIRD	25 -29/9/2017
Dr Ainslie Denham	DPIRD	25 -29/9/2017
Dr Alex Hesp	DPIRD	25 -29/9/2017
Mr Martin Holtz	DPIRD	25 -29/9/2017
Dr Rod Lenanton	DPIRD	25 -29/9/2017
Mr Tim Nicholas	DPIRD	25 -29/9/2017
Dr Kim Smith	DPIRD	25 -29/9/2017
Dr Gary Jackson	DPIRD	25 -29/9/2017
Dr Malcolm Haddon (funded by DPIRD to participate)	CSIRO	25 -29/9/2017
Dr Mike Steer	SARDI	25 -29/9/2017
Shane Miles	Commercial Fisher	28 -29/9/2017
Mr Jonathan McPhail	PIRSA	28 -29/9/2017
Ms Eve Bunbury	DPIRD	29/9/2017
Mr Chris Marsh	DPIRD	29/9/2017
Dr Rodney Duffy	DPIRD	29/9/2017
Dr Andrew Rowland	Recfishwest	29/9/2017
Mr Leyland Campbell	Recfishwest	29/9/2017
Dr Brett Molony	DPIRD	25 -29/9/2017

On the final day, a Weight of Evidence approach for the West Australian salmon stock was presented to attendees who discussed each line of data before determining the current state of the stock using a similar risk-based approach (Appendix 5). Overall, the current risk status of the West Australian salmon stock was estimated to be LOW, generated by the combination of C2 (moderate level of stock depletion) and L2 (likelihood level of 5-20% probability). This risk level reflects the productivity of the species and the very low levels of recent and current catches that has likely allowed the stock to rebuild to above the target biomass reference point. It is likely that stock biomass will continue to increase if catches do not increase. New sampling is proposed to commence in 2019 with a new assessment proposed to be undertaken in 2022.

The workshop achieved all objectives and outputs, and provides scientific advice to allow options for future management and industry development to be discussed and considered.

Structure of the Report

This report works though the objectives of the workshop, grouping these where appropriate. In keeping with Departmental protocol, the report presents the weight of evidence assessment as a table that summarises the lines of evidence for each criterion that contributes to the overall weight-of evidence, followed by the risk assessment section.

It is important to recognise that this report strives to include the considerable amounts of information that was presented at the workshop to facilitate shared understanding of the data during the weight of evidence assessments during the workshop. To facilitate readability, every piece of information used in the workshop is not specifically referred to in the lines of evidence part of the assessment table because this would be unwieldy to read. Rather, each category of the WOE identifies an accompanying attachment(s) but will not refer to each individual figure therein.

1. Objectives 1 and 2. Review available Australian herring informaiton and complete a new Australian herring stock assessment based on the recent available data using a weight of evidence approach.

Table 2. Australian herring Weight-of-Evidence Table (September 2017)

Category	Lines of evidence
Catch (Herring Attachment 1)	In all 3 management areas (West Coast Bioregion (WCB), South Coast Bioregion (SCB) and South Australia(SA)), commercial and recreational catches followed a broadly similar trend, with commercial catches declining from ~1990 to ~2010, then stabilising (South Australia), declining further (SCB) or increasing (WCB) in subsequent years (Herring Attachment 1, Catch Figure 1). Recreational catch estimates remain uncertain. The commercial catch declines since 1995 were largely attributable to changes in effort as a result of changes in fisher behaviour, particularly in response to reduced markets and reduced commercial access on the lower West Coast. Recreational catch trends are not readily attributable to changes in effort and may reflect changes in fish availability. **Noting that recent commercial catches have been lower as a result of fisher behaviour (e.g. reduced market demand), declines in catches between 1990 and 2010 could be interpreted as stock depletion. However, the reduced catches (e.g. due to declining market demand) since the early 2000s, later combined with the cessation of G-trap fishing and reductions in recreational bag limits in 2015, has likely allowed stock biomass to increase.**
Catch distribution (Herring Attachment 2)	The distribution of the commercial catch of Australian herring in Western Australia (Herring Attachment 2A) extends from Geraldton to Esperance. The majority of the catch was concentrated from Perth to Bunbury (and Geographe Bay) in the WCB and Albany to the Bremer Bay area in the SCB. Since 1999 catches from these centres have declined, specifically in the South West Beach Seine and South Coast Trap ('G–Net') Net Fisheries. These declines were influenced by weakening market demand and management arrangements that aimed to reduce effort (i.e. netting closures, 'G-Net' Fishery closure). The distribution of the commercial catch of Australian herring in South Australia (Herring Attachment 2B) has remained relatively consistent from 1983 onwards, and has predominantly been concentrated within northern gulf waters and in close proximity to regional centres along the western and southern coasts. The majority of catch (>94%) is landed by the hauling net sector. A series of management arrangements, specific to the hauling net sector implemented from 2005 onwards (i.e. spatial netting closures, buy-outs), has confined fishing activity to the northern gulfs. Australian herring is a popular target among recreational fishers throughout WA and SA. Although there are limited series of catch and effort data for this sector in both State jurisdictions (particularly in the WCB and South Australia), their overall pattern of fishing activity tends to align with coastal population centres. In WA this sector is more concentrated within the Perth to Bunbury and Cape Leeuwin area. **Catch distributions provide no evidence that unacceptable stock depletion may have occurred.**

Effort (Herring Attachment 3)	Effort in the commercial fisheries is spatially restricted (e.g. G-traps can only operate on certain beaches). Commercial effort tends to reflect changes in management and reduced markets. Recreational effort is permitted throughout the range of the species but is higher in the WCB due to being adjacent to larger population centres. Recreational effort trends are largely unknown but likely reflect changes in human populations (i.e. higher effort in the West Coast than South Coast). **Effort trends provide no evidence that unacceptable stock depletion may have occurred.**
Catch rates (Herring Attachment 3)	With the exception of the South Coast Trap Net Fishery which specifically targets Australian herring, all other commercial fisheries are non-specific (i.e. multi species) fisheries. The dynamic nature of the gear used to catch Australian herring, along with the capacity of the fishers to adjust their activity and target species in line with market demand, compromises the ability to infer relative abundance from catch rate data. **Catch rate trends provide no evidence that unacceptable stock depletion may have occurred.**
Vulnerability (Productivity Susceptibility Analysis [PSA]) (Herring Attachment 4)	Australian herring are relatively short-lived (maximum recorded age 12 years) and fast growing. Stock structure- The most parsimonious stock structure is a single genetic stock with three management units – West Coast of WA, South Coast of WA and South Australia (Herring Attachment 4A). There is no evidence of the occurrence of mature (breeding) fish, or any significant commercial or recreational fishing for herring in waters east of the Bremer Bay region. Growth and maturity - There are persistent growth differences between South Coast and West Coast fish apparent through years (South Coast length > West Coast length for a given age) (Herring Attachment 4Bi). Available estimates of size at maturity, based on data from 2009-2011, show that females attain maturity at a larger size along the South Coast (L_{50} = 219.6 mm TL) compared to the West Coast (L_{50} = 194.1 mm TL). Explorations of data from individual years indicate that the observed size at maturity can vary by up to 20 mm among years (Herring Attachment 4Bii). This may be at least partly influenced by the challenges in obtaining representative maturity data for herring in each Bioregion due to the relatively short spawning period. This is further complicated by the apparent changes in sex ratio among years and among samples, even those collected on fine temporal scales (weeks) (Herring Attachment 4Biii). PSA – For the vulnerability assessment, two time periods were considered (pre and post management changes, which were implemented in 2015) and both WA management areas assessed separately (South Coast and West Coast) (Herring Attachment 4C). Based on available information on the biological characteristics of Australian herring, the productivity score was 1.43 (Herring Attachment 4C). Prior to changes in management, the PSA indicated a medium relative risk to the stock in the West Coast (PSA = 67) and South Coast (PSA = 75) Bioregions and a low relative risk after the management changes (both West Coast and South Coast management units had PSA = 83). **This level of vulnerability would indicate that while an unacceptable level of stock depletion is possible for this species, there is a low risk after management changes**.

Length composition (1 and 2 management units) (Herring Attachment 5)	Length composition provides evidence of variable recruitment among years. However, length composition data show that many samples are biased towards female fish, particularly in recreational samples. This may be a result of differential growth, schooling by size (and therefore sex) or greater catchability of females on baited hooks. **Length composition trends provide no evidence that unacceptable stock depletion may have occurred. This may be a result of the schooling by size by the species and the highly selective nature of the fishing methods used when collecting samples.**
Age composition (1 and 2 management units) (Herring Attachment 5)	Age compositions provided clear evidence of variable recruitment between years. Strong year classes recruiting as 2 year olds in 2009/10 and 2014/15 into the fishery were easily tracked through samples from consecutive biological years. The variability in recruitment may influence the availability of older fish (> 6 years of age) in samples. While age 1+ fish are uncommon in catches by both commercial and recreational fishers on the west coast (Herring Attachment 5, Figure 1 and 2), they are more often retained on the south coast, particularly by the commercial sector. Sampling from some sectors and regions may not be representative of the wider stocks (e.g. South Coast recreational age samples). When plotted by sex, age composition data show that many samples were biased towards females, particularly in recreational samples. This may be a result of differential growth and a preference for retaining larger fish, schooling by size (and therefore sex) and that females may be more available on baited hooks. **Age composition trends suggest that some truncation of the age distribution occurred in the past. However, strong recruitment in more recent samples provides evidence of recovery.**
Fishing mortality (*F*) (Herring Attachment 6)	Due to the biased sex ratios, catch curve analyses of age composition data were based on female samples only. Estimates of fishing mortality (F) were calculated by subtracting the assumed Hoenig estimated of natural mortality (M) for herring (maximum age =12, M=0.4 year^{-1}) from each catch curve estimate of Z (i.e. $F = Z - M$) The F/M ratios based on estimates from the method that considers variable recruitment (Model 5) ranged from 1.36 for the south coast recreational fishery to 2.20 for the west coast commercial fishery (Herring Attachment 6, Table 1). Estimates of selectivity produced by this model (Model 5) were relatively similar across the regions and sectors, suggesting that 50% of females become vulnerable to fishing by an age of 2.5-2.9 years. **Estimates of fishing mortality varied among methods as a result of data issues, evidence of strong recruitment events and consequently breaching the equilibrium assumption. Although not in equilibrium, relatively strong recruitment in samples from 2009/10 and 2014/15 provides evidence of recovery.**

Index of spawning stock biomass (Spawning Potential Ratio [SPR]) (Herring Attachment 7)	Length Based – Analyses demonstrated that estimates of SPR and relative spawning biomass were sensitive to input parameters used to describe selectivity. As a result, estimates of SPR were generally higher for the West Coast management unit than the South coast management unit, albeit with wide confidence intervals. Age based analyses demonstrated that estimates of SPR and relative spawning biomass were also sensitive to input parameters used to describe selectivity; spawning potential reduced when selectivity was assumed to occur at a younger age, such as appears to occur in the South Coast management unit. In addition to these uncertainties and in ability to satisfy equilibrium assumptions of analyses, estimates of SPR contained wide confidence intervals. **Estimates of SPR were strongly influenced by selectivity and maturity ogives for both length and age based methods, and both approaches produced estimates with wide confidence intervals.**
Stock Reduction Analyses (Catch-MSY methods) (Herring Attachment 8)	Catch MSY analyses undertaken on both management units suggested that catches exceeded estimated MSY the 1980s and 1990s in both management units. Simulations showed increasing biomass in both management units from about 2006-2008, which would continue under current arrangements with more than 50% of trajectories exceeding 30% unfished biomass in recent years. There were large uncertainties associated with the outputs for both management units. **Catch-MSY analyses suggested depletion of the stock in both management units, especially in 1980s and 1990s. Recent estimates of biomass suggest increasing trends in biomass that began in about 2008 in both management units and that would continue under current management arrangements. The cessation of G-trap fishing and reductions in recreational bag limits since 2015 has reduced fishing mortality and should allow the stock to increase although it is too soon to determine this potential effect. Catch-MSY results suggest that biomass will increase in both management units under current management arrangements as well as under some scenarios of increases in total catches.**
Simulation Modelling (Herring Attachment 9)	Simulation trials using the combined catches from all regions provided support that the abundance of the biological stock is expected to be at or above the target level if current catches are maintained for a further five years. **Simulation modelling results suggest that biomass will increase under current management arrangements and low catches. However, accurate predictions were not possible because of data limitations and the complex dynamics of the Australian herring population.**
Evaluation of Integrated model (Herring Attachment 10)	A sex- and age-structured integrated assessment model fitted separately to data for the west coast and south coast management units lacked sufficient information to allow reliable estimation of biomass and mortality trends. This model, given current available data, was unable to estimate current stock status. **The results produced by modelling were highly uncertain, reflecting in part, lack of informative data, so could not be used to assess current status. Model projections provided indications that if catches remain at the current low levels over the next few years the spawning biomass would increase rapidly on the south coast (to above the target by 2021) and more modestly on the west coast (to above the threshold by 2021).**

2. Objective 3. Determine current Australian herring stock status including scientific advice to management

2.1 Risk Assessment

All of the lines of evidence outlined above were combined within the Department's ISO 31000 based risk assessment framework (Fletcher, 2015; Appendix 1) to determine the most appropriate combinations of consequence and likelihood to determine the overall current risk status of the stock. All attendees discussed all lines of evidence before agreeing on the following risk analysis.

Risk matrix					
Consequence (stock depletion) Level	Likelihood Level				**Risk Score**
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)	
C1 Minimal (above target)	X				1
C2 Moderate (above threshold)				X	8
C3 High (below threshold)		X			6
C4 Major (below limit)	X				4

C1 (Minimal Stock Depletion): L1. Overall risk score - 1.

A range of analyses show an increase in biomass in recent years (post 2015 G trap closure) suggesting that some level of biomass reductions had occurred. Models showed increasing biomass in many projections. The species is highly productive; however, SPR estimates (length or age based) remain highly uncertain because of variation between samples. Nevertheless, very few fish from any area sampled have been close to the maximum age of the species.

Thus, there was a remote likelihood that the status is currently above target levels or will be so within five years. Data sources lack information and models remain highly uncertain.

C2 (Moderate Stock Depletion): L4. Overall risk score - 8.

A range of analyses and models showed an increase in biomass in recent years (since mid-2000s) and in immediate out-years. The species is relatively productive (PSA) and SPR estimates (length and age based) show increases in recent years, albeit with high uncertainties.

All assessments undertaken show increasing trends in biomass since mid-2000s. Catch based stock reduction models resulted in a high probability for the stock to be in this category (moderate stock depletion).

Thus, it was likely that the status is, or will be within five years, between threshold and target levels. Current data sources contain limited information and models remain highly uncertain.

C3 (High Stock Depletion): L2. Overall risk score - 6.

A range of analyses and models showed an increase in biomass in recent years and in immediate out-years. The species is relatively productive (PSA) and SPR estimates (length and age based) show increases in recent years, albeit with high uncertainties (due to data issues and equilibrium assumptions).

All assessments undertaken show increasing trends in biomass since mid-2000s. Catch-based stock reduction models resulted in a high probability in this category.

There is a possibility that the current status is in this category, mainly a result of the uncertainties in data inputs and model outputs. However, it was unlikely to remain within this category in the next five years under current management settings due to the productivity of the species.

C4 (Major Stock Depletion): L1. Overall risk score - 4.

Analyses and model outputs suggested it was plausible for the stock to be in this category, although data and model outputs remain highly uncertain. Assuming catch declines (post 1992) are entirely market driven and not a result of depletion, there is only a remote possibility that the stock is below the limit level using currently available lines of evidence. Additionally, a majority of model outputs predict stock increases as a result of the high productivity of the species (and the recent management settings, including the G-Trap closure and recreational changes in 2015, may assist with this).

Thus, there was a remote likelihood that the status is, or will be, below limit levels. Data sources lack information and models remain highly uncertain.

2.2 Current Risk Status of the Stock

The current risk score was estimated to be MEDIUM generated by the combination of C2 and L4. This risk level reflects the productivity of the species and the management arrangements introduced in 2015 that have allowed for increasing biomass. It is likely that stock biomass will continue to increase under current management arrangements and even under a few scenarios of modestly increased catch.

3. Objective 4. Recommended monitoring programs or assessment methodologies that could be adopted that would reduce uncertainties in future Australian herring stock status and sustainable catch levels

Workshop attendees discussed current data limitations and future monitoring and assessment needs for Australian herring. Attendees also proposed the future schedules for sampling and assessment. These are listed below. Priority projects (identified by three asterisks ***) and those already in progress (identified by one asterisk *) were identified by workshop attendees.

Objectives:

- Stock status
- Sustainable catch levels
- Rebuilding rates at different catch levels

Monitoring

Commercial catch and effort -

- More fine scale logbook (daily); releases from nets(?); searching v catching; catch & discard *(Proposed; timing dependant on new Act)
- Electronic reporting *(Proposed; timing dependant on new Act; SA proposed to roll e-catch out to herring)
- Drivers of seasonal catch (e.g. markets); Economics – * SA has some information.
- Review of industry data.

Recreational catch and effort

- Bioregional estimate of herring catches (iSurvey being expanded to generate estimates of shore-based catches) (*Ongoing anyway)
- Registration/licence - complete frame

Catch reconstruction ***

- Important for stock reduction analyses
- Other assessment models

Age & length composition data of the fisheries -

- Design representative collection of age and length to use in assessments (desktop)***
    - Commercial sampling
    - Rec frame collection - review – spatial analyses (etc.).
- Value add (sex ratio, maturity/reproductive stage)
- Victorian data?

Stock indices

- Given complexity of the stock makes it expensive
- From
    - Breeding stock (e.g. CPUE), Fishery independent and/or fishery dependent;
    - Recruitment, unlikely in short term
- Improved catch and effort collected may possibly lead to improved standardisation

Distribution/Movement

- Traditional tagging – 2-3% returns unlikely to generate robust information. Any tag study needs appropriate design.
- Otolith chemistry and morphometrics (location signature, Lag/correlations; preliminary work shows potential; part of ongoing sampling design (e.g. length and age collection)* (synergies with age-length sampling).
- Biological parameters – variations between and within areas (space and time); noise or 'real' difference; Further investigation on existing commercial and recreational data***
    - Growth
    - Maturity

Sex ratios – important while collecting length and age data.*

- Differential sex ratios between sectors and time.
- Real?
- Finer temporal scale.
- Overall v temporal variability.

Selectivity – (Note, SA has undertaken work in this area) – No need for additional work except spatial structuring.

- Selectivity vs availability
- Empirical tests (for commercial nets) – refer to SA information; Note, G traps and beach seine nets designed to catch all herring.
- Recreational hook selectivity – difficult.

Environmental influences –

- SST, Current strengths and directions, Fremantle sea level, Albany sea level (*Ongoing)
- Account for anomalies or correlations (with lags).
- Habitat preferences/changes; modelling

Predation (additional mortality) – *See comments for West Australian salmon

- West Australian salmon (diet shift from pilchards to herring)
- Changes in total herring mortality (longevity).

Assessments

Catch only (SRA/Catch-MSY) –

- Method is based on catch data with no index of relative abundance and outputs are therefore highly uncertain.
- Interpolation of recreational catches and (WCRL) bait for sensitivity analyses.
- Projections (and uncertainties) under different constant catch level scenarios

Catch and age (SRA) –

- As above
- Include time series of age data in to reduce uncertainty.
- Need to include representative age structure, selectivity and assumptions around sex ratio (or use females only)

Age and Length SPR –

- Need to be aware of equilibrium assumption
- Needs/estimate selectivity functions and biological parameters (maturity etc.)
- Methods could be extended to overcome some equilibrium assumptions
- Scenarios of SPR under a range of *F*s and *F/M*s compared to Biological Reference Points

Catch rates –

- Attempting to generate an index of abundance
- Commercial - If finer temporal scale 'logbooks' rolled out, then value in reanalysing.
- Recreational – shore based surveys generating a series of comparable catch rates (retained plus discarded). Caution with extrapolating beyond metropolitan area.
- Recreational – Boat based catch rates (iSurvey) to be considered too.

Integrated Model – catch, age, catch rate, length etc. –

- An index of abundance would be useful. Extending age sampling may provide an alternative to catch rate-based index.
- Projections (and uncertainties) under different constant catch level scenarios.
- Simulation model – could inform how much more data would be needed.
- Explore 'Fleets as areas' approach – 'borrow' information between bioregions, estimate selectivity by fleet.

Operating model

- Refine model to better inform simulation model (using above additional data sources).

3.1 Next Assessment

As the stock is likely to be above the threshold, and rebuilding is underway, the next assessment is scheduled for 2021 (see table below). However, if significant events occur in interim (e.g. massive increases in catches, structural changes in fisheries, etc.), then schedule can be reviewed.

Year	Comment
2017	2017 Assessment
2018	Sample
2019	Sample
2020	Sample
2021	2021 Assessment

4. Objective 5. Develop Recommendations for Monitoring and Assessment Approaches Suitable to Determine Sustainable Catch Levels for West Australian Salmon

A DPIRD weight of evidence assessment for West Australian salmon was presented and discussed at the workshop on the final day (Appendix 5). The current stock status was concluded to be sustainable and likely to be above the target reference point for biomass, with a low risk to the ongoing sustainability of the stock. This is a result of the very low levels of recent and current catches.

Workshop attendees discussed current data limitations and future monitoring and assessment needs for West Australian salmon. Attendees also proposed the future schedules for sampling and assessment. These are listed below. Priority projects (identified by three asterisks ***) and those already in progress (identified by one asterisk *) were identified by workshop attendees. Note that South Australia is already developing a FRDC EOI for West Australian salmon work.

Objectives:

- Stock status
- Sustainable catch levels
- FRDC EOI

Monitoring

Commercial catch and effort -

- More fine scale logbook (daily); releases from nets; searching v catching; catch & discard *(Proposed; timing dependant on new Act)
- Electronic reporting *(Proposed; timing dependant on new Act; SA proposed to roll e-catch out to West Australian salmon (SA-MSF))
- Drivers of seasonal catch (e.g. markets); Economics – * SA has some information.
- Review of industry data.

Recreational catch and effort

- Bioregional estimate of catches (iSurvey being expanded to generate estimates of shore-based catches) (*Ongoing anyway)
- Value of Registration/licence to catch and effort- complete frame (expand in report – noting beyond scope of workshop).

Catch reconstruction ***

- Investigate any evidence for historical 'bait' catches (e.g. pre 1970s like for herring)
- Important for stock reduction analyses
- Other assessment models

Age & length composition data of the fisheries

- Review collection of age and length to use in assessments for representativeness (desktop)***
  - Commercial sampling
  - Commence recreational frame collection.
- Value add (sex ratio, maturity/reproductive stage)
- Victorian and Tasmanian data? Value?

Stock indices

- Given complexity of the stock makes it expensive
- From
  - Breeding stock (e.g. CPUE), Fishery independent and/or fishery dependent;
  - Recruitment, unlikely in short term
- Improved catch and effort collected may possibly lead to improved standardisation
- Review previous aerial survey data***

Distribution/Movement

- Traditional tagging – 2-3% returns unlikely to generate robust information at this stage. Any tag study needs appropriate design.
- Otolith chemistry and morphometrics (location signature, Lag/correlations; preliminary work shows potential; part of ongoing sampling design (e.g. length and age collection)* (synergies with age-length sampling)).
- Biological parameters – variations between and within areas (space and time); noise or 'real' difference; Further investigation on existing commercial and recreational data***
  - Growth
  - Maturity

Sex ratios – important while collecting length and age data.*

- Differential sex ratios between sectors and time.
- Real?
- Finer temporal scale.
- Overall v temporal variability.

Selectivity – (Note, SA has undertaken work in this area) – No need for additional work except spatial structuring.

- Selectivity v availability
- Empirical tests (for commercial nets) – refer to SA information; Note, nets designed to catch all West Australian salmon.
- Recreational hook selectivity – v. difficult.

Environmental influences –

- SST, Current strengths and directions, Fremantle sea level, Albany sea level (*Ongoing)
- Account for anomalies or correlations (with lags).
- Habitat preferences/changes; modelling

Predation (additional mortality) – See comments for Australian herring

- West Australian salmon (diet shift from pilchards to herring) (Linked to biological sampling)

Assessments

Catch only (SRA) –

- Method is based on catch data with no index of relative abundance and outputs are therefore highly uncertain.
- Interpolation of recreational catches and (WCRL) bait for sensitivity analyses.
- Projections (and uncertainties) under different constant catch level scenarios

Catch and age (SRA) –

- As above
- Include time series of age data in to reduce uncertainty.
- Include recent representative age structure, selectivity and assumptions around sex ratio (or use females only)

Age and Length SPR –

- Need to be aware of equilibrium assumption
- Needs/estimate selectivity functions and biological parameters (maturity etc.)
- Methods could be extended to overcome some equilibrium assumptions
- Scenarios of SPR under a range of *F*s and *F/M*s compared to Biological Reference Points

Catch rates –

- Attempt to generate an index of abundance
- Commercial - If finer temporal scale 'logbooks' rolled out, then value in reanalysing.
- Recreational – shore based surveys generating a series of comparable catch rates (retained plus discarded). Caution with extrapolating beyond metropolitan area.
- Recreational – Boat based catch rates (iSurvey) to be considered too.

Integrated Model – catch, age, CR, length etc. –

- An index of abundance would be useful. Continue age sampling to provide an alternative to catch rate-based index.
- Projections (and uncertainties) under different constant catch level scenarios.
- Simulation model – could inform how much more data would be needed.
- Explore 'Fleets as areas' approach – 'borrow' information between bioregions, estimate selectivity by fleet.

Operating model

- Refine model to better inform integrated model (above).

4.1 Next Assessment

The current assessment indicates a low risk to the sustainability of the stock. As a result, the next assessment is scheduled for 2022 (see table below). However, if significant events occur in interim (e.g. massive increases in catches, structural changes in fisheries, a successful FRDC proposal by SA/WA, etc.), then schedule can be reviewed.

Year	Comment
2016	2016 Assessment (DPIRD)
2017	
2018	
2019	Sample
2020	Sample
2021	Sample
2022	2022 Assessment

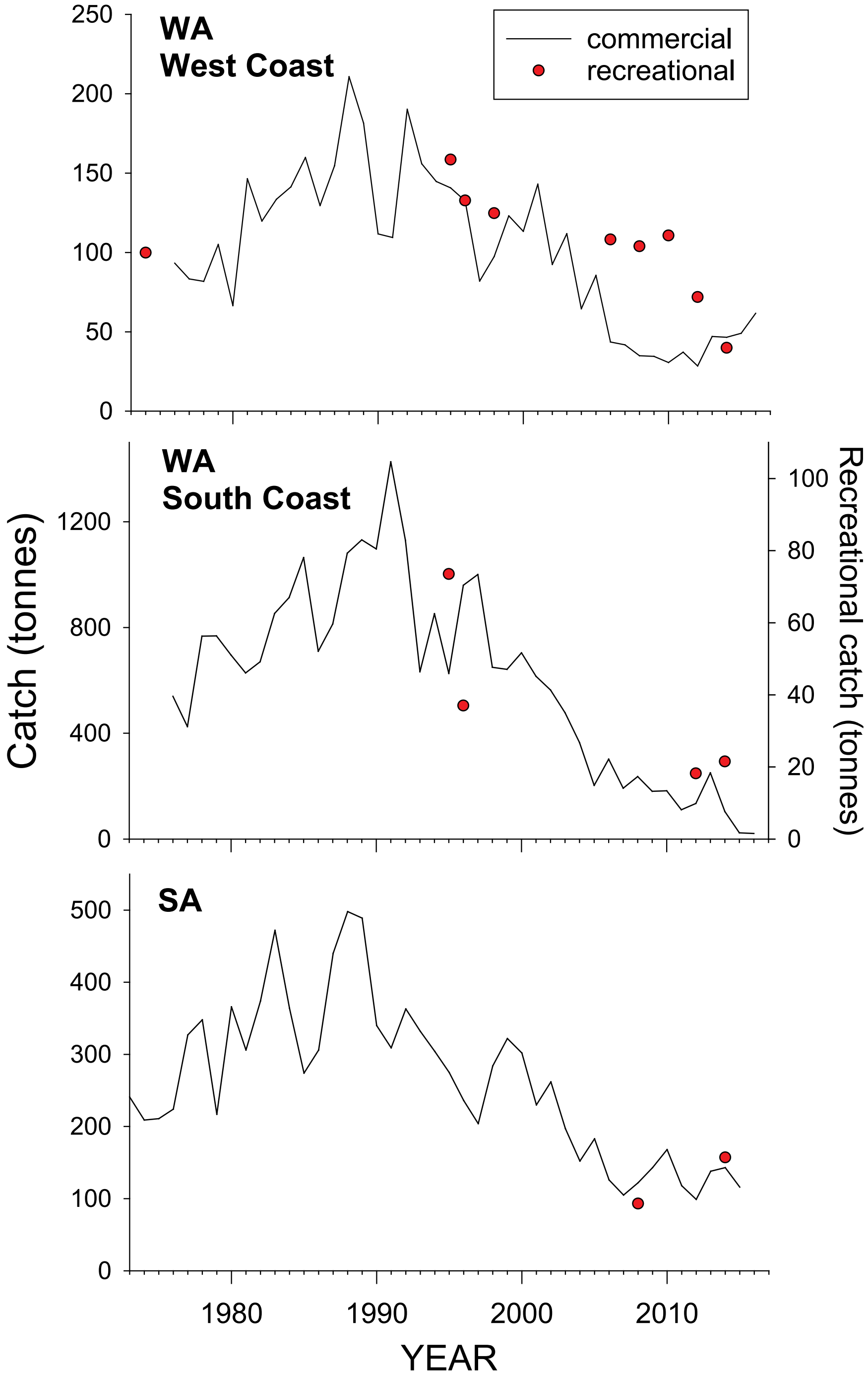
5. Herring Attachment 1. Western Australian Catches.

In all 3 management areas (WCB, SCB and South Australia) the commercial catch peaked about 1990 and then declined until about 2010. After 2010, the WCB catch then increased, while the SCB declined further and the SA catch remained stable. Commercial catch trends are strongly affected by changes in effort (including no. of active vessels and degree of targeting) in the major fisheries. For example, SCB catch declines largely reflect declines in targeting by the Trap Net Fishery (and the closure of this fishery in 2015 onwards), while the increasing WCB catch since 2010 reflects an increase in targeting of herring (and decrease in targeting of other species) by the CSFN Fishery. The stabilising of catches in SA over recent years also coincided with an increase in targeting of this species.

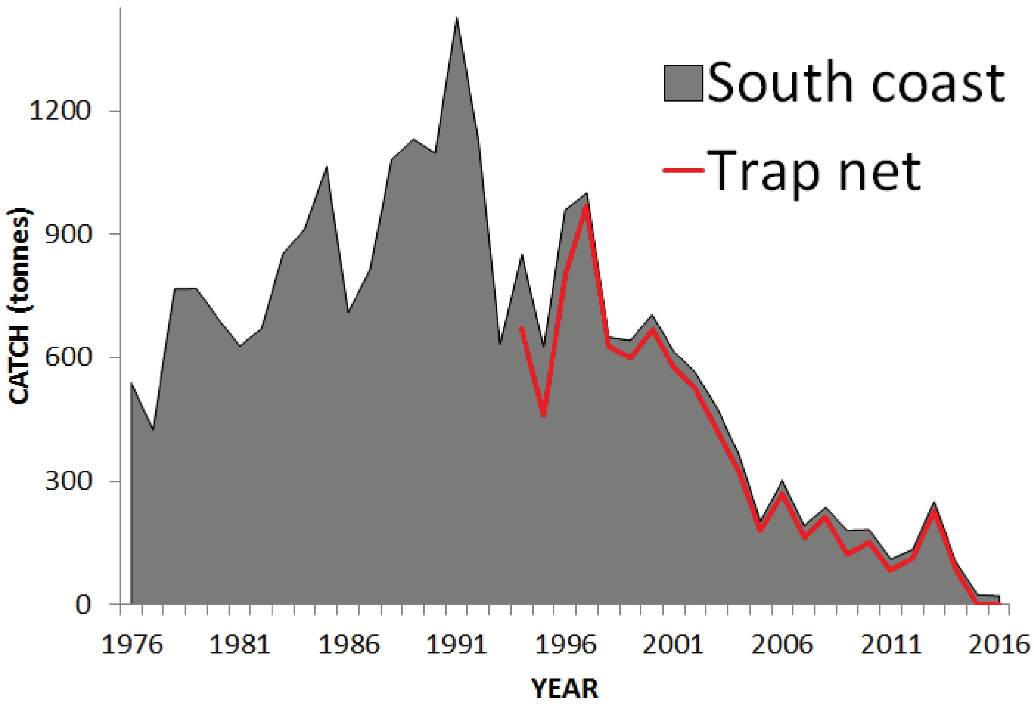
Estimates of recreational catch in each area are uncertain and are restricted to survey years (Herring Attachment 1, Catch Figure 1). In the WCB and SCB, the most recent (post-2010) bioregion-wide catch estimates are lower than those in the mid-1990s. Similarly, in SA, the recent state-wide recreational catches (Herring Attachment 1.Figure 1) are lower than those estimated in 2000/01 (not shown in Figure 1). Within the WCB, i) catches by boat-based fishers declined between surveys in 1995/6, 2011/12 and 2013/14 (Herring Attachment 1.Catch Table 1) and ii) catches by shore-based fishers declined between 2010 and 2016 (Herring Attachment 1.Catch Table 2).

In all 3 management areas (WCB, SCB and South Australia), commercial and catches followed a broadly similar trend: declining from ~1990 to ~2010, then stabilising or increasing in subsequent years (Catch Figure 1). The commercial catch declines are largely attributable to changes in effort, but could also be partly driven by fish availability. Recreational catch trends are not readily attributable to changes in effort and so are more likely to reflect changes in fish availability.

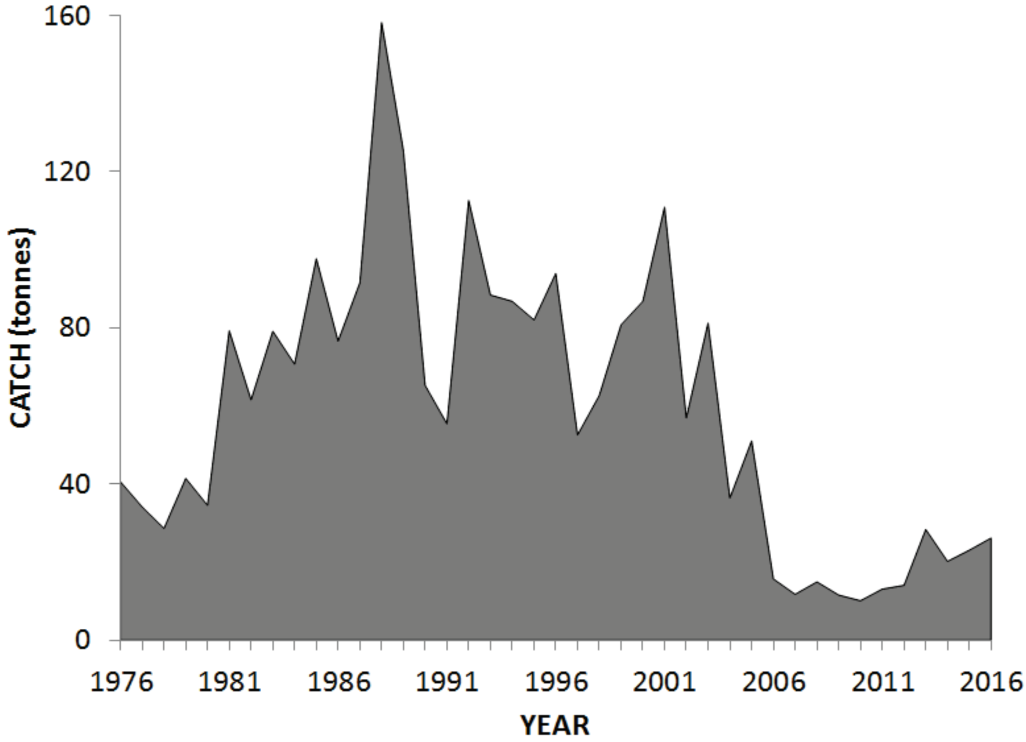
Catch trends provide evidence that unacceptable stock depletion may have occurred.



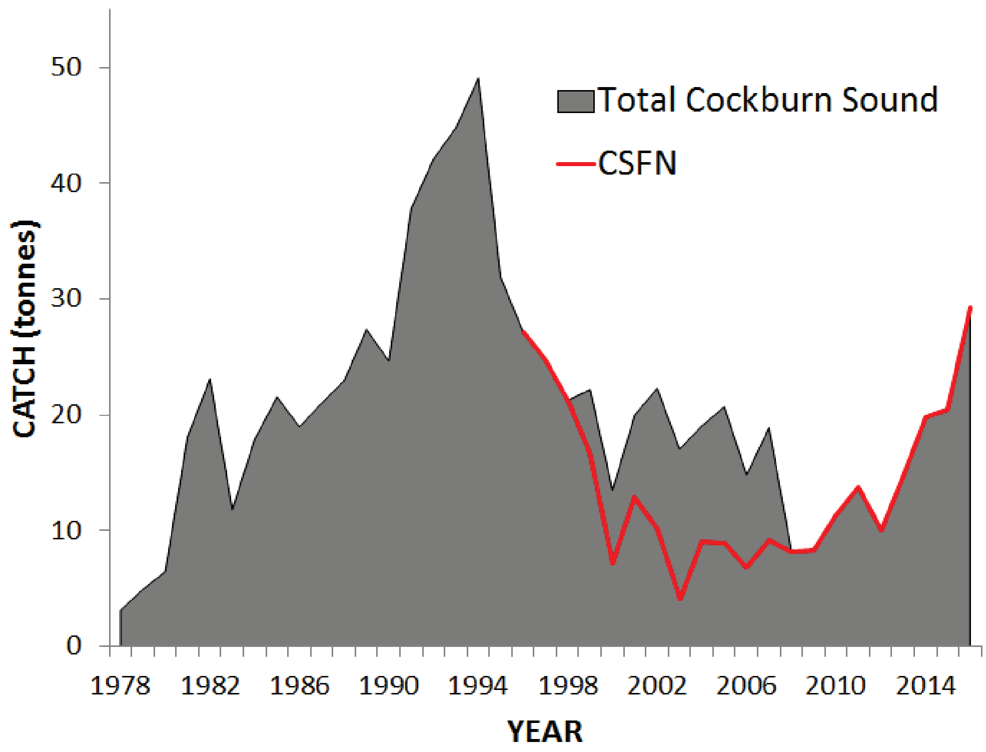
Herring Attachment 1. Catch Figure 1. Annual commercial catches (black line) and estimated recreational catches in years when surveys are conducted (red dots) of Australian herring in each management area. Note: 2000/01 National Survey estimates are not shown.



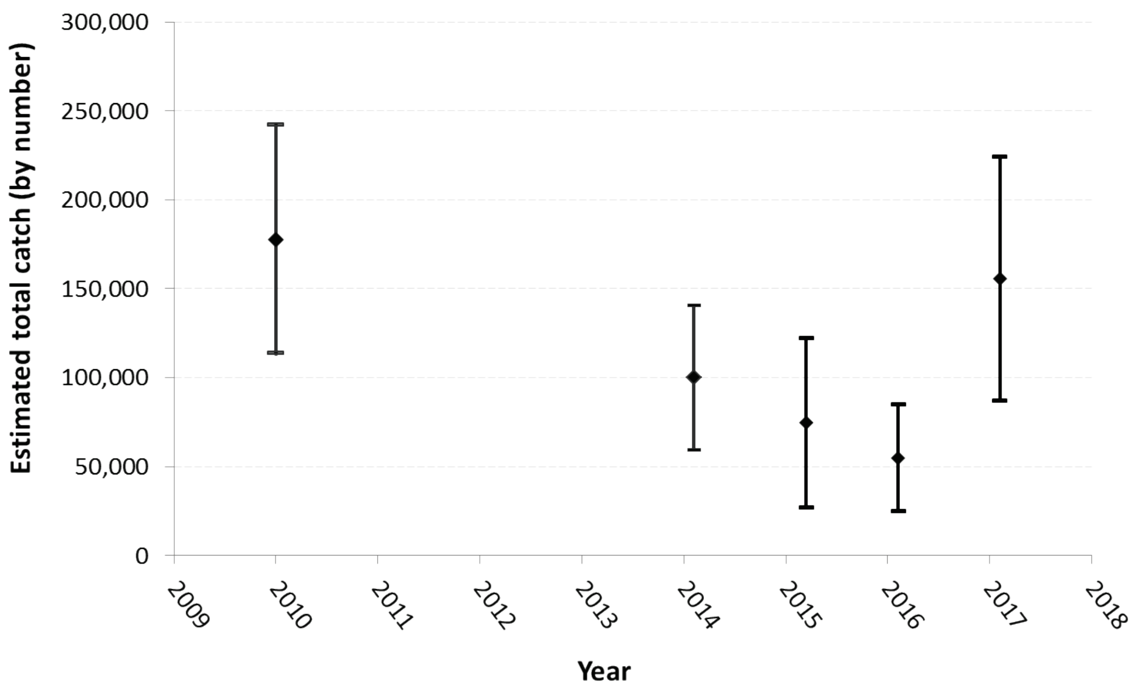
Herring Attachment 1. Catch Figure 2. Annual commercial catch of Australian herring by Trap Net Fishery 1994-2014 (red line) and total South Coast Bioregion ocean landings of herring (grey) 1996-2016.



Herring Attachment 1. Catch Figure 3. Annual commercial catch of Australian herring by South-west Beach Seine Fishery (operating in Bunbury/Busselton area, catches taken by beach seine). Note, the greatly expanded y-axis scale relative to Figure 2.



Herring Attachment 1. Catch Figure 4. Annual commercial catch of Australian herring by Cockburn Sound Fish Net Fishery 1996-2016 (red line) and all landings of herring in Cockburn Sound (grey) 1978-2016.



Herring Attachment 1. Catch Figure 5. Estimated total recreational catch (by number) of Australian herring retained by shore-based fishers from April –June in Perth metro zone surveys.

Herring Attachment 1. Catch Table 1. Boat-based recreational fishing surveys

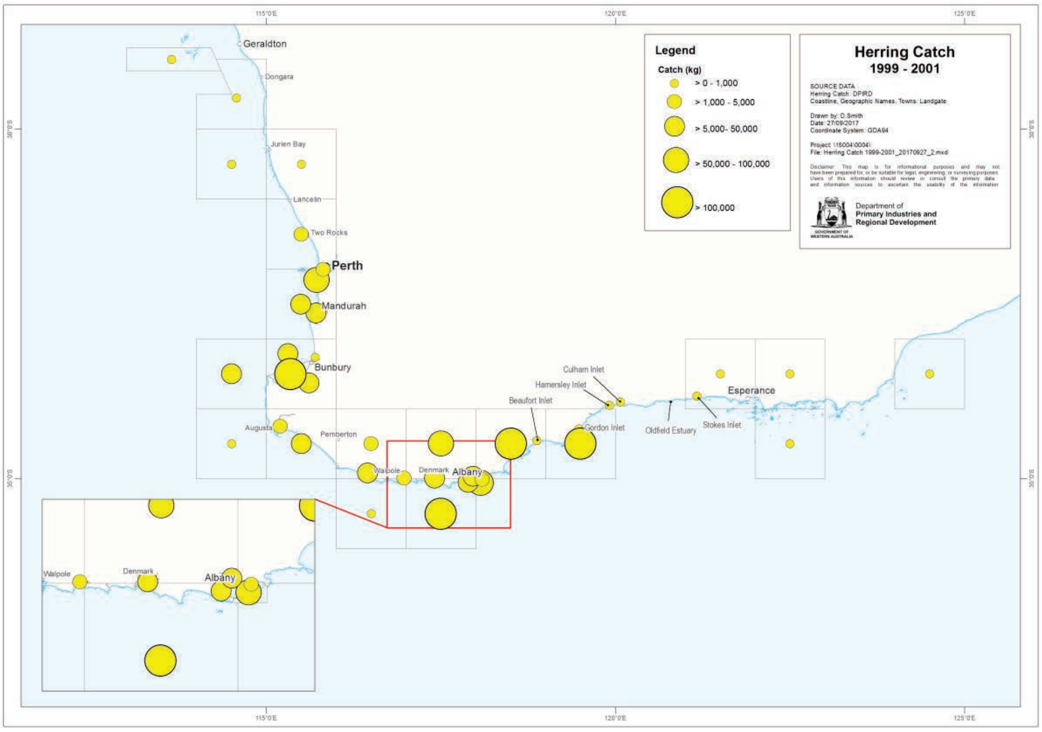
Survey method	Spatial scope	Temporal scope	Catch estimates (Herring)
Phone-diary	WCB & SCB	2015/16	-
Phone-diary	WCB & SCB	20 13/14	173,408 SE± 15,113 (total)
Phone-diary	WCB & SCB	2011/12	249,721 SE± 21,238 (total)
Access point	WCB	2005 /06	288,392 SE± 14,658
Access point	Oyster Harbour & Walpole\Nornalup Inlets	2002/03	**Wpole/Nornlp** (9,863 SE± 3,101) **Princess RH** (4,925 SE± 1,192) **Oyster H** (13,599 SE± 3,004)
Phone-diary (S & B)	**State-wide**	**2000/01**	**3,873,411 SE± 339,084**
Access point	Peel Harvey Estuary	1998 /99	21,553 SE± 1,550
Access point	Swan-Canning Estuary	1998 /99	843 SE± 152
Access point	Leschenault Estuary	1998 /98	822 SE± 454
Access point	WCB	1996/97	416,657 SE± 26,621
Roving creel	WCB & SCB (combined)	1994/95/96	**1994** (455,900) **1995** (182,924) **1996** (176,442)
Roving	Peel-Harvey Estuary & Wilson Inlet	1994 /95	-

Herring Attachment 1. Catch Table 2. Shore-based recreational fishing surveys.

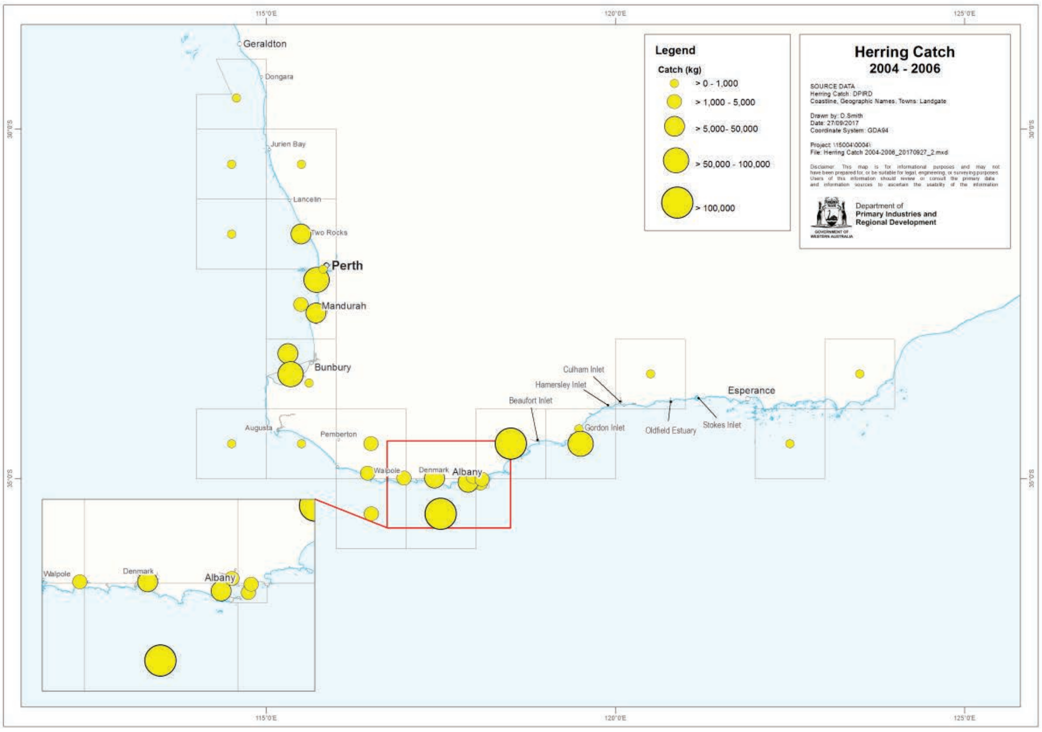
Survey method	Spatial scope	Temporal scope	Species	Total catch estimates (Herring)
Roving creel	Perth metro	2014 –17 (Feb- Jun)	Finfish	**2014** (100,064 SE± 40,727) **2015** (74,732 SE± 47,528) **2016** (54,782 SE± 30,095) **2017** (155,668 SE± 68,577)
Roving creel	Perth metro	2010 (Apr-Jun)	Finfish	177,653 SE± 64,316
Roving creel	Oyster Harbour & Walpole\Nornalup Inlets	2002/03	All Aquatic	**Wpole/Nornlp** (774 SE± 567) **Princess RH** (1,935 SE±1,232) **Oyster H** (Insig)
Roving creel	Peel Harvey Estuary	1998 /99	All Aquatic	25,989 SE± 5,066
Roving creel	Swan-Canning Estuary	1998 /99	All Aquatic	831 SE± 288
Roving creel	WCB and SCB	1994 /95/96	Finfish	**1994** (779,456) **1995** (668,909) **1996** (189,883)
Roving creel	Leschenault Estuary	1998 /98	All Aquatic	Negligible
Roving creel	Perth metro and Rottnest Island	1973	Herring	711,000 (gross estimate)

6. Herring Attachment 2. Australian Herring Catch Distribution Data.

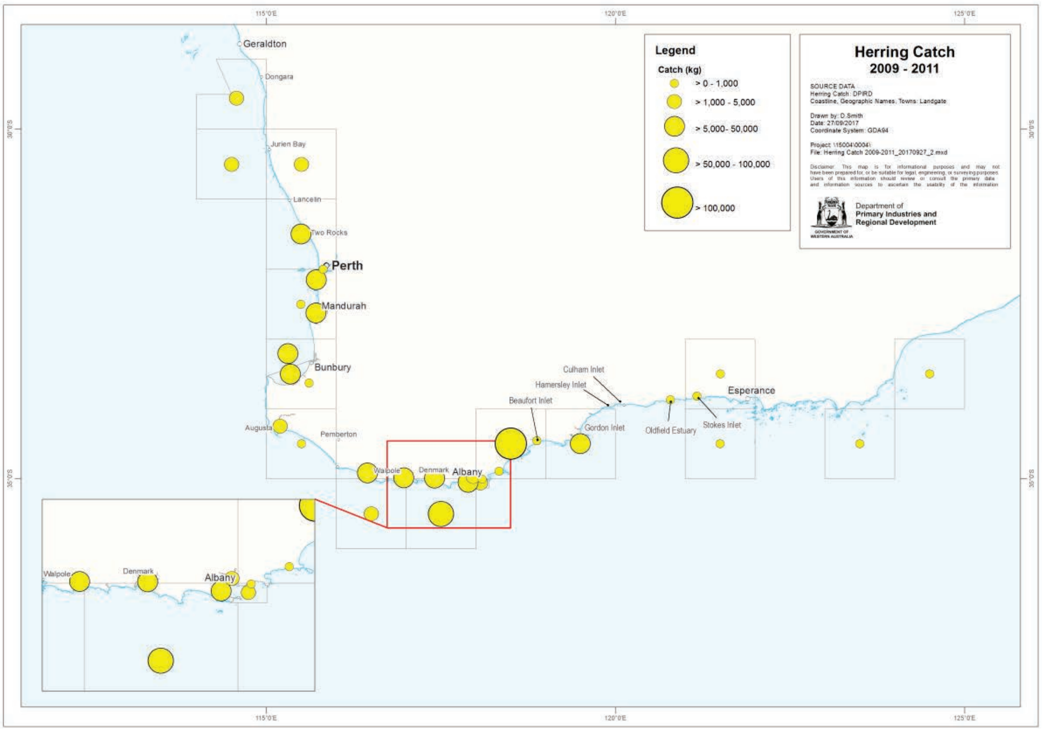
Herring Attachment 2A. Western Australia



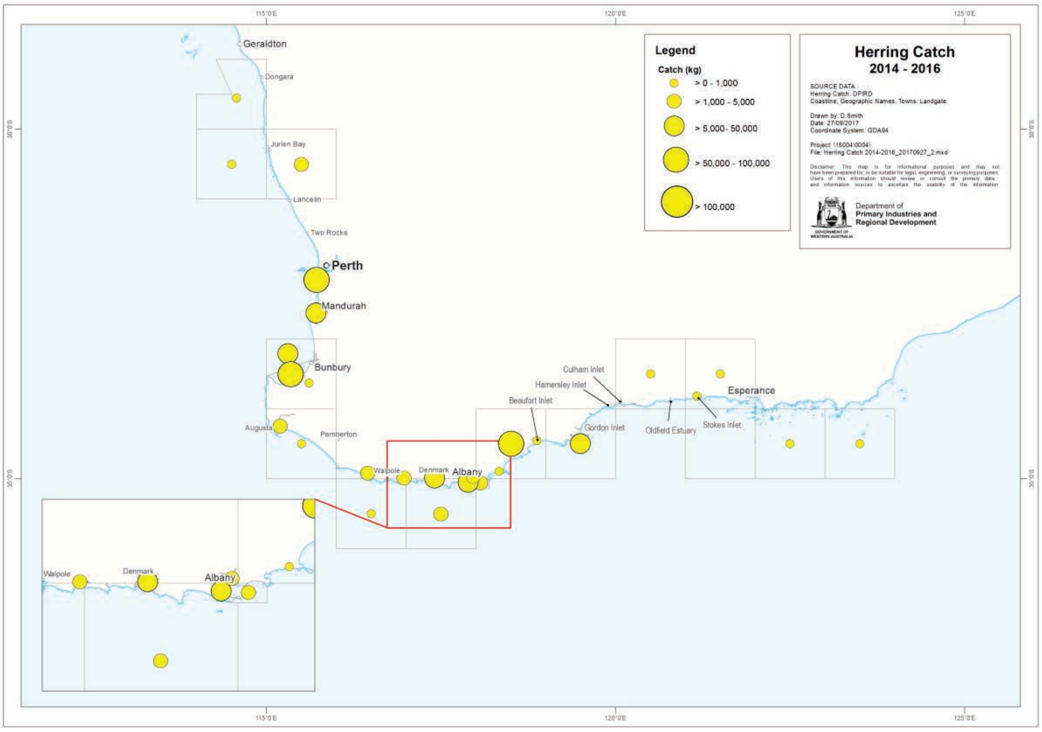
Herring Attachment 2A. Figure 1. 1999-2001



Herring Attachment 2A. Figure 2. 2004-2006

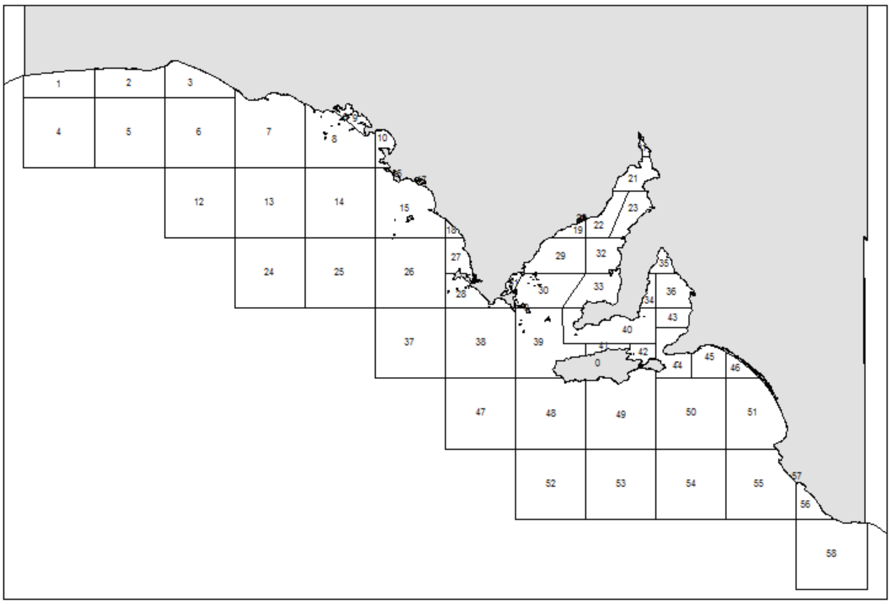


Herring Attachment 2A. Figure 3. 2009-2011

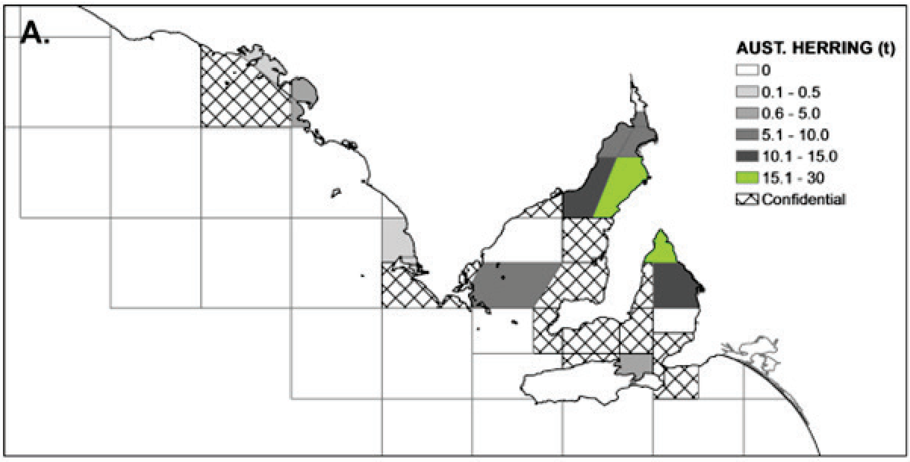


Herring Attachment 2A. Figure 4. 2014-2016

Herring Attachment 2B. South Australia



Herring Attachment 2B. Figure 1. Commercial marine fishing areas (reporting blocks)



Herring Attachment 2B. Figure 1. Distribution of total catch of Australian herring 2016

7. Herring Attachment 3. Australian Herring Commercial Catch and Effort Data.

7.1 Background

There is considerable diversity in the dynamics of the Australian herring fisheries throughout the Western Australian coast. The fisheries in each bioregion are effectively independent due to different market demands and other local factors. Despite these differences, long-term trends in the catch rates are relatively similar (Smith et al. 2013).

7.2 Objectives

- To update long term commercial catch rates for each of the 'independent' fisheries to include 2016/17.
- Compare trends between four selected fisheries that are largely uncompromised by management intervention, fisher dynamics and market demands.

7.3 Method

Annual catch rates for each Western Australian fishery was calculated as mean daily catch ± 95% CI during the peak fishing season (November –April) from 1975/76 to 2016/17. Fishing effort outside of this season was negligible. Historic fishers, who have exited the fishery pre-1985 were identified in the analysis.

Annual catch rates for herring in South Australia was calculated as a mean daily catch ± 95% CI for the hauling net sector.

7.3.1 Fisheries

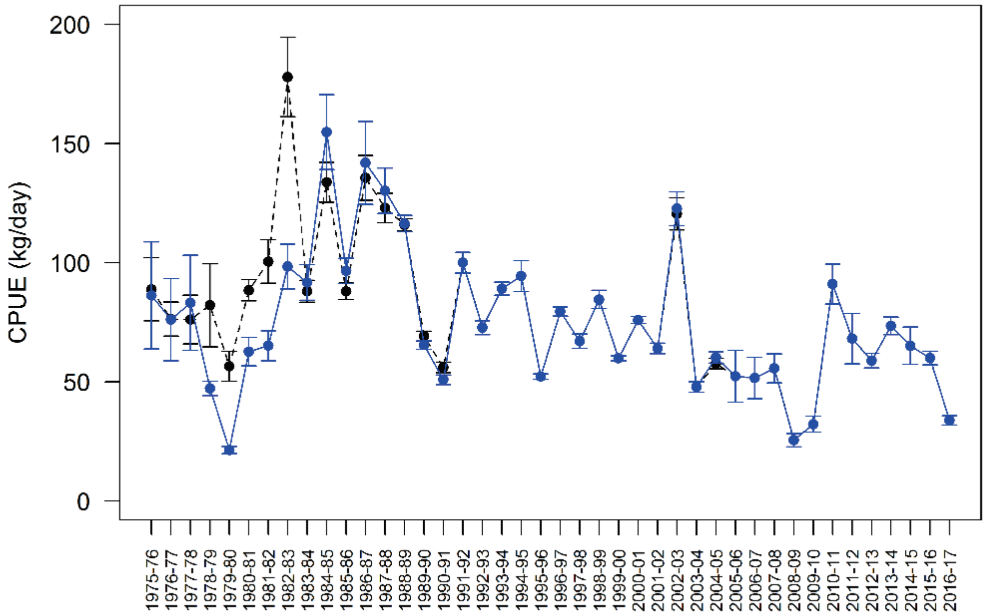
1. South Coast Trap Net Fishery

The catch rate of the trap net fishery can be influenced by many factors, in addition to the abundance of Australian herring, and so may be an inaccurate index of the abundance of Australian herring (see Smith et al. 2013).

2. Geographe Bay Bunbury Seine Net Fishery.

Average annual catch rates peaked above 150 kg/boatday in the mid-1980s declining to below 50 kg/boatday in 2008/09. During this time catch rates were highly variable, regularly fluctuating by approximately 50% over a two-year period. From 2000 onwards a number of management arrangements were implemented to reduce fishing capacity in the Western Australian Salmon Fishery which had flow on ramifications to the broader seine net fishery (including buy-outs and netting closures). Since 2009/10 average catch rates increased to a contemporary peak of approximately 80 kg/boatday in 2010/11 and remained above 60

kg/boatday for the next five years. The most recent catch rates (2016/17) have declined below 50 kg/boatday, representing a decline of approximately 40% and returning to a similar level seen in 2008/09. The most recent annual catch rate is amongst the lowest on record.



Herring Attachment 3. Figure 1. Annual average (±95% CI) catch rates for Seine net fishers taking Australian herring in the Geographe Bay/Bunbury Fishery. Black dashed line includes all fishers, blue line excludes historic fishers who have exited the fishery.

3. Cockburn Sound Fishery

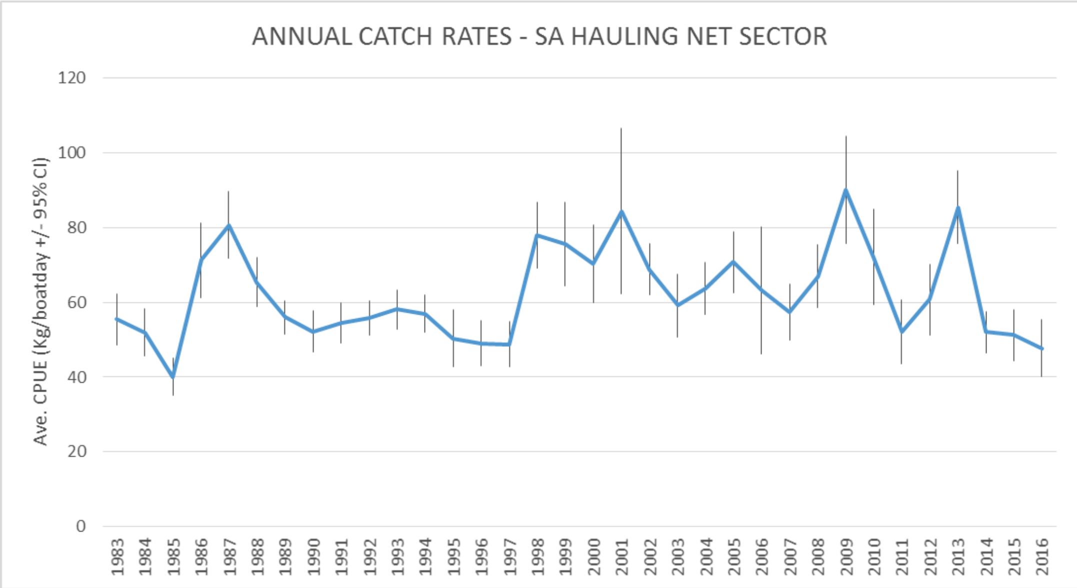
Cockburn Sound catch rate data are likely to reflect the market demand for Australian herring rather than the relative abundance of the resource. This fisher has historically targeted Southern garfish, where Australian herring constituted a by-product species. Since the decline of the Garfish fishery in 2012/13, this fisher's emphasis has switched toward Australian herring. Annual catch rates of Australian herring since 2012/13 have increased substantially.

4. South Australian Hauling Sector, Marine Scalefish Fishery.

Australian herring are a 'secondary' species among South Australia's multi-species, multi-gear Marine Scalefish Fishery. This species is relatively low-value and generally retained as by-product when fishers target more valuable species such as Southern Garfish, King George Whiting and Southern Calamari. The majority of the catch (>95%) is landed by the hauling net sector of the fishery.

Average annual catch rates of Australian herring in South Australia's hauling net fishery have ranged from 40 to 90 kg/boatday. There have been four notable peaks when catch rates exceeded 80 kg/boatday, 1987, 2001, 2009 and 2013. From 1987 to 1998 annual catch rates

were remarkably stable averaging approximately 50 kg/boatday. Since then catch rates have fluctuated more widely around 70 kg/boatday per year. From 2014 onwards, annual catch rates have returned to similar levels observed in the late 80s and 90s.



Herring Attachment 3. Figure 2. Annual average (±95% CI) catch rates for the SA haul net sector taking Australian herring.

7.4 Synthesis

Fluctuating annual catch rates were a consistent feature for three of the four fisheries investigated in this section of the report. The only discernible trend related to the single fisher operating in Cockburn Sound, where catch rates have continued to increase since 2012/13. This increase is likely to be driven by external market influences and decreased opportunity to target garfish. Overall, the time series of catch rates do not suggest evidence of any substantial change in the herring abundance over the past three decades.

With the exception of the South Coast Trap Net Fishery which specifically targets Australian herring, all other fisheries are non-specific (i.e. a multi species fishery). The dynamic nature of the gear used to catch Australian herring, along with the capacity of the fishers to adjust their activity and target species in line with market demand, compromises our ability to infer relative abundance from catch rate data.

Catch rate trends provide no evidence that unacceptable stock depletion may have occurred.

7.5 Reference

Smith, K., Brown, J., Lenanton, R., Molony, B., 2013. Status of nearshore finfish stocks in south-western Western Australia Part 1 : Australian herring NRM Project 09003 Final Report. Department of Fisheries, Perth, Western Australia.

8. Herring Attachment 4. Vulnerability Assessment.

8.1 Herring Attachment 4a. Australian herring Stock structure

While a single genetic stock, the sub population structure of Australian herring is complicated due to complex movements that vary among years. This may be a result of major current systems of south-western Australia, the strength of which vary among years (e.g. Pearce et al. 2011) and low and variable productivity (Molony et al. 2011). The most parsimonious outcome is three management units – West Coast of WA, South Coast of WA and South Australia – broadly reflective of the current management of Australian herring.

Tagging studies demonstrate that the three management units are connected by a level of adult movement from the south to west coasts which are variable among years. Genetic studies suggest the regions are also linked to some extent by larval transport via the Leeuwin Current from west to south coast regions. The strength of both linkages varies among years depending on the environmental factors including the strength of the Leeuwin Current and other features that may influence coastal enrichment (Chari ref).

Date/evidence	Comments
Genetics	Single genetic stock with enough gene flow for a single stock (noting that relatively low levels of gene flow typically result in a genetically homogenous stock). No further science requirement as unlikely to be informative.
Otolith Chemistry/morphology	Largely inconclusive, noting there is evidence that at least some fish are capable of moving large distances (e.g. see Ayvazian et al. 2004). No further science requirement noting that some work is to be written up.
Tagging	Most fish were recaptured within their zone of release (see Ayvazian et al. 2004, Smith et al. 2014). A small number of fish moved west and north around the Capes into the western zones from the southern zones. A smaller number of fish tagged in the western southern zone were recaptured east of where they were tagged. Interpretation of tagging results is complicated by low return rates and unquantified recapture effort. Without addressing these limitations there seems little scientific value from further investment in tagging studies.
Life history characteristics	All stages of maturity observed in both Western SC and Lower WC suggesting spawning in both bioregions. There appears to be differences in size-at-age between SC and WC which may be mathematically and/or biologically significant, suggesting a degree of independence.
Fishery data trends	No information on stock structure from catch and effort data; fishery catches in different zones appear unrelated.
Fisher observations	Fisher experience suggests different trends between SC and WC commercial fisheries. No apparent increase in WC catches since G trap closure. Fish move westerly along the south coast (determines direction trap of set – G opening is east). There appears that there may be an offshore movement of dispersed fish eastwards (termed a 'back run' by fishers) after the spawning period. Spawning occurs within both western south and west coasts.
Oceanography & Bathymetry Three influences • Larval distribution) • Movement of adults • Location and timing of spawning of adults	Oceanographic influences poorly described/understood. Leeuwin Current provides a mechanism to move eggs and larvae south and eastwards. Strength of the linkage varies among years depending on the environmental factors including the strength of the Leeuwin Current and other features that may influence coastal enrichment. Bathymetric features (e.g. canyons) occur in west and south coasts that may act to concentrate productivity under certain environmental conditions.

8.1.1 References

Ayvazian SG, Bastow TP, Edmonds JS, How J and Nowara G. 2004. Stock structure of Australian herring (*Arripis georgiana*) in southwestern Australia. *Fisheries Research* 67:39-53.

Pattiaratchi, C. and M. Woo. 2009. The mean state of the Leeuwin Current system between North West Cape and Cape Leeuwin. *Journal of the Royal Society of Western Australia*. 92: 221-241.

B.W. Molony, S.J. Newman, L. Joll, R.C.J. Lenanton and B. Wise. 2011. Are Western Australian waters the least productive waters for finfish across two oceans? A review with a focus on finfish resources in the Kimberley region and North Coast Bioregion, *Journal of the Royal Society of Western Australia*. 94 : 323–332.

Pearce A, Lenanton R, Jackson G, Moore J, Feng M and Gaughan D. 2011. The 'marine heat wave' off Western Australia during the summer of 2010/11. Fisheries Research Report No. 222. Department of Fisheries, Western Australia. 40 pp.

Smith, K. and Brown, J. 2014. Biological synopsis of Australian herring (*Arripis georgianus*). Fisheries Research Report No. 251. Department of Fisheries, Western Australia. 40pp.

8.2 Herring Attachment 4B. Australian herring growth

8.2.1 Herring Attachment 4Bi. Analyses by Malcolm Haddon (26th September 2017)

Summary

Both von Bertalanffy growth curves and empirical length-at-age estimates were made so as to compare the size of fish from the 'South' and the 'Metro' zones. This entailed selecting from the available data to ensure the comparisons were of groups of observations that could be validly compared. We considered the zone (only South and Metro), the year (the biological year runs from the previous May to the year's June), the sex (only "f" and "m"), recreational/commercial, and ocean/estuary factors when selecting for data to examine and analyse.

In general the mean length-at-age for females aged between 1.6 - 1.9 years was smaller in the South than in the Metro, but all other ages (X.6 - X.9; up to age X = 5) were larger in the South than in the Metro zone.

The differences between the length-at-age for the South and Metro zones is generally greater in females than males, though often only by about 5mm.

The difference is apparent through years and so does appear to provide some evidence that there are persistent differences between the South and Metro zones.

Methods

Alex Hesp has provided the WA herring data as a single '.csv' file entitled *Herring_ages_extraction_19_09_17.csv*. He also provided the following explanatory notes:

This data file contains data provided by Kim Smith (available Fisheries data from 1999. Does not include data from the Fisheries nearshore juvenile seine netting program).

I've appended the file with early data from the Murdoch University/Fisheries study, from 1996-98. Note, age/length data in some earlier years are not likely to be directly comparable with later years due to differences in sampling methods/aims etc. Data from 2009 onwards are most comparable, as these were collected by the same methods/researchers.

This data is read in and to simplify referencing the different fields all field names have been set to lowercase.

Herring Attachment 4Bi. Table 1. Data format and indicative contents used in the following analyses. If example column is empty this denotes missing data for that record.

	Index	isNA	Unique	Class	Min	Max	Example
common.name	1	0	1	character	0	0	Herring, Australian
otolithcode	2	0	29468	character	0	0	AH-3F1
project.code	3	0	7	character	0	0	RI7SPCOM
region	4	0	2	character	0	0	SOUTH
zone	5	0	10	character	0	0	Southeast
sitename	6	0	233	character	0	0	Poison Creek Beach
sample.date	7	0	1587	character	0	0	14/09/2000
year	8	0	20	integer	1996	2017	2000
month	9	0	12	integer	1	12	9
fin.year	10	0	20	character	0	0	2000
gmethod	11	0	43	character	0	0	BEACH SEINE, 61 METRE
tl	12	452	319	integer	31	390	105
fl	13	6813	213	integer	69	346	94
totalwt	14	16407	9127	numeric	0.36	899.4	11.6
sex	15	0	7	character	0	0	J
stage	16	3532	9	integer	1	8	1
gonad_wt	17	6775	1495	numeric	0.01	107.13	
otolithtaken	18	6540	2	logical	0	0	TRUE
age	19	6299	593	numeric	0.09	12	
type	20	0	3	character	0	0	Ocean

First there is some tidying of the data to do, for example currently there are uppercase and lowercase letters used for the sexes so those are made uniform. Also, some zone names have spaces in them so those are removed to simplify selecting by zone.

```
dat$sex <- tolower(dat$sex)
dat$zone <- gsub(" ","",dat$zone)
```

In addition, in the R file sent with the data file by Alex Hesp he introduced the notion of a biological year, stating: *for each date of capture, specify the current "biological year", assuming a birth date of 1 June for herring. That is, the biological year extends from June 1 to May 31. e.g. if calendar year is 2000, biological year is 1999 if month < 6, otherwise, it is 2000*

Also, each fish with age data was given an ageclass, which is essentially the integer value of year, essentially converting a 5+ to a 5. Any age classes with missing values (no age data) were then removed. It was also possible to then calculate the yearclass for each fish. These new fields demonstrated that across all areas and genders there were ages from 0 to 12:

```
dat$biolYr <- dat$year
dat$biolYr[which(dat$month < 6)] <- dat$year[which(dat$month<6)] - 1
dat$age.class <- floor(dat$age)
dat <- dat[!is.na(dat$age.class),]
# calculate the year class for each fish
dat$yearclass <- dat$biolYr - dat$age.class

print(sort(unique(dat$age.class)))

## [1]  0  1  2  3  4  5  6  7  8  9 10 11 12
```

Level of analysis

Before beginning to analyse the available length at age data it was necessary first to determine at what geographical scale to examine the data. The Bioregions found in 'dat$region' were just SOUTH and WEST, which were potentially too coarse There were 233 unique 'sitename' values so that level was considered to be too fine. A compromise was found with the 'zone' data field.

There are two other fields that needed to be taken into account. These were the 'project.code', which describes the sampling and identifies whether the sampling was from or by: the recreational, commercial, University, or Fisheries sectors. Interest is focussed on the recreational and commercial sampling.

Finally, the primary interest was on oceanic sampling rather than estuarine, as the estuarine fish are not considered typical of the wider stock of fish.

We thus need to consider the zone, the year, the sex, recreational/commercial, and ocean/estuary factors when selecting for data to examine and analyse.

```
table(dat$year,dat$zone)

##
##            Kalbarri Metro Midwest South Southeast Southwest
##   1996  0        0   110       2   136       247       453
##   1997  1        0   557      26   590      1106      1234
##   1998  0        0   567      42   178       435       856
##   1999  0        0    11       0    54         0       105
##   2000  0        0    60       0   188         1        92
##   2001  0        0    82       0   139         0        60
##   2004  0        0    59       0     0         0         0
##   2005  0        0   212      23     0         0       106
##   2006  0        0   321       0    55         0         0
##   2007  0        0   130       0     0         0         0
##   2008  0        0    26       0     0         0         0
##   2009  0        0   695     267   307         1       838
##   2010  2        1  2810    1071   643        18       411
##   2011  0        0  1576       3   303         0        87
##   2012  0        0   993       0  1402        33         0
##   2013  0        0  1014       0  1296        40         9
##   2014  0        0   946      13     0         0       267
##   2015  0        0  1905      59   323         0       665
```

```
## 2016 0 0 1220 5 490 0 619
## 2017 0 0 634 0 315 0 163
```

First select only 'ocean', 'commercial', 'recreational', 'South', and 'Metro' samples and put them into a separate data.frame.

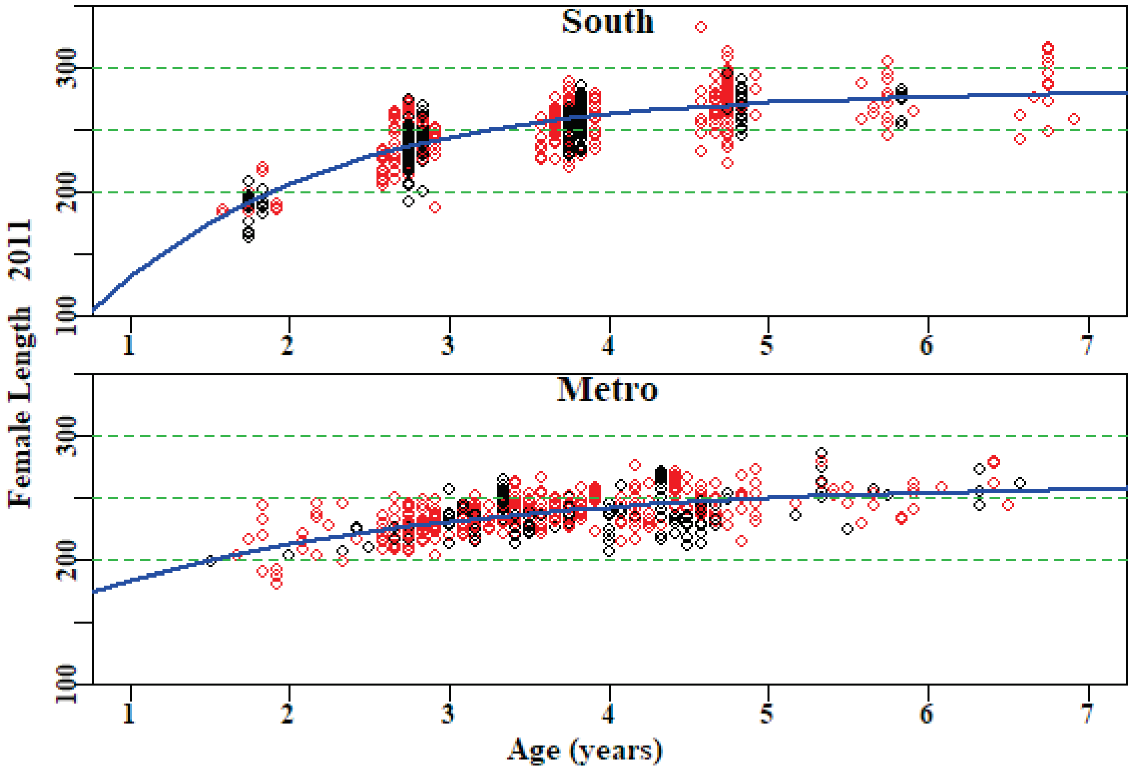
```
pick <- which((dat$zone %in% c("South","Metro")) & (dat$type == "Ocean") &
         (dat$project.code %in% c("COM","COMMSAMP","REC","RECSAMP")) &
         (dat$age >= 0) & (dat$tl >= 0))

dat1 <- droplevels(dat[pick,])
dim(dat1)

## [1] 16070 23
```

Now examine some of the properties of each zone by listing the sampling projects they came from and the number of observations of each sex:

```
pickZ <- which((dat1$zone == "South"))
datS <- droplevels(dat1[pickZ,])

cat(" South \n")

## South

cbind(table(datS$biolYr,datS$project.code),
    table(datS$biolYr,datS$sex))

##      COMMSAMP RECSAMP   f  j   m  u
## 2005        0      54   1  25  6  22  0
## 2008      175       0   0 116  0  58  1
## 2009      411      18   1 197  1 230  0
## 2010      194      11   0 111  0  94  0
## 2011      571     399  26 643  0 301  0
## 2012     1003     478  42 862  0 577  0
## 2013        0      27   0  25  0   2  0
## 2015        0     457  12 402  0  43  0
## 2016        0     330  13 291  0  26  0
## 2017 0 5 0 5 0 0 0

cat("\n\n\n")

pickZ2 <- which((dat1$zone == "Metro"))
datM <- droplevels(dat1[pickZ2,])
cat(" Metro \n")

## Metro

cbind(table(datM$biolYr,datM$project.code),
    table(datM$biolYr,datM$sex))
```

##		COMMSAMP	RECSAMP		f	j	m	u
##	2004	0	169	41	101	0	27	0
##	2005	0	217	67	128	0	22	0
##	2006	0	148	12	86	0	32	18
##	2007	0	1	0	1	0	0	0
##	2008	0	6	0	4	0	0	2
##	2009	1478	552	11	1242	1	772	4
##	2010	932	1199	50	1250	1	830	0
##	2011	453	561	39	491	0	484	0
##	2012	604	509	34	556	3	520	0
##	2013	525	327	54	458	0	340	0
##	2014	602	903	146	781	5	573	0
##	2015	660	942	194	830	1	577	0
##	2016	560	512	48	583	0	441	0
##	2017	0	77	10	43	0	24	0

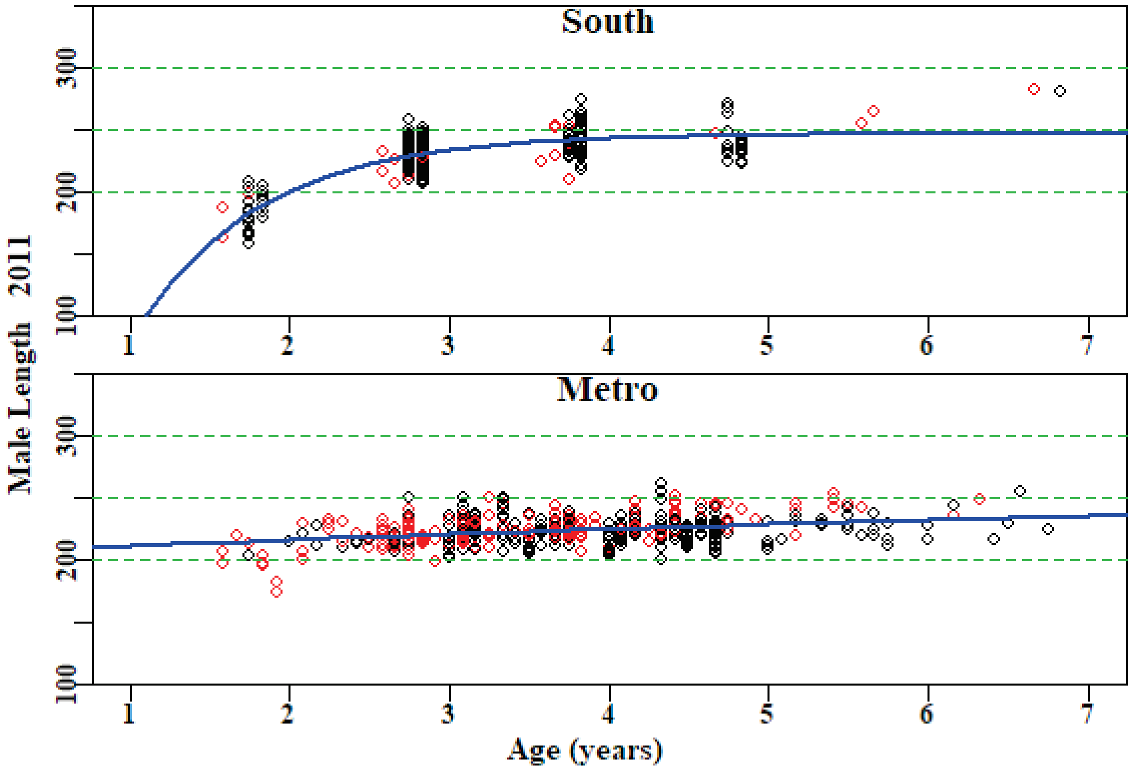
In order to compare the length at age between the South and Metro zones it will be necessary to have sufficient observation to make useful comparisons. In terms of biological years, the two tables by sampling project and by sex indicate that only biological years 2011 and 2012 have acceptable numbers, and possible also 2009.



Herring Attachment 4Bi. Figure 1. A comparison of female length at age for the South and Metro zones using data from 2011. South: 281.638 0.694 0.086 Metro: 261.751 0.468 -1.591

Herring Attachment 4Bi. Table 2. Mean length at age for the samples of females from the South and Metro for the year 2011.

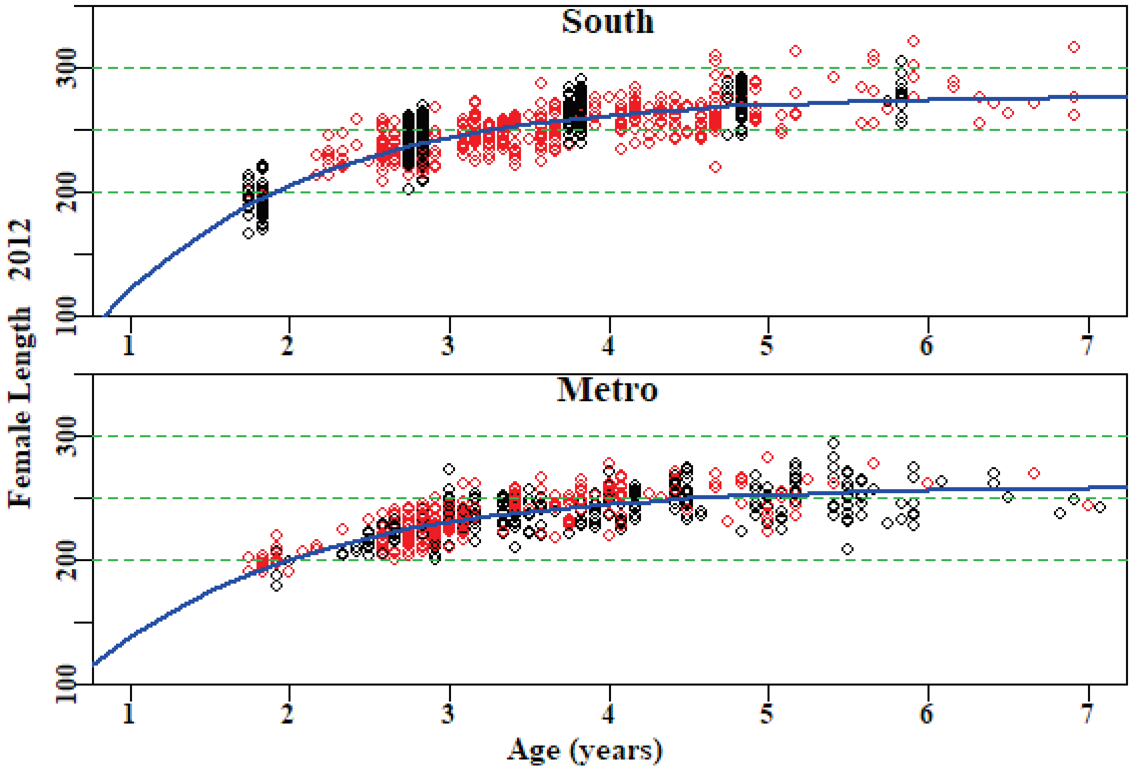
Age	AvSouth	AvMetro	Diff	nSouth	nMetro	sdSouth	sdMetro
1.7	192.071	217.667	-25.595	28	6	13.115	18.726
2.7	241.613	226.667	14.947	212	57	14.047	10.497
3.7	257.161	239.872	17.289	199	39	13.406	7.609
4.7	273.427	243.000	30.427	96	21	16.385	12.598
5.7	274.056	245.333	28.722	18	6	16.214	10.250



Herring Attachment 4Bi. Figure 2. A comparison of male length at age for the South and Metro zones using data from 2011. South: 247.397 1.257 0.671 Metro: 276.838 0.076 -17.894.

Herring Attachment 4Bi. Table 3. Mean length at age for the samples of males from the South and Metro for the year 2011.

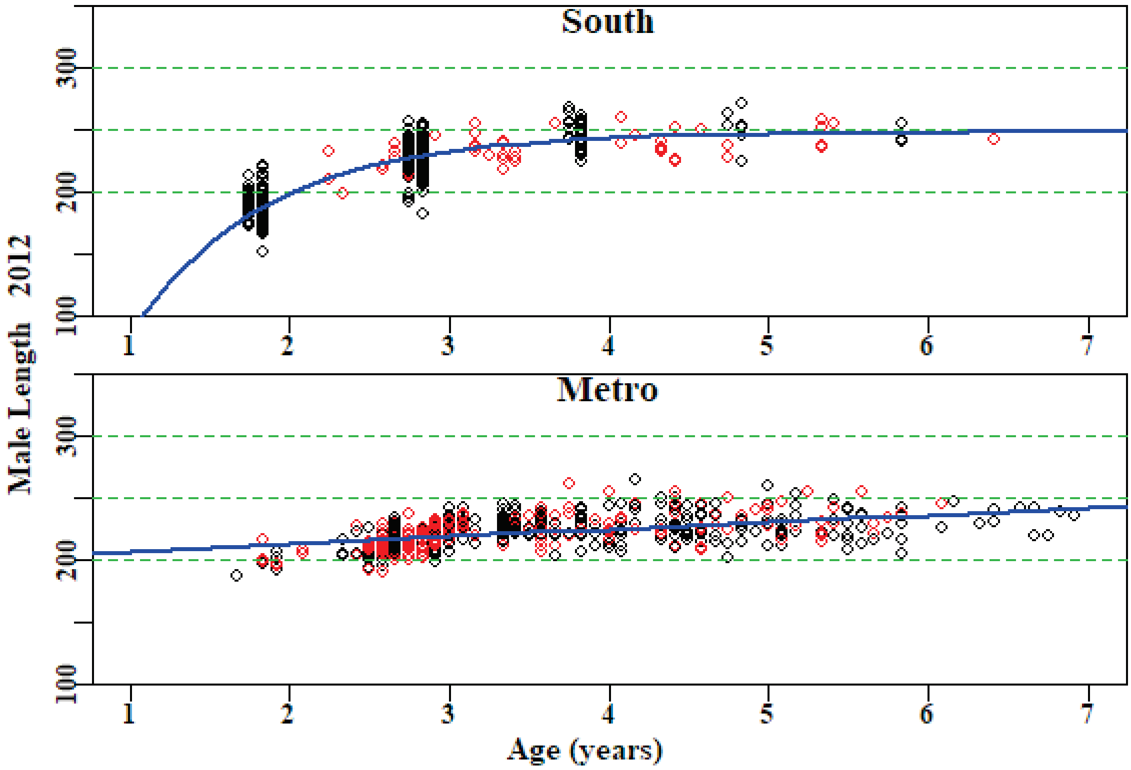
Age	AvSouth	AvMetro	Diff	nSouth	nMetro	sdSouth	sdMetro
1.7	185.000	205.167	-20.167	24	6	14.328	9.600
2.7	230.257	220.435	9.822	183	46	8.973	9.128
3.7	241.852	224.216	17.637	61	51	11.777	7.606
4.7	241.565	225.809	15.757	23	47	13.531	9.282
5.7	265.000	222.714	42.286	1	7		8.597



Herring Attachment 4Bi. Figure 3. A comparison of female length at age for the South and Metro zones using data from 2012. South: 277.759 0.769 0.244 Metro: 259.232 0.724 -0.057.

Herring Attachment 4Bi. Table 4. Mean length at age for the samples of females from the South and Metro for the year 2012.

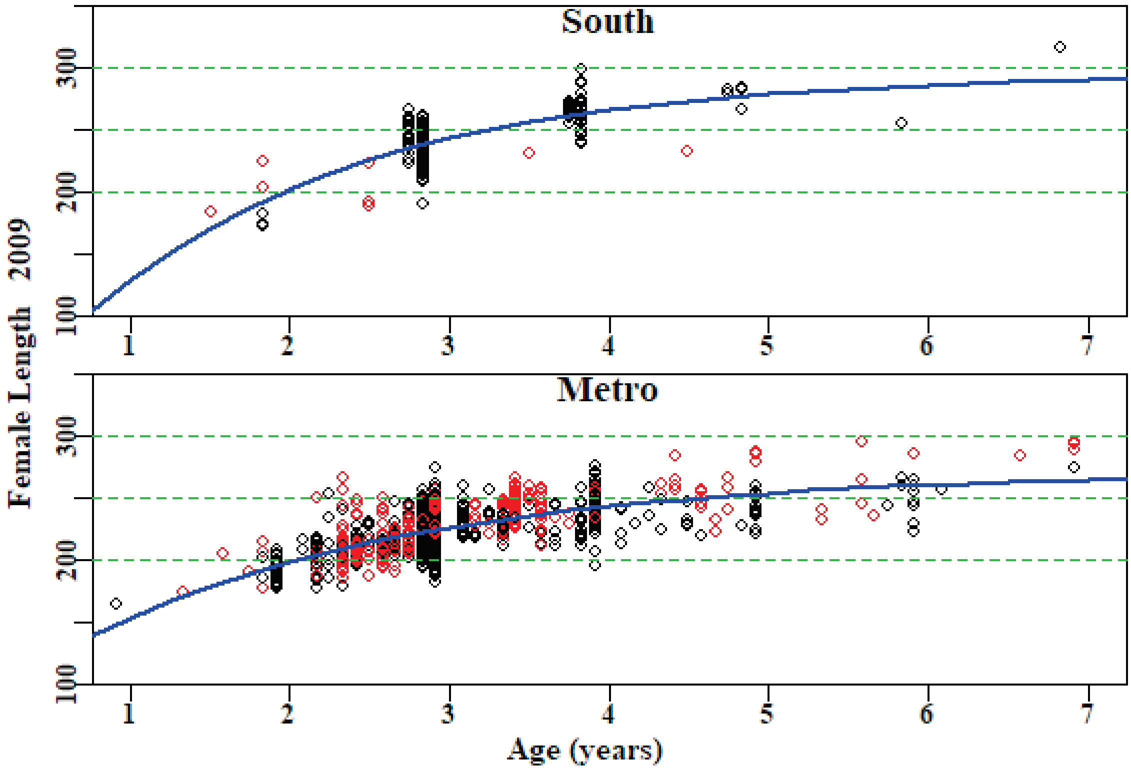
Age	AvSouth	AvMetro	Diff	nSouth	nMetro	sdSouth	sdMetro
1.7	192.123	196.571	-4.448	73	7	11.838	5.412
2.7	239.989	225.432	14.558	283	95	11.533	10.692
3.7	260.650	241.321	19.328	137	28	11.096	11.554
4.7	270.536	253.333	17.203	69	9	15.183	16.424
5.7	278.167	247.833	30.333	18	6	17.209	17.128



Herring Attachment 4Bi. Figure 4. A comparison of male length at age for the South and Metro zones using data from 2012. South: 248.448 1.171 0.624 Metro: 384.578 0.036 -20.16.

Herring Attachment 4Bi. Table 5. Mean length at age for the samples of males from the South and Metro for the year 2012.

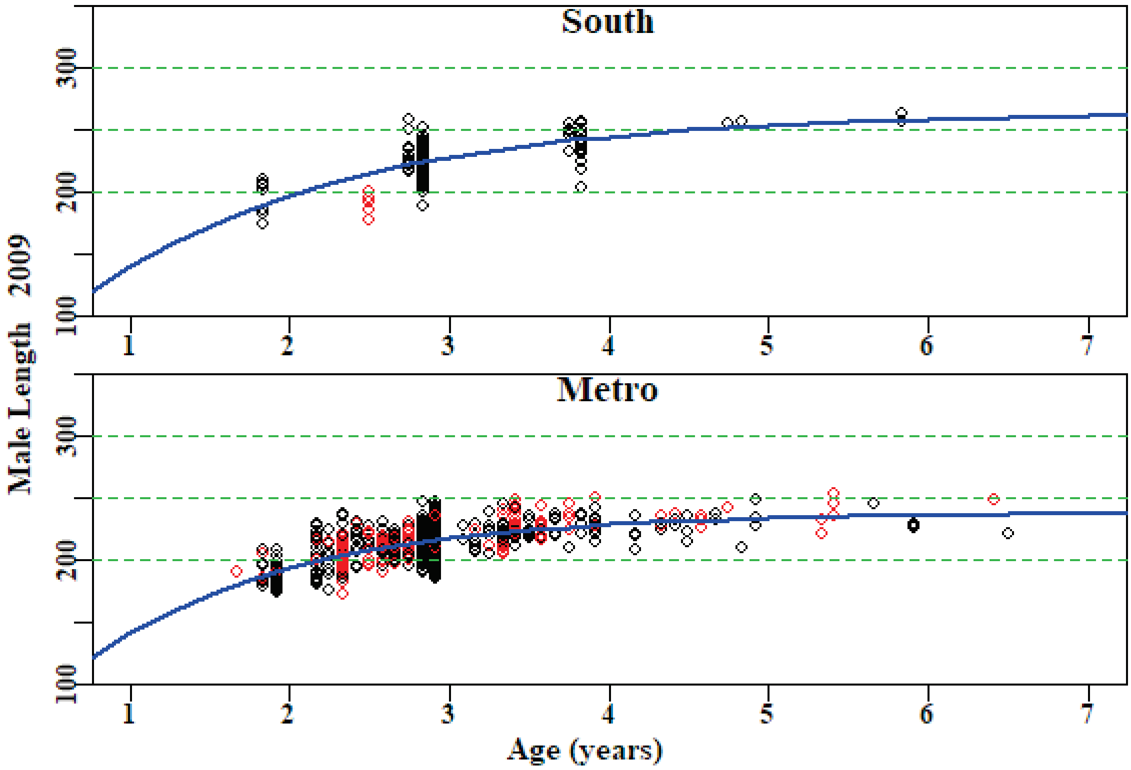
Age	AvSouth	AvMetro	Diff	nSouth	nMetro	sdSouth	sdMetro
1.7	186.845	200.000	-13.155	155	5	12.245	10.817
2.7	229.283	215.920	13.362	315	88	10.635	7.571
3.7	245.020	228.207	16.813	50	29	9.556	11.791
4.7	248.154	227.500	20.654	13	20	12.635	11.601
5.7	246.333	225.583	20.750	3	12	7.572	10.841



Herring Attachment 4Bi. Figure 5. A comparison of female length at age for the South and Metro zones using data from 2009. South: 295.446 0.581 0.006 Metro: 271.205 0.479 -0.752.

Herring Attachment 4Bi. Table 6. Mean length at age for the samples of females from the South and Metro for the year 2009.

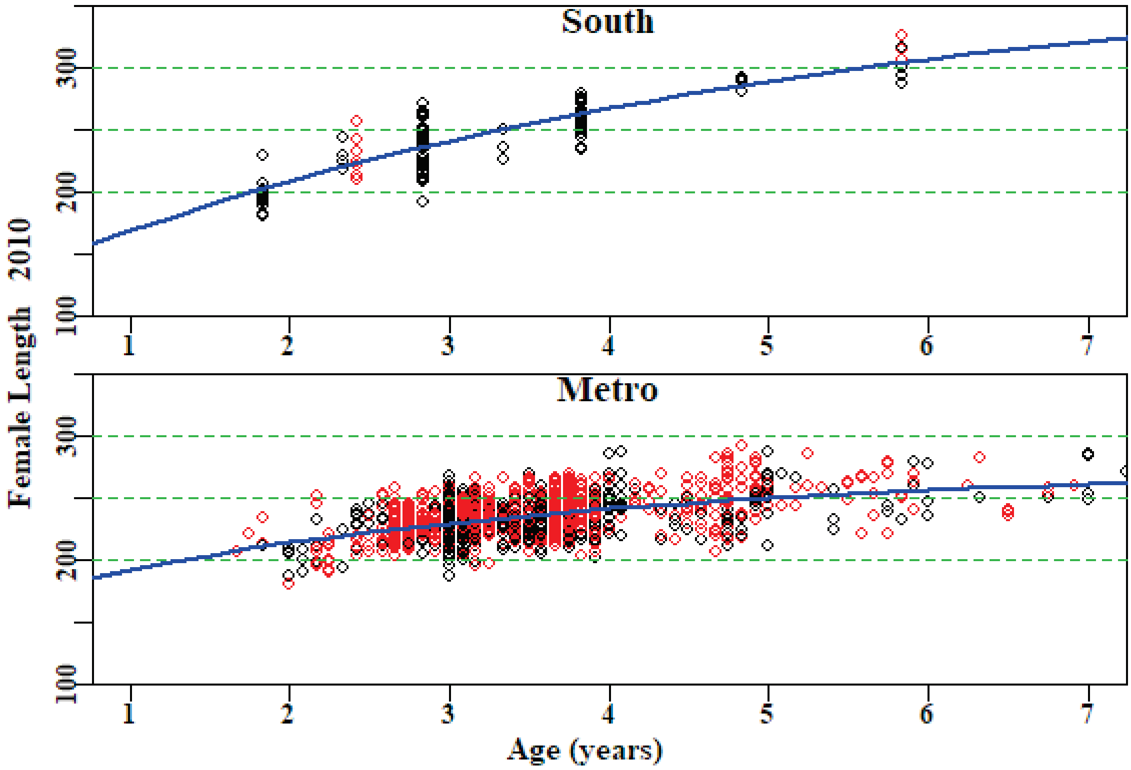
Age	AvSouth	AvMetro	Diff	nSouth	nMetro	sdSouth	sdMetro
1.7	191.40	199.000	-7.600	5	7	22.323	14.399
2.7	238.31	222.131	16.179	142	245	12.389	12.517
3.7	265.20	228.720	36.480	35	25	12.490	12.482
4.7	280.00	241.500	38.500	6	6	6.573	17.886
5.7	256.00	251.250	4.750	1	4		14.268



Herring Attachment 4Bi. Figure 6. A comparison of male length at age for the South and Metro zones using data from 2009/ South: 264.043 0.62 -0.231 Metro: 237.959 0.771 -0.182.

Herring Attachment 4Bi. Table 7. Mean length at age for the samples of males from the South and Metro for the year 2009.

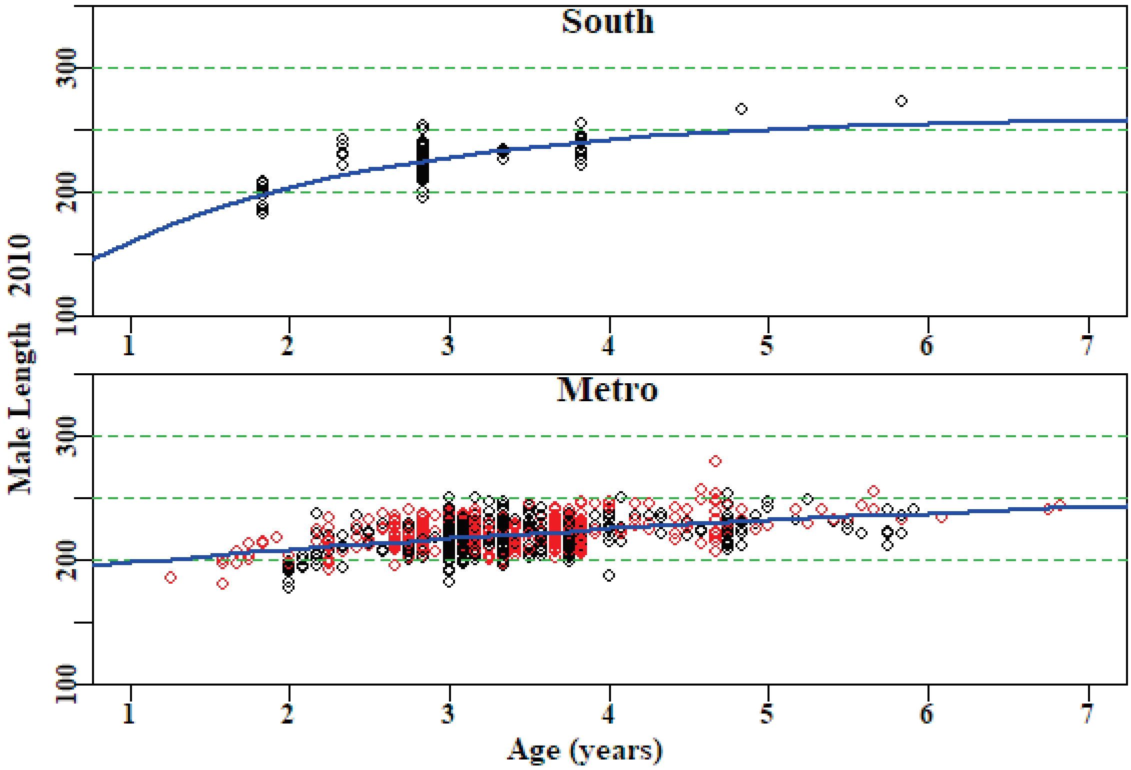
Age	AvSouth	AvMetro	Diff	nSouth	nMetro	sdSouth	sdMetro
1.7	192.500	191.357	1.143	8	14	15.119	8.758
2.7	225.223	213.099	12.124	184	243	10.010	9.973
3.7	240.929	229.500	11.429	28	16	12.171	8.959
4.7	256.500	230.250	26.250	2	4	0.707	14.104
5.7	260.000	246.000	14.000	2	1	4.243	



Herring Attachment 4Bi. Figure 7. A comparison of female length at age for the South and Metro zones using data from 2010. South: 389.202 0.197 -1.913 Metro: 274.895 0.299 -3.039.

Herring Attachment 4Bi. Table 8. Mean length at age for the samples of females from the South and Metro for the year 2010.

Age	AvSouth	AvMetro	Diff	nSouth	nMetro	sdSouth	sdMetro
1.7	197.500	217.200	-19.700	12	5	12.450	10.686
2.7	238.022	226.878	11.144	45	148	17.419	10.626
3.7	260.643	238.616	22.027	28	164	11.179	14.821
4.7	288.500	244.852	43.648	4	54	5.260	21.826
5.7	306.857	251.917	54.940	7	12	13.957	18.628



Herring Attachment 4Bi. Figure 8. A comparison of male length at age for the South and Metro zones using data from 2010. South: 260.724 0.568 -0.686 Metro: 275.264 0.145 -7.766.

Herring Attachment 4Bi. Table 9. Mean length at age for the samples of males from the South and Metro for the year 2010.

Age	AvSouth	AvMetro	Diff	nSouth	nMetro	sdSouth	sdMetro
1.7	195.500	206.857	-11.357	16	7	8.892	7.081
2.7	225.451	218.475	6.976	51	80	12.869	10.230
3.7	236.438	220.932	15.506	16	146	9.381	9.785
4.7	266.000	228.522	37.478	1	46		14.278
5.7	273.000	231.111	41.889	1	9		13.271

8.3 Herring Attachment 4Bii. Analyses of female size at maturity

The parameters of the fitted relationship between the probabilities that female herring are mature (i.e. has ovaries that have macroscopic stages of 3 to 8) and their total lengths (TL, mm) have previously been found to differ between the West and South Coast Bioregions, based on samples from the key spawning period (April to June) from 2009 and 2011 (Smith et al. 2013 Table 5.8; Table 1). Further maturity analyses conducted during the workshop showed that the inclusion of more recent data (2009-2017) resulted in little change in the estimated size at which females mature (see Table 2), therefore the published parameter estimates for females in each of the two regions reported by Smith et al. (2013) were applied in the workshop assessments. The estimated lengths at which 50% and 95% of females have attained maturity in the South Coast Bioregion are 219.6 and 265.3 mm, respectively, compared to 194.1 and 250.8 mm in the West Coast Bioregion (Herring Attachment 4Bii. Table 1).

Herring Attachment 4Bii. Table 1. Estimates of female size at maturity from Smith et al. (2013) based on data from 2009-2011.

Region	L_{50} (mm TL)	L_{95} (mm TL)
West Coast Bioregion	194.1	250.8
South Coast Bioregion	219.6	265.3

Herring Attachment 4Bii. Table 2. Estimates of female size at maturity based on data from 2009-2017.

Region	L_{50} (mm TL)	L_{95} (mm TL)
West Coast Bioregion	197.6	269.4
South Coast Bioregion	226.8	269.5

Available maturity data collected since 2009 were also examined for individual calendar years to explore inter-annual variation in female size at maturity in each region. Data from both regions for 2010, 2012, 2013 and 2015 were sufficient for comparison, so subsequent analyses were restricted to these datasets. For each dataset, frequencies of immature and mature females within each 10 mm length class, and proportions of these fish which were mature, were calculated. The resulting proportions of mature females were plotted against the midpoints of the length classes and the empirical relationships compared among calendar years.

Both the West and South Coast Bioregions, empirical relationships between proportions of mature females and length exhibited essentially logistic forms. However the proportions of females and males from the West Coast Bioregion appeared to have an asymmetrical rather than symmetrical relationship with length for fish from the South Coast Bioregion. Further explorations indicate that there is inter-annual variation in the observed size at maturity, with the lengths at which 50% of females were mature differing by up to about 20 mm between years. The data underpinning the results for the two regions differ in that the majority of the data for the South Coast Bioregion were collected in April (prior to peak spawning) while those from the West Coast Bioregion are more evenly spread across April, May and June.

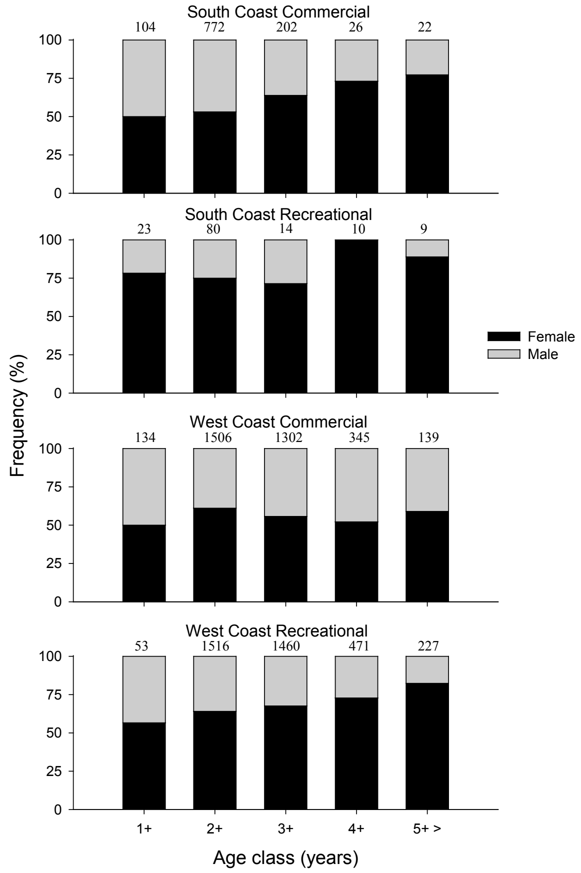
Thus it is possible that variation in maturity between regions, at least in part, represent differences in sampling in the two areas. Due to the very short spawning period of herring, combined with the limited period of availability/targeting of fish prior to the spawning period, obtaining representative maturity data for this species is difficult. As it is possible that the patterns observed were due to the paucity of data, this introduces uncertainty in per recruit analyses.

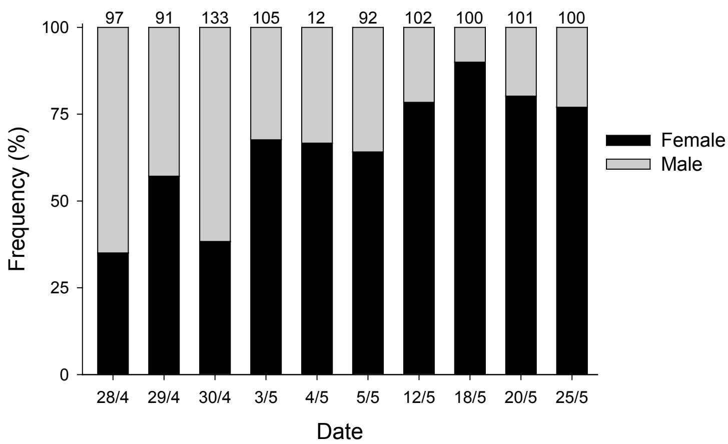
8.3.1 Reference

Smith, K., Brown, J., Lenanton, R., Molony, B., 2013. Status of nearshore finfish stocks in south-western Western Australia Part 1 : Australian herring NRM Project 09003 Final Report. Department of Fisheries, Perth, Western Australia.

8.4 Herring Attachment 4Biii. Sex ratio

Sex ratio varies by fish size, age, location of sampling, date (and potentially time) of sampling an fishing method fishing method. This may be a result of the schooling nature of the species. Overall, fishery landings show a bias towards females which is strongest in recreational samples and may be due to the larger and more actively feeding females.





Herring Attachment 4Biii. Figure 1. Daily variation in sex ratio from daily samples from Cockburn Sound commercial landings, 28 April to 25 May 2010.

8.5 Herring Attachment 4C. Productivity Susceptibility Analysis (PSA)

Productivity Susceptibility Analysis (PSA) is used in Marine Stewardship Council (MSC) assessments to score data-deficient stocks (Hobday et al. 2011; MSC 2014). The PSA approach is based on the assumption that the relative risk to a stock depends on two characteristics: (1) the productivity of the species, which will determine the capacity of the stock to recover if the population is depleted, and (2) the extent of the impact on the stock due to fishing, which will be determined by the susceptibility of the species to fishing activities.

Although a valuable tool for determining the overall inherent vulnerability of a stock to fishing, the simplicity and prescriptiveness of the PSA approach means that productivity and susceptibility scores are very sensitive to input data and there is no ability to consider all management measures implemented in fisheries to reduce the overall risk to a stock (e.g. 50% reductions in catch). Consequently, the PSA was scored for both pre- and post-management change to demonstrate the change in relative risk that these actions resulted in.

Based on available information on the biological characteristics of Australian herring, the productivity score was 1.43 (Herring Attachment 4C. Table 1). Due to being a short-lived and productive species, all attributes were scored 1 (low risk), with the exception of the maximum age (scored a 2, based on a maximum observed age of 12 years) and trophic level (scored a 3, based on the trophic level value of 4.3 accessed in fishbase.org).

Herring Attachment 4C. Table 1. PSA productivity scores (1-3, where 1 reflects low vulnerability/ risk) for Australian herring. As there was no difference in scores between the west and south coasts, the results are presented together.

Productivity attribute	Herring
Average maximum age	**2**
Average age at maturity	**1**
Average maximum size	**1**
Average size at maturity	**1**
Reproductive strategy	**1**
Fecundity	**1**
Trophic level	**3**
Total productivity (average)	**1.43**

The weighted (by approximate catches of each fishery/sector) susceptibility scores were based on a high (>30%) areal overlap (distribution of fishing effort relative to stock range) for the South Coast Trap Net Fishery and the recreational fisheries, while the other commercial fisheries extend over a more limited area (Tables 2 and 3). The vertical overlap

(by depth) was assumed high (3) for all fisheries as herring represents a key target species. Similarly, post-capture mortality is scored as high (3) for retained species. Selectivity of fish, as reflected by the relative proportion of captured fish that are immature, was scored as medium (2) for the commercial fisheries and high (3) for the recreational fisheries prior to the management change. For the recreational fisheries, the selectivity score was reduced to medium (2) post management change to reflect the likely effect of bag limit reductions on catches.

Prior to changes in management, the PSA indicated a medium relative risk to the stock in the West Coast and South Coast and a low relative risk after the management changes (Herring Attachment 4C. Tables 2 and 3).

Herring Attachment 4C. Table 2. PSA susceptibility scores (1-3, where 1 reflects low vulnerability/ risk) for each fishery/ sector that impact on herring in the South Coast Bioregion, pre- and post-management change (i.e. closure of trap net fishery and reduction in recreational bag limits, changes to scores indicated in red with grey fill).

Susceptibility attribute	South Coast Trap Net Fishery	South Coast Estuarine Fishery	Recreational Fishery
Pre-management change			
Areal overlap	3	1	3
Vertical overlap	3	3	3
Selectivity	2	2	3
Post-capture mortality	3	3	3
Approximate catch (tons)	200	20	50
			PSA = 75 (MEDIUM RISK)
Post-management change			
Areal overlap	3	1	3
Vertical overlap	3	3	3
Selectivity	2	2	**2**
Post-capture mortality	3	3	3
Approximate catch (tons)	**0**	20	50
			PSA = 83 (LOW RISK)

Herring Attachment 4C. Table 3. PSA susceptibility scores (1-3, where 1 reflects low vulnerability/ risk) for each fishery/sector that impact on herring in the West Coast Bioregion, pre- and post-management change (i.e. reduction in recreational bag limits, changes to scores indicated in red with grey fill).

Susceptibility attribute	West Coast Estuarine Fishery	South West Beach Seine Fishery	Cockburn Sounds Fish Net Fishery	Recreational Fishery
Pre-management change				
Areal overlap	1	1	1	3
Vertical overlap	3	3	3	3
Selectivity	2	2	2	3
Post-capture mortality	3	3	3	3
Approximate catch (tons)	5	15	20	125
				PSA = 67 (MEDIUM RISK)
Post-management change				
Areal overlap	1	1	1	3
Vertical overlap	3	3	3	3
Selectivity	2	2	2	2
Post-capture mortality	3	3	3	3
Approximate catch (tons)	5	15	20	125
				PSA = 83 (LOW RISK)

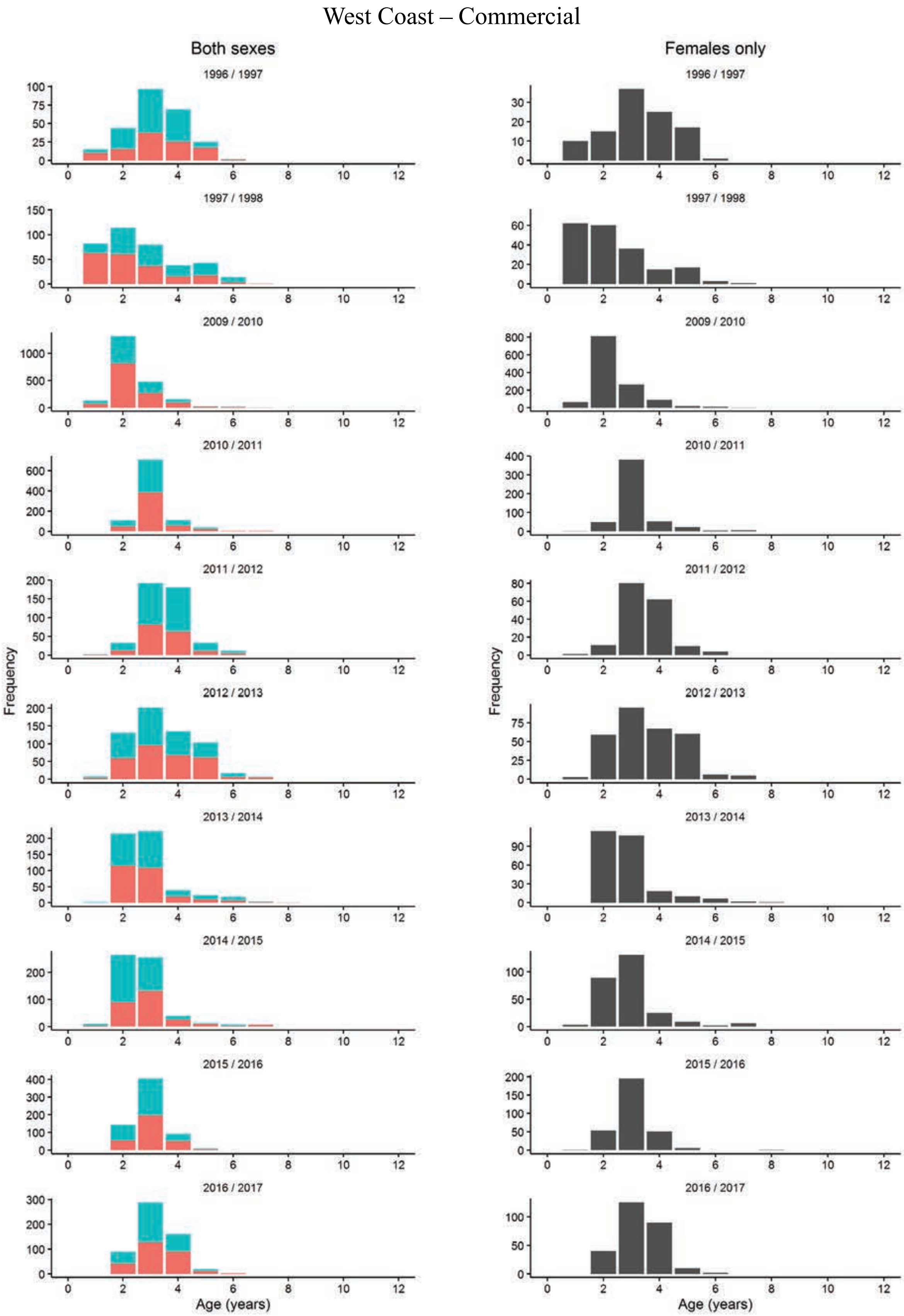
9. Herring Attachment 5. Age and Length Composition Data.

Age and length composition samples collected for herring since 1996 were plotted for each region and sector (see Herring Attachment 5. Figures, below). Fish caught in estuaries were excluded to minimise biases that may result from these environments contributing to faster growth, with closed sandbars possibly preventing individuals from leaving. Commercial samples were limited to those caught by beach seine and haul netting methods, including G-trap nets. For the recreational samples, only fish caught by line fishing were included. To enable the tracking of individual cohorts (year classes), the data were separated into biological years rather than calendar years. The biological year for herring is considered to extend from 1 June to 31 May, i.e. starting at the peak of the spawning period.

The age compositions (Herring Attachment 5. Figures 1-4) and length compositions (Herring Attachment 5. Figures 5-8) suggest that data collected in the earlier years are not directly comparable with more recent samples. In particular for the commercial sector, early samples contain substantial numbers of smaller and younger fish, possibly associated with fishers retaining these for research purposes (Herring Attachment 5. Figures 5 and 7). Any subsequent analyses will need to remove these research samples. Data from 2009/10 onwards are most comparable and likely better reflect the retained catches by each sector. The workshop identified several issues that suggest the samples are not always representative of the population sampled. The commercial fishers do not always retain all fish caught in a net, possibly leading to sampling towards larger and older fish. Further, recreational fishers on the south coast may be high-grading their catches note size distributions of competition catches).

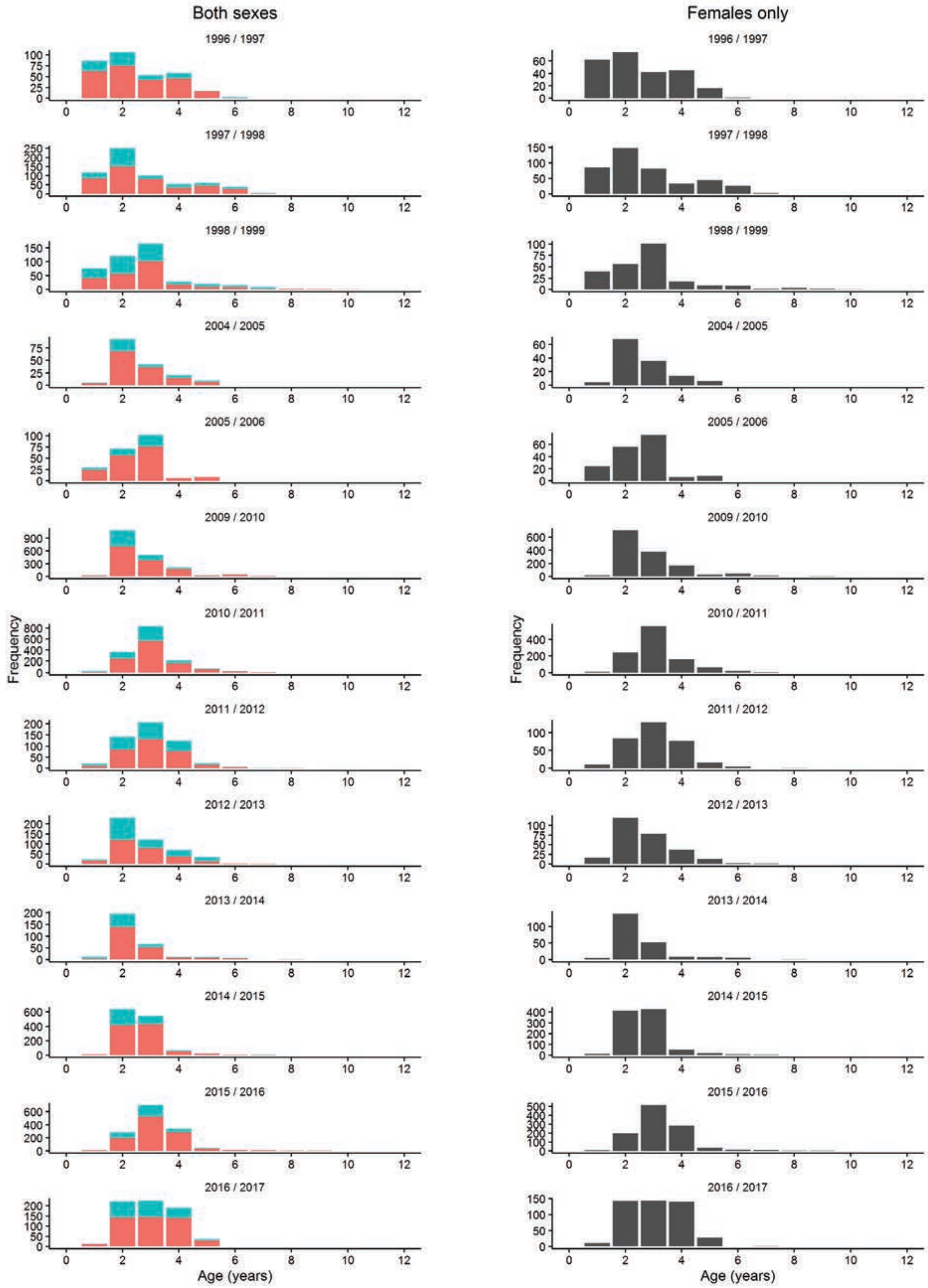
When plotted by sex, the age and length composition data show that many samples, particularly from the recreational sector (e.g. Herring Attachment 5. Figures 2 and 4), are biased towards female fish (red bars). Possible reasons for bias towards females provided during the workshop were (i) differences in growth between the two sexes, with the larger females more likely to be caught and retained by fishers (ii) anecdotal evidence from commercial and recreational fishers indicates that herring typically school by size and therefore by sex (iii) females caught during the spawning season are more voracious and thus more easily caught by line fishing using baited hooks. Due to the biased sex ratios, subsequent analyses were based on female data only.

Age and length composition samples provide clear evidence of variable recruitment between years. Strong year classes recruiting into the fishery as 2 year old females in 2009/10 and 2014/15 are easily tracked (Herring Attachment 5. Figures 1 and 2) through samples from consecutive biological years. The varibility in recruitment also appears to influence the lack of older fish (> 6 years of age) in samples. While age 1+ fish are uncommon in catches by both comemrcial and recreational fishers on the west coast (Herring Attachment 5. Figures 1 and 2), they are more often retained on the south coast, particularly by the commercial sector.

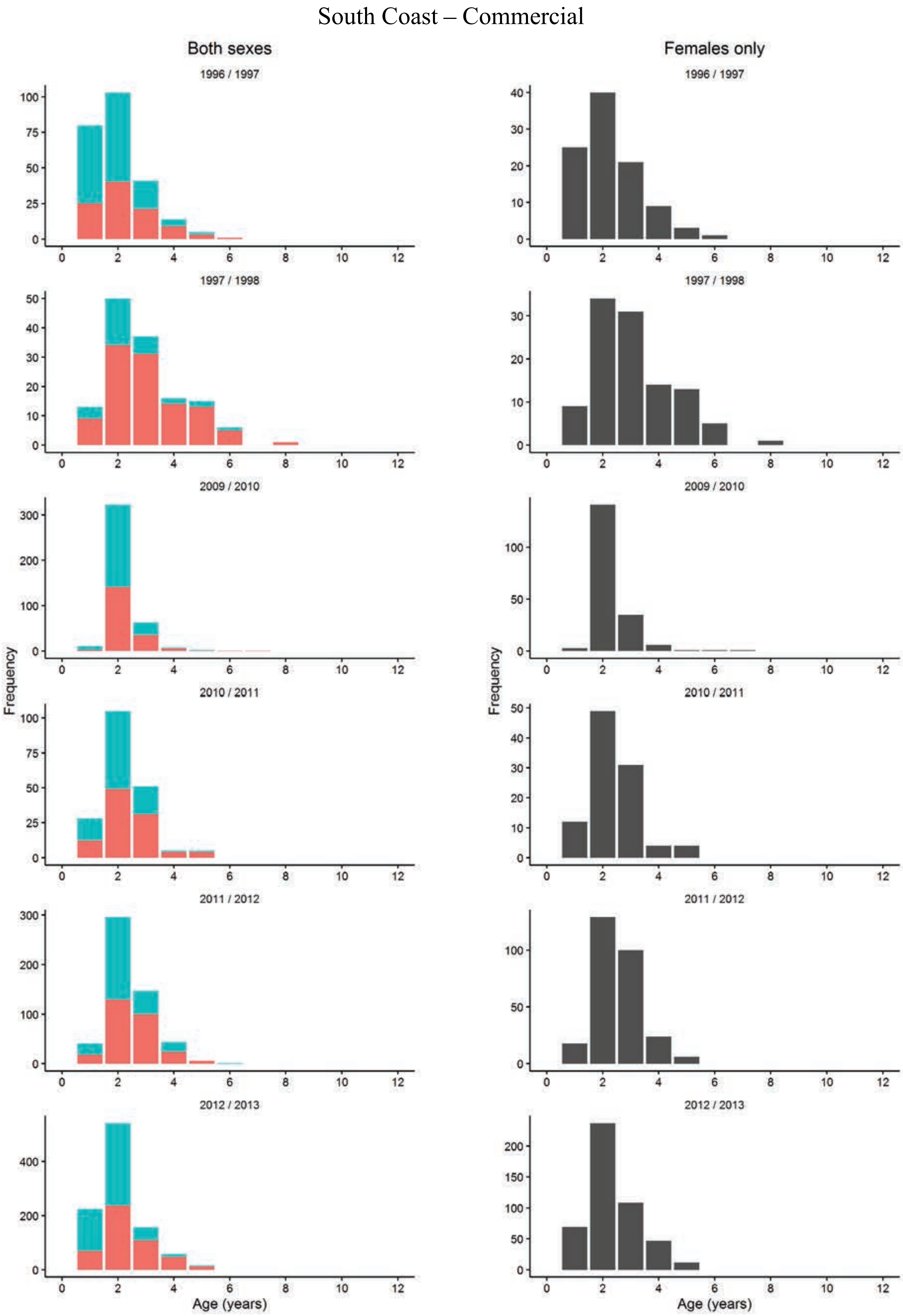


Herring Attachment 5. Figure 1. Age composition samples from commercial catches on the West Coast, separated by sexes (left, females = red, males = blue) and showing females only (right).

West Coast – Recreational

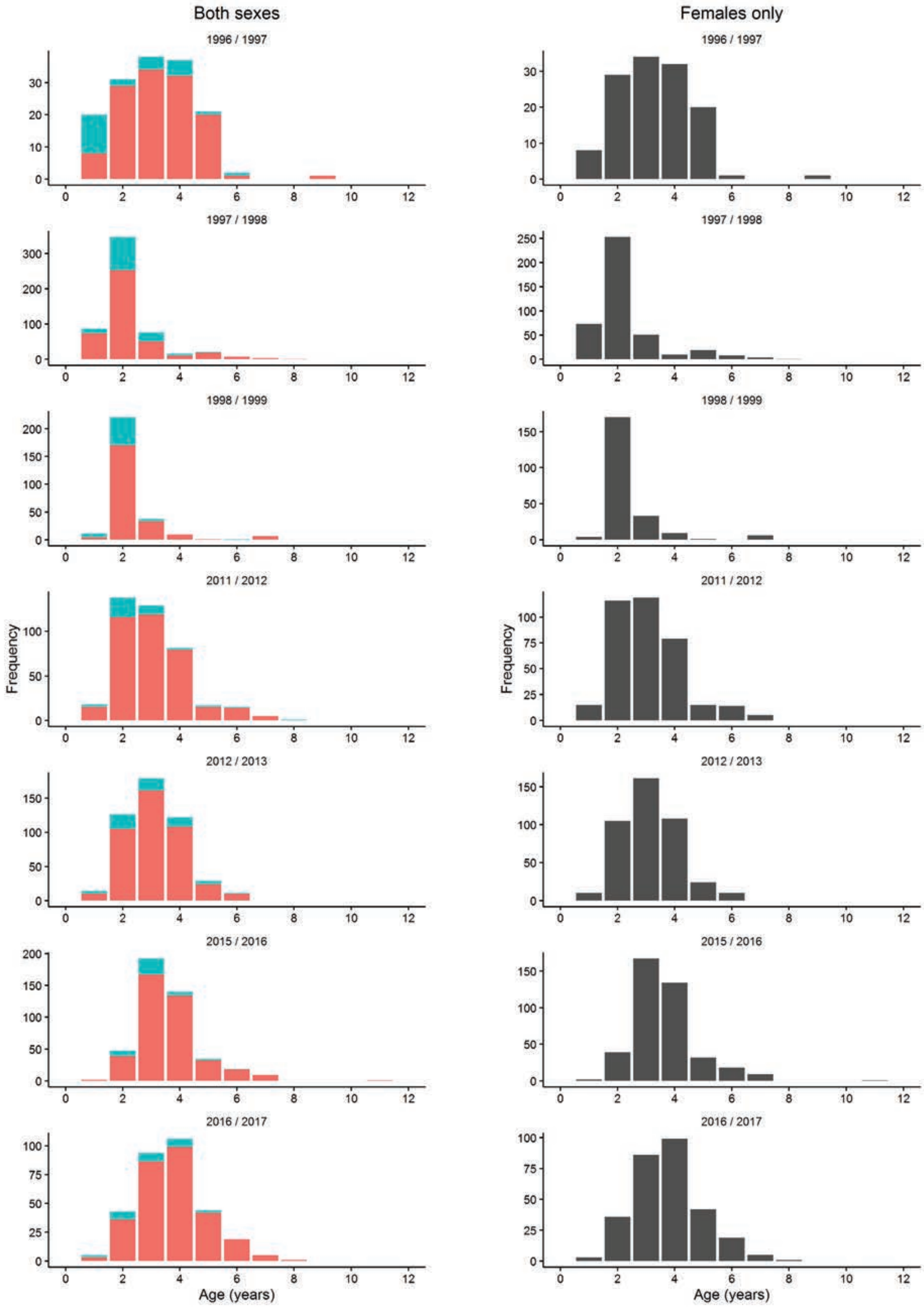


Herring Attachment 5. Figure 2. Age composition samples from recreational catches on the West Coast, separated by sexes (left, females = red, males = blue) and showing females only (right).



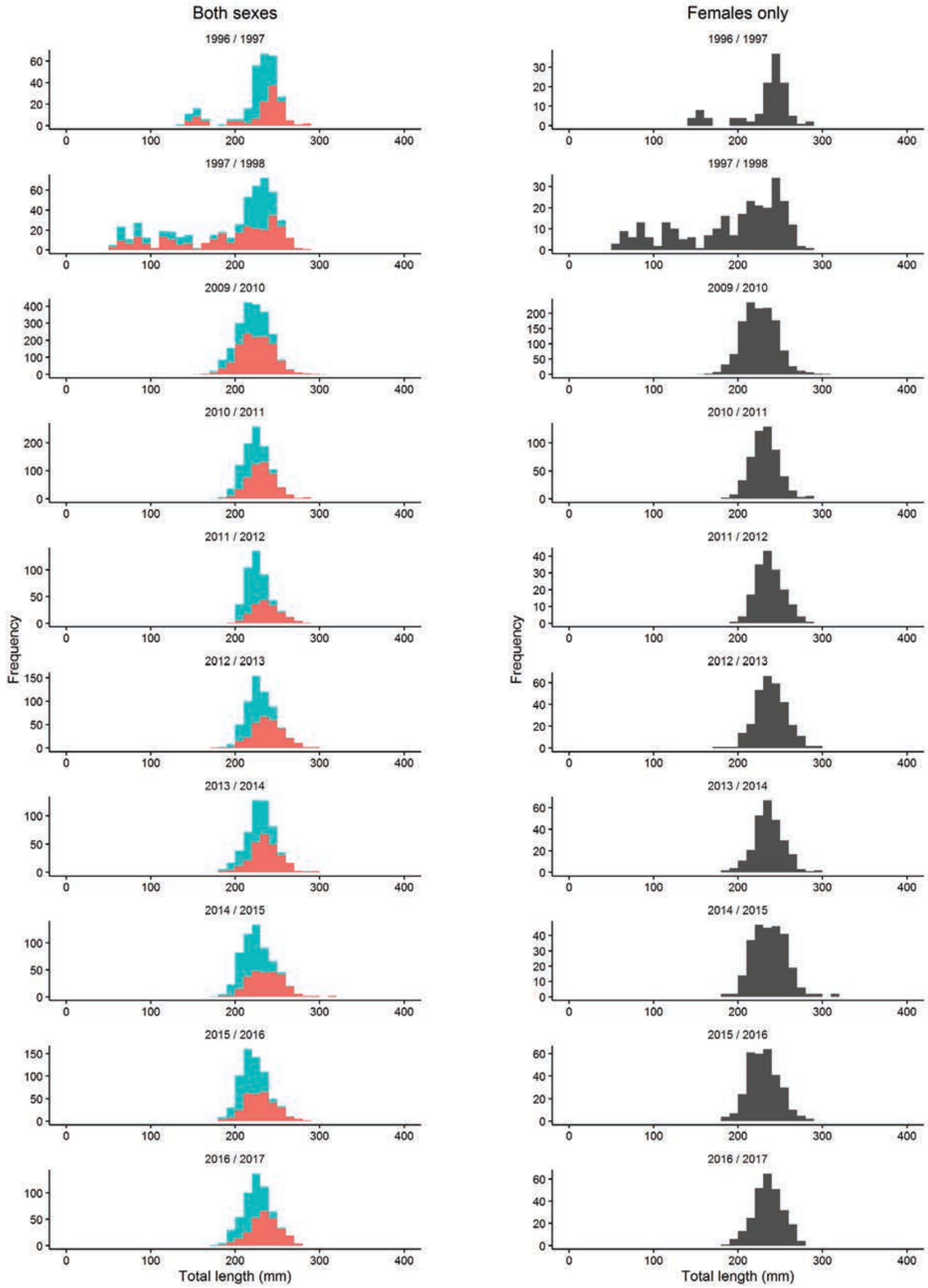
Herring Attachment 5. Figure 3. Age composition samples from commercial catches on the South Coast, separated by sexes (left, females = red, males = blue) and showing females only (right).

South Coast – Recreational

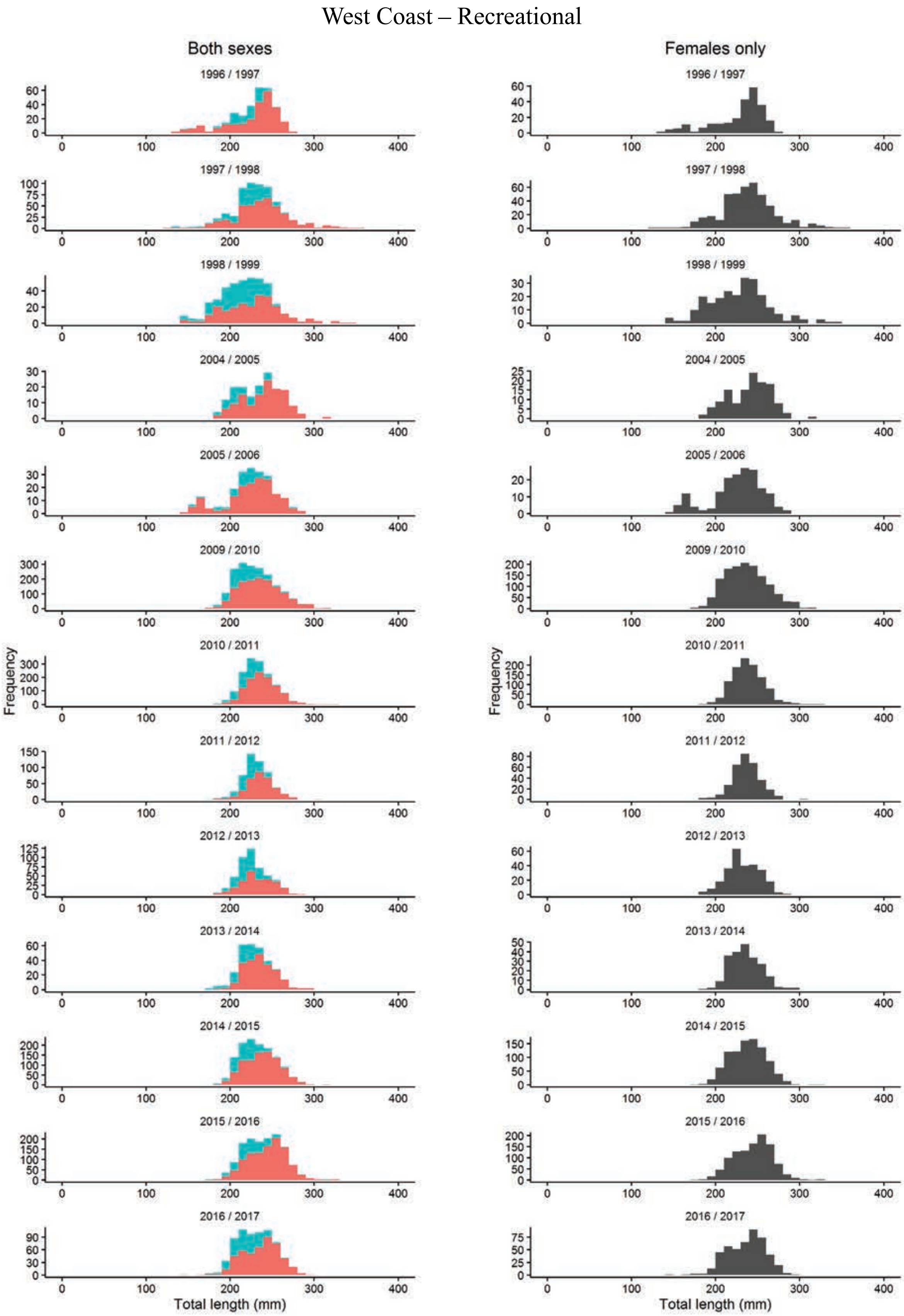


Herring Attachment 5. Figure 4. Age composition samples from recreational catches on the South Coast, separated by sexes (left, females = red, males = blue) and showing females only (right).

West Coast – Commercial

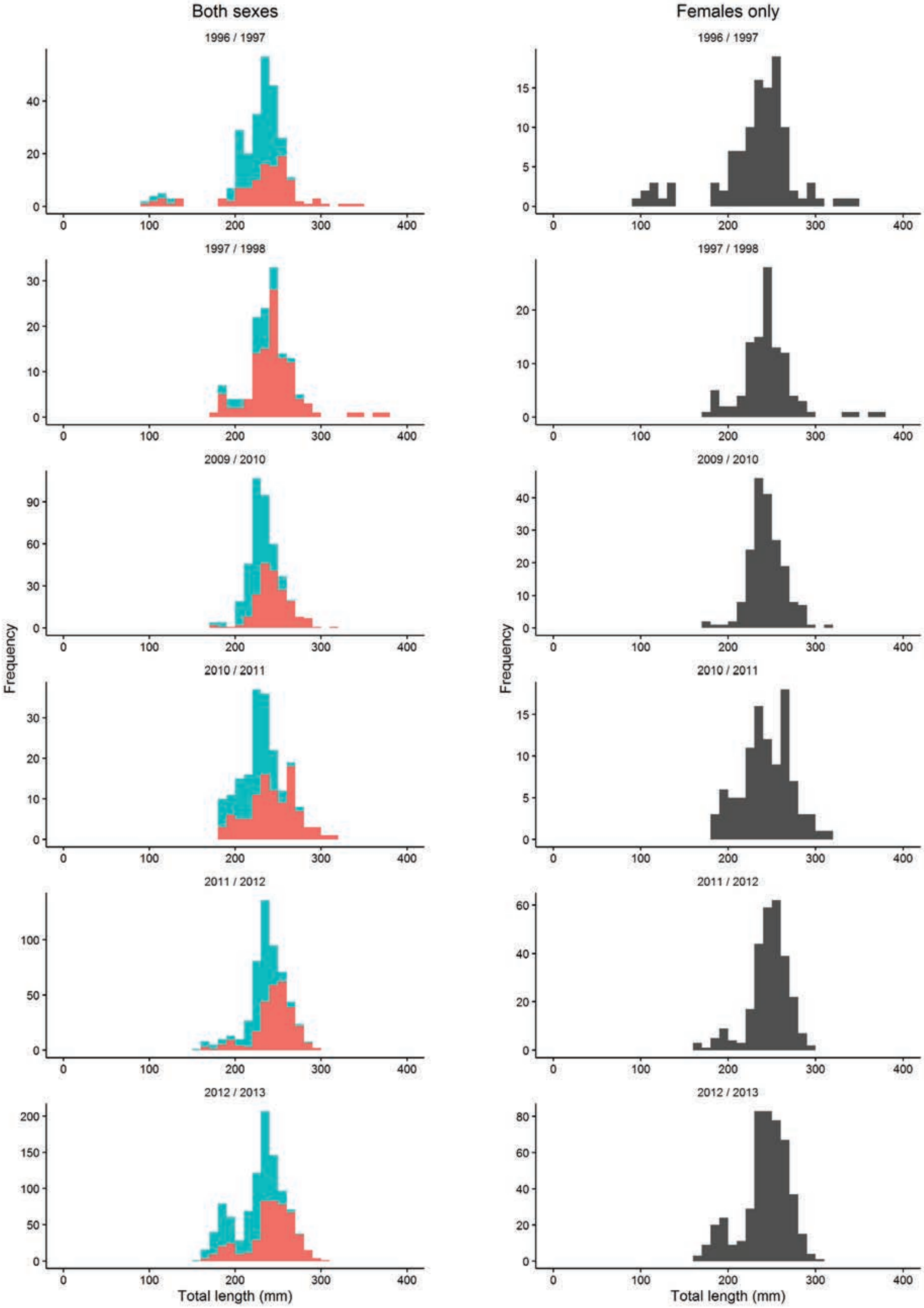


Herring Attachment 5. Figure 5. Length composition samples from commercial catches on the West Coast, separated by sexes (left, females = red, males = blue) and showing females only (right).



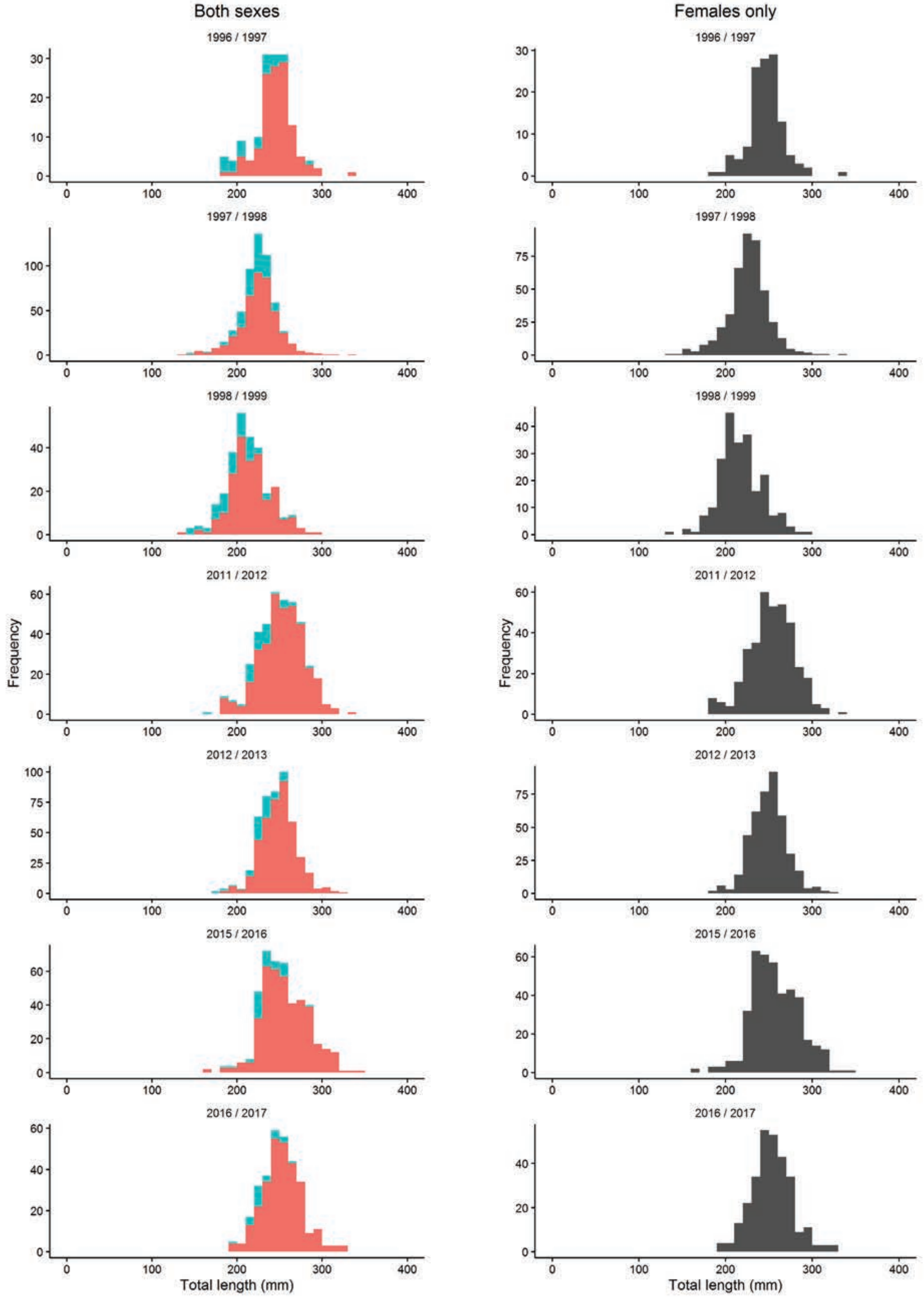
Herring Attachment 5. Figure 6. Length composition samples from recreational catches on the West Coast, separated by sexes (left, females = red, males = blue) and showing females only (right).

South Coast – Commercial



Herring Attachment 5. Figure 7. Length composition samples from commercial catches on the South Coast, separated by sexes (left, females = red, males = blue) and showing females only (right).

South Coast – Recreational



Herring Attachment 5. Figure 8. Length composition samples from recreational catches on the South Coast, separated by sexes (left, females = red, males = blue) and showing females only (right).

10. Herring Attachment 6. Estimation of Fishing Mortality from Age Composition Data.

Estimates of the instantaneous rate of total mortality (*Z*, year-1) and associated 95% confidence intervals were derived by fitting alternative catch curve models to the two most recent years of age composition data (collected in the 2015/16 and 2016/17 biological years) for each region and sector. Note that no recent age samples were available for the south coast commercial fishery, which has been closed since 2014. Although the age composition samples used in the analyses were limited to female fish caught in ocean waters to minimise known biases, the results should be interpreted with caution due to the inability to be certain that the strong equilibrium assumptions that mortality and recruitment remain constant over time.

The different catch curve models used in the analyses (Herring Attachment 6, Table 1) have been previously applied to explore the extent to which model uncertainty impacts on assessment results for other species. The first four basic models (Herring Attachment 6, Table 1) assume constant annual recruitment and were fitted to single biological years of age composition data. Model 5 (Herring Attachment 6, Table 1) attempts to account for inter-annual variability in recruitment by simultaneously fitting to age composition data for at least two consecutive years.

Estimates of fishing mortality (*F*) were calculated by subtracting the assumed value of natural mortality (*M*) for herring (0.4 $year^{-1}$) from each catch curve estimate of *Z*, i.e. $F = Z – M$. Due to the low number of age classes present in herring samples, the age at full recruitment for these analyses were considered as the age of peak frequency for each sample. Repeating the analyses based on the age at full recruitment being the peak age +1 resulted in markedly different results, with higher estimates of total mortality (not presented).

A summary of the key outputs from the catch curve analyses are provided in Table 2 and Table 3. Estimates of F derived from each age composition sample (2015/16 and 2016/17) were typically similar among the alternative catch curve models 1-4, with the exception of Model 4 which consistently produced higher *F* estimates (Herring Attachment 6, Table 2). Model 5 attempts to account for recruitment variability between years and produced an estimate mid –range of the other model estimates in both years. The *F/M* ratios based on estimates from this method ranged from 1.36 for the south coast recreational fishery to 2.20 for the west coast commercial fishery (Herring Attachment 6, Table 2). Estimates of selectivity produced by Model 5 were relatively similar across the regions and sectors, suggesting that 50% of females are vulnerable to fishing by an age of 2.5-2.9 years (Herring Attachment 6, Table 3).

Herring Attachment 6. Table 1. Alternative catch curve models applied to estimate mortality of herring. Detail methods can be found in Norriss et al. (2016).

Catch curve model	Brief description
Model 1 – Linear catch curve	Linear regression fitted to the logged frequencies of fish from the age of full recruitment to that prior to the age with the first zero frequency. Assumes constant recruitment, mortality and knife-edge selectivity at the age of full recruitment.
Model 2 – Chapman & Robson estimator	Estimator of survival that assumes a geometric distribution of the population age composition and knife-edge selectivity at the age of full recruitment. Assumes constant recruitment, mortality and knife-edge selectivity at the age of full recruitment.
Model 3 – Multinomial catch curve, with knife-edge age-based selectivity	Assumes a multinomial distribution of age compositions and knife-edge selectivity at the age of full recruitment. Assumes constant recruitment, mortality and knife-edge selectivity at the age of full recruitment.
Model 4 – Multinomial catch curve, with logistic age-based selectivity	Extends Model 3 to estimate logistic, age-based selectivity. Assumes constant recruitment and mortality. Estimates age-based selectivity, described by a logistic (asymptotic) curve where the parameters A_{50} and A_{95} represent the ages by which 50 and 95% of fish are selected by fishers, respectively.
Model 5 – Multi-year catch curve that estimates age-based selectivity and accounts for recruitment variability	Extends Model 4 by fitting separate curves simultaneously to age composition data for consecutive biological years to account for variable recruitment, but noting the inability to correctly scale data based on catches. Assumes constant mortality. Estimates age-based selectivity, described by a logistic (asymptotic) curve where the parameters A_{50} and A_{95} represent the ages by which 50 and 95% of fish are selected by fishers, respectively.

Herring Attachment 6. Table 2. Estimates of fishing mortality produced by catch curve analyses.

Region/Sector	Method	Fishing mortality (*F*; year^{-1}) 2015/16 Estimate (95% CI)	2016/17 Estimate (95% CI)	*F/M* (based on most recent *F* estimate)
West Coast - Commercial	1	1.38 (0.93-1.82)	1.09 (0.57-1.620)	2.74
	2	1.18 (1.13-1.22)	0.71 (0.66-0.760)	1.78
	3	1.19 (0.98-1.40)	0.71 (0.57-0.860)	1.78
	4	1.54 (0.78-2.31)	2.17 (1.21-3.130)	5.43
	5 (both years)	0.88 (0.75-1.02)		2.20
West Coast - Recreational	1	0.59 (0.34-0.84)	0.45 (-0.45-1.350)	1.13
	2	0.70 (0.68-0.73)	0.57 (0.53-0.610)	1.42
	3	0.70 (0.63-0.78)	0.57 (0.46-0.680)	1.43
	4	1.01 (0.81-1.21)	1.64 (0.87-2.40)	4.09
	5 (both years)	0.66 (0.60-0.72)		1.64
South Coast - Recreational	1	0.42 (0.24-0.59)	0.76 (0.56-0.970)	1.91
	2	0.42 (0.39-0.46)	0.61 (0.55-0.670)	1.52
	3	0.43 (0.34-0.51)	0.61 (0.46-0.770)	1.53
	4	0.71 (0.53-0.90)	0.76 (0.49-1.020)	1.89
	5 (both years)	0.54 (0.43-0.66)		1.36

Herring Attachment 6. Table 3. Estimates of age-based, logistic selectivity produced by catch curve Model 5 using data from biological years 2015/16 and 2016/17.

Region/Sector	Method	A_{50} selectivity (years, 95% CI)	A_{95} selectivity (years, 95% CI)
West Coast - Commercial	5	2.8 (2.7-2.9)	3.5 (3.2-3.9)
West Coast - Recreational	5	2.5 (2.5-2.6)	3.2 (3.1-3.3)
South Coast - Recreational	5	2.9 (2.6-3.2)	3.8 (3.3-4.2)

Reference

Norriss, J. V., E.A. Fisher, S.A. Hesp, G. Jackson, P.G. Coulson, T. Leary and A.W. Thomson. 2016. Status of inshore demersal scalefish stocks on the South Coast of Western Australia. Fisheries Research Report No. 276, Department of Fisheries, Western Australia. 116 pp.

11. Herring Attachment 7. Estimation of Relative Reproductive Potential.

Herring Attachment 7A. Estimation of relative reproductive potential from length composition data (LBSPR Analyses, Jeremy Prince)

Methods

With the initial aim of updating stock indices using recent data a newly developed (Hordyk et al 2013) length base method for assessing spawning potential ratio (SPR) and relative fishing pressure (F/M) was used to assess length frequency data for female Australian herring collected 2014 -2017. These preliminary assessments focused from the outset on the length data collected from the recreational rod and line fishers as there were no recent data from the commercial sector on the south coast. To increase sample sizes data were aggregated over each of the two management units; for the south and south east regions (referred to here as south coast), and for the southwest, metro and midwest regions (referred to here as west coast). For comparison data from the South Coast were aggregated over 1996 and 1997 for all gears combined, and for the commercial sector alone, and the recreational fishery alone, and also from the south coast trap net fishery for 2012 and 2013. For west coast comparisons data from 1997 and 1998 were aggregated for the recreational, and also the commercial sectors alone. Data for the west coast recreational fishery in 2010 were also compared with data from the commercial haul net fishery in Cockburn Sound.

The LBSPR analysis uses as input parameters estimates taken from Smith et al. (2013) of asymptotic size (296 mm, 271 mm) and size of maturity (220 mm, 194 mm) for the south and west coasts respectively. The other input parameter *M/k* (natural mortality divided by growth rate) was bounded by the values 0.73 & 0.88 which correspond with *M*= 0.38 & 0.42 thought to bound estimates of natural mortality, and *k*= 0.48 and 0.52 a range estimated by Smith et al. (2013) for the two management units.

Results

<u>West Coast</u>

The estimates of SPR derived from the recreational rod and line length data 2014 -2017 were consistently high and relatively stable (0.52 – 0.66) which reflects the relatively high abundance in these samples of fish around the asymptotic size (194 mm). Estimates of relatively mortality (*F/M*) were highly variable (0.58 – 3.54) reflecting a much greater presence of small herring (200 – 240 mm size classes) observed in the samples from 2015 and 2017, which the LBSPR methodology interprets as a significantly smaller size of selectivity in those years ($SL_{50\%}$ = 246 - 257 mm in 2015 & 2017 cf. $SL_{50\%}$ = 214 - 226 mm in 2014 & 2016), and a correspondingly higher *F/M* in 2015 & 2017 and lower in 2014 &

2016. The co-varying estimates of size of selectivity and relative fishing maturity, combine to produce the relatively stable estimates of SPR. The contrasting stability of the SPR estimates are primarily informed by the relatively high and consistent presence of fish attaining or exceeding the west coast estimate of asymptotic size (271 mm).

Estimates from the recreational rod and line fishery in 2010 suggest a higher level of SPR than the data from the commercial haul net fishery in Cockburn Sound (0.50 – 0.59 cf. 0.29 – 0.35) and a correspondingly lower level of relative fishing pressure (*F/M* = 0.77 – 1.09 cf. 3.09 – 3.87). Estimates from the 1997 & 1998 data suggest higher levels of SPR than in 2010 and lower fishing pressure. The estimates from the 1997 & 1998 are midway between the estimates for 2010 and the most recent data, which at face value suggests stock status declined from 1997/1998 to 2010, and subsequently increased. As with the 2010 data, the 1997 & 1998 data from the recreational sector produced higher estimates of SPR, and lower *F/M*, than the data from the Cockburn Sound haul net fishery (SPR = 0.58 – 0.65 cf. 0.43 – 0.54; *F/M* = 0.60 – 0.81 cf. 0.79 – 1.17).

South Coast

In contrast to the west coast the south coast estimates of the size of selectivity ($SL_{50\%}$ = 211 – 240 mm) bracket the size of south coast estimate of maturity ($L_{50\%}$ = 220 mm). The length data from the trap fishery in 1996-97 and 2012-13 suggest $SL_{50\%}$ = 240-242 mm was greater than the $L_{50\%}$ = 220 mm, while that of the recreational catch in 1996 & 1997 ($SL_{50\%}$ = 220 mm) was the same. The recent recreational data estimate $SL_{50\%}$ to be around $L_{50\%}$ depending on the prevalence of the smaller (200 – 240mm) size classes.

The estimates of SPR derived from the 2014 -2017 data from the recreational rod and line sector on the south coast were also lower than for the west coast (0.29 – 0.44). A result driven by the relatively fewer fish in these samples around and above the south coast estimate of asymptotic size (296 mm). As with the west coast, estimates of relatively mortality (*F/M*) were highly variable (1.08 – 2.73) reflecting a much greater presence of small herring (200 – 240mm size classes) in the samples from 2014 and 2017, which the LBSPR methodology again interprets as a smaller size of selectivity in those years ($SL_{50\%}$ = 211 - 226 mm cf. $SL_{50\%}$ = 234 mm) and a correspondingly higher F/M, which combine to produce the relatively stable estimates of SPR.

Estimates from the 2012 & 2013 data collected from the trap net fishery produced estimates of SPR = 0.30 – 0.35, with estimates of relative mortality *F/M* = 3.12 – 3.92 and $SL_{50\%}$ = 242 mm. The data from all sectors combined (excluding research sampling) during 1996 & 1997 produced lower estimates of SPR = 0.17 – 0.22 and correspondingly higher estimates of relative fishing mortality *F/M* = 3.6 – 4.5 with $SL_{50\%}$ = 229mm. In contrast to the west coast estimates, analysing the 1996 & 1997 data from the commercial sectors produced higher estimates of SPR = 0.23 – 0.28 and lower estimates of *F/M* = 2.99 – 3.77; $SL_{50\%}$ = 240 mm, than from the recreational data SPR = 0.15 – 0.19, *F/M* = 3.42 – 4.28; $SL_{50\%}$ = 220 mm.

Discussion of Results

West Coast

In all years and gear combinations the size of selectivity on the west coast ($SL_{50\%}$ = 209 – 257 mm) is greater than the size of maturity ($L_{50\%}$ = 194 mm) and in the recent years 2014 & 2016 considerably greater ($L_{50\%}$ = 194 mm cf. $SL_{50\%}$ = 246-257 mm). The effect of this is that, on the west coast the estimates of high (>2) relative fishing mortality (*F/M*) are compatible with the estimated high level of SPR (>0.5).

The data from the commercial fishery in 1997 and 1998 and again in 2010 produced lower estimates of SPR, and higher estimates of *F/M* than the concurrent data from the recreational sector. The lowest estimates of SPR (0.29 – 0.35) were derived from the Cockburn Sound haul net fishery in 2010, and all the other estimates suggest SPR has remained relatively stable and high (<0.43) through the period analysed.

South Coast

In contrast to the west coast analyses, on the south coast the size of selectivity is estimated to be around the size of maturity (211 – 242 mm cf. 220 mm) and estimates of high relatively mortality are estimated to have resulted in correspondingly lower levels of SPR. Estimates based on both commercial and recreational data aggregated over 1996 and 1997 suggest relatively low levels of SPR (0.15 – 0.28) that have since increased (0.30 – 0.44).

Conclusions

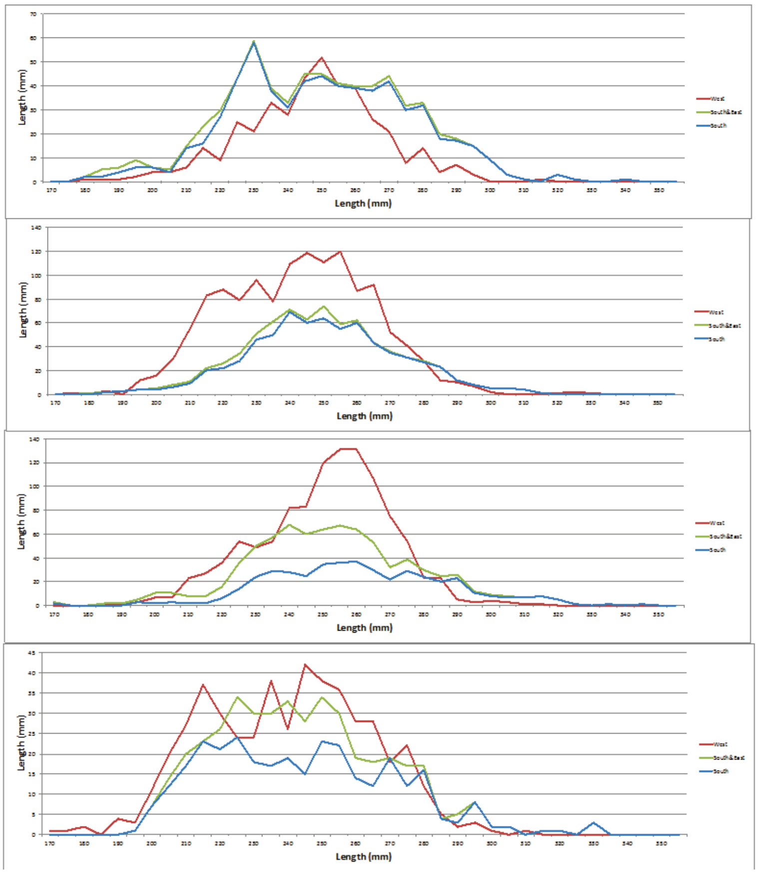
Taken at face value these results suggest:

1. The potential for relatively localized patterns of fishing pressure as evidenced by the lower estimates of SPR produced for the west coast with the commercial data compared to the concurrent recreational data.
2. The low size of maturity on the west coast relative to the size of maturity has generally maintained high levels of SPR through the period analysed, suggesting the perceived period of lower recreational catches and catch rates on the west coast resulted from factors other than recruitment overfishing.
3. The larger size of maturity on the south coast relative to the size of selectivity has made this area less resilient to fishing pressure, and during the late 1990s SPR was reduced, but has since increased.
4. A, perhaps, surprising lack of recovery in the SPR on the south coast given the extended period or relatively low catches. This might be explained by:
    a. A substantial movement of adults from the south to west coast, but this seems at variance with the observed fixed smaller size of maturity and asymptotic size on the west coast.
    b. A degree of stock localisation within the two management units so that samples maybe indicative of localized areas of stock rather than broader stock trends.
    c. A systemic change in stock productivity so that more recent lower catches are being taken from a smaller stock, which could be hypothesized to result from increased predation rates by West Australian salmon and / or long term reduction in productivity.

References

Hordyk, A., Ono, K., Valencia, S.V., Loneragan, N., Prince, J.D. 2015. A novel length-based estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. *ICES J. Mar. Sci. doi:10.1093/icesjms/fsu004*

Smith, K., Brown, J., Lenanton, R., Molony, B., 2013. Status of nearshore finfish stocks in south-western Western Australia Part 1 : Australian herring NRM Project 09003 Final Report. Department of Fisheries, Perth, Western Australia.



Herring Attachment 7A. Figure 1. Length Frequency histograms of female Australian herring caught by rod and line 2014-2017.

Herring Attachment 7A. Table 1. Parameters used.

Region	M/k	L_{50}	M	k	L_{95}	L_{∞}
SC	0.88	220	0.42	0.48	265	296
SC	0.73	220	0.38	0.52	265	296
WC	0.88	194	0.42	0.48	251	271
WC	0.73	194	0.38	0.52	251	271

Herring Attachment 7A. Table 1.

A. West Coast Results

Gear	Year	Reg.	M/k	SPR	SPR 95%	F/M	F/M 95%	SL_{50}	95% SL_{50}	SL_{95}	95% SL_{95}
Rec. Rod & Line	2017	WC	0.88	**0.66**	0.48-0.83	**0.58**	0.58-1.11	215	200-230	246	222-230
Rec. Rod & Line	2017	WC	0.73	0.56	0.41-0.72	0.84	0.20-1.48	214	199-229	247	221-272
Rec. Rod & Line	2016	WC	0.88	**0.61**	0.56-0.66	**2.87**	2.08-3.66	257	252-261	294	288-3.67
Rec. Rod & Line	2016	WC	0.73	0.54	0.49-0.60	3.54	2.60-4.48	257	252-262	296	289-302
Rec. Rod & Line	2015	WC	0.88	**0.60**	0.53-0.67	**0.98**	0.60-1.36	226	219-233	258	247-233
Rec. Rod & Line	2015	WC	0.73	0.52	0.44-0.59	1.34	0.89-1.79	226	219-233	259	248-270
Rec. Rod & Line	2014	WC	0.88	**0.59**	0.50-0.67	**2.07**	1.09-3.05	246	237-255	282	270-294
Rec. Rod & Line	2014	WC	0.73	0.52	0.43-0.61	2.62	1.43-3.81	246	237-255	283	2.70-296
Rec. Rod & Line	2010	WC	0.73	**0.5**	0.46-0.54	**1.09**	0.87-1.31	213	210-216	236	230-241
Rec. Rod & Line	2010	WC	0.88	0.59	0.54-0.64	0.77	0.59-0.95	213	210-241	236	230-241
Haul net	2010	WC	0.73	**0.29**	0.28-0.33	**3.87**	3.06-4.68	219	215-224	249	242-256
Haul net	2010	WC	0.88	0.35	0.31-0.39	3.09	2.42-3.76	219	215-224	249	242-256
Rec. Only	1997 & 98	WC	0.73	**0.58**	0.49-0.66	**0.81**	0.48-1.14	217	207-226	271	257-284
Rec. Only	1997 & 98	WC	0.88	0.65	0.56-0.75	0.6	0.31-0.89	217	208-2227	271	257-284
Comm Only	1997 & 98	WC	0.73	**0.43**	0.24-0.62	**1.17**	0.32-2.02	209	163-255	356	295-417
Comm Only	1997 & 98	WC	0.88	0.54	0.33-0.75	0.79	0.12-1.46	212	168-256	353	297-409

B. South Coast Results

Gear	Year	Reg.	M/k	SPR	SPR 95%	F/M	F/M 95%	SL_{50}	95% SL_{50}	SL_{95}	95% SL_{95}
Rec. Rod & Line	2017	SC	0.88	**0.39**	0.31-0.47	**1.08**	0.73-1.43	211	205-216	229	218-240
Rec. Rod & Line	2017	SC	0.73	0.32	0.25-0.38	1.45	1.04-1.86	211	205-216	229	218-239
Rec. Rod & Line	2016	SC	0.88	**0.44**	0.39-0.50	**1.33**	0.98-1.68	234	229-239	269	260-278
Rec. Rod & Line	2016	SC	0.73	0.37	0.32-0.42	1.74	1.32-2.16	234	228-239	269	261-278
Rec. Rod & Line	2015	SC	0.88	**0.35**	0.30-0.40	**2.16**	1.60-2.72	234	229-240	268	259-277
Rec. Rod & Line	2015	SC	0.73	0.29	0.25-0.34	2.73	2.06-3.40	234	229-240	268	259-277
Rec. Rod & Line	2014	SC	0.88	**0.43**	0.35-0.50	**1.21**	0.79-1.63	226	217-234	262	249-276
Rec. Rod & Line	2014	SC	0.73	0.35	0.29-0.42	1.6	1.10-2.10	225	217-234	262	249-276
Trap Net Only	2012/13	SC	0.73	**0.3**	0.25-0.34	**3.92**	2.68-4.96	242	237-246	264	257-272
Trap Net Only	2012/13	SC	0.88	0.35	0.30-0.40	3.12	2.27-3.97	242	237-246	264	257-272
All gears	1996/97	SC	0.73	**0.17**	0.14-0.21	**4.5**	3.53-5.47	229	222-235	280	271-235
All gears	1996/97	SC	0.88	0.22	0.18-0.25	3.6	2.8-4.4	229	223-235	279	270-288
Comm Only	1996/97	SC	0.73	**0.23**	0.17-0.30	**3.77**	2.42-5.12	240	230-251	303	287-318
Comm Only	1996/97	SC	0.88	0.28	0.21-0.36	2.99	1.87-4.11	240	230-251	301	287-316
Rec Only	1996/97	SC	0.73	**0.15**	0.12-0.18	**4.28**	3.35-5.21	220	214-226	261	252-270
Rec Only	1996/97	SC	0.88	0.19	0.15-0.22	3.42	2.65-4.19	220	214-226	261	252-270

Herring Attachment 7B. Estimation of relative reproductive potential from age composition data

Catch curve (Model 5) estimates of *F* and the selectivity parameters A_{50} and A_{95} for female herring were used to determine the current female spawning potential ratio (SPR, based on spawning stock biomass per recruit) and current reproductive potential relative to that of an unfished stock. The analyses incorporate available growth and size at maturity information for this species, applying the parameters estimated separately for females on the west and south coasts by Smith et al. (2013). Further details of the equilibrium-based models used in the analysis can be found in Norriss et al. (2016).

A summary of the key model outputs are provided in Table 4. Point estimates of female SPR produced by the traditional per-recruit model were the same across the regions and sectors (Herring Attachment 7B. Table 1), despite the slightly different estimates of *F* produced by the catch curve analysis. This is due to the variation in parameter values describing the selectivity and maturity of fish across the regions/sectors. Further exploration demonstrated that estimates of SPR and relative spawning biomass are sensitive to input parameters used to describe the selectivity of fish, for example, the spawning potential reduced when selectivity is assumed to occur at a younger age.

Overall estimates of SPR were around the threshold reference level of 0.3 (Herring Attachment 7B. Table 1).

Herring Attachment 7B. Table 1. Estimates of female spawning potential ratio (SPR) and relative spawning biomass for 2015/16-2016/17.

Region/Sector	SPR	Relative spawning biomass
West Coast - Commercial	0.38 (0.35-0.40)	0.32 (0.29-0.35)
West Coast - Recreational	0.38 (0.36-0.40)	0.32 (0.29-0.35)
South Coast - Recreational	0.38 (0.34-0.44)	0.33 (0.28-0.39)

References

Smith, K., Brown, J., Lenanton, R., Molony, B., 2013. Status of nearshore finfish stocks in south-western Western Australia Part 1 : Australian herring NRM Project 09003 Final Report. Department of Fisheries, Perth, Western Australia.

Norriss, J.V., E.A. Fisher, S.A. Hesp, G. Jackson, P.G. Coulson, T. Leary and A.W. Thomson. 2016. Status of inshore demersal scalefish stocks on the South Coast of Western Australia. Fisheries Research Report No. 276, Department of Fisheries, Western Australia. 116 pp.

12. Herring Attachment 8. Stock Reduction Analyses (Catch-MSY method) (Malcolm Haddon).

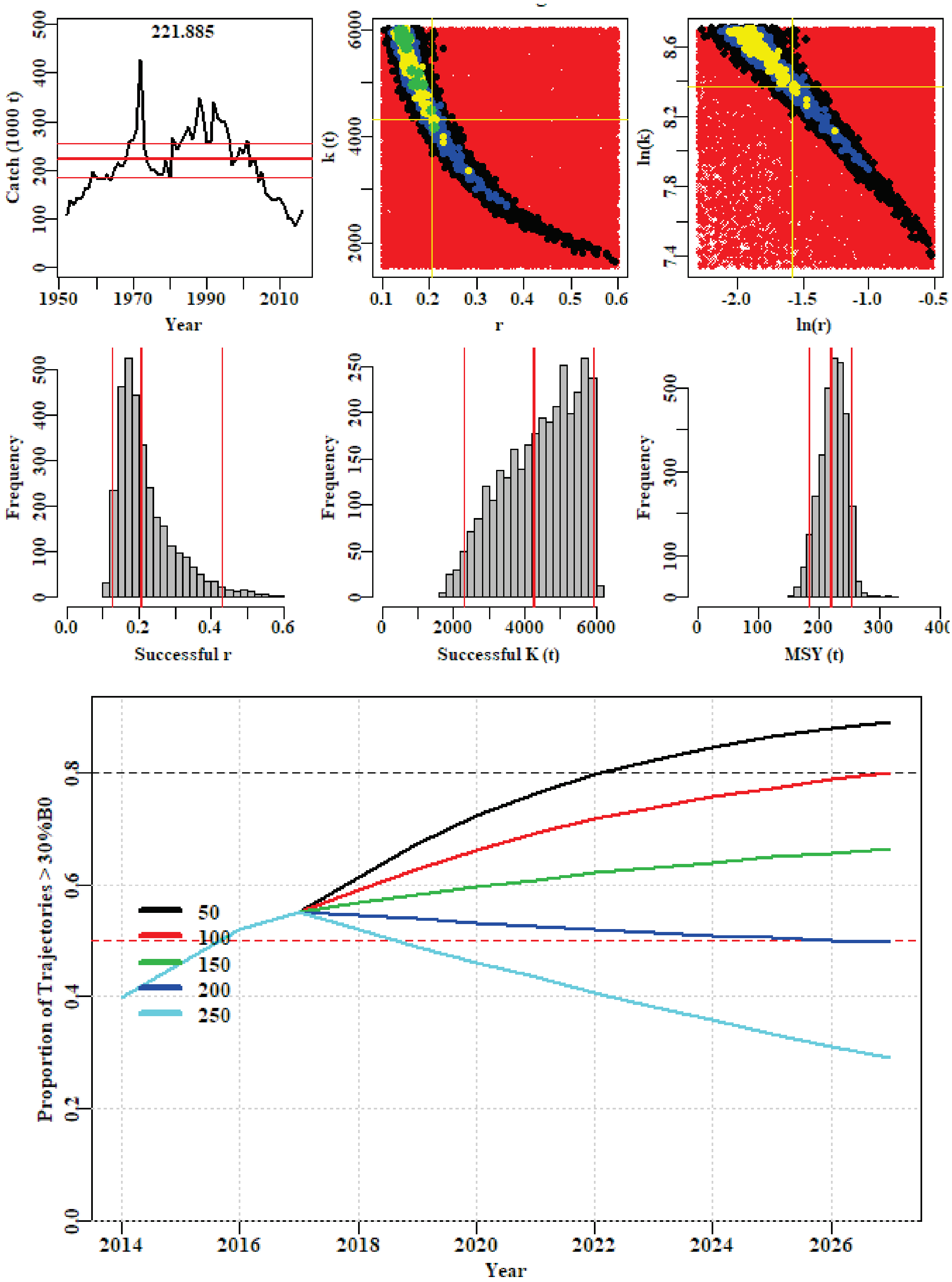
The Catch-MSY method (Martell and Froese, 2013; Froese et al. 2016) uses the relatively simple Schaefer surplus production model as the basis for describing the dynamics of the stock being described. Such surplus-production (or biomass dynamic) models usually require both a time-series of total catches (landings plus discards) and a time-series of an index of relative abundance (Haddon, 2011). In Australia the index of relative abundance is most often a time-series of standardised CPUE. Rather than using surplus production models, empirical harvest strategies have been developed for the Southern and Eastern Scalefish and Shark Fishery (SESSF) that use these time-series in empirical relationships that give rise directly to management related advice on catch levels (Little et al., 2011; Haddon, 2014). However, more widely than the SESSF there are many fisheries within Australia that may only have a time-series of catches with only limited information related to a useable index of relative abundance. In addition, such catch time-series may not be available from the beginning of the fishery, which means that methods such as Depletion-Based Stock Reduction Analysis cannot be validly applied (although, as shown in Haddon et al [2015], if sufficient years of catches are present (perhaps >25) then the method can still provide approximate estimates of management related parameters). Under such data-limited situations other catch-only based assessment methods can provide the required estimates of management interest.

As with many of the more capable catch-only data-poor approaches the Catch-MSY method evolved from the stock reduction analyses of Kimura and Tagart (1982), Kimura et al. (1984), and eventually Walters et al. (2006). It uses a discrete version of the Schaefer surplus production model (Schaefer, 1954, 1957; Haddon, 2011) to describe the stock dynamics in each case. The Catch-MSY requires a time-series of total removals, prior ranges for the _*r*_ and _*K*_ parameters of the Schaefer model, and possible ranges of the relative stock size (depletion levels) in the first and last years of the time-series. As described by Martell and Froese (2013) the range of initial depletion levels can be divided into a set of initial values, and a stock reduction using the known total removals, applied to each of these combined with pairs of _*r-K*_ parameters randomly drawn from uniform distributions across the prior ranges of those parameters. Each of these parameter pairs plus depletion levels are accepted or rejected depending the stock does not collapse, or exceed the carrying capacity, and that results in the final depletion level falling within the assumed final range. Other criteria can be included to further constrain the biomass trajectories if extra evidence is available.

West Coast

Outputs of the Catch-MSY model for the West Coast suggest that catches exceeded simulated MSY in the 1970s and during the 1980s and 1990s (Herring Attachment 8. Figure 1, Table 1). The models suggest that the biomass in the West Coast management unit has increased in recent years with more than 50% of trajectories exceeding 30% of unfished biomass since 2016. MSY for the West Coast management unit was estimated at approximately 220 t per year. Projected outcomes of an additional 50 t per year (in addition to recent catches of

approximately 100 t) would result in more than 80 % of trajectories exceeding 30% unfished biomass by approximately 2022. An additional 100 t of catches would result in more than 80 % of trajectories exceeding 30% unfished biomass by approximately 2027. Higher catches were projected to not achieve more than 80 % of trajectories exceeding 30% unfished biomass by 2027 or result in decline trajectories.



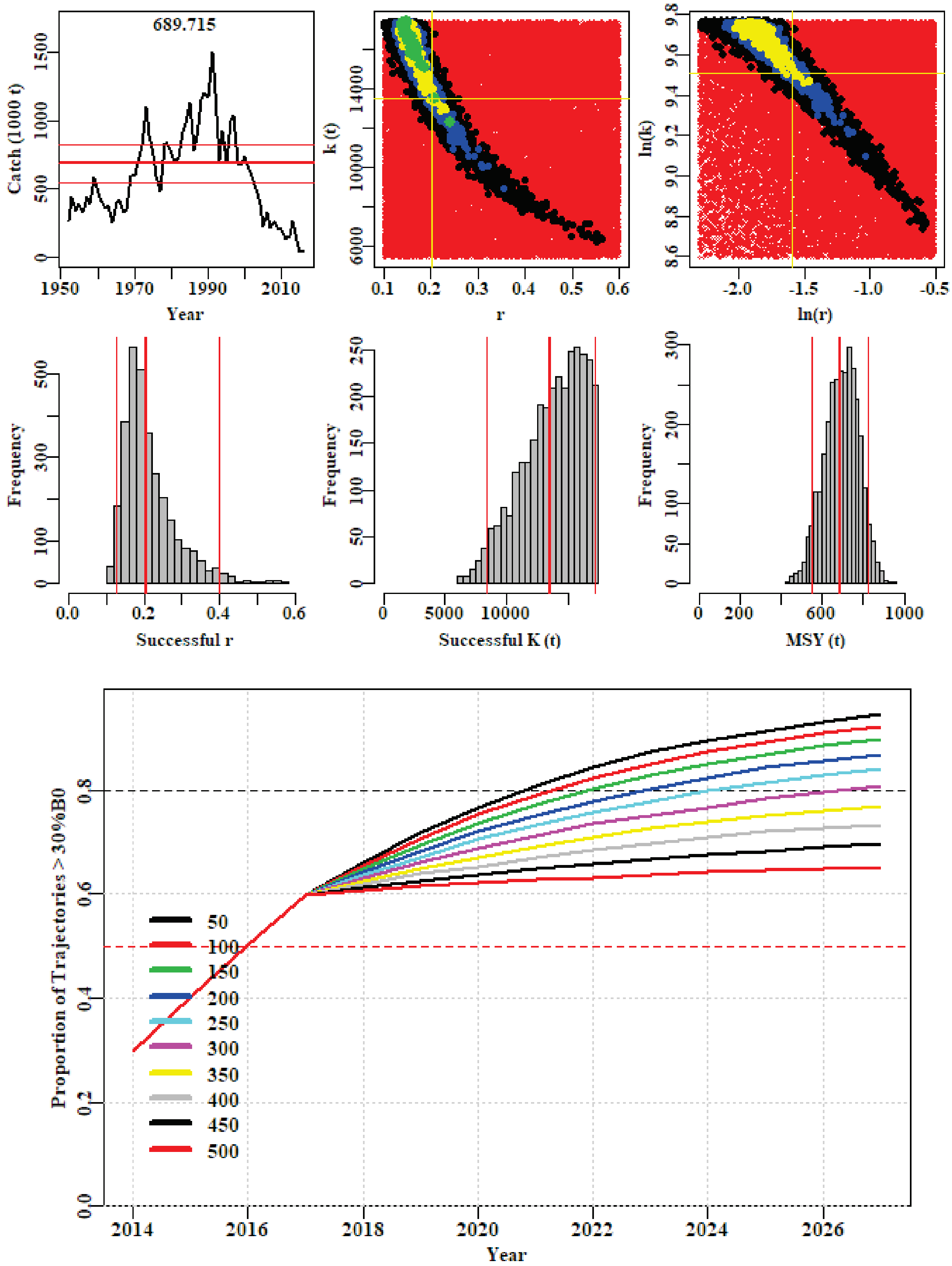
Herring Attachment 8. Figure 1. Outputs of the Catch-MSY model for the West Coast.

Herring Attachment 8. Table 1. Projected proportion of trajectories under simulated levels of additional catches above recent catches (approximately 100 t) that would result in more than 80 % of trajectories (yellow highlights) exceeding 30% unfished biomass by projection year.

	Additional annual catches				
Year	**50**	**100**	**150**	**200**	**250**
2014	0.399	0.399	0.399	0.399	0.399
2015	0.461	0.461	0.461	0.461	0.461
2016	0.519	0.519	0.519	0.519	0.519
2017	0.552	0.552	0.552	0.552	0.552
2018	0.612	0.591	0.568	0.545	0.519
2019	0.673	0.626	0.582	0.539	0.488
2020	0.722	0.660	0.597	0.531	0.461
2021	0.762	0.691	0.608	0.525	0.435
2022	0.795	0.716	0.621	0.519	0.408
2023	0.821	0.737	0.630	0.514	0.383
2024	0.844	0.757	0.639	0.509	0.358
2025	0.864	0.771	0.649	0.505	0.335
2026	0.877	0.787	0.656	0.500	0.312
2027	0.890	0.799	0.664	0.497	0.291

South Coast

Outputs of the Catch-MSY model for the South Coast suggest that catches exceeded simulated MSY in the 1970s and during the 1980s and 1990s (Herring Attachment 8. Figure 2, Table 2). The models suggest that the biomass in the South Coast management unit has increased in recent years with more than 50% of trajectories exceeding 30% of unfished biomass since 2016. MSY for the South Coast management unit was estimated at approximately 690 t per year. Projected outcomes of an additional 50 t - 300 t per year (in addition to recent catches of approximately 40 t) would result in more than 80 % of trajectories exceeding 30% unfished biomass by approximately 2027. Higher catches were projected to not achieve more than 80 % of trajectories exceeding 30% unfished biomass by 2027.



Herring Attachment 8. Figure 2. Outputs of the Catch-MSY model for the West Coast.

Herring Attachment 8. Table 2. Projected proportion of trajectories under simulated levels of additional catches above recent catches (approximately 100 t) that would result in more than 80 % of trajectories (yellow highlights) exceeding 30% unfished biomass by projection year.

	Additional annual catches									
Year	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
2014	0.297	0.297	0.297	0.297	0.297	0.297	0.297	0.297	0.297	0.297
2015	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401
2016	0.501	0.501	0.501	0.501	0.501	0.501	0.501	0.501	0.501	0.501
2017	0.597	0.597	0.597	0.597	0.597	0.597	0.597	0.597	0.597	0.597
2018	0.660	0.654	0.649	0.643	0.637	0.630	0.625	0.620	0.612	0.606
2019	0.718	0.706	0.695	0.683	0.671	0.660	0.649	0.639	0.626	0.615
2020	0.767	0.753	0.737	0.720	0.705	0.688	0.671	0.653	0.638	0.622
2021	0.807	0.791	0.771	0.752	0.732	0.711	0.692	0.669	0.649	0.627
2022	0.844	0.822	0.801	0.779	0.756	0.735	0.710	0.685	0.659	0.632
2023	0.873	0.850	0.828	0.803	0.777	0.752	0.726	0.698	0.667	0.638
2024	0.895	0.874	0.849	0.823	0.799	0.767	0.740	0.710	0.676	0.643
2025	0.914	0.893	0.867	0.843	0.813	0.783	0.750	0.720	0.683	0.646
2026	0.931	0.909	0.885	0.857	0.828	0.796	0.761	0.726	0.692	0.650
2027	0.946	0.922	0.897	0.868	0.841	0.808	0.770	0.734	0.698	0.653

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13. Herring Attachment 9. Simulation Using an Age-and Sex-Structured Model (Norm Hall).

Objectives

An age- and sex-structured simulation model using biological parameters for Australian herring (and subsequently Western Australian salmon) was developed. The model was run repeatedly with each run using values of average annual recruitment of the unexploited stock, R_0, and steepness, h, of a Beverton and Holt stock-recruitment relationship, selected randomly from ranges for these parameters considered likely to encompass the distributions of feasible values. Note that the steepness parameter of this relationship reflects the productivity of the stock and its ability to recover after a decline in abundance. For each simulation run, the initial system state was set to that of an unexploited population of fish with the given average annual recruitment. The recorded annual catches for the real fishery were then successively removed, with the abundance of the simulated population responding to the removals and the resultant annual recruitment.

Because historical catches from the Australian herring fishery increased to a peak, then declined in more recent years, the simulated population was expected to experience a decrease in abundance, due to the large catches that were removed, followed by a recovery in response to subsequent reduced catches. If the average annual recruitment of the unexploited stock and productivity of the stock are too small, the simulated population cannot produce sufficient fish to satisfy the actual catches taken by the real fishery, and the simulated population goes extinct. Such a result is infeasible and simulation runs with this response are eliminated from subsequent analysis.

If the average annual recruitment of the unexploited stock is extremely large relative to the catches that were removed, the decrease in abundance due to the removal of those catches is very small. Depending on the magnitude of average annual recruitment of the unexploited stock, R_0, and steepness, h, the simulated fish population is expected to experience depletion due to the peak in actual catches that may extend from slightly above zero to slightly less than 100%.

The questions of interest to the 2017 Australian herring workshop were whether the abundances of Australian herring in the two management units (i.e. West and South Coast Bioregions) would be expected to recover to the target level of depletion, i.e. 40% of the unfished spawning female biomass, if catches are maintained at current levels for a further five years.

The model was run separately for catches taken from the fisheries in (1) the West Coast Bioregion, (2) the combined South Coast Bioregion and Eastern States, and (3) the entire biological stock of Australian herring. For each of these scenarios, a large number of simulations were undertaken, discarding trials that resulted in population extinction. Recognising that the distribution of values of R_0 and h is determined by the algorithm used to draw samples, simulation results were considered in the context of the extent to which, if the

abundance of the simulated stock had been reduced following the historical period of high catches, it recovered to the target level following a further five years of fishing with current levels of catch.

Generic description of model

The age- and sex-structured simulation model, which was developed for this study, treated the population as a single biological unit and represented the commercial and recreational fisheries of the different regions as separate fleets, each possessing a different pattern of age- and sex-dependent selectivity and thereby allowing for the spatial and temporal availability of the fish to each fleet and the different fishing gears employed by the fishers. The spawning biomass of the stock (i.e., biomass of mature females) was scaled by the average annual recruitment of the unexploited stock, R_0, and the steepness, h, of the stock-recruitment relationship, with auto-correlated log-normal recruitment deviations ($\sigma_{\ln R}, \rho$) and 'observed' annual catches of the different fleets determining the trajectory of the resulting time series of spawning biomass. Missing catches, e.g. recreational catches, were imputed from recorded commercial catches using, for example, interpolated values between ratios of recreational to commercial catches for recorded estimates, or linear interpolation to ramp the catches from an assumed unexploited state in 1930 to the beginning of the recorded catch values for some fleets. Catches from Victoria were pooled with South Australian catches.

The model employed equations of the forms typically employed in age- and sex structured model, using parameters of fitted growth and maturity curves, and fitted weight-length relationships. The simulated population was assumed to be at an unfished equilibrium in 1930. In each subsequent biological year (i.e. 12-month period starting at the June 1 birthdate for Australian herring or May 1 birthdate for West Australian salmon), the biomass of mature females was calculated using the numbers of females in each age class at the beginning of the biological year and the body mass and proportion of mature females at the integer age associated with that age class. The latter proportion was calculated using a published maturity-length relationship. The expected recruitment, which was calculated using the Beverton and Holt stock-recruitment relationship with parameters R_0 and h, was multiplied by a factor calculated using a randomly drawn value from a log-normal distribution with standard deviation $\sigma_{\ln R} = 0.3$ and with auto-correlation $\rho = 0.1$. Such annual variation is relatively conservative, as a more typical estimate is $\sigma_{\ln R} = 0.6$.

The selectivity patterns of the commercial and recreational fishing fleets in the east coast fishery were described using dome-shaped, double logistic curves, the parameters for which were determined subjectively from visual examination of the occasional published age compositions for the species in that region. Fishing mortalities were calculated for these two fleets, using the Newton-Raphson approach, such that expected catches matched the recorded (or imputed) catches. For this calculation, the selectivities and body masses of the females and males within the different age classes were calculated using values for the midpoint of the ages of the fish within those age classes. As the herring caught in the traps on the south coast of Western Australia were apparently fish that were maturing or had matured, and

which were caught as they migrated towards their spawning grounds, and the peak period of catches on the west coast appeared to focus on aggregations of fish that had migrated to the region to spawn, it was assumed that the majority of Australian herring caught in Western Australian waters were maturing/mature fish that were removed from the population immediately prior to spawning.

Natural mortality was assumed to be 0.38 year-1, and was calculated using a maximum observed age of 12 years. Growth was assumed to be represented by von Bertalanffy curves, with the parameters being those reported by Smith et al. (2013) for curves fitted to data for each sex from pooled samples collected from the western and southern coasts of Western Australia between 2009-11. Logistic maturity curves were derived from re-analysis of 1997/98 data, for May-June, based on fish with gonads at macroscopic maturity stages 5-8 (A. Hesp, pers. comm.).

A large number of simulations were run for each set of catch data. Random values of R_0, h, and annual recruitment deviations were drawn and applied in each of these simulation trials (Herring Attachment 9. Figures 1, 2, 4, 5, 7 and 8). Simulation runs that, given the time series of catches removed by the different fishing fleets, resulted in recruitment failure and population extinction were classified as infeasible and discarded.

Results

Results from large numbers of simulation trials using the age- and sex-structured model developed for Australian herring supported the Workshop conclusion that abundance in each of the two management units is expected to be at or above the target level if current catches are maintained for a further five years (Herring Attachment 9. Figures 3 and 6). Simulation trials using the combined catches from all regions provided similar support that the abundance for the biological population is expected to be at or above the target level if current catches are maintained for a further five years (Herring Attachment 9. Figure 9).

Because the simulation approach is relatively subjective, results of the study can be accepted as being only broadly indicative of the behaviour of a fish population with biology and catch history similar to that of the Australian herring. The simulation cannot provide accurate predictions due to the limitations of information that can be derived from the data that are available for the Australian herring population and the complexity resulting from the dynamics of that population.

References

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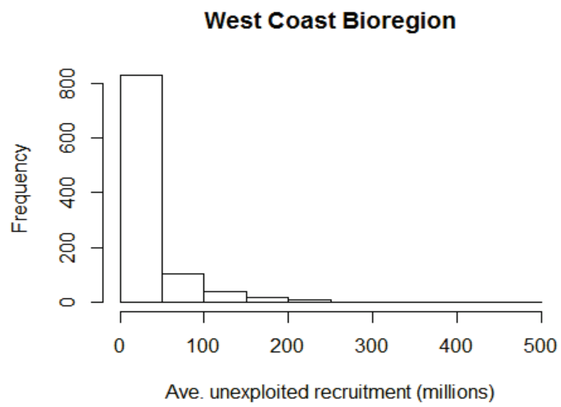
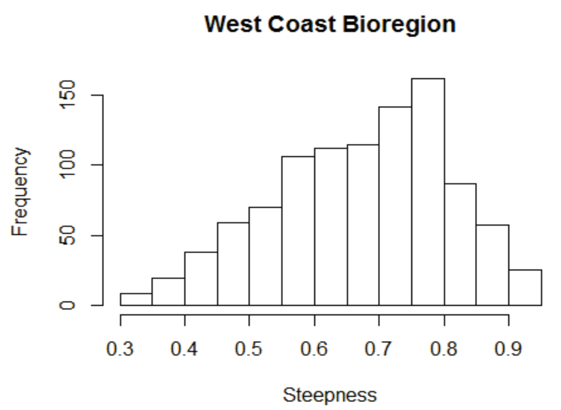
Disclaimer

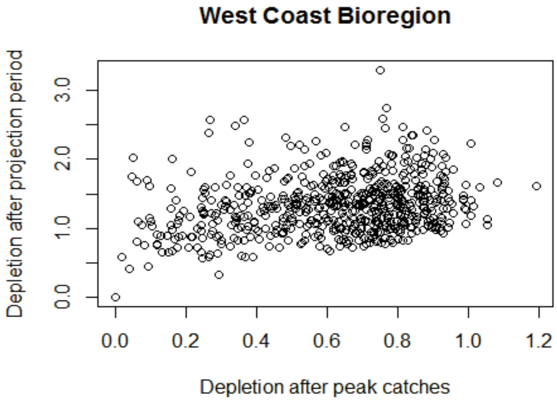
Caution should be exercised when using the results from these simulations. In particular, it should be recognised that considerable uncertainty exists in the imputed estimates of recreational catch. Alternative algorithms to draw samples for the parameters of the stock-recruitment relationship should be explored, with consideration being given to different levels of variability and auto-correlation of annual recruitment deviations. Finally, it should be noted that the results reported in this document represent work undertaken for the 2017 Australian herring Workshop, and thus have not been subjected to the critical peer review that is normally undertaken before results are published.



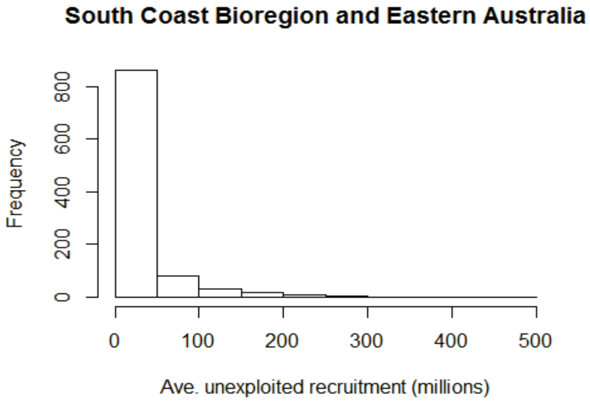
Herring Attachment 9. Figure 1. Distribution of sampled values of average unexploited equilibrium recruitment (millions of age 0 year-old recruits) for Australian herring in the West Coast Bioregion. The distribution is an artefact of the sampling algorithm.



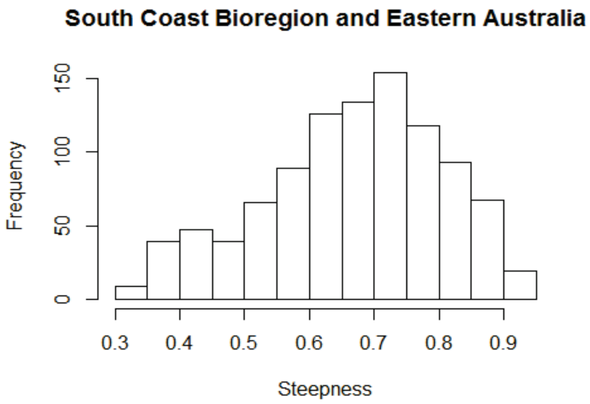
Herring Attachment 9. Figure 2. Distribution of sampled values of steepness of Beverton and Holt stock-recruitment relationship for Australian herring in the West Coast Bioregion. The distribution is an artefact of the sampling algorithm.



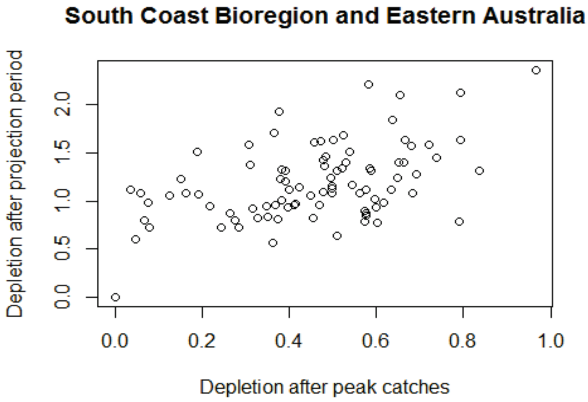
Herring Attachment 9. Figure 3. Relationship between the state of depletion for Australian herring in the West Coast Bioregion after the peak period of catches and that following five further years with current catches.



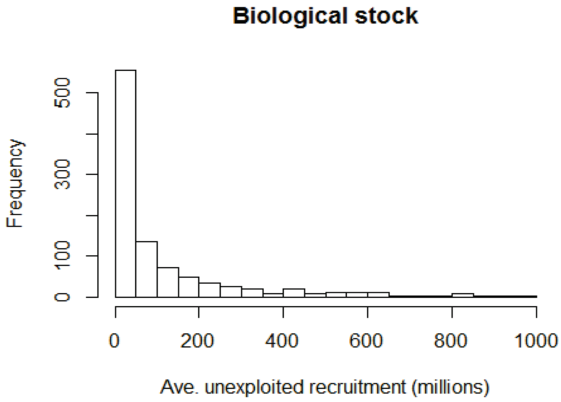
Herring Attachment 9. Figure 4. Distribution of sampled values of average unexploited equilibrium recruitment (millions of age 0 year-old recruits) for Australian herring in the South Coast Bioregion and eastern Australia. The distribution is an artefact of the sampling algorithm.



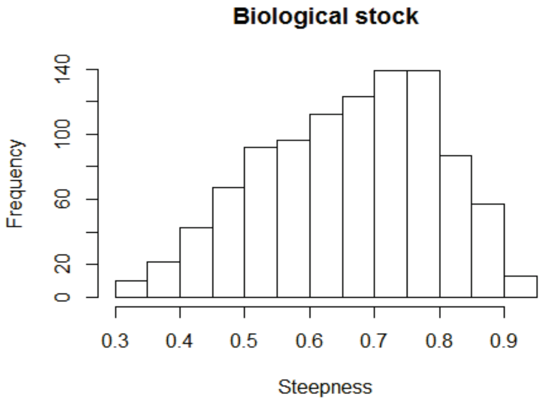
Herring Attachment 9. Figure 5. Distribution of sampled values of steepness of Beverton and Holt stock-recruitment relationship for for Australian herring in the South Coast Bioregion and eastern Australia. The distribution is an artefact of the sampling algorithm.



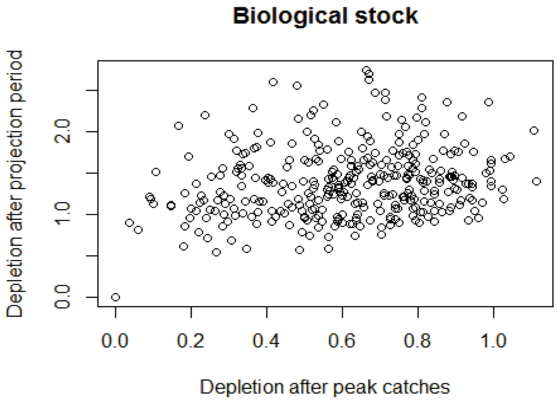
Herring Attachment 9. Figure 6. Relationship between the state of depletion for Australian herring in the South Coast Bioregion and eastern Australia after the peak period of catches and that following five further years with current catches.



Herring Attachment 9. Figure 7. Distribution of sampled values of average unexploited equilibrium recruitment (millions of age 0 year-old recruits) for the biological stock of Australian herring. The distribution is an artefact of the sampling algorithm.



Herring Attachment 9. Figure 8. Distribution of sampled values of steepness of Beverton and Holt stock-recruitment relationship for the biological stock of Australian herring. The distribution is an artefact of the sampling algorithm.



Herring Attachment 9. Figure 9. Relationship between the state of depletion for the biological stock of Australian herring after the peak period of catches and that following five further years with current catches.

14. Herring Attachment 10. Testing the Efficacy of an Integrated Assessment Model for Australian Herring based on Currently Available Data.

Assessment overview

Objectives

1) Assess whether it is possible to fit a sex- and age-structured integrated assessment model to available catch and commercial age composition data for Australia herring in the west coast and south coast bioregions (fitting the model separately for each region).
2) Assess whether results from the model are likely to be informative about current stock status
3) Assess whether results from the model projections are informative about trends in abundance over the next five years, if the current low catch levels (in each region) are maintained over the next five years.

Generic description of model

A single area, sex-structured age-structured integrated assessment model was fitted separately to data for Australian herring on the west coast (i.e. West Coast Bioregion) and south coast (i.e. South Coast Bioregion). The data used for assessment, for each coast, included time series of total catch from 1952-2016 (for all sectors, Herring Attachment 10. Table 1) and age composition data commercial catch rates and age composition data for the commercial fishing sector. Since 2009, four years of commercial age data were available for the south coast and eight were available for the west coast (Herring Attachment 10. Table 2). The reduced data set for the south coast reflects, in part, the closure of the trap fishery on that coast in 2015.

Available age composition data not used for analysis included age composition data from:

(1) recreational fishers - considered less likely than commercial samples to constitute representative samples from the population, e.g. associated with effects of high-grading

(2) for earlier years - sampling methodology less consistent for earlier years than from 2009 and thus less comparable among yeas, and conducted for purposes other than dedicated stock monitoring, e.g. opportunistic sampling or biological research (1996-98).

The model requires a full time series of total stock removals. Although commercial catches are available for all years, information on recreational catches is limited to data from recreational surveys conducted in several years. The full time series of recreational catches was “constructed” based on estimates from these surveys and linear interpolation (same time series as used in SRA model by Malcolm Haddon).

The model also incorporates biological parameters that have been separately estimated and pre-specified, e.g. for describing growth, weight-at-length relationships and size at maturity of fish based on 2009-11 data, derived by Smith et al. (2013).

The age-structured population model, which is very similar to that used for the Gascoyne pink snapper stock in Western Australia, starts with an assumed age distribution of fish based on the numbers of fish reducing in each age class as a result of an initial specified fishing mortality F_0. The population dynamic model consists of:

1. A Beverton and Holt stock-recruitment relationship with a fixed value for steepness (default = 0.75). Log-normal recruitment deviations with a mean of zero are estimated to account for annual variation in recruitment around the value predicted by the stock-recruitment relationship.
2. A deterministic sexual maturity vector for females, derived from parameters of a logistic function fitted to maturity data for females, calculated external to the assessment model (Smith et al., 2013).
3. A deterministic weight-at-age vector, determined from parameters of a von Bertalanffy growth curve and weight-length relationship, calculated external to the assessment model (Smith et al., 2013).
4. A logistic function with median age and slope at the inflection point estimated in the model, used to calculate the vector of vulnerability at age.
5. A pre-specified value for natural mortality M (0.38 y^{-1}), based on an observed maximum age of 12 y, and using equation of Hoenig (1983) for calculating this parameter.
6. The annual age composition data, which were observed for each species, were assumed to be drawn from a multinomial distribution. The "effective" sample size of the age composition data was not estimated (to enable more rapid production of results for the herring workshop, and noting that as the model was not fitted to a catch rate time series, scaling between likelihoods associated with catch rate and age data was not required.
7. Harvest rate (*H*), estimated as the quotient of observed catch to estimated vulnerable biomass. The values of H were converted to values of fishing mortality (*F*) applying the equation $= -\ln(1 - H)$.
8. The overall log-likelihood has contributions associated with age composition data and recruitment deviations. The natural logarithms of the recruitment deviations are assumed to be normally distributed, with a mean of zero and a standard deviation of 0.6.
9. The model contains a penalty function that constrains the vulnerable biomass in each year to be at least twice the catch taken in that year.

10. The model estimates, as parameters, the initial recruitment, the parameters of a logistic retention curve, and recruitment deviations for all years for which there are catch data, including for a five-year projection period.

The stock assessment model was run using the software package AD Model Builder (ADMB) with point estimates and their associated upper and lower 95% confidence limits determined for various quantities of interest based on estimates of the asymptotic standard errors (i.e. using sd_report variables). The key quantities of interest were annual female spawning biomass as a percentage of estimated unfished female biomass, total annual vulnerable biomass, annual fishing mortality, and annual recruitment.

Summary results

South coast - age compositions:

For each coast, the model provided reasonable "visual fits" to the observed commercial age composition data in each (biological) year (Herring Attachment 10. Figure 1).

West coast - age compositions:

As with the south coast, the model provided reasonable "visual fits" to the observed commercial age composition data for the west coast in each (biological) year (Herring Attachment 10. Figure 2). Particularly for the west coast, the model was thus able to capture well the presence of a relatively strong year class (2007) that persisted for a number of years.

South coast - estimated biomass trends:

On the south coast, the estimated annual vulnerable biomass exhibited a gradual declining trend between 1952 until ~1990 coinciding with increasing catches (Herring Attachment 10. Figure 3a). The vulnerable biomass then declined further, despite declining catches, to reach a very low minimum (< 300 t) in ~2011, before exhibiting an increasing trend. Over the five year model projection period (2017-2021), with catches specified as being maintained at the current low level, vulnerable biomass is projected to increase very rapidly, attaining close to the estimated unfished level in 2021. The uncertainty associated with the annual vulnerable biomasses is very large in most years (reflecting limited data for the model), but is negligible between 2000-2013. The relative female spawning biomass exhibited a similar trend to that described for vulnerable biomass (Herring Attachment 10. Figure 3b) although the degree of uncertainty is comparatively less. The estimated spawning biomass is at about the limit level in 2016 and, given the specified low catch level for the projection period, is predicted to increase rapidly to well above the target by 2021.

West coast - estimated biomass trends:

The trends for annual vulnerable biomass (Herring Attachment 10. Figure 4a) and female spawning biomass (Herring Attachment 10. Figure 4b) on the west coast are similar to those described for the south coast, except that the extent of increase in biomass over the projection period is much less (particularly so for vulnerable biomass). The model projects that by the end of the 2021 projection period, female spawning biomass will have increased to above the threshold levels.

South coast – fishing mortality:

The estimated annual fishing mortality (Herring Attachment 10. Figure 3c) increased progressively from a low level in 1952 to a maximum of ~0.7, and essentially remained at this level from 2000-2013, after which it declined rapidly. It is apparent that the steady mortality from 2000-2013 reflects the effect of a model penalty to prevent an unrealistically-excessive harvest rate (i.e. the vulnerable biomass is constrained to remain at least twice the catch taken in any year). The effect of this penalty on the results obtained from the fitted model suggests that the amount of data available is insufficient to fully inform the model. Consequently, estimates of annual biomass may not be reliable.

West coast – fishing mortality:

On the west coast, annual fishing mortality (Herring Attachment 10. Figure 4c) increased progressively from a low level in 1952 to a relatively high level in 1980, and remained at about that level for most remaining years. As with the south coast, the constant level of fishing mortality over many years likely reflects the influence of a model penalty. In turn, this reflects inadequate data, implying that estimates of annual biomass may not be reliable.

South coast – recruitment deviations:

Plotting the estimated annual recruitment values over the estimated stock-recruitment curve highlights that, in several years, the levels of recruitment deviate substantially from the curve (Figure 3d). For example, the estimated recruitment in the mid-2000s (Herring Attachment 10. Figure 3e) is far lower than the recruitment predicted, given the female spawning biomass in that year, on the basis of the deterministic curve. The lower recruitment in the mid-2000s may reflect the model “adjusting” recruitment to better fit the first observed annual age composition in 2009, i.e. a statistical artefact, rather than actually low recruitments in these years. With the increasing female biomass over the 5 year projection period from 2017-2021, recruitment is expected to increase progressively (Herring Attachment 10. Figure 3f).

West coast – recruitment deviations:

Similar features to that described above for the south coast are evident in the estimated annual recruitments for herring on the west coast (Herring Attachment 10. Figure 4e,f), i.e.

low recruitment in the mid-2000s (possibly for the same reason as suggested above for the south coast). There is also a very evident recruitment spike in 1970 (Herring Attachment 10. Figure 4d) that may be associated with a short period of high reported catches around this time. That is, without further information (such as from an abundance index), the high catches reported around 1970, relative to the estimated available biomass, is made possible in the model by means of a recruitment spike. Although the female spawning biomass is predicted to increase over the projection period, the increase is not marked and recruitment is predicted to remain relatively constant (Herring Attachment 10. Figure 4f).

Conclusions (modelling objectives)

Objective 1: Assess whether it is possible to fit an integrated assessment model to available catch and commercial age composition data (separately) for Australia herring in the west coast bioregion and south coast bioregion.

The preliminary analyses undertaken during the workshop have demonstrated that it is possible to "fit", separately, integrated age-structured models to the above data for Australian herring in each region. That is, given the specified biological parameters and dynamics of the population model, it is possible to match relatively well the observed catches and age compositions, and achieve model convergence, according to the criteria required by AD Model Builder (i.e. small likelihood gradient and ability to invert the hessian matrix). This does not imply, however, that the model provides reliable outputs for assessing past, current of future stock status.

Objective 2: Assess whether results from the model are informative about current stock status.

The model appears to lack sufficient data to allow reliable estimation of biomass and mortality trends in each year. It is not recommended that this model, given current available data, be used to estimate current stock status.

Objective 3: Assess whether results from the model projections are informative about trends in abundance over the next five years, if the current low catch levels (in each region) are maintained over the next five years.

Although the results produced by the modelling are highly uncertain, reflecting in part, lack of available data, and should not be used to assess current status, model projection analyses do provide indications that, if catches remain at the current low levels, spawning biomass should increase over the next few years. Caution is advised.

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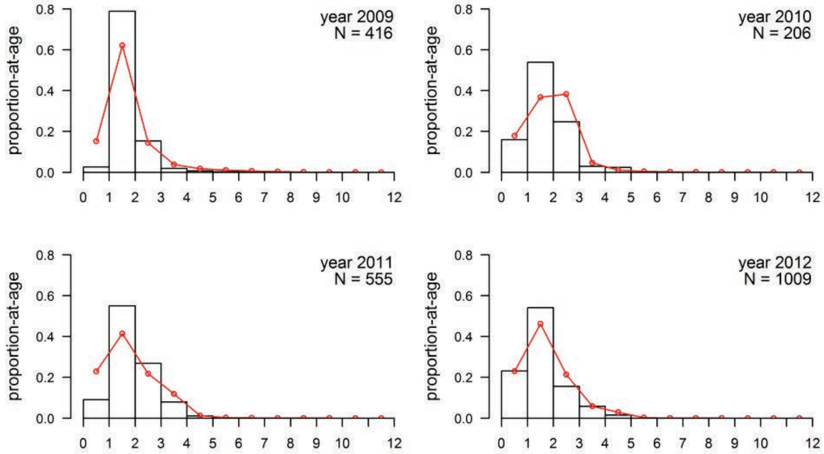
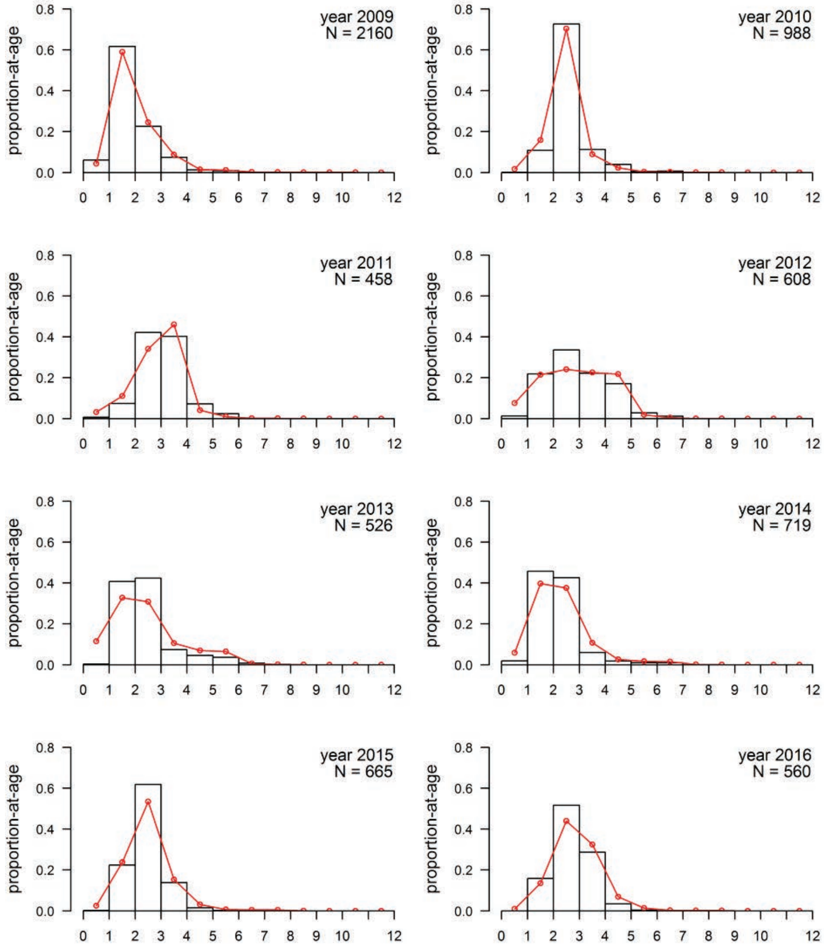
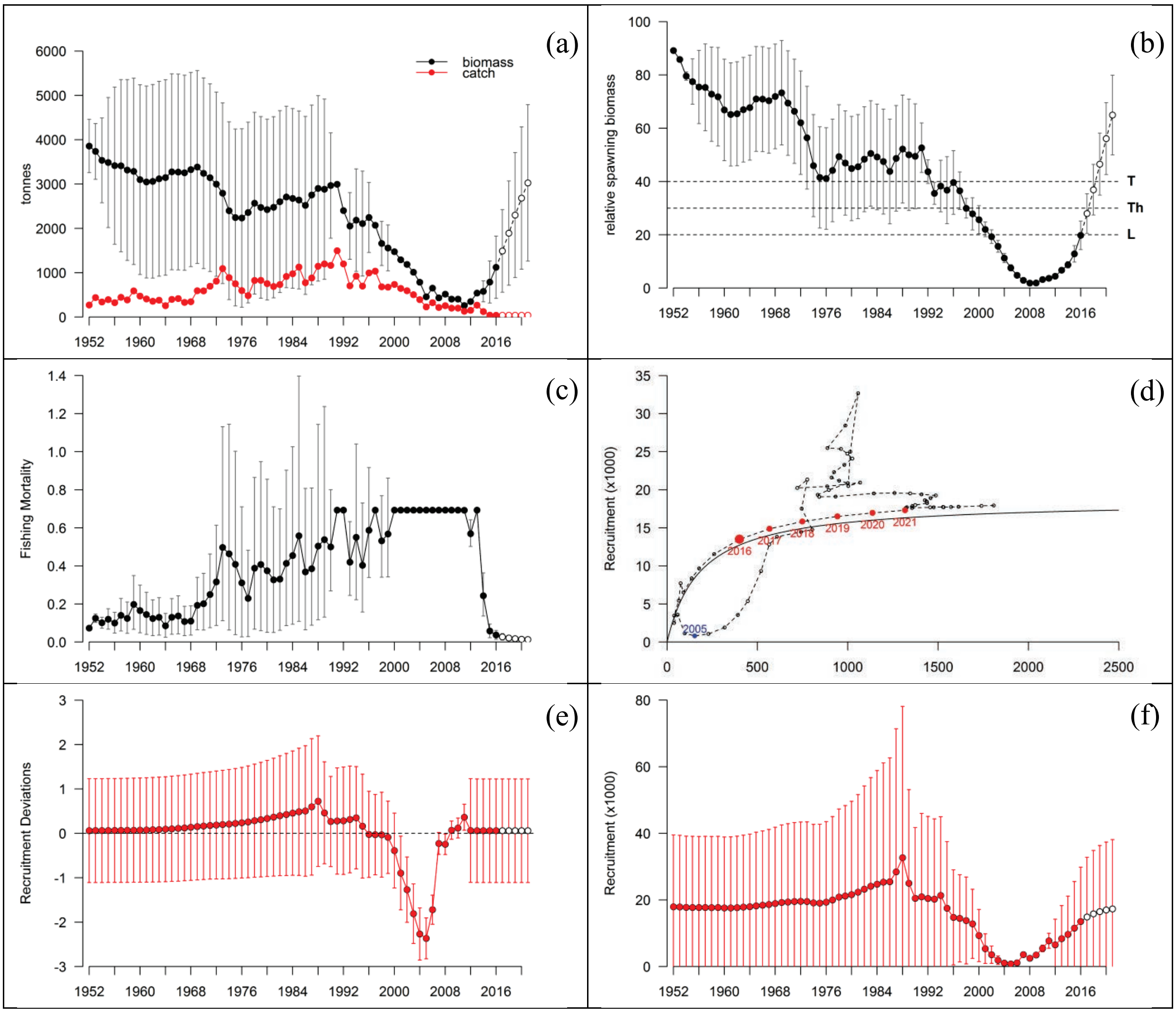


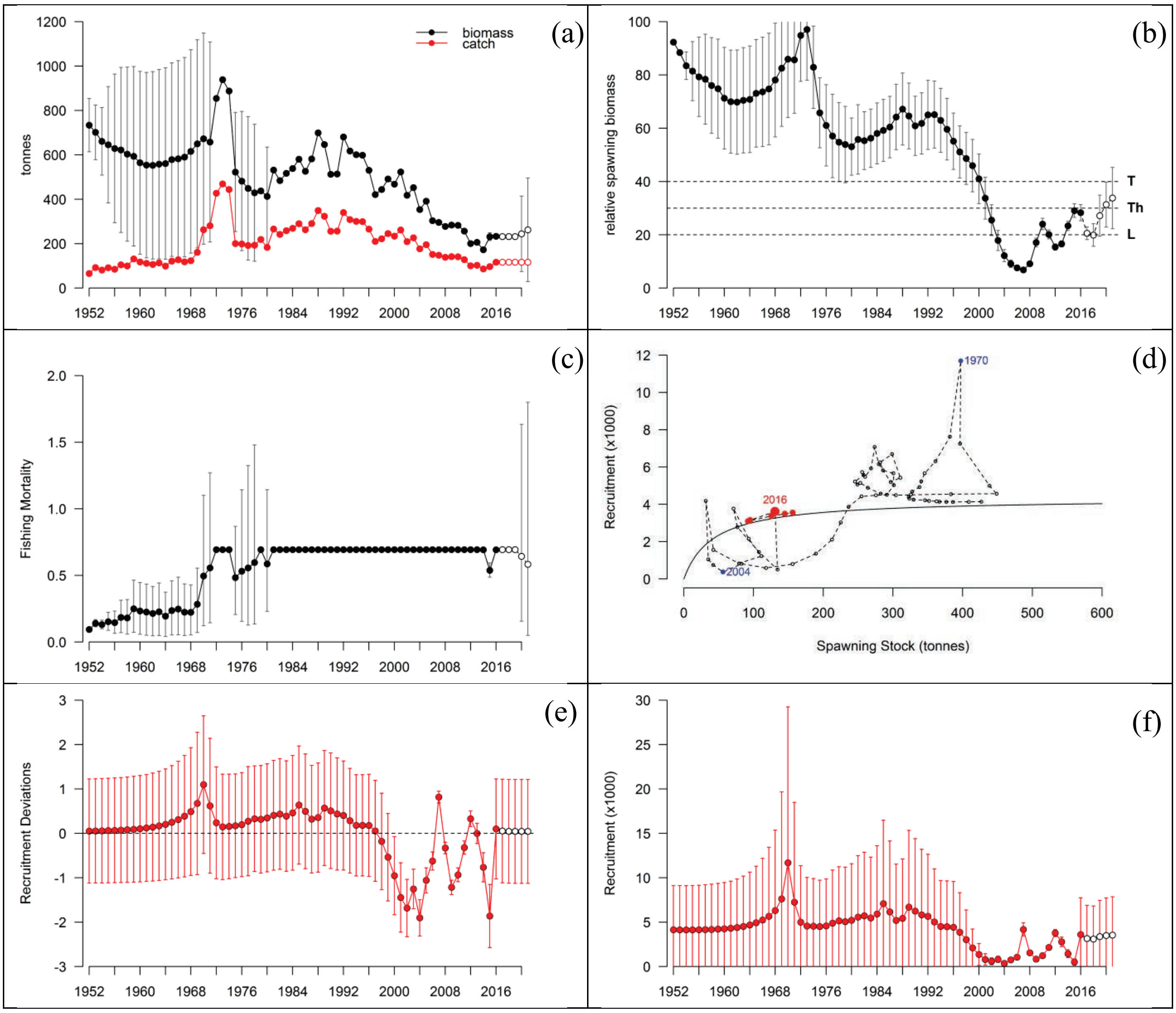
Herring Attachment 10. Figure 1. Age-composition data for South Coast Bioregion.



Herring Attachment 10. Figure 2. Age-composition data for West Coast Bioregion.



Herring Attachment 10. Figure 3. Model outputs for age-structured model fitted to catch and age data in South Coast bioregion. (a) Vulnerable biomass with 95% confidence intervals and observed catch (b) relative spawning biomass, to unfished level, with 95% confidence intervals and associated target, threshold and limit reference levels (c) fishing mortality with 95% confidence intervals (d) Beverton and Holt stock-recruitment-relationship with current year and prediction years indicated in red and year of minimum recruitment indicated in blue (e) recruitment deviations with 95% confidence intervals, and (f) recruitment numbers with 95% confidence intervals.



Herring Attachment 10. Figure 4. Model outputs for age-structured model fitted to catch and age data in West Coast bioregion. (a) Vulnerable biomass with 95% confidence intervals and observed catch (b) relative spawning biomass, to unfished level, with 95% confidence intervals and associated target, threshold and limit reference levels (c) fishing mortality with 95% confidence intervals (d) Beverton and Holt stock-recruitment-relationship with current year and prediction years indicated in red and year of minimum and maximum recruitment indicated in blue (e) recruitment deviations with 95% confidence intervals, and (f) recruitment numbers with 95% confidence intervals.

Herring Attachment 10. Table 1. Total catches (recreational and commercial sectors) for South Coast and West Coast Bioregions. Catches for prediction years in model are set to current catch level (2016) and indicated in red italics with grey fill.

Year	West Coast (tonnes)	South Coast (tonnes)	Year	West Coast (tonnes)	South Coast (tonnes)
1952	66.0	272.5	1987	290.9	880.7
1953	92.3	439.1	1988	349.7	1,149.1
1954	81.3	340.1	1989	323.3	1,200.2
1955	91.7	393.6	1990	256.2	1,166.7
1956	85.1	325.4	1991	256.8	1,497.3
1957	104.8	445.5	1992	340.3	1,200.8
1958	99.8	388.6	1993	308.8	704.5
1959	131.0	590.7	1994	300.5	925.2
1960	117.5	473.4	1995	299.3	699.9
1961	111.5	409.8	1996	265.2	997.2
1962	106.8	355.3	1997	210.7	1,036.6
1963	113.2	380.5	1998	222.1	684.6
1964	99.0	258.0	1999	245.8	675.5
1965	121.7	398.8	2000	233.9	737.0
1966	127.6	420.1	2001	261.6	647.2
1967	118.2	332.7	2002	208.9	594.0
1968	123.2	347.1	2003	226.3	506.4
1969	160.7	593.9	2004	176.8	392.5
1970	263.2	590.8	2005	195.8	229.5
1971	280.9	695.9	2006	151.8	327.4
1972	427.1	811.8	2007	147.9	216.3
1973	469.6	1094.3	2008	138.8	259.3
1974	443.9	890.4	2009	141.9	202.4
1975	200.3	752.9	2010	141.3	203.2
1976	198.8	597.8	2011	128.4	130.0
1977	191.6	483.6	2012	100.3	152.5
1978	192.9	827.0	2013	102.9	270.5
1979	218.9	828.8	2014	86.5	125.5
1980	183.2	756.9	2015	96.5	44.3
1981	265.9	690.5	2016	116.7	40.8
1982	242.0	733.2	***2017***	***116.7***	***40.8***
1983	258.5	916.9	***2018***	***116.7***	***40.8***
1984	269.2	977.9	***2019***	***116.7***	***40.8***
1985	290.4	1,130.1	***2020***	***116.7***	***40.8***
1986	263.0	776.3	***2021***	***116.7***	***40.8***

Herring Attachment 10. Table 2. Age-composition data for South Coast and West Coast Bioregions.

	West Coast								South Coast			
Age	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2009**	**2010**	**2011**	**2012**
1	132	1	3	8	2	14	1	0	11	33	50	233
2	1332	107	34	133	214	329	149	89	328	111	305	546
3	487	718	193	204	223	306	411	289	64	51	149	157
4	159	111	184	135	39	43	92	161	8	6	44	58
5	28	39	33	104	24	13	10	19	3	5	6	15
6	19	5	11	17	19	7	1	2	1	0	1	0
7	3	7	0	7	4	7	0	0	1	0	0	0
8	0	0	0	0	1	0	1	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
Total	**2,160**	**988**	**458**	**608**	**526**	**719**	**665**	**560**	**416**	**206**	**555**	**1,009**

Appendix 1. Australian Herring and Salmon Scientific Workshop.

TERMS OF REFERENCE & RISK ASSESSMENT APPROACH

TERMS OF REFERENCE

Workshop participants to:

1. Review available Australian herring information.
2. Complete a new Australian herring stock assessment based on the recent available data using a Weight of Evidence approach.
3. Determine current Australian herring stock status including scientific advice to management.
4. Recommend monitoring programs or assessment methodologies that could be adopted that would reduce uncertainties in future Australian herring stock status and sustainable catch levels.
5. Develop recommendations for monitoring and assessment approaches suitable to determine sustainable catch levels for West Australian salmon.

When: 25th to 29th September 2017

Duration: 5 days

Chair: Brent Wise

Proposed attendees:

- Malcolm Haddon (independent scientist)
- Jeremy Prince (scientist)
- Primary Industries and Regions South Australia (to be advised)
- DPIRD Scientists (Brett Molony, Kim Smith, Gary Jackson, Ainslie Denham, Alex Hesp, Rod Lenanton, David Fairclough, Alissa Tate and Emily Fisher)
- DPIRD Managers (Tim Nicholas and Martin Holtz)
- South Coast and West Coast Industry members
- WAFIC (to be advised)
- Recfishwest (to be advised)

Agenda

Day 1

- Background to workshop including a description of the Risk-based Weight of Evidence approach
- Review information for Australian herring

Day 2

- Define analyses to the undertaken and allocate attendees to working groups
- Working groups undertake analyses

Day 3

- Update Weight of Evidence with analyses
- Complete risk assessment component of the Weight of Evidence and determine Australian herring stock status

Day 4

- Recommend monitoring programs or assessment methodologies that could be adopted that would reduce uncertainties in future herring stock status and sustainable catch levels.

Day 5

- Review information for West Australian salmon
- Develop recommendations for monitoring and assessment approaches suitable to determine sustainable catch levels for West Australian salmon.

Workshop Outputs – to be made publicly available

- Australian herring Weight of Evidence assessment and risk assessment
- Updated Australian herring stock status and scientific advice to management
- Australian herring future monitoring and assessment recommendations
- West Australian salmon future monitoring and assessment recommendations.

Potential Working Groups

1. Catch, catch distribution, effort, catch rates
2. PSA, stock structure
3. Length composition, Length-based SPR
4. Age composition, *F,* Age-based SPR
5. Drafting WoE

Weight of Evidence Table

Category	Lines of evidence
Catch	
Catch distribution	
Effort	
Catch rates	
Vulnerability (Productivity Susceptibility Analysis [PSA])	
Stock structure	
Length composition (1 and 2 stocks)	
Age composition (1 and 2 stocks)	
Fishing mortality (*F*) (1 and 2 stocks) (Age, length, Age&length)	
Index of spawning stock biomass (Spawning Potential Ratio [SPR]) (1 and 2 stocks) (Age, length, Age & length)	

Risk Assessment

All of the lines of evidence outlined above are combined within the Department's ISO 31000 based risk assessment framework (Fletcher, 2015; Appendix 1) to determine the most appropriate combinations of consequence and likelihood to determine the overall current risk status of the stock.

Risk matrix					
Consequence (stock depletion) Level	Likelihood Level				**Risk Score**
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)	
C1 Minimal (above target)					
C2 Moderate (above threshold)					
C3 High (below threshold)					
C4 Major (below limit)					

C1 (Minimal Stock Depletion): XXXX L? – *explanation*.

C2 (Moderate Stock Depletion): XXXX L? – *explanation*.

C3 (High Stock Depletion): XXXX L? – *explanation*.

C4 (Major Stock Depletion): XXXX L? – *explanation*.

Current Risk Status of the Stock

The current risk score was estimated to be XXXX generated by the combination of C? and L?. This **XXXX risk** reflects *explanation* (See Appendix 1).

CODE OF CONDUCT FOR FISHERIES SCIENTIFIC MEETINGS AND WORKSHOPS

Purpose

To set out expected conduct and behaviour of participants at Fisheries Scientific Meetings and Workshops. It is recognised that difficult and challenging scientific issues often result in robust discussions, and it is expected that conduct will at all times be in line with the following standards.

Participants will

- behave honestly and with integrity and act with care and diligence
- treat everyone with respect and courtesy, and without harassment or discrimination
- use appropriate and respectful language at all times
- share and exchange information in a professional manner and in a spirit of cooperation
- disclose, and take reasonable steps to avoid, any conflict of interest (real or apparent)
- use government resources in a proper manner complying with all applicable Australian laws

The group will

- listen and respect everyone's input – one person speaks at a time
- be positive and constructive with counter arguments – play the ball not the person
- identify issues and problems, and more importantly establish solutions
- consist of various roles and ensure behaviour is in accordance to those roles
- maintain appropriate confidentiality of all information and material
- bring closure to decisions and take responsibility for the outcome

Managing Behaviour

The Chairperson shall have absolute discretion to take action if the behaviour of one or more participants is considered to be inconsistent with this code. Such action may include

- asking the participant(s) displaying poor behaviour to leave the meeting or workshop
- suspending the meeting or workshop for a period of time to address the behaviour issue
- calling the meeting or workshop off.

CONSEQUENCE, LIKELIHOOD AND RISK LEVELS (BASED ON ISO 31000)

CONSEQUENCE LEVELS

1. Minimal – Measurable but minor levels of depletion of fish stock (above target)

2. Moderate – Maximum acceptable level of depletion of stock (above threshold)

3. High – Level of depletion of stock unacceptable but still not affecting recruitment level of the stock (below threshold)

4. Major – Level of depletion of stock are already (or will definitely) affect future recruitment potential level of the stock (below limit)

LIKELIHOOD LEVELS

1. Remote – Never heard of but not impossible here (< 5 % probability)

2. Unlikely – May occur here but only in exceptional circumstances (5-20 %)

3. Possible – Clear evidence to suggest this is possible in this situation (20-50 %)

4. Likely – It is likely, but not certain, to occur here (> 50 %)

	Consequence Level			
Likelihood Level	**Minimal (1)**	**Moderate (2)**	**High (3)**	**Major (4)**
Remote (1)	Negligible	Negligible	Low	Low
Unlikely (2)	Negligible	Low	Medium	Medium
Possible (3)	Low	Medium	High	High
Likely (4)	Low	Medium	Severe	Severe

Risk Category	Description	Likely Reporting Requirements	Likely Management Response
Negligible	Acceptable, not an issue	Minimal	Nil
Low	Acceptable; no specific control measures needed	Justification required	None specific
Medium	Acceptable; with current risk control measures in place (no new management required)	Full performance report	Specific management and/or monitoring required
High	Not desirable; continue strong management actions OR new and/or further risk control measures to be introduced in near future	Full performance report	Increases to management activities may be needed
Severe	Unacceptable; if not already introduced, major changes are required to management in immediate future	Full performance report	If increases to management activities likely to be needed urgently

References

Fletcher, W.J. (2015). Review and refinement of an existing qualitative risk assessment method for application within an ecosystem-based management framework. ICES Journal of Marine Science, 72(3), 1043-1056.

Appendix 2. Western Australia Australian Herring Presentation (Kim Smith).

Australian herring stock assessment workshop

25 September 2017

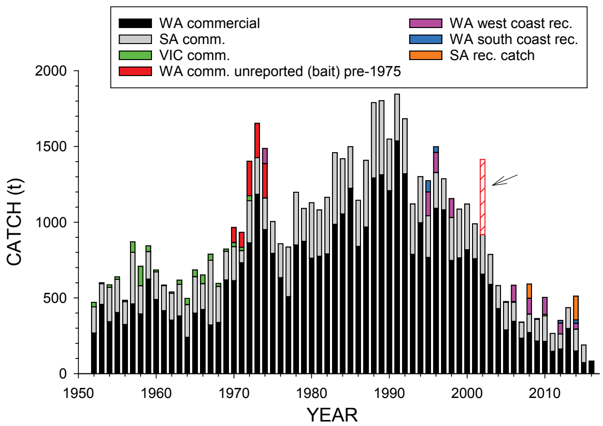
Fisheries Division
Department of Primary Industries & Regional Development

Overview of information for WOE assessment

1. Catch overview – all sectors
2. Key fisheries - catch, effort & nominal catch rates
3. Biology
   - Taxonomy
   - Stock distribution & habitat
   - Stock structure
   - Movement
     - observations
     - tagging
   - Reproduction
     - location/timing of spawning
     - fecundity, eggs, larvae
   - Age & growth
     - ageing methods
     - growth rate
     - age/length at maturity
     - maximum age/length
4. Catch composition
   - history of sampling
   - length
   - age
   - sex ratio
5. Recruitment index

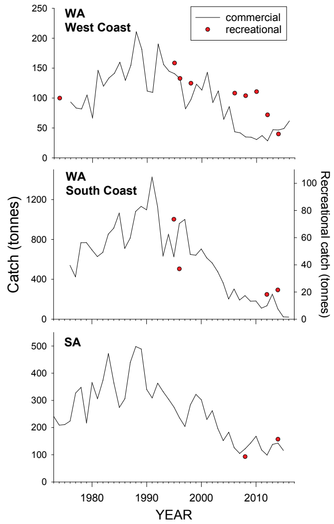
WA Bioregions

Catch



Catch

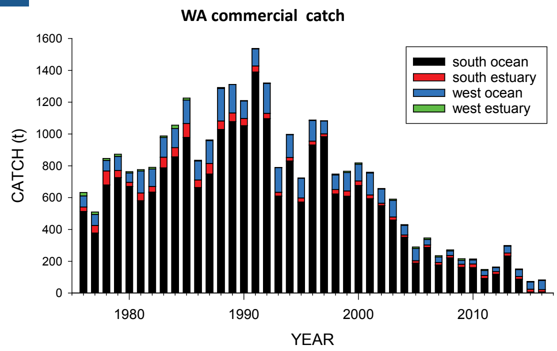
National catch



Note: 2000/01 National Survey estimates not shown

Catch

WA commercial catch



Catch

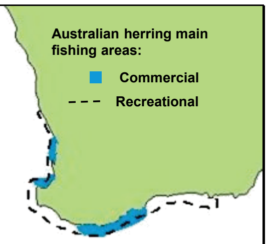
WA recreational catch

- No precise estimate available for the current total recreational catch of herring in WA.
- National Rec. Fishing Phone Survey in 2000/01 is the only 'comprehensive' recreational fishing survey conducted in WA (i.e. all regions, all sectors).
- Subsequent surveys in WA have been spatially restricted (e.g. boat only).
- The 2000/01 catch estimate is out-of-date, but the catch distribution (see Table) is still likely to be indicative of the current fishery.
- West Coast shore-based fishery takes largest share of WA rec catch.

National Rec. Fishing Survey 2000/01, herring catch shares:

Bioregion	Habitat	% of retained WA catch	
		Boat	Shore
West Coast	Ocean	27.4	49.0
	River/Estuary	1.6	5.8
South Coast	Ocean	2.3	13.2
	River/Estuary	0.6	0.1

Key fisheries – catch & effort

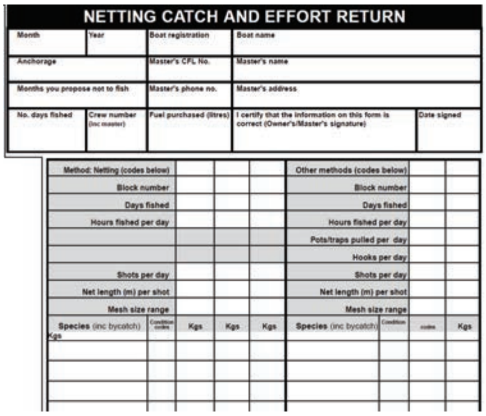


- **Herring Trap Net Fishery**
- **South West Beach Seine Fishery**
- **Cockburn Sound Fish Net Fishery**
- South Coast Estuary Fishery*
  (comprised of 13 estuaries, some with sand bars, making catch/catch rate trends difficult to interpret.)*

- **West Coast recreational fishery (especially shore-based)**

Key fisheries – catch & effort

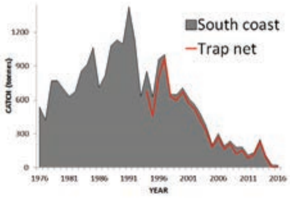
- Commercial catch & effort reported by fishers via compulsory monthly returns.
- Stored in 'CAES' database.
- 'days fished' is generally the best available measure of effort.
- other effort data (hours, shots, net length, mesh size, crew number) problematic due to being a monthly summary.
- Usually can't determine targeted effort towards a particular species.



Key fisheries – catch & effort

Herring Trap Net ('G trap') commercial fishery

- fishery closed in 2015.
- operated on beaches in Albany area (south coast).
- 1st record of 'trap netting' in 1953.
- targeting herring only.
- seasonal (March-April).



Issues with catch & effort data:

- became a limited entry fishery in 1991, but fishing occurring prior to this.
- in CAES database, this method is usually recorded as 'beach seine' until early 2000s.
- since ~1996, limited market demand/low prices, limits set by factories, partial catches are released (or schools not targeted), catch level does not always reflect fish availability.
- quantifying monthly effort in 'days' may be problematic, due to inclusion of search time.
- Historically, unit of effort = no. of active teams per year.

For details of 'trap net' method & history of fishery see :
i) Walker & Clarke (1987) and ii) Ayvazian *et al.* (2004)

Key fisheries – catch & effort

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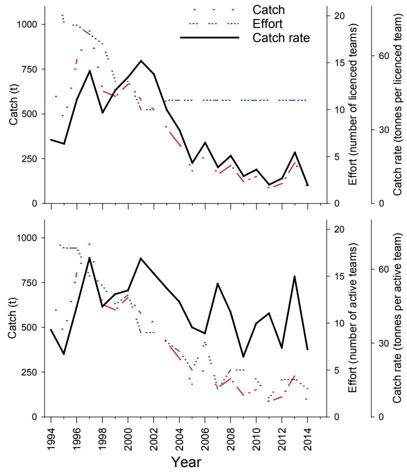
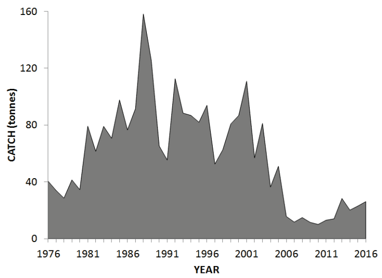


Key fisheries – catch & effort

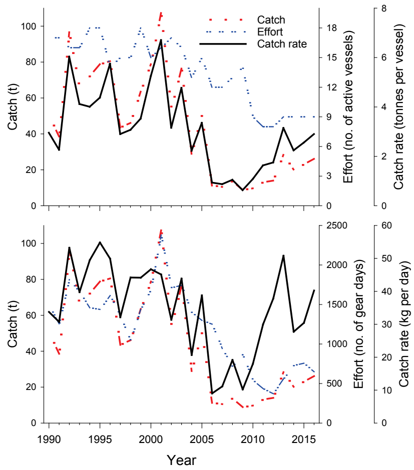
South West Beach Seine Commercial Fishery

- operates on beaches in Bunbury area (west coast).
- method = beach seine.
- multi-species.
- became a limited entry fishery in 1990 but fishing occurred prior to this.
- interactions with the west coast Australian salmon fishery.



Key fisheries – catch & effort

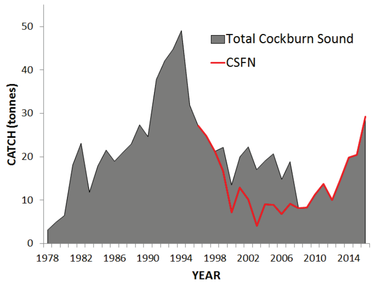
South West Beach Seine Nominal catch rates



Key fisheries – catch & effort

Cockburn Sound Fish Net Fishery

- boat-based fishery operating in Cockburn Sound (Perth)
- method = haul net
- multi -species
- limited entry in 1995 but fishing occurred prior to this.

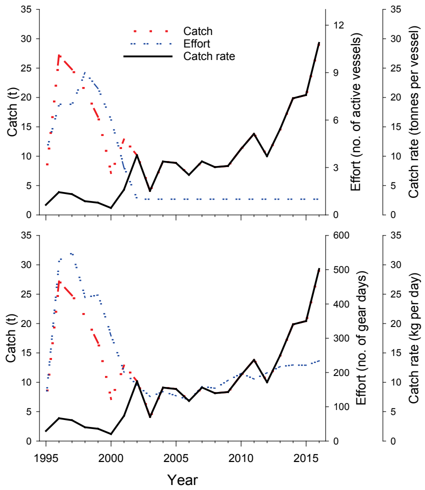


Key fisheries – catch & effort

Cockburn Sound Fish Net Nominal catch rate

Average catch per vessel →

Average catch per day →



Key fisheries – catch & effort

Recreational fishing survey designs

- Designs guided by objectives, fishery characteristics and available funding etc.
- Usually off-site and on-site
- Scope and bias varies among the different survey designs

For herring in WA, the following designs have been used:

Survey type	Fishers in scope	Data collected
Roving creel	Shore- and boat-based	Catch and effort
Access point (Bus-route)	Boat-based	Catch and effort
Phone diary	Shore- and boat-based	Catch and effort

Key fisheries – catch & effort

Boat-based recreational fishing surveys

Survey method	Spatial scope	Temporal scope	Catch estimates (Herring)
Phone-diary	WCB & SCB	2015/16	-
Phone-diary	WCB & SCB	20 13/14	173,408 SE± 15,113 (total)
Phone-diary	WCB & SCB	2011/12	249,721 SE± 21,238 (total)
Access point	WCB	2005 /06	288,392 SE± 14,658
Access point	Oyster Harbour & Walpole\Nornalup Inlets	2002/03	**Wpole/Nornlp** (9,863 SE± 3,101) **Princess RH** (4,925 SE± 1,192) **Oyster H** (13,599 SE± 3,004)
Phone-diary (S & B)	State-wide	2000/01	3,873,411 SE± 339,084
Access point	Peel-Harvey Estuary	1998 /99	21,553 SE± 1,550
Access point	Swan-Canning Estuary	1998 /99	843 SE± 152
Access point	Leschenault Estuary	1998 /98	822 SE± 454
Access point	WCB	1996/97	416,657 SE± 26,621
Roving creel	WCB & SCB (combined)	1994/95/96	**1994** (455,900) **1995** (182,924) **1996** (176,442)
Roving	Peel-Harvey Estuary & Wilson Inlet	1994 /95	-

Key fisheries – catch & effort

Shore-based recreational fishing surveys

Survey method	Spatial scope	Temporal scope	Species	Total catch estimates (Herring)
Roving creel	Perth metro	2014 –17 (Feb- Jun)	Finfish	**2014** (100,064 SE± 40,727) **2015** (74,732 SE± 47,528) **2016** (54,782 SE± 30,095) **2017** (155,668 SE± 68,577)
Roving creel	Perth metro	2010 (Apr-Jun)	Finfish	177,653 SE± 64,316
Roving creel	Oyster Harbour & Walpole\Nornalup Inlets	2002/03	All Aquatic	**Wpole/Nornlp** (774 SE± 567) **Princess RH** (1,935 SE±1,232) **Oyster H** (Insig)
Roving creel	Peel-Harvey Estuary	1998 /99	All Aquatic	25,989 SE± 5,066
Roving creel	Swan-Canning Estuary	1998 /99	All Aquatic	831 SE± 288
Roving creel	WCB and SCB	1994 /95/96	Finfish	**1994** (779,456) **1995** (668,909) **1996** (189,883)
Roving creel	Leschenault Estuary	1998 /98	All Aquatic	Negligible
Roving creel	Perth metro and Rottnest Island	1973	Herring	711,000 (gross estimate)

Key fisheries – catch & effort

Current surveys

Perth metro shore-based

- Roving creel survey with face-to-face interviews
- 2010, 2014-present, annual

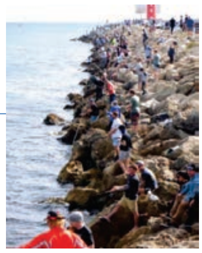
State-wide boat-based

- Phone-diary
- 2011/12 to present, biennial
- 2017-18 include shore-based fishers

Key fisheries – catch & effort

Perth metro shore-based recreational fishing survey

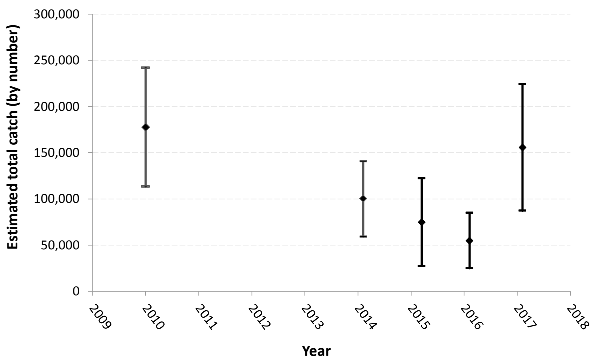
Objective	Estimate total shore-based recreational catch and effort
Design	Roving creel
Sampling frame	Shore-based fishers in Perth metro area
Data	Shore-based effort & catch (kept & rel)
Fishing methods	Shore-based fishing methods (rod and handline)
Species	130 species
Spatial	Perth metro zone
Temporal	5 months (Feb-Jun)
Years	2010, 2014, 2015, 2016, 2017



Herring:

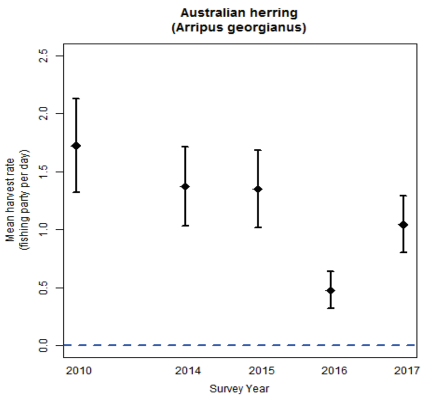
- Most commonly targeted species (29%)
- Highest harvest (kept) between April - June

Key fisheries – catch & effort



Estimated total recreational catch by number for species retained by shore-based fishers from April –June

Key fisheries – catch & effort



Biology

Taxonomy & identification

Distribution of herring & WA salmon

Arripidae contains 1 genus (*Arripis*) and 4 species:
1. *Arripis georgianus* - Australian herring
2. *Arripis truttaceus* - western Australian salmon
3. *Arripis trutta* - eastern Australian salmon / kahawai
4. *Arripis xylabion* - northern kahawai/giant kahawai

Arripids are endemic to areas within temperate Australian or New Zealand waters (Paulin 1993)

❖ *Juvenile salmon ('salmon trout') can be misidentified as herring, but only when very small.*

Biology

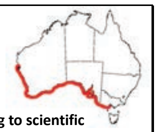
Distribution & habitat

- Australian herring occurs from Shark Bay (WA) to Port Phillip Bay (Vic).
- Inhabits coastal waters (inner shelf), lower parts of estuaries.
- Spawning occurs in marine waters.
- Juveniles occur in sheltered marine embayments (not estuaries)
- Forms mid-water schools over a range of habitats (reef/ seagrass/sand).

Main reference:
<u>Hutchins JB. & Swainston R. 1986.</u> Sea Fishes of Southern Australia. Complete field guide for anglers and divers. Perth. Swainston Publishing. 180 pp.

Biology

Studies of population structure



<u>Malcolm WB. 1973.</u> Western Fisheries Research Committee, Documents relating to scientific workshop on salmon & herring, 1972. Dept. of Fisheries & Fauna, WA (internal report).
- morphology/meristics → no differences between fish in SA & WA.

<u>Ayvazian SG, Bastow TP, Edmonds JS, How J & Nowara GB. 2004.</u> Stock structure of Australian herring (*Arripis georgiana*) in southwestern Australia. Fish. Research 67:39-53.
- oxygen isotopes in otoliths, tagging → high level of movement by individual fish (low residency); direction of movement was east→ west.
- genetics → "*negligible genetic differentiation*" across the species range .

<u>Moore GI & Chaplin JA. 2013.</u> Population genetic structures of three congeneric species of coastal pelagic fishes (*Arripis*: Arripidae) with extensive larval, post-settlement and adult movements. Environ. Biol. Fish. 96:1087-1099.
- *"no evidence of genetic subdivision" ; "genetically homogeneous over… the entire geographic range"*

Biology

Movement (observations)

Chief Fisheries Inspectors annual report 1900:
[in the Perth area] *"…supply and demand was good up to the 1st week in April, when unfortunately the burial of a plague-stricken body in the sea almost paralysed the trade, and as it happened at the season of the year when the herrings in great shoals pass along the coast off Fremantle, the loss may be estimated at between £3000 and £4000."*

Tubb 1940 (Council for Scientific and Industrial Research):
"… [herring] *is one of the four most important commercial fish of WA…"*

"… show a migratory movement similar to that shown by the salmon. [On the south coast] *fishermen at Esperance stated that the Tommy Rough enter Esperance Bay during …late summer.*

In the Busselton-Bunbury region the schools usually appear early in April and last through until the beginning of July. Large quantities are regularly caught along the coast some distance north of Fremantle…"

"The spawning season appears to be about May and June."

6th annual conference of inspectors, 1948:
"… during the herring season at Rottnest large quantities are taken for 2 or 3 months…"

Biology

Movement (observations)

Pollard (1969):
"Rottnest is famous as the spawning ground for herring. For as long as fisherman can remember, big herring schools that swim around from the Bight each autumn gather at Rottnest at the start of May in such numbers that the sea is often black over large areas."

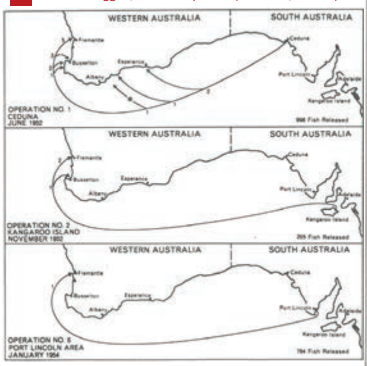
R. Hunt (in WFRC 1973), a south coast fishing industry representative:
"…are captured as far east as Point Charles [~Bremer Bay]. *The fishery in this area normally commences towards the end of March. …the peak of herring movement occupies a period of 14 days and moves progressively from this eastern fringe of the fishery to the western end. Aerial observations of herring indicate their occurrence as far east as Esperance in sizeable schools."*

R. Lenanton (in WFRC 1973) summarising state of knowledge in 1972:
"adults migrate in a westerly direction from the nursery areas for spawning, meeting the eastern WA coast… continuing on to the Busselton/Perth coastal area where spawning is probably most intensive and schools break down into smaller groups. A post-spawning back run has not been established."

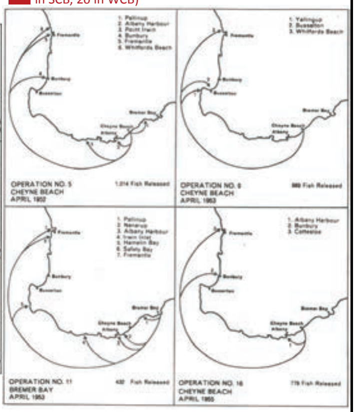
Biology

Movement (tagging – 1950s)

1 SA. 6693 tagged; 0.4% recaptured (19 in WA, 8 in SA)



2 WA. South Coast. 4784 tagged; 2.5% recaptured (101 in SCB, 20 in WCB)



3 WA West Coast (Geographe Bay, Garden/Rottnest Islands). 484 fish tagged. 12.8% recaptured locally.
(longest movement: 1 fish tagged Rottnest Island June 1954, recaptured Geographe Bay Nov 1954).

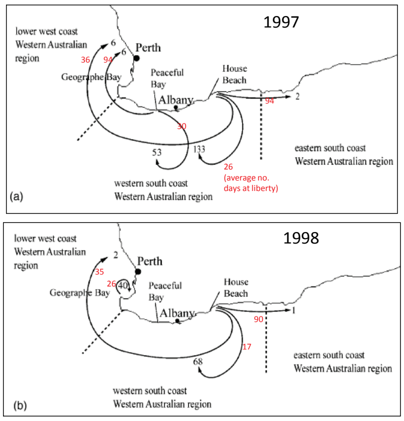
Source: Malcolm (1973, in WFRC)

Biology

Movement (tagging - 1990s)

- All tagging in March/April.
- 16,245 tagged south coast
- 2,509 tagged west coast
- Overall 2.3% were recaptured
- Most recaptured locally & at liberty for <50 days.
- 1 fish tagged in Geo. Bay at liberty for 326 days.
- Several fish swimming House Beach→ Perth in ~1 month

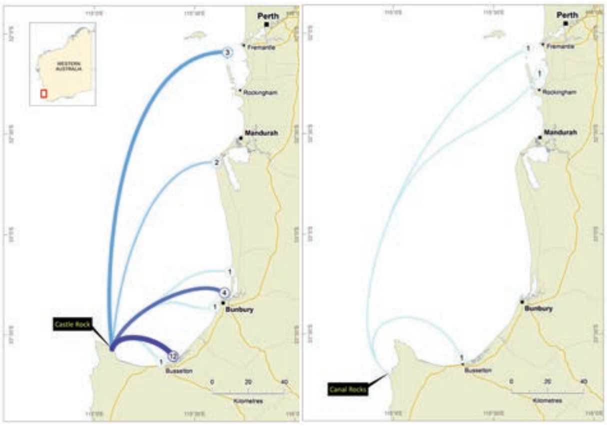
Source: Ayvazian SG, Bastow TP, Edmonds JS, How J & Nowara GB. 2004. Stock structure of Australian herring (*Arripis georgiana*) in southwestern Australia. Fish. Research 67:39-53.



Biology

Movement (tagging - 2012)

- late May 2012, 1552 fish tagged around Cape Naturaliste.
- 2.3% recaptured, at liberty for 5-331 days (average 52 days).



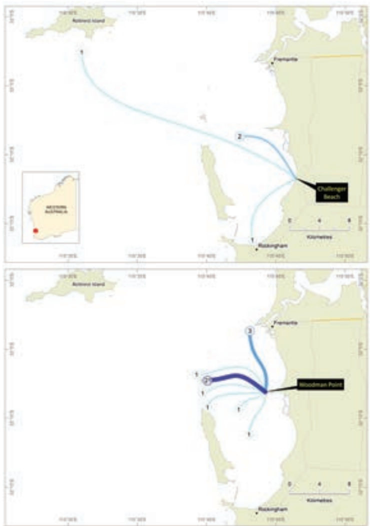
Source: Smith K & Brown J. 2014. Fisheries Research Report 251.

Biology

Movement (tagging - 2012)

- Nov/Dec 2012
- 2045 fish tagged in Cockburn Sound
- 1.6% recaptured, all locally.
- at liberty for 7 to 162 days (average 76 days).

Source: Smith K & Brown J. 2014. Fisheries Research Report 251.



Biology

Location/timing of spawning

Malcolm (1972)
- Sampled in SA, 1960s(?) [*gonad macroscopic staging, histology, length composition*]

→ Mostly juveniles, no gonad development in SA.

Lenanton (1978)
- Examined ovaries at Rottnest Island in 1973.

→ Observed spawning activity in 'early June'.

Fairclough *et al.* (2000)
- Sampled in WA & SA, 1996-1999. [*GSI, gonad macroscopic staging, histology*]

→ No gonad development in SA or south-east zone of SCB (WA).

→ In WA, found prespawning/spawning/spent fish (stages 5-7) from Abrolhos Islands to Bremer Bay.

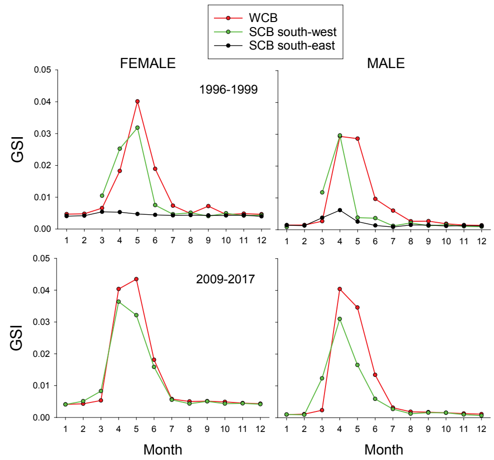
→ Gonad development indicated spawning in late May/early June.

WA Fisheries (Smith *et al.* 2013 and unpubl.)
- Sampled in WA, 2009-2017. [*GSI, gonad macroscopic staging*]

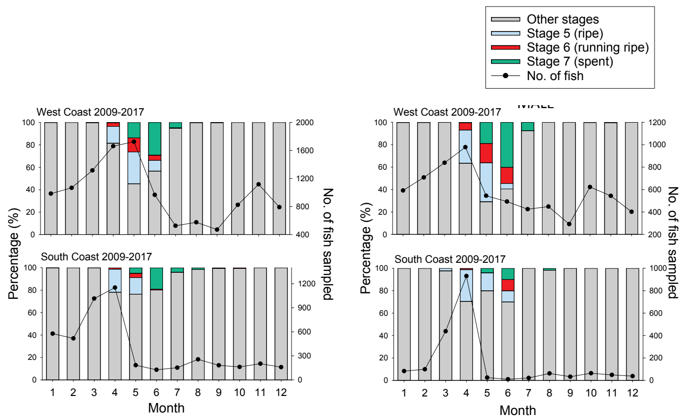
→ Gonad stages 5-7 found in WCB & south-west zone of SCB

→ Gonad development indicated spawning in late May/early June.
(similar to Fairclough)

Biology

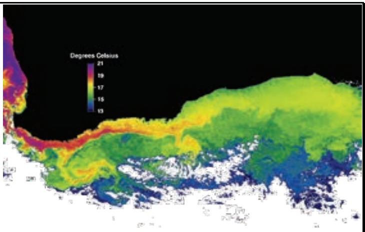


Biology



Biology

Eggs and larvae



- Planktonic eggs & larvae likely to be dispersal by Leeuwin Current (spawning period coincides with peak flow).
- Larval dispersal model estimated ~30-40 days to Albany, ~60 days to Esperance (from Perth), ~100-150 days to SA. (Ayvazian *et al.* 2004)
- Larvae caught between Bremer Bay & SA were aged 43-81 days (back-calculated birthdates of late May/early June) (Fahlbusch 1995).

Total fecundity:
- 32,000 to 207,000 eggs (Fairclough *et al.* 2000, fish length range 197-335 mm TL).
- Similar to Lenanton (1978) - 80,000 to 200,000 eggs.

Biology

Ageing procedure

- aged from whole otoliths.
- no difference in ages from whole v. sectioned otoliths (Fairclough *et al.* 2000) .
- annual periodicity of increments is validated (Fairclough *et al.* 2000; also Fisheries unpubl. data).
- quality control protocols are followed : *reference collection of otoliths, training/re-training schedule, within & between reader comparisons, precision & bias standards.* (Dowling *et al.* in prep)

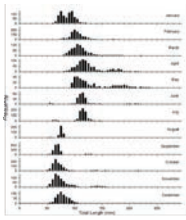
Maximum reported age = Female 12 y ; Male 11 y

Maximum reported length = 41 cm TL (Hutchins & Swainston 1986)

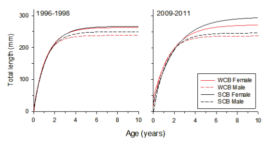
Biology

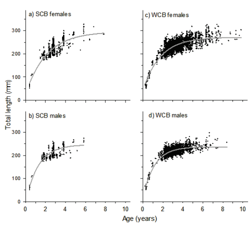
Growth rate

- estimated for 2 periods (1996-98 & 2009-11).
- females attain slightly larger size-at-age.
- slower growth in SCB (evident in juveniles; but confounding factors when estimating adult growth in SCB)



Year	Bioregion	Sex	L_∞	K	t_0	Sample
1996-98	Pooled	F	263.6 (±0.7)	0.81 (±0.01)	-0.04 (±0.01)	2412
		M	239.4 (±0.6)	1.02 (±0.01)	0.02 (±0.01)	1708
1996-98	West Coast	F	262.8 (±0.8)	0.82 (±0.01)	-0.04 (±0.01)	1954
		M	238.0 (±0.6)	1.04 (±0.02)	0.02 (±0.01)	1479
1996-98	South Coast	F	266.2 (±1.5)	0.78 (±0.02)	-0.03 (±0.02)	458
		M	249.8 (±2.2)	0.89 (±0.04)	-0.01 (±0.02)	229
2009-11	Pooled	F	272.8 (±1.1)	0.57 (±0.01)	-0.26 (±0.03)	5157
		M	237.3 (±0.7)	0.87 (±0.02)	-0.06 (±0.02)	3210
2009-11	West Coast	F	271.5 (±1.1)	0.57 (±0.01)	-0.30 (±0.03)	4565
		M	236.7 (±0.8)	0.86 (±0.02)	-0.08 (±0.02)	2731
2009-11	South Coast	F	295.8 (±6.2)	0.48 (±0.03)	-0.20 (±0.08)	592
		M	246.0 (±3.2)	0.79 (±0.05)	0.02 (±0.05)	479

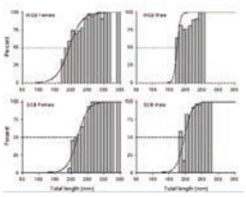




Biology

Length & age at maturity

- estimated for 2 periods (1996-98 & 2009-11)
- females mature at greater size, & slightly older age.
- later maturity in SCB (but confounding factors when estimating growth in SCB).



'mature' = gonad stage 3-8

Year	Bioregion	Sex	$L_{50\%}$ (95% C.I.)	$L_{95\%}$ (95% C.I.)	Sample
1996-98	Pooled	F	207.2 (206.0-208.4)	243.1 (239.7-246.5)	723
		M	188.1 (183.9-192.2)	213.6 (202.0-225.1)	387
1996-98	WCB	F	202.6 (201.5-203.7)	233.2 (230.1-236.2)	650
		M	185.0 (182.8-187.3)	201.0 (194.7-207.5)	282
1996-98	SCB	F	228.3 (224.9-231.8)	255.7 (246.2-265.2)	164
		M	216.7 (205.9-227.4)	265.4 (234.2-296.6)	105
2009-11	Pooled	F	198.9 (194.4-203.4)	254.2 (241.3-267.0)	2,099
		M	181.0 (174.5-187.5)	217.8 (199.1-236.5)	1,279
2009-11	WCB	F	194.1 (171.8-216.3)	250.8 (189.0-312.7)	1,781
		M	174.4 (170.9-177.8)	188.8 (178.7-198.9)	971
2009-11	SCB	F	219.6 (215.4-223.7)	265.3 (253.5-277.1)	318
		M	196.4 (188.0-204.9)	231.1 (206.5-255.6)	308

Year	Bioregion	Sex	$A_{50\%}$ (95% C.I.)	$A_{95\%}$ (95% C.I.)
1996-98	Pooled	F	1.99 (1.93-2.05)	2.86 (2.57-3.16)
		M	1.85 (1.70-2.00)	2.40 (2.02-2.79)
1996-98	WCB	F	1.88 (1.79-1.97)	2.51 (2.15-2.86)
		M	1.81 (1.35-2.26)	2.25 (1.67-2.82)
1996-98	SCB	F	2.58 (2.47-2.68)	3.45 (3.25-3.66)
		M	2.37 (2.37-2.38)	2.99 (2.98-3.00)
2009-11	Pooled	F	2.35 (1.12-3.58)	4.07 (0.65-7.49)
		M	1.80 (1.49-2.10)	2.44 (1.81-3.06)
2009-11	WCB	F	2.19 (1.93-2.44)	3.97 (3.24-4.70)
		M	1.76 (1.08-2.45)	2.27 (1.47-3.07)
2009-11	SCB	F	2.77 (2.75-2.78)	3.81 (3.77-3.85)
		M	1.90 (1.81-2.00)	3.47 (3.19-3.76)

Catch composition

Sampling history

Table refers to WA sampling where biological data is collected (i.e. length/age /sex).

Additional sampling:

- 1940-55, WA commercial catch (length only, n = 18,000)
- 1950-55, SA commercial catch (length only, n = 16,000)
- 1977-80, SA (length only, n= ?)
- 1997-98, WA tagging study (length only, n = 18,750)
- 1999-2000, WA market sampling (length only, n = 7,123)
- 1996-98, SA (Ayvazian *et al.* 2000) (length/age/sex).

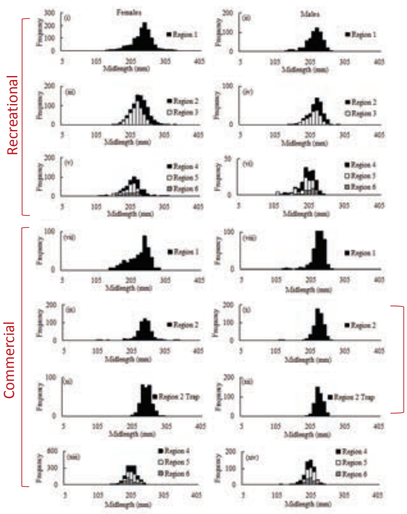
No. of fish sampled in WA fishery landings

	SOUTH COAST BIOREGION				WEST COAST BIOREGION			
Year	Commercial		Recreational		Commercial		Recreational	
	Lengths	Otoliths	Lengths	Otoliths	Lengths	Otoliths	Lengths	Otoliths
1974								21
1975					50	123		
1976					47	34	27	
1977	550				628	50	20	
1978	657	75				34	14	
1979	39				20		68	65
1980								
1981	1095	550						
1982								
1983								
1984	640	640						
1985	810	810						
1986								
1987								
1988								
1989								
1990								
1991								
1992								
1993								
1994								
1995	4,088	1667						
1996	6,339	1725	39	45	120	111	172	156
1997	1111	1021	606	398	451	398	482	388
1998	1273	1267	605	541	492	435	1,148	943
1999	210	134	69	69	313	232	24	35
2000	379	189			551	152		
2001	212	144			327	142		
2002								
2003								
2004							59	58
2005			13	13			392	328
2006			55	55			323	321
2007							135	125
2008							27	26
2009	266	266	60	60	1084	1084	784	770
2010	598	598	69	69	2169	2117	2345	2343
2011	329	333	230	230	574	573	1700	1686
2012	659	660	893	832	514	514	1138	1009
2013	1025	1014	708	589	583	583	1060	775
2014	80	80	969	828	645	765	1259	1027
2015			947	933	679	778	2230	2220
2016	22	22	1072	940	632	632	1874	1555
2017			436	435	259	259	1109	845

Catch composition

Length

- *Average length in SA smaller than in WA.*
- *In WA, west & south coast lengths similar.*
- *Females are larger than males.*



Example from Ayvazian *et al.* (2000), sampled in 1996-1998.

Catch composition

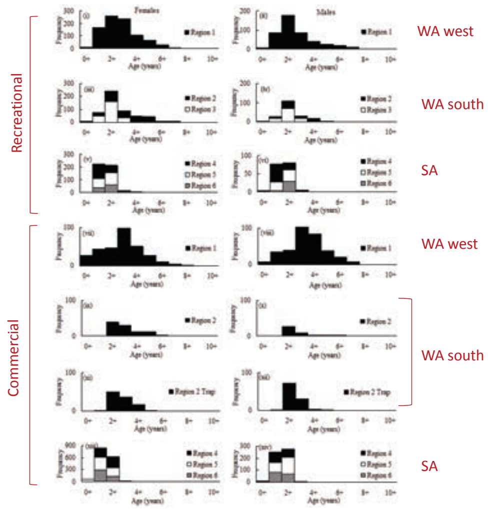
Age

SA: catches dominated by juveniles (1+ & 2+).

WA south coast: catches dominated by new recruits (2+ & 3+).

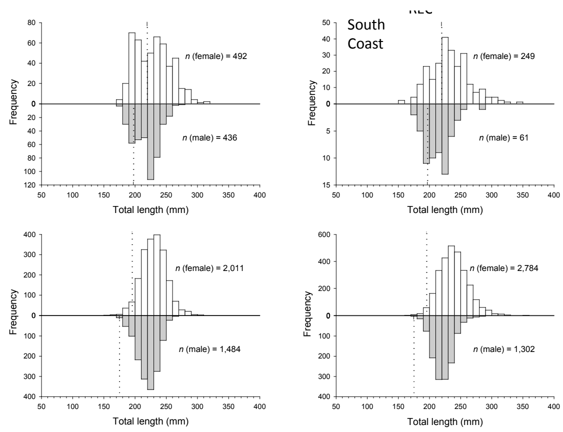
WA west coast:
- *all ages represented (1+ & older).*
- *similar age distribution for both sexes.*

Example from Ayvazian *et al.* (2000), sampled in 1996-1998.

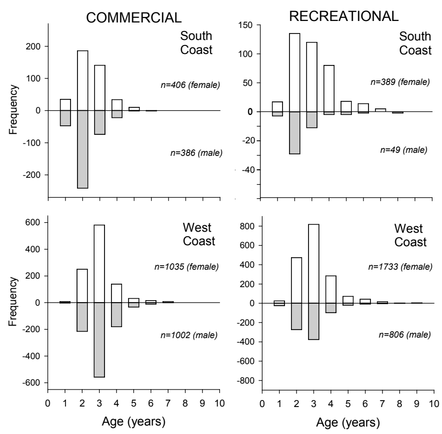


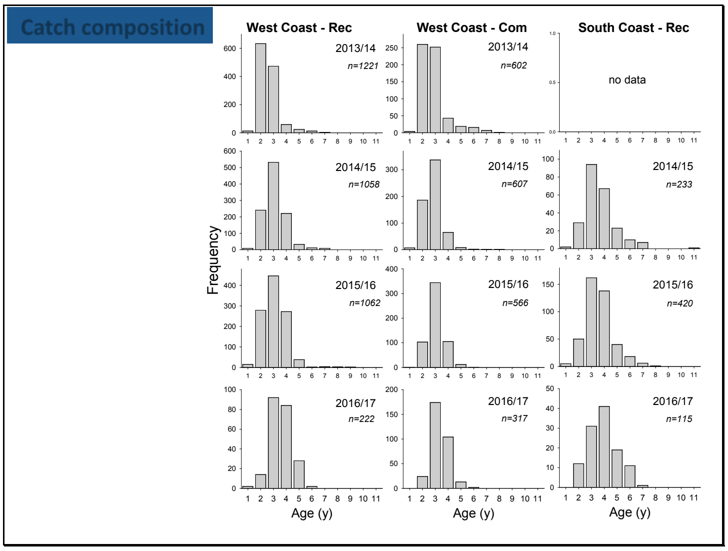
Catch composition

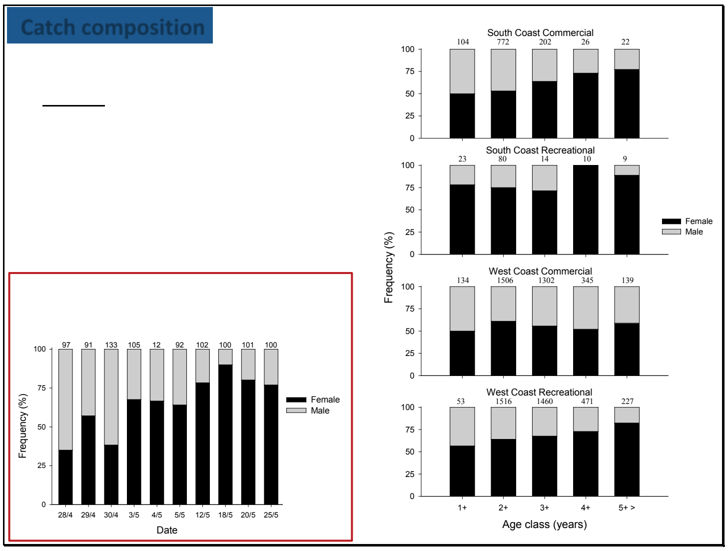
Length : female versus male

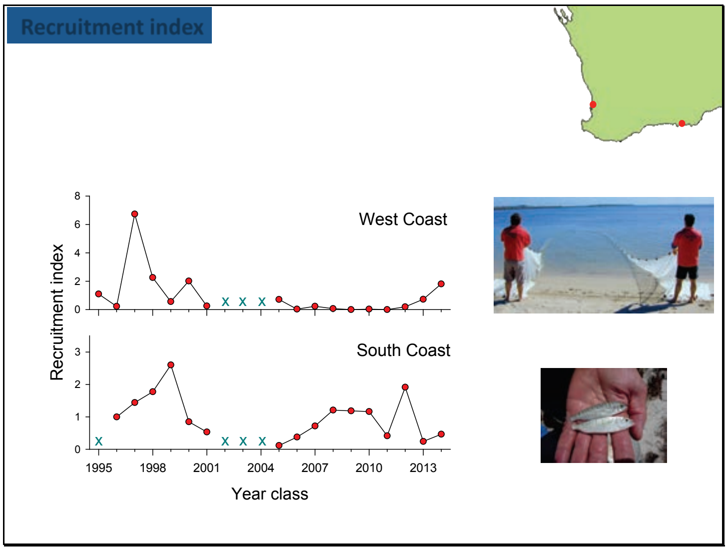


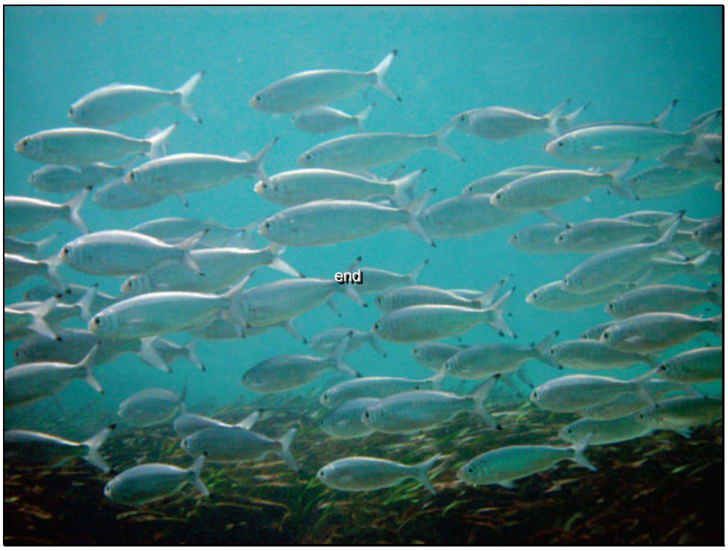
Catch composition



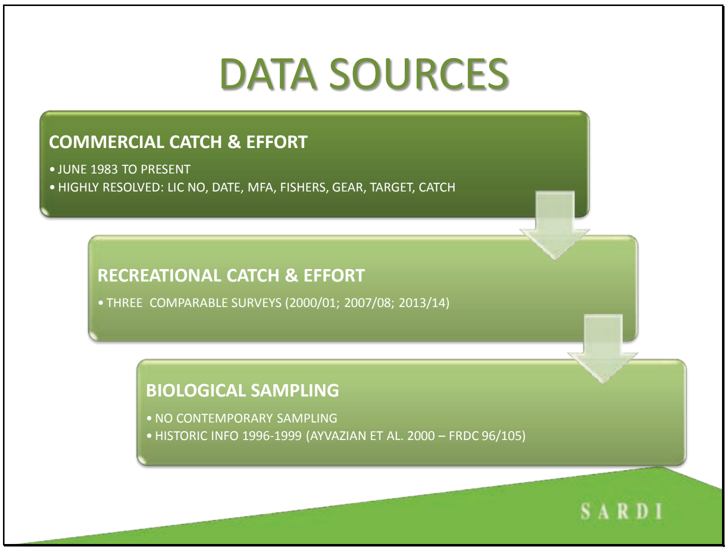

Catch composition
West Coast - Rec
West Coast - Com
South Coast - Rec
2013/14
n=1221
2013/14
n=602
no data
2014/15
n=1058
2014/15
n=607
2014/15
n=233
2015/16
n=1062
2015/16
n=566
2015/16
n=420
2016/17
n=222
2016/17
n=317
2016/17
n=115
Frequency
Age (y)
Age (y)
Age (y)

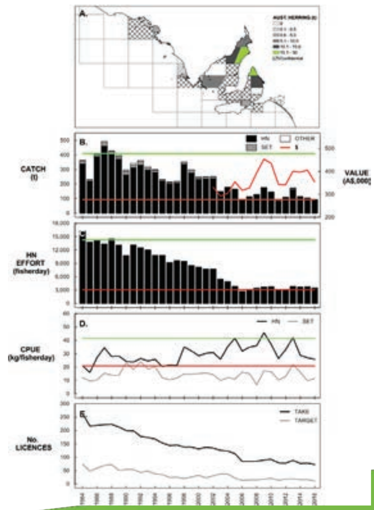

Catch composition
Frequency (%)
Female
Male
28/4
29/4
30/4
3/5
4/5
5/5
12/5
18/5
20/5
25/5
Date
South Coast Commercial
South Coast Recreational
West Coast Commercial
West Coast Recreational
Female
Male
Frequency (%)
1+
2+
3+
4+
5+ >
Age class (years)

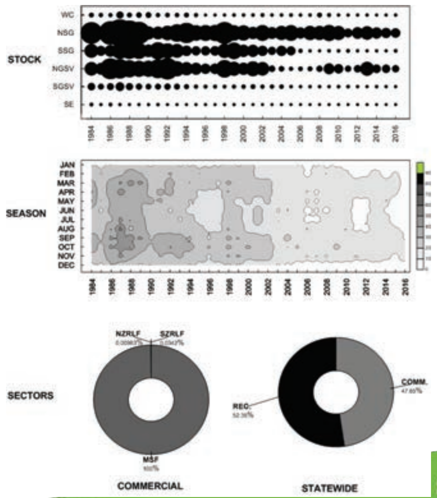

Recruitment index
West Coast
South Coast
Recruitment index
1995
1998
2001
2004
2007
2010
2013
Year class


end

Appendix 3. South Australia Australian Herring Presentation (Mike Steer).



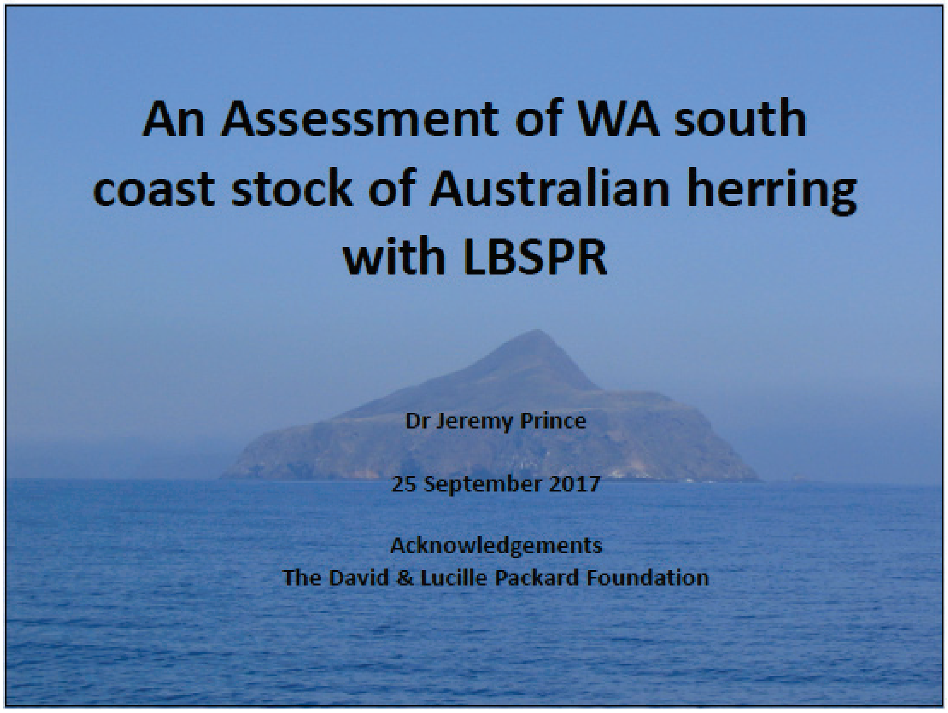




	Stock status	Description	Potential implications for management of the stock
	Sustainable	Stock for which biomass (or biomass proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (i.e. not recruitment overfished) and for which fishing pressure is adequately controlled to avoid the stock becoming recruitment overfished	Appropriate management is in place
↑	Transitional–recovering	Recovering stock—biomass is recruitment overfished, but management measures are in place to promote stock recovery, and recovery is occurring	Appropriate management is in place, and the stock biomass is recovering
↓	Transitional–depleting	Deteriorating stock—biomass is not yet recruitment overfished, but fishing pressure is too high and moving the stock in the direction of becoming recruitment overfished	Management is needed to reduce fishing pressure and ensure that the biomass does not deplete to an overfished state
	Overfished	Spawning stock biomass has been reduced through catch, so that average recruitment levels are significantly reduced (i.e. recruitment overfished). Current management is not adequate to recover the stock, or adequate management measures have been put in place but have not yet resulted in measurable improvements	Management is needed to recover this stock; if adequate management measures are already in place, more time may be required for them to take effect
	Environmentally limited	Spawning stock biomass has been reduced to the point where average recruitment levels are significantly reduced, primarily as a result of substantial environmental changes/impacts, or disease outbreaks (i.e. the stock is not recruitment overfished). Fisheries management has responded appropriately to the environmental change in productivity	Appropriate management is in place
	Undefined	Not enough information exists to determine stock status	Data required to assess stock status are needed

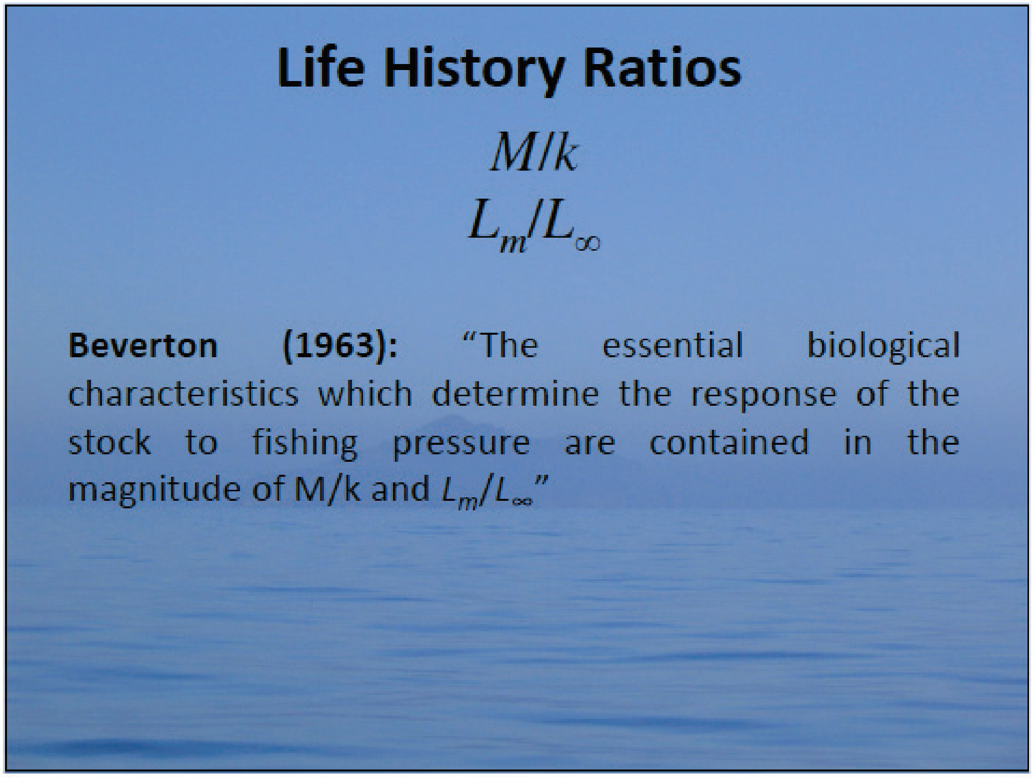
SARDI

Appendix 4. Australian Herring Presentation by Jeremy Prince.

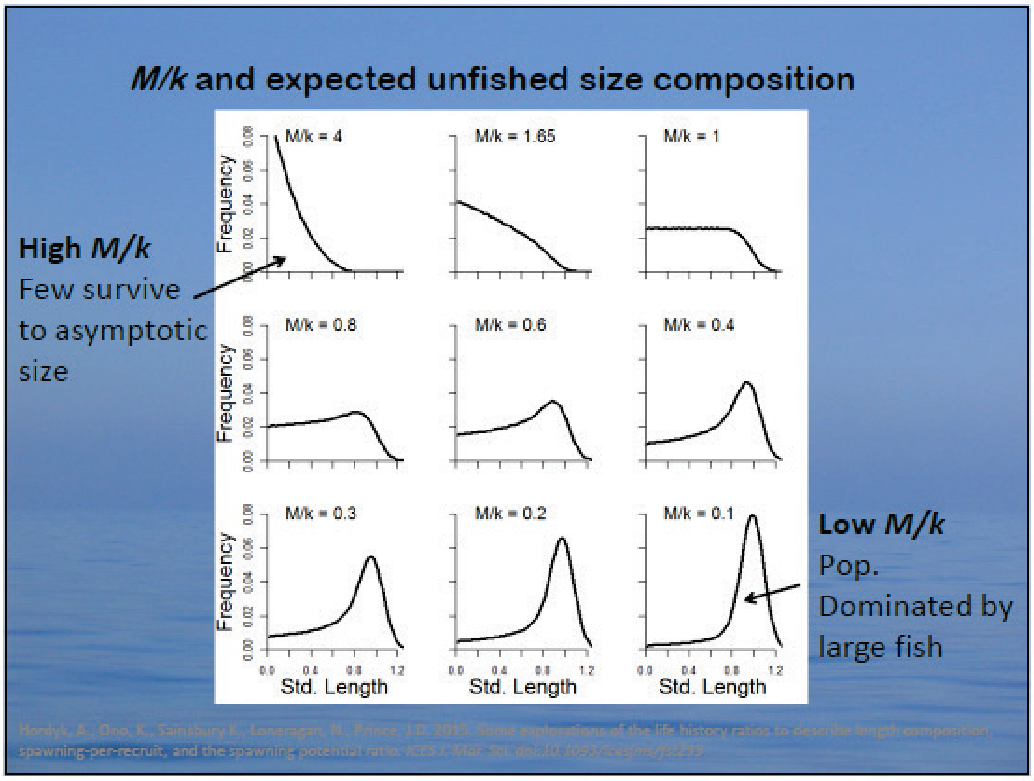



Length Based Assessment of
Spawning Potential Ratio
Beverton & Holt Life History Invariants:
Natural Mortality / Growth (M/k) = 1.5
Size of maturity / Asymptotic Size
$L_m/L_\infty = 0.65$


Length Based Assessment of
Spawning Potential Ratio
Beverton & Holt Life History Invariants:
Natural Mortality / Growth (M/k) = 1.5
Size of maturity / Asymptotic Size
$L_m/L_\infty = 0.65$
Life History Ratios (LHR)



Life History Ratios
M/k
Lm/L∞
Beverton (1963): "The essential biological characteristics which determine the response of the stock to fishing pressure are contained in the magnitude of M/k and Lm/L∞"

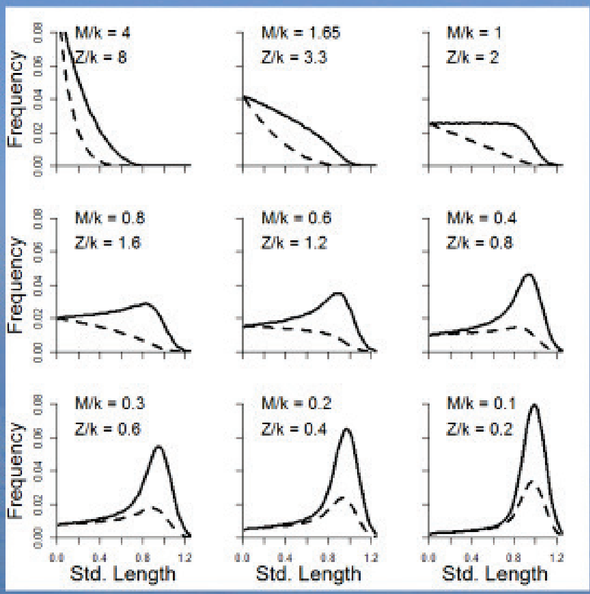


M/k and expected unfished size composition
High M/k
Few survive to asymptotic size
Low M/k
Pop. Dominated by large fish
M/k = 4
M/k = 1.65
M/k = 1
M/k = 0.8
M/k = 0.6
M/k = 0.4
M/k = 0.3
M/k = 0.2
M/k = 0.1
Frequency
Std. Length
Hordyk, A., Ono, K., Sainsbury K., Loneragan, N., Prince, J.D. 2015. Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. ICES J. Mar. Sci. doi:10.1093/icesjms/fst235

M/k and expected fished size composition

All selected

F/M = 1



Hordyk, A., Ono, K., Sainsbury K., Loneragan, N., Prince, J.D. 2015. Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. *ICES J. Mar. Sci.* doi:10.1093/icesjms/fst235

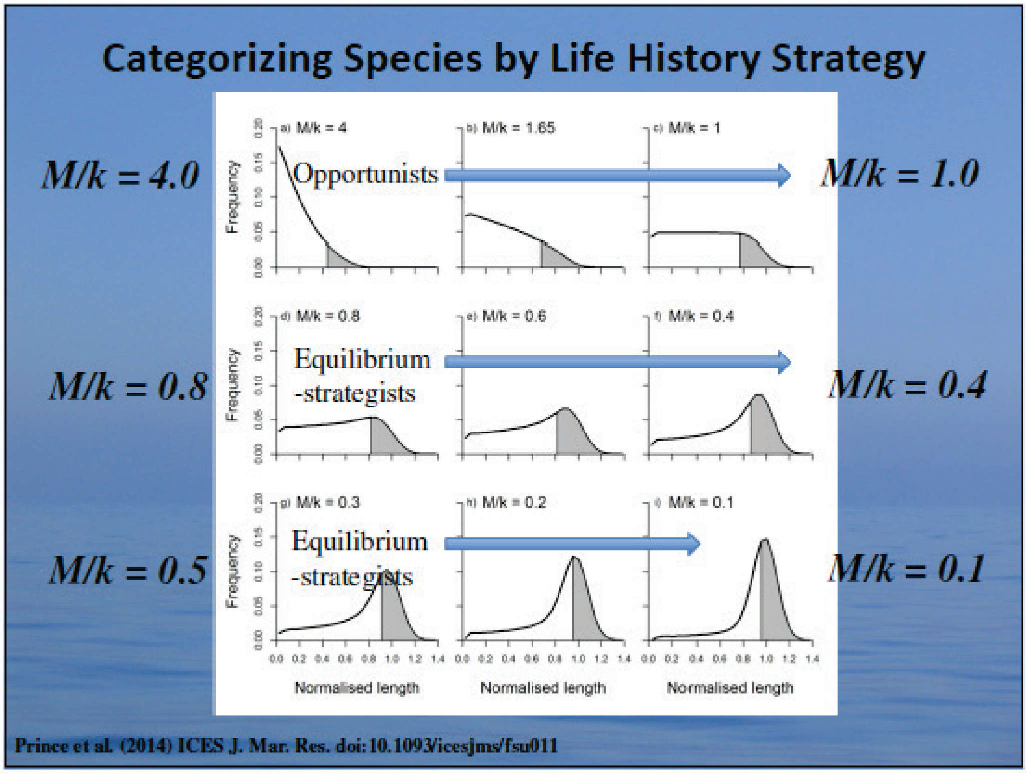
Life History Ratios

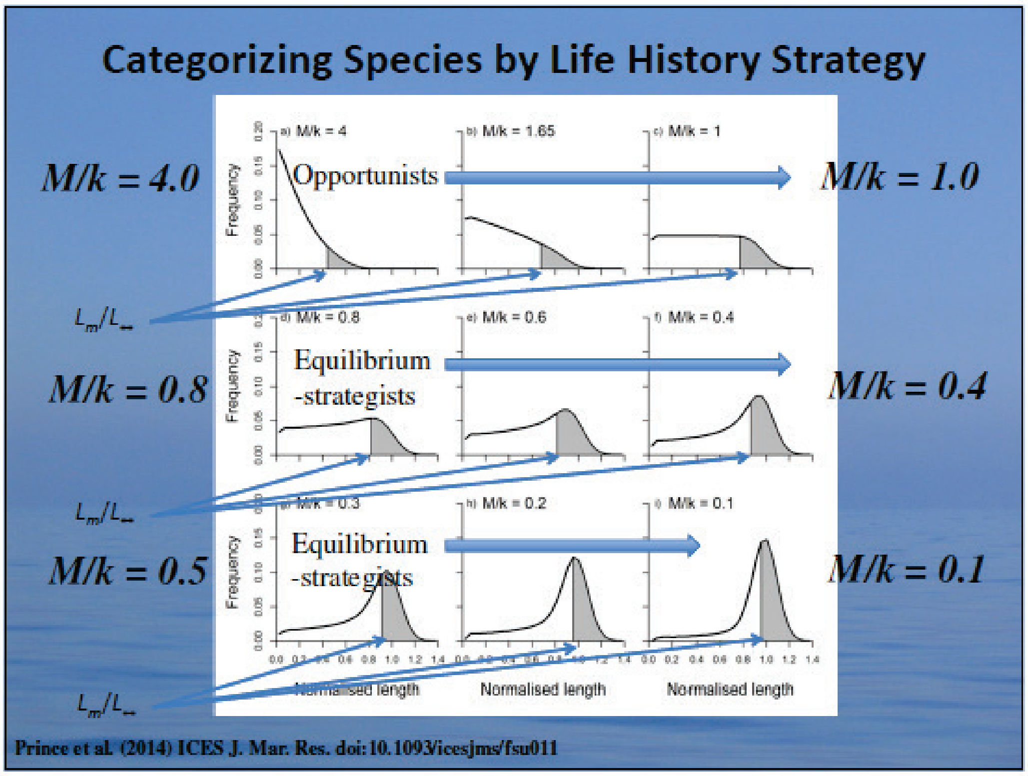
M/k

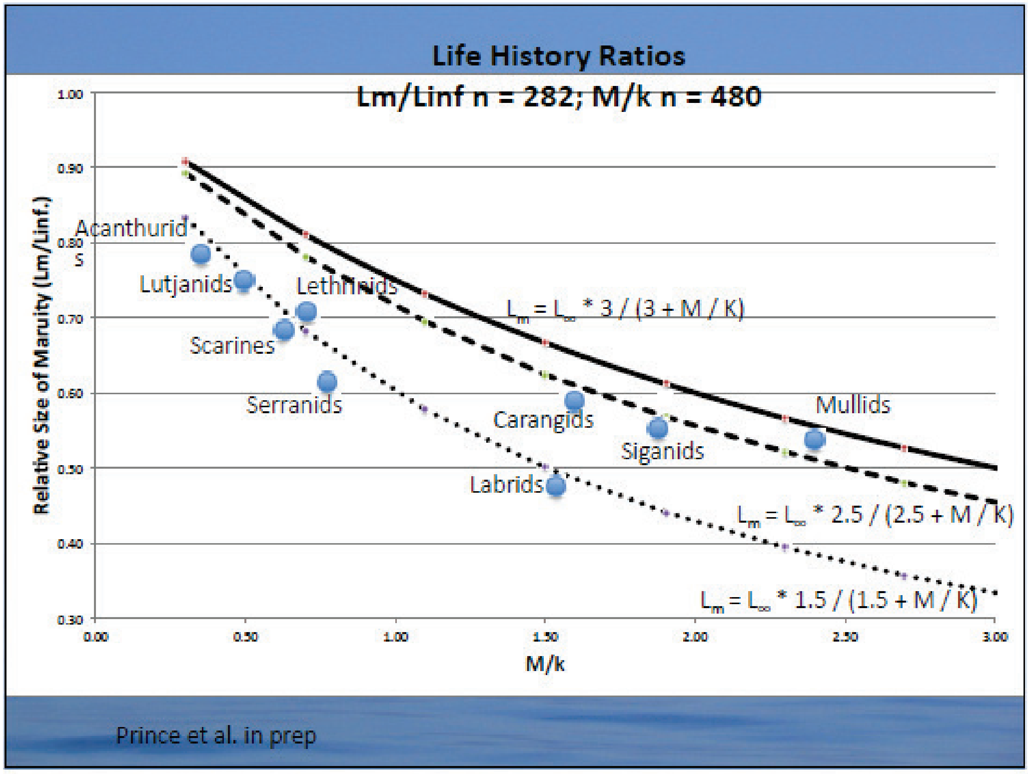
L_m/L_∞

Beverton (1963): "The essential biological characteristics which determine the response of the stock to fishing pressure are contained in the magnitude of M/k and L_m/L_∞"

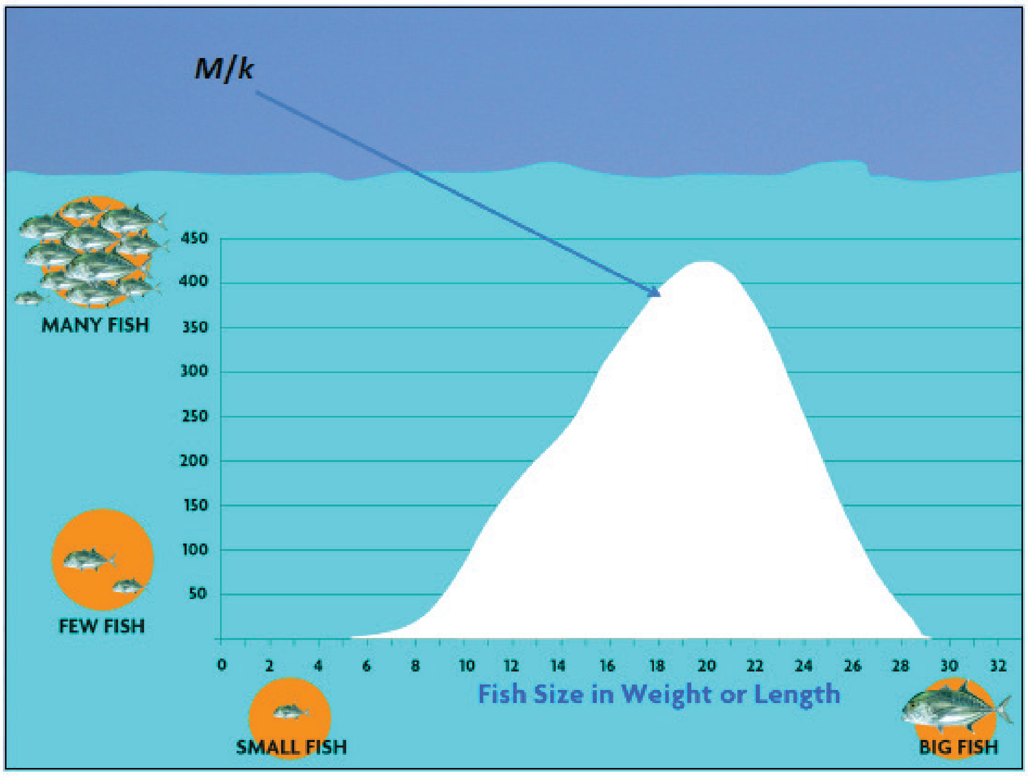
Holt (1958): LHR are more informative and useful for data-poor stock assessment because they are less variable than individual parameters

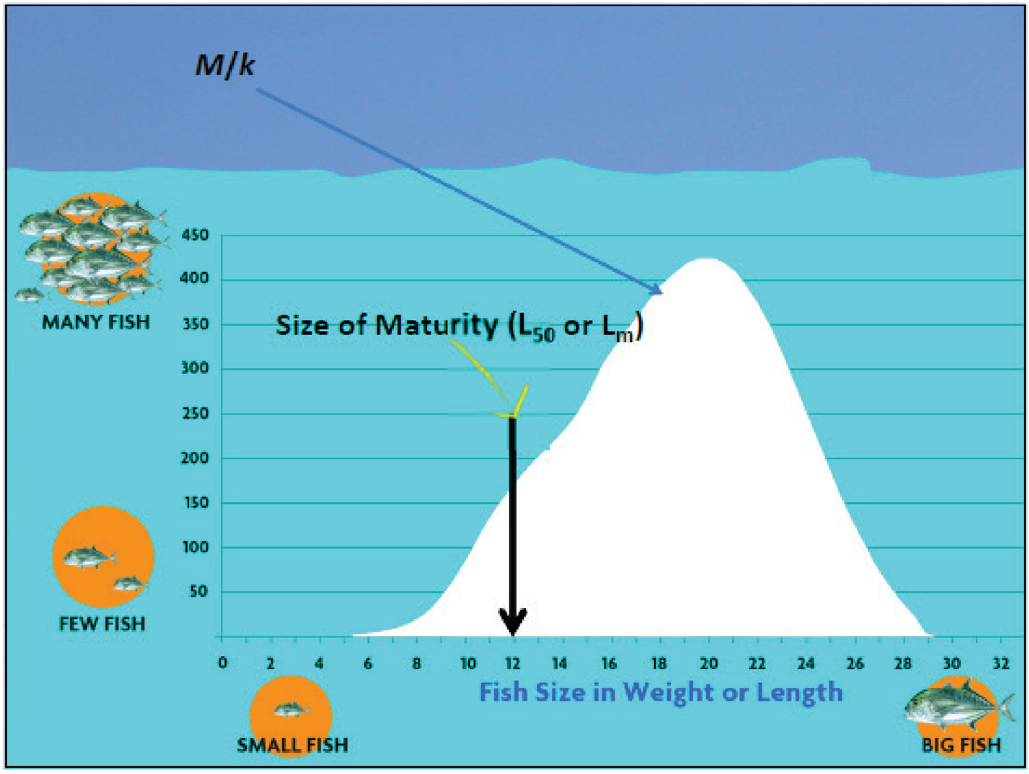

Categorizing Species by Life History Strategy
M/k = 4.0
M/k = 1.0
M/k = 0.8
M/k = 0.4
M/k = 0.5
M/k = 0.1
Opportunists
Equilibrium
-strategists
Equilibrium
-strategists
a) M/k = 4
b) M/k = 1.65
c) M/k = 1
d) M/k = 0.8
e) M/k = 0.6
f) M/k = 0.4
g) M/k = 0.3
h) M/k = 0.2
i) M/k = 0.1
Frequency
Normalised length
Prince et al. (2014) ICES J. Mar. Res. doi:10.1093/icesjms/fsu011

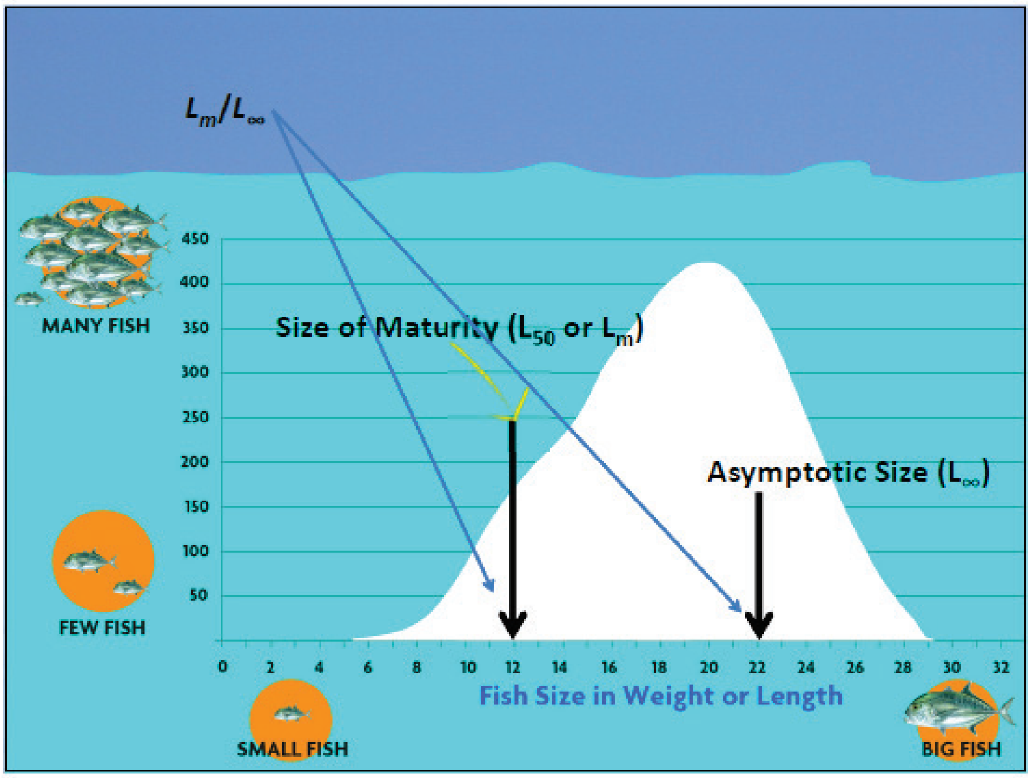

Categorizing Species by Life History Strategy
M/k = 4.0
M/k = 1.0
M/k = 0.8
M/k = 0.4
M/k = 0.5
M/k = 0.1
Opportunists
Equilibrium
-strategists
Equilibrium
-strategists
L_m/L_∞
L_m/L_∞
L_m/L_∞
Frequency
Normalised length
Prince et al. (2014) ICES J. Mar. Res. doi:10.1093/icesjms/fsu011

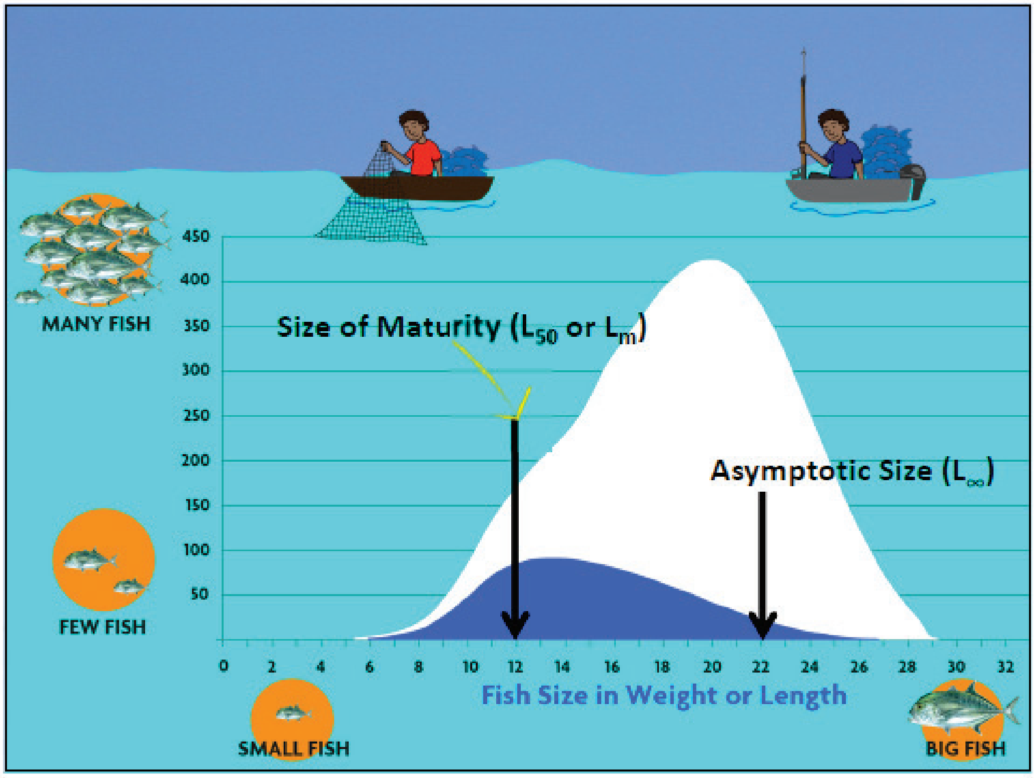

Life History Ratios
Lm/Linf n = 282; M/k n = 480
Relative Size of Maruity (Lm/Linf.)
M/k
Acanthurids
Lutjanids
Lethrinids
Scarines
Serranids
Carangids
Siganids
Mullids
Labrids
$L_m = L_\infty * 3 / (3 + M / K)$
$L_m = L_\infty * 2.5 / (2.5 + M / K)$
$L_m = L_\infty * 1.5 / (1.5 + M / K)$
Prince et al. in prep


What we need to know
Catch lengths
Size of Maturity

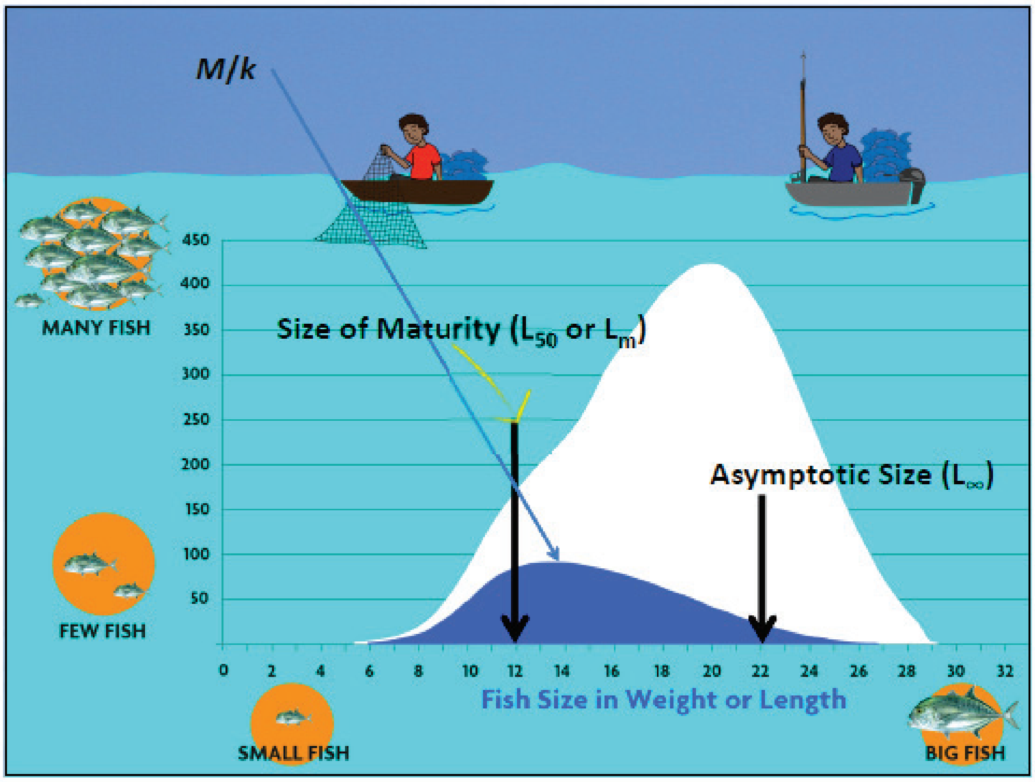

M/k
MANY FISH
FEW FISH
450
400
350
300
250
200
150
100
50
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
Fish Size in Weight or Length
SMALL FISH
BIG FISH


M/k
MANY FISH
Size of Maturity (L50 or Lm)
FEW FISH
450
400
350
300
250
200
150
100
50
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Fish Size in Weight or Length
SMALL FISH
BIG FISH

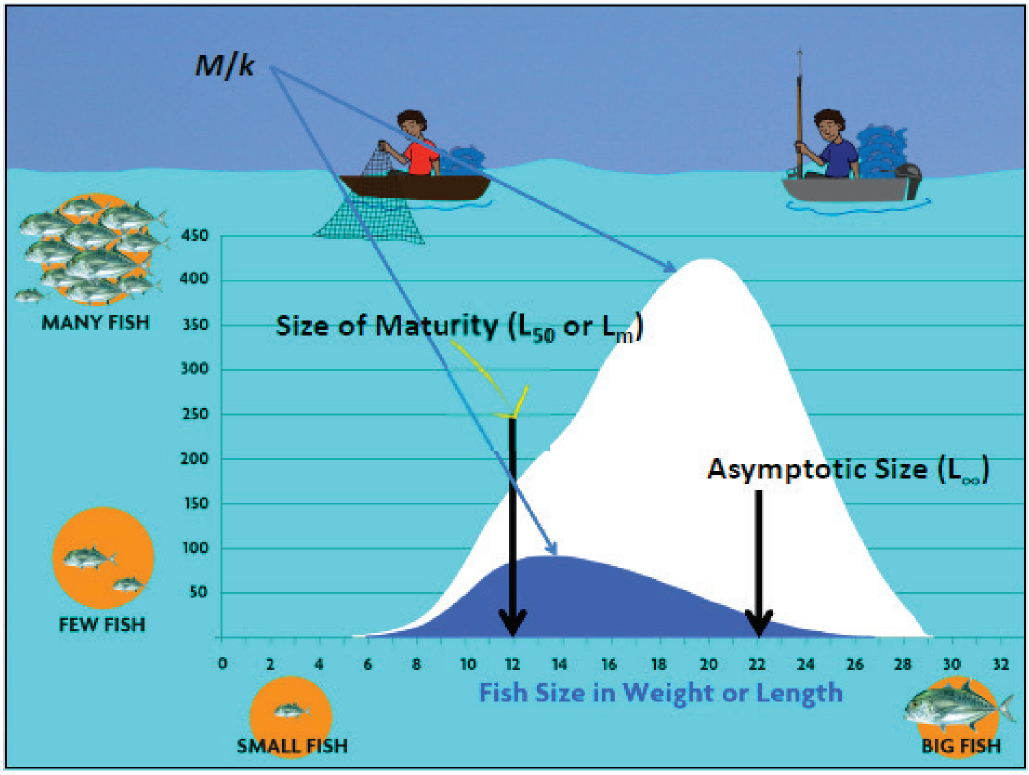

Lm/L∞
MANY FISH
Size of Maturity (L50 or Lm)
Asymptotic Size (L∞)
FEW FISH
450
400
350
300
250
200
150
100
50
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Fish Size in Weight or Length
SMALL FISH
BIG FISH

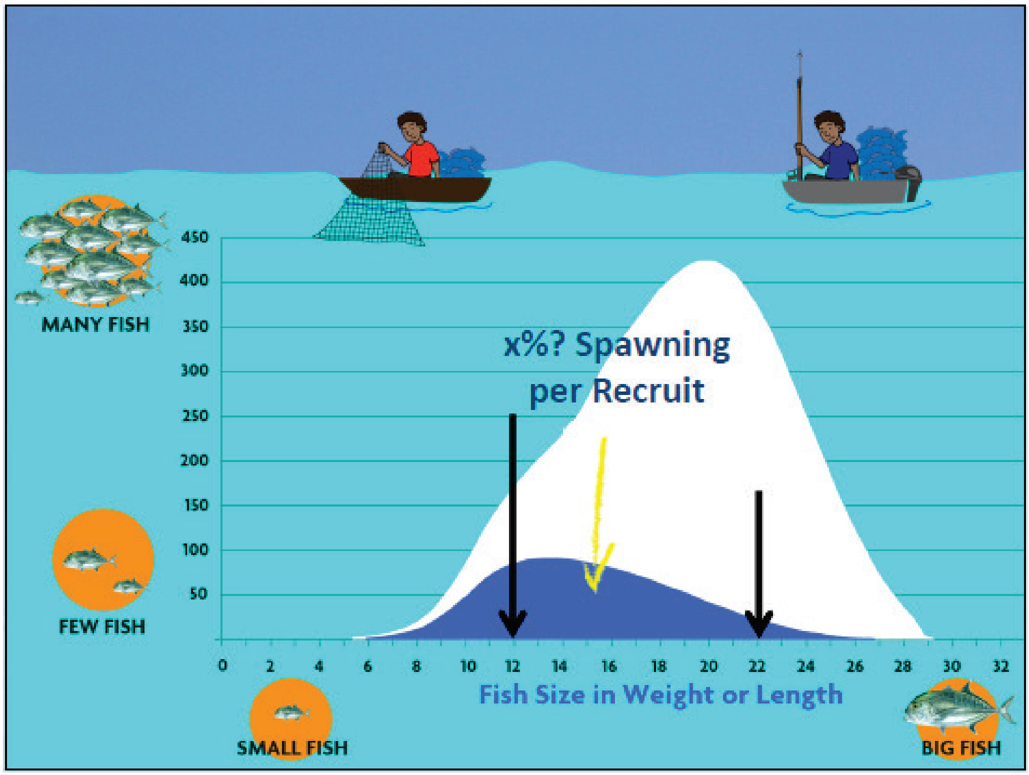


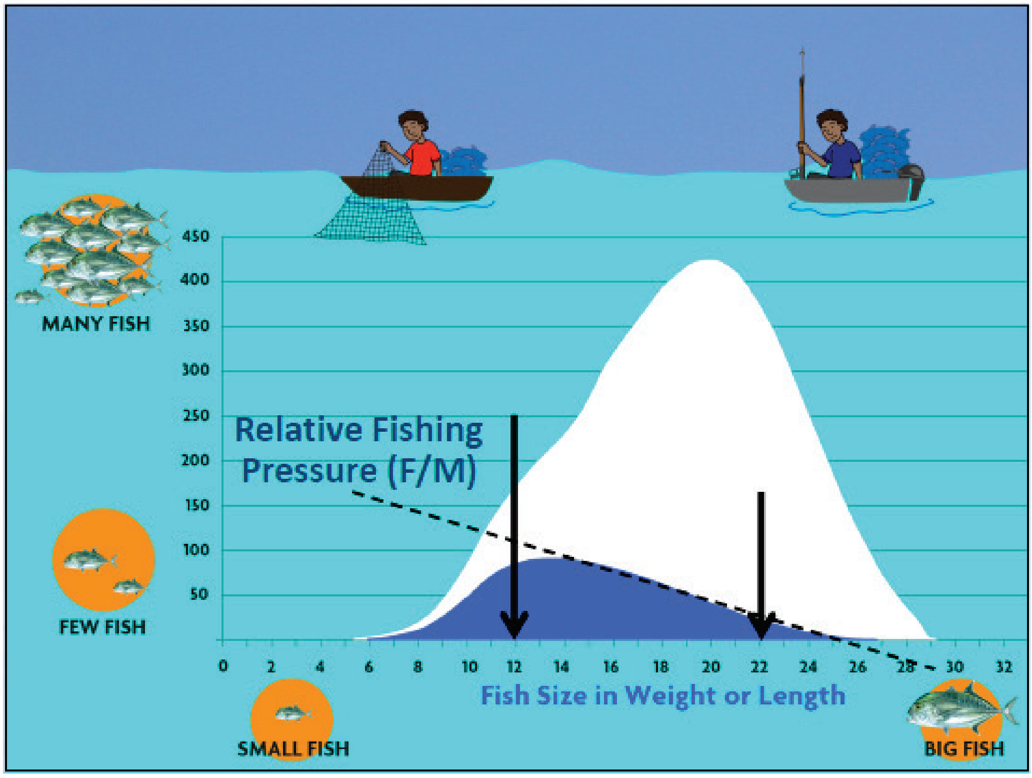
MANY FISH
FEW FISH
450
400
350
300
250
200
150
100
50
Size of Maturity (L50 or Lm)
Asymptotic Size (L∞)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Fish Size in Weight or Length
SMALL FISH
BIG FISH

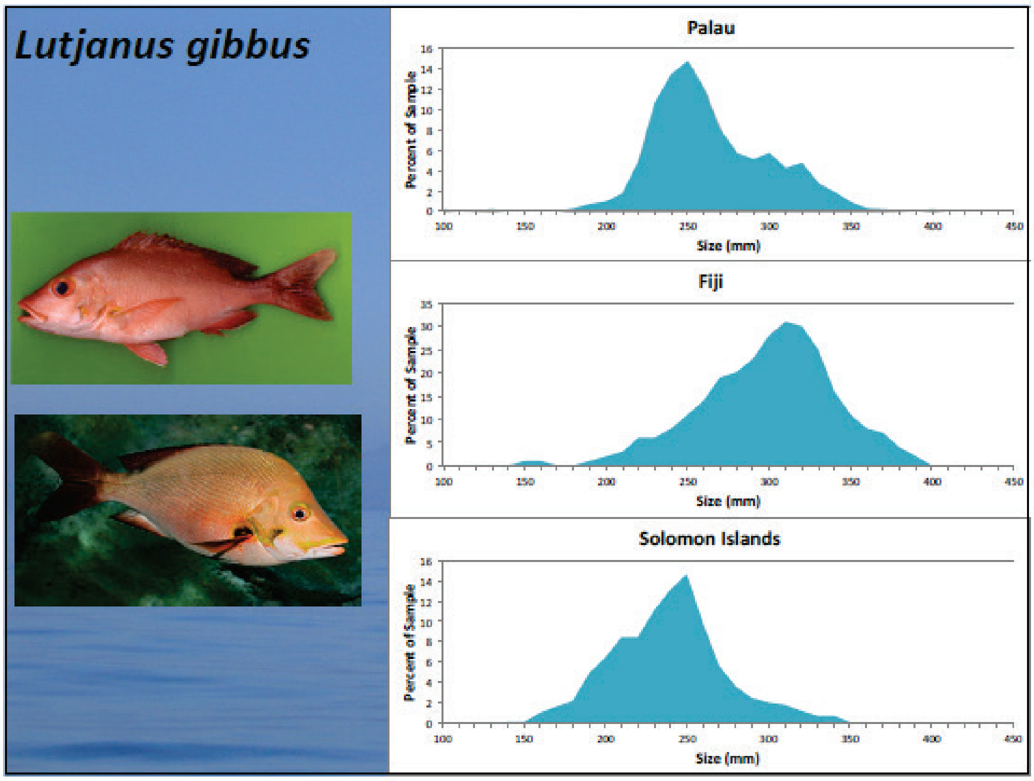


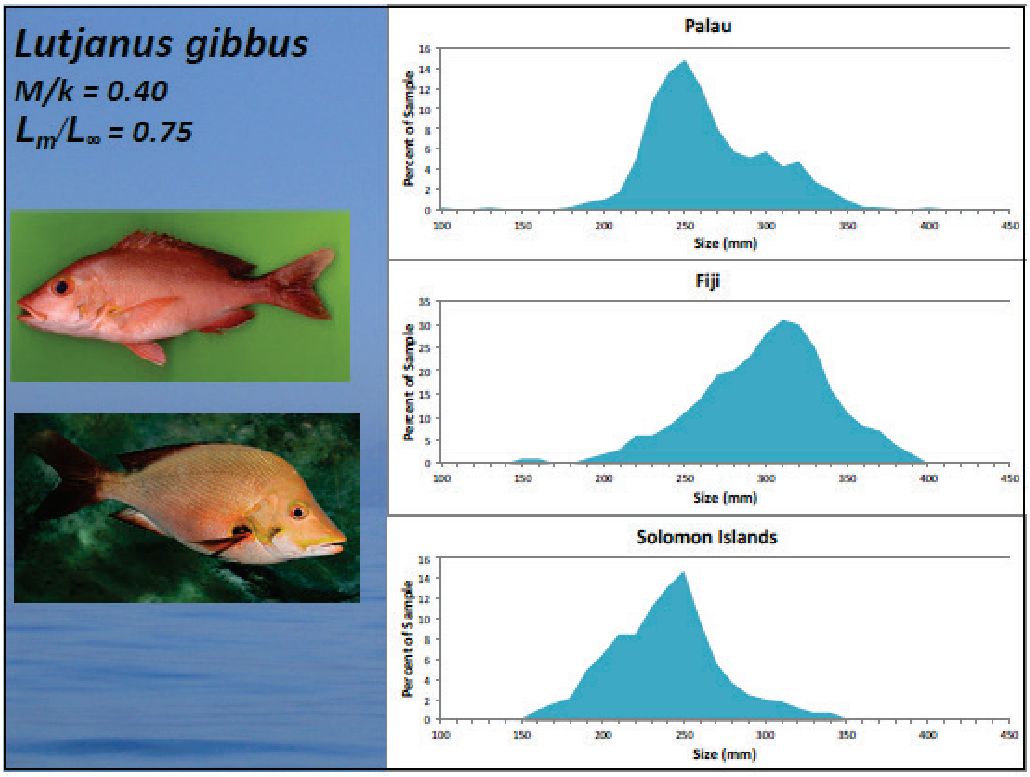
M/k
MANY FISH
FEW FISH
450
400
350
300
250
200
150
100
50
Size of Maturity (L50 or Lm)
Asymptotic Size (L∞)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Fish Size in Weight or Length
SMALL FISH
BIG FISH

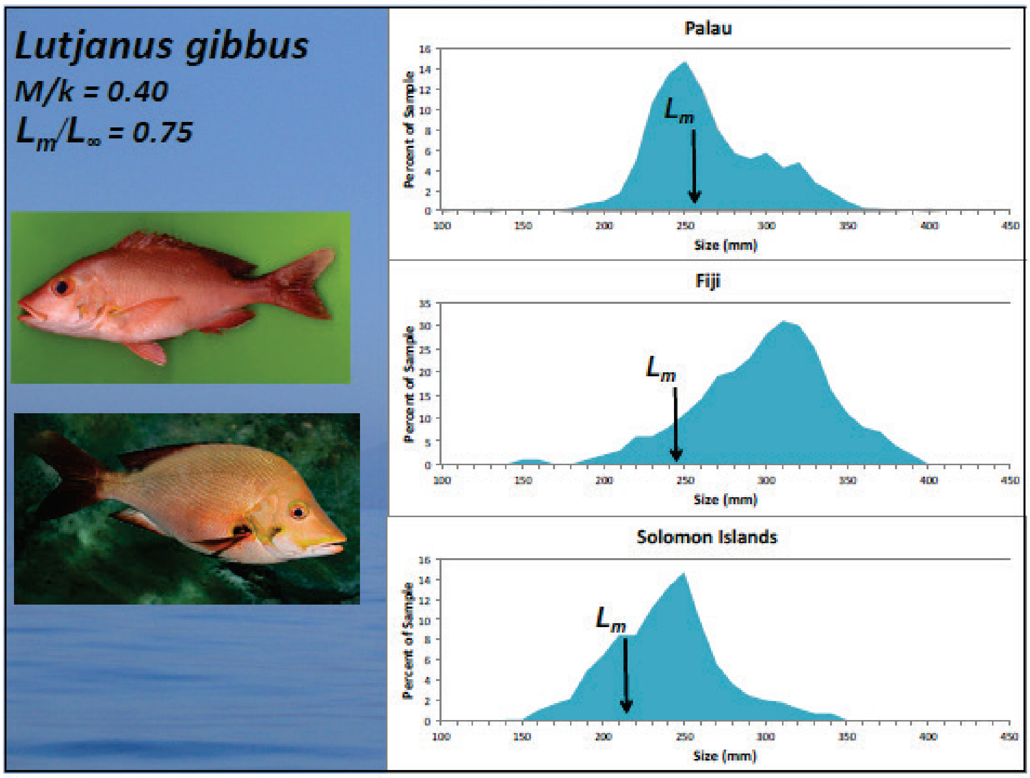

M/k
MANY FISH
FEW FISH
Size of Maturity (L_{50} or L_m)
Asymptotic Size (L_∞)
450
400
350
300
250
200
150
100
50
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Fish Size in Weight or Length
SMALL FISH
BIG FISH

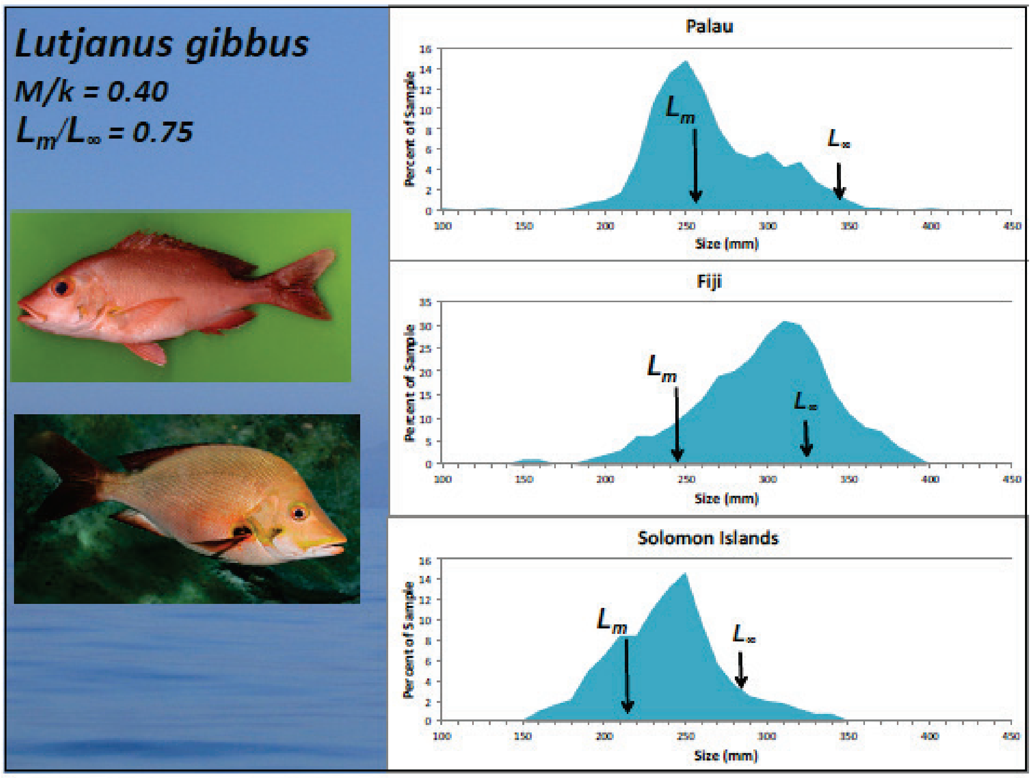

MANY FISH
FEW FISH
x%? Spawning
per Recruit
450
400
350
300
250
200
150
100
50
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Fish Size in Weight or Length
SMALL FISH
BIG FISH

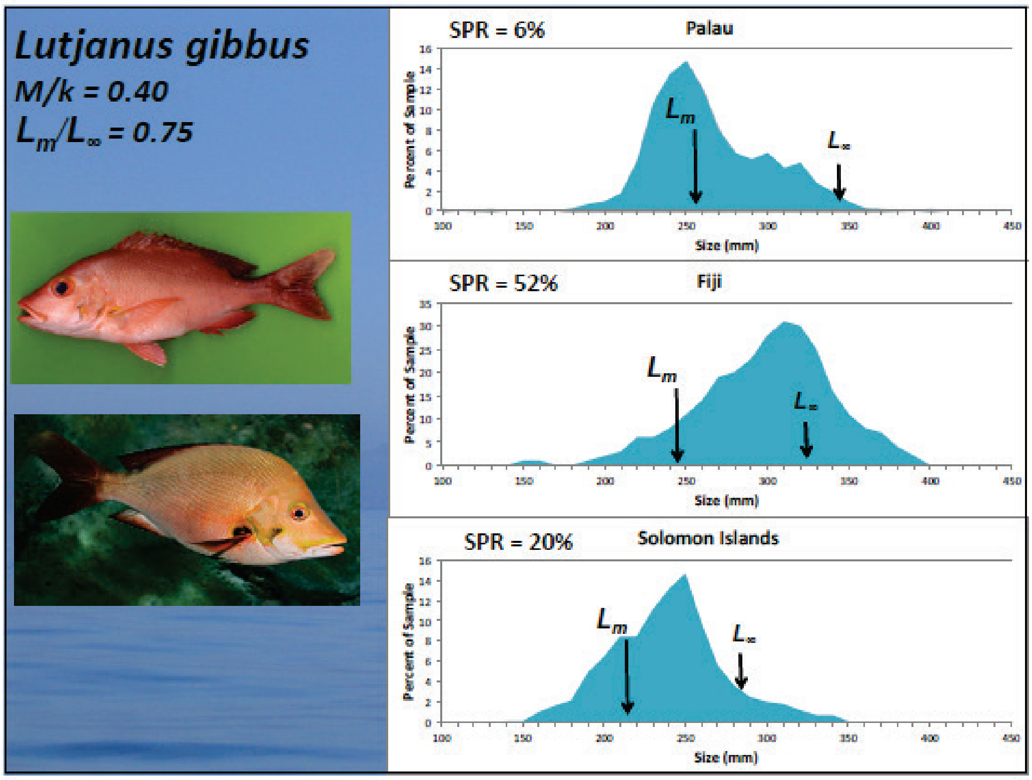

MANY FISH
FEW FISH
SMALL FISH
BIG FISH
Relative Fishing Pressure (F/M)
Fish Size in Weight or Length
450
400
350
300
250
200
150
100
50
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32


Lutjanus gibbus
Palau
Fiji
Solomon Islands
Percent of Sample
Size (mm)
100 150 200 250 300 350 400 450


Lutjanus gibbus
M/k = 0.40
Lm/L∞ = 0.75
Palau
Percent of Sample
Size (mm)
Fiji
Percent of Sample
Size (mm)
Solomon Islands
Percent of Sample
Size (mm)


Lutjanus gibbus
M/k = 0.40
Lm/L∞ = 0.75
Palau
Lm
Percent of Sample
Size (mm)
Fiji
Lm
Percent of Sample
Size (mm)
Solomon Islands
Lm
Percent of Sample
Size (mm)


Lutjanus gibbus
M/k = 0.40
L_m/L_∞ = 0.75
Palau
Fiji
Solomon Islands
L_m
L_∞
Percent of Sample
Size (mm)


Lutjanus gibbus
M/k = 0.40
L_m/L_∞ = 0.75
SPR = 6%
Palau
SPR = 52%
Fiji
SPR = 20%
Solomon Islands
L_m
L_∞
Percent of Sample
Size (mm)

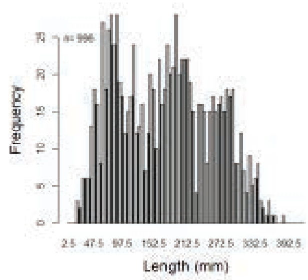
Uptake of LBSPR

	Country	Sessions	% Sessions
1.	United States	210	30.88%
2.	Indonesia	83	12.21%
3.	Brazil	60	8.82%
4.	Fiji	56	8.24%
5.	(not set)	40	5.88%
6.	Chile	39	5.74%
7.	Philippines	24	3.53%
8.	Turkey	17	2.50%
9.	Papua New Guinea	16	2.35%
10.	Australia	13	1.91%

ASFB & OCS Adelaide
15-18 July 2012

Case Studies: Shark Bay Whiting

Sillago schomburgkii



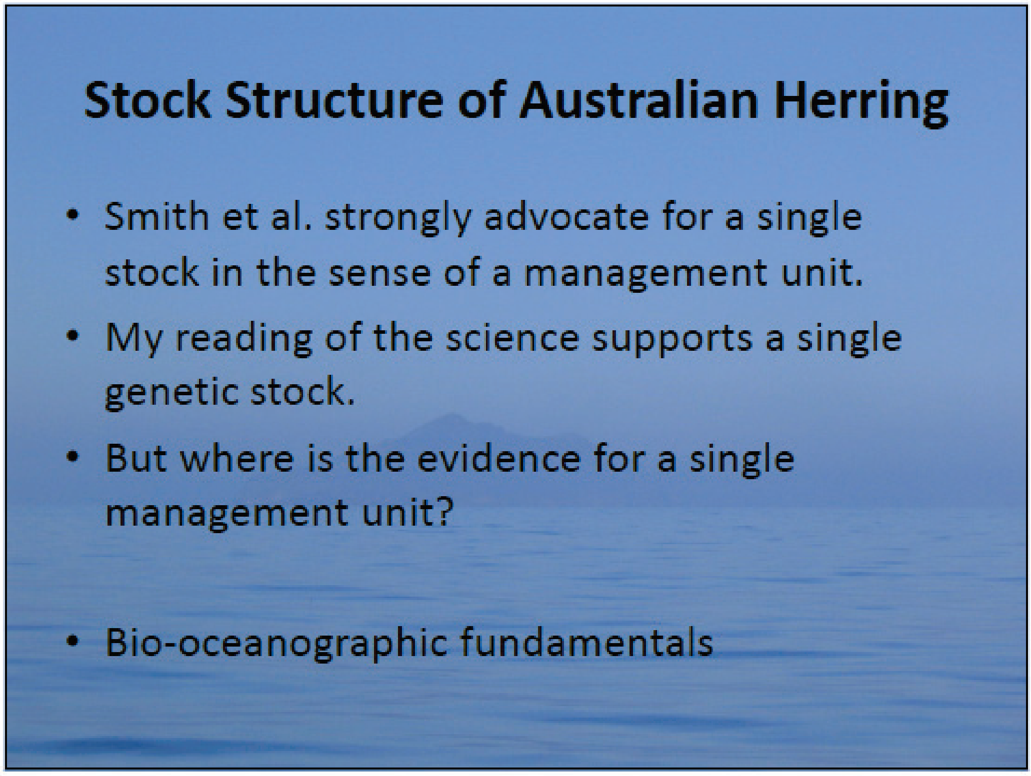
Length frequency of sample

Reported parameters						Estimated parameters			
L_∞	M^*	k	M/k	F	F/M	F/M	S_{L50}	S_{L95}	SPR**
346	0.42	0.477	0.88	0.13	0.31	0.52	36.8	56.44	0.39

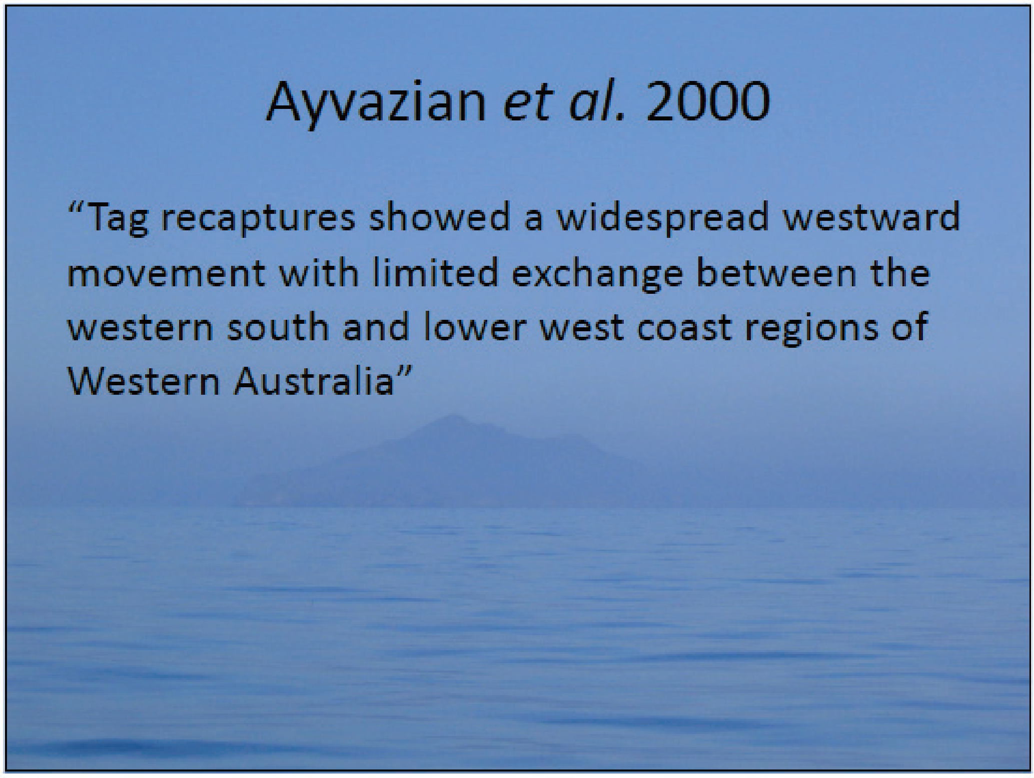
*Estimated using Hoenig equation

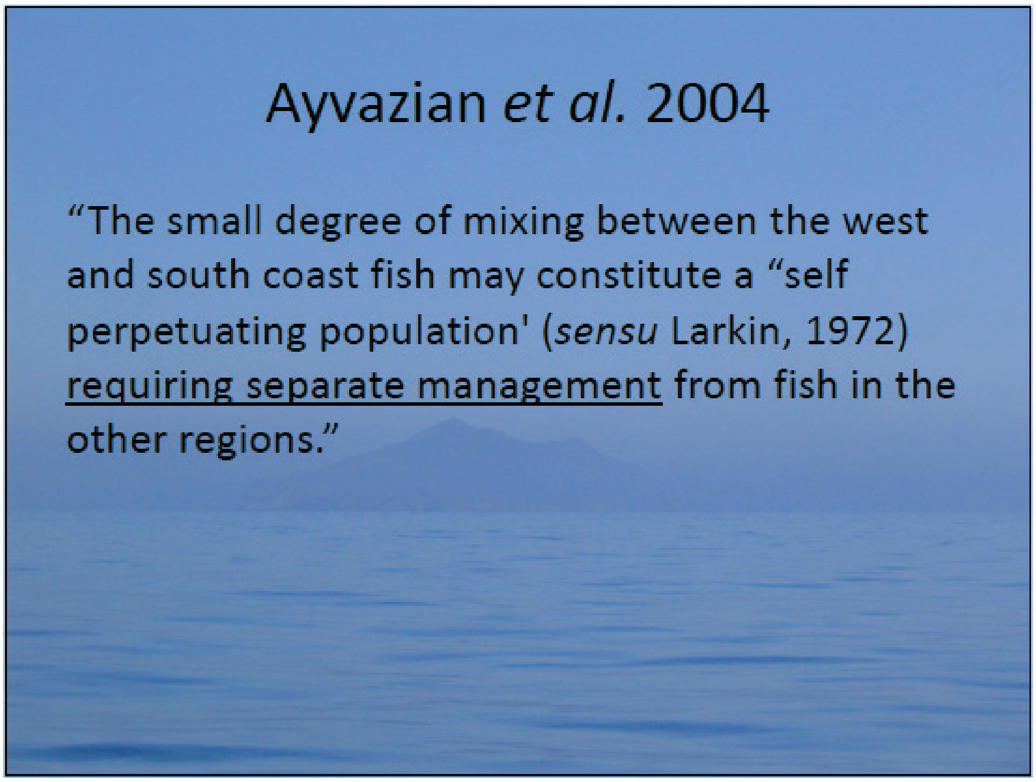
** Scientific sampling , not commerical catch data

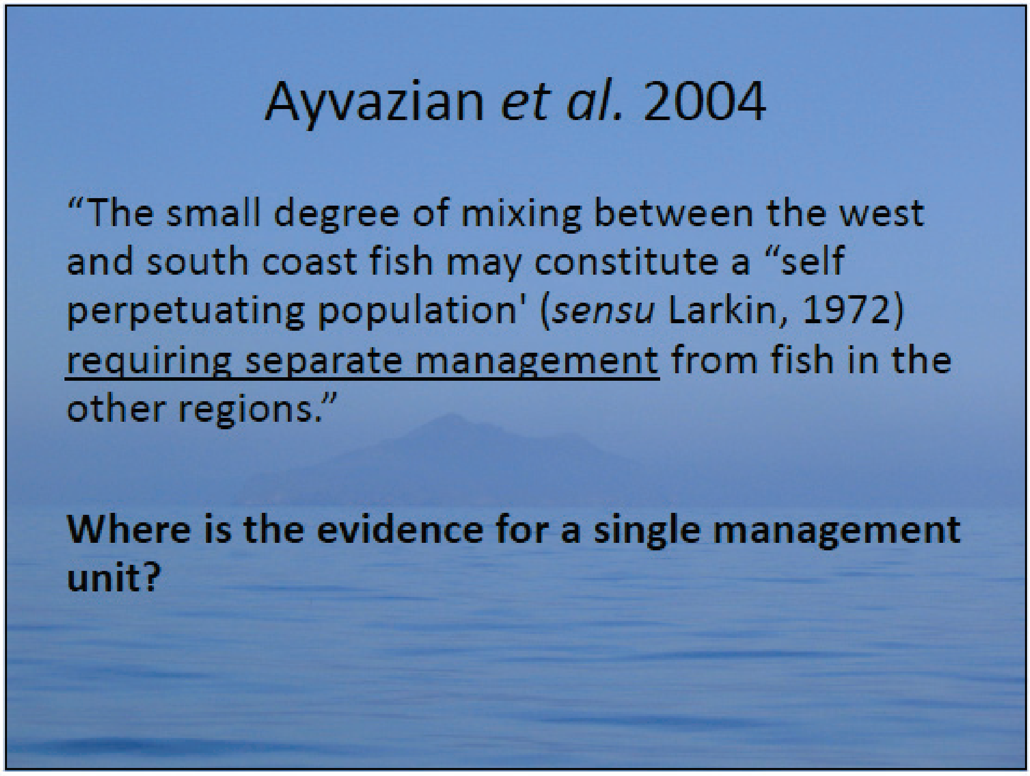
Data from Coulson *et al*, 2005


Stock Structure of Australian Herring
• Smith et al. strongly advocate for a single stock in the sense of a management unit.
• My reading of the science supports a single genetic stock.
• But where is the evidence for a single management unit?
• Bio-oceanographic fundamentals


Fairclough et al. 2000
"Larvae and juveniles produced a little further offshore and particularly along the south coast would be more likely to come under the influence of the eastward-moving currents that prevail at that time and thus be carried towards and into South Australian waters"


Ayvazian *et al.* 2000
"Tag recaptures showed a widespread westward movement with limited exchange between the western south and lower west coast regions of Western Australia"


Ayvazian *et al.* 2004
"The small degree of mixing between the west and south coast fish may constitute a "self perpetuating population' (*sensu* Larkin, 1972) requiring separate management from fish in the other regions."



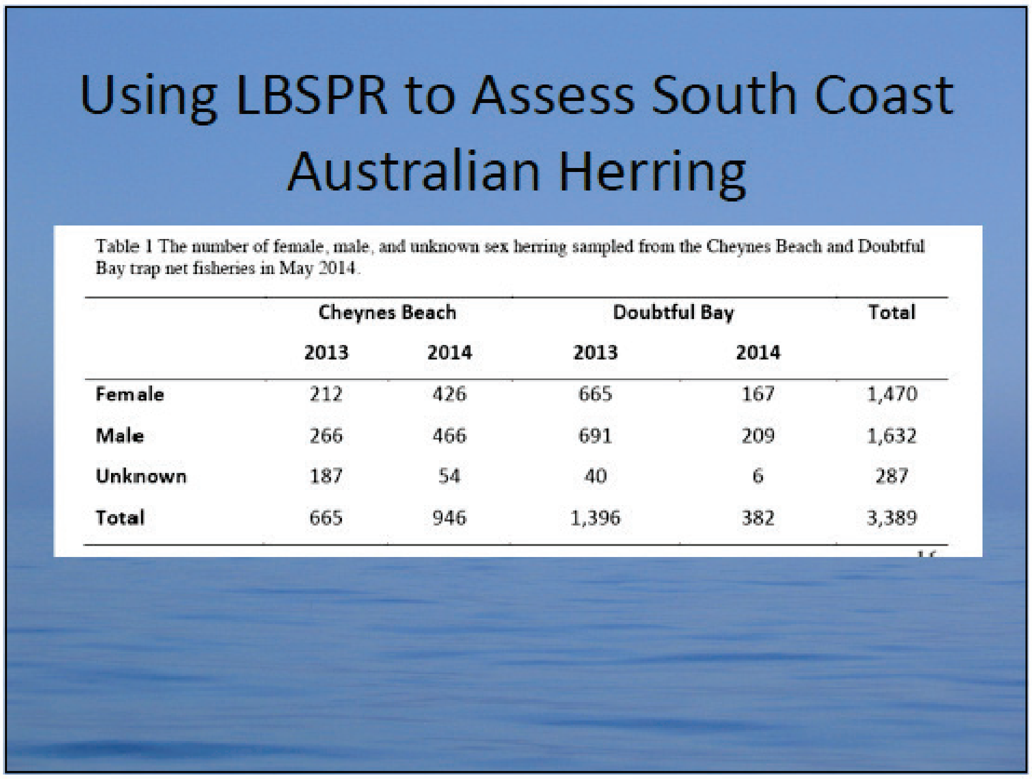
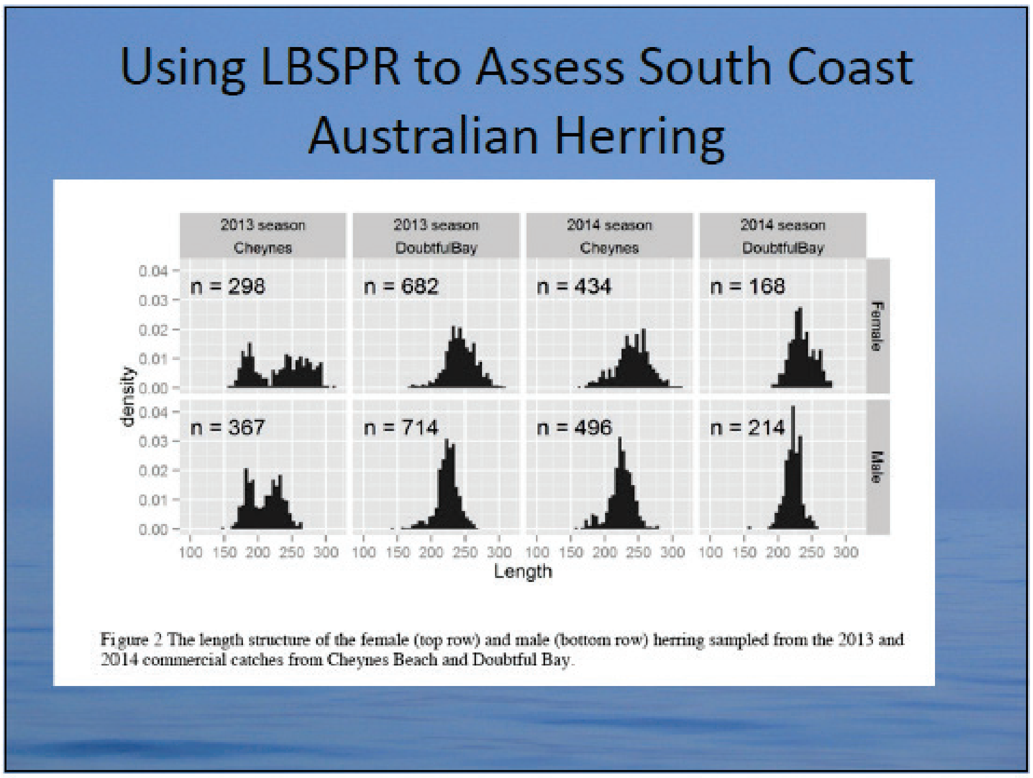
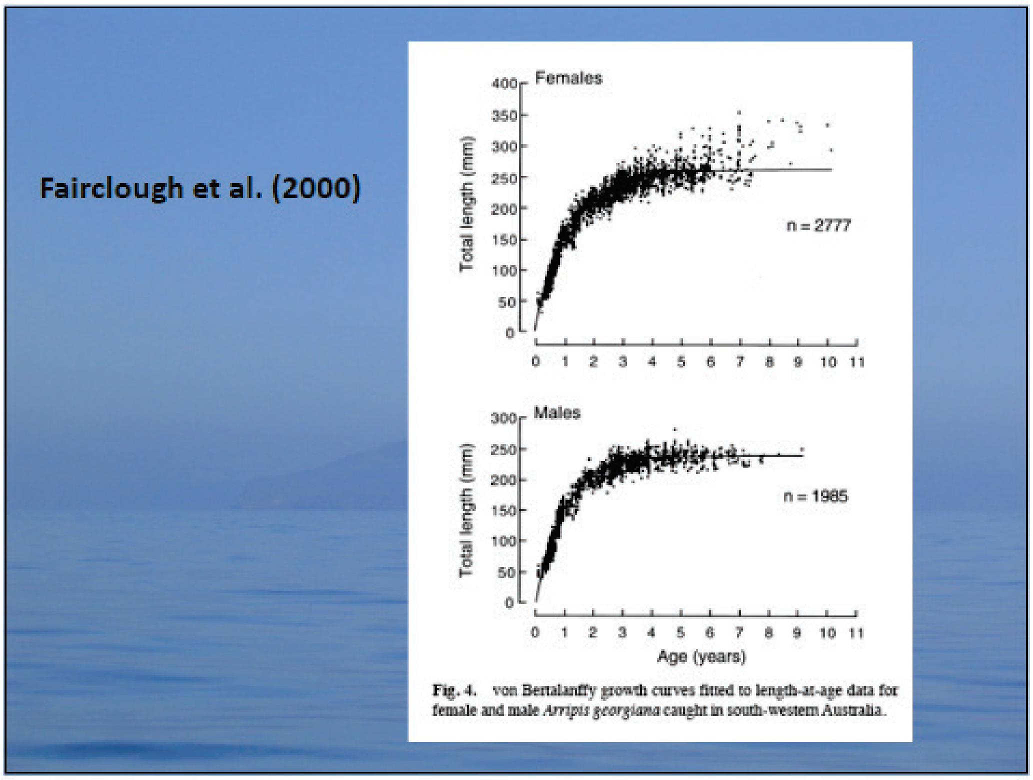


Table 1 The number of female, male, and unknown sex herring sampled from the Cheynes Beach and Doubtful Bay trap net fisheries in May 2014.

	Cheynes Beach		Doubtful Bay		Total
	2013	2014	2013	2014	
Female	212	426	665	167	1,470
Male	266	466	691	209	1,632
Unknown	187	54	40	6	287
Total	665	946	1,396	382	3,389


Using LBSPR to Assess South Coast Australian Herring
2013 season Cheynes
2013 season DoubtfulBay
2014 season Cheynes
2014 season DoubtfulBay
n = 298
n = 682
n = 434
n = 168
n = 367
n = 714
n = 496
n = 214
Female
Male
density
Length
Figure 2 The length structure of the female (top row) and male (bottom row) herring sampled from the 2013 and 2014 commercial catches from Cheynes Beach and Doubtful Bay.


Fairclough et al. (2000)
Females
Total length (mm)
n = 2777
Males
n = 1985
Age (years)
Fig. 4. von Bertalanffy growth curves fitted to length-at-age data for female and male Arripis georgiana caught in south-western Australia.

Smith et al. (2013)

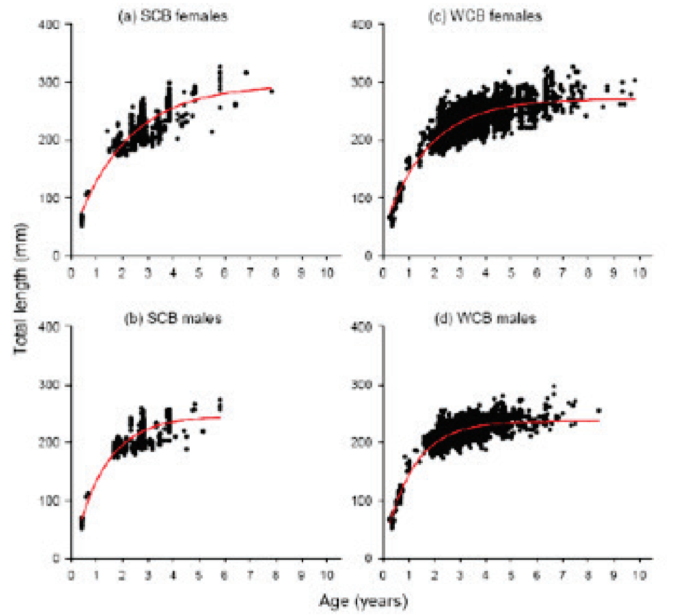
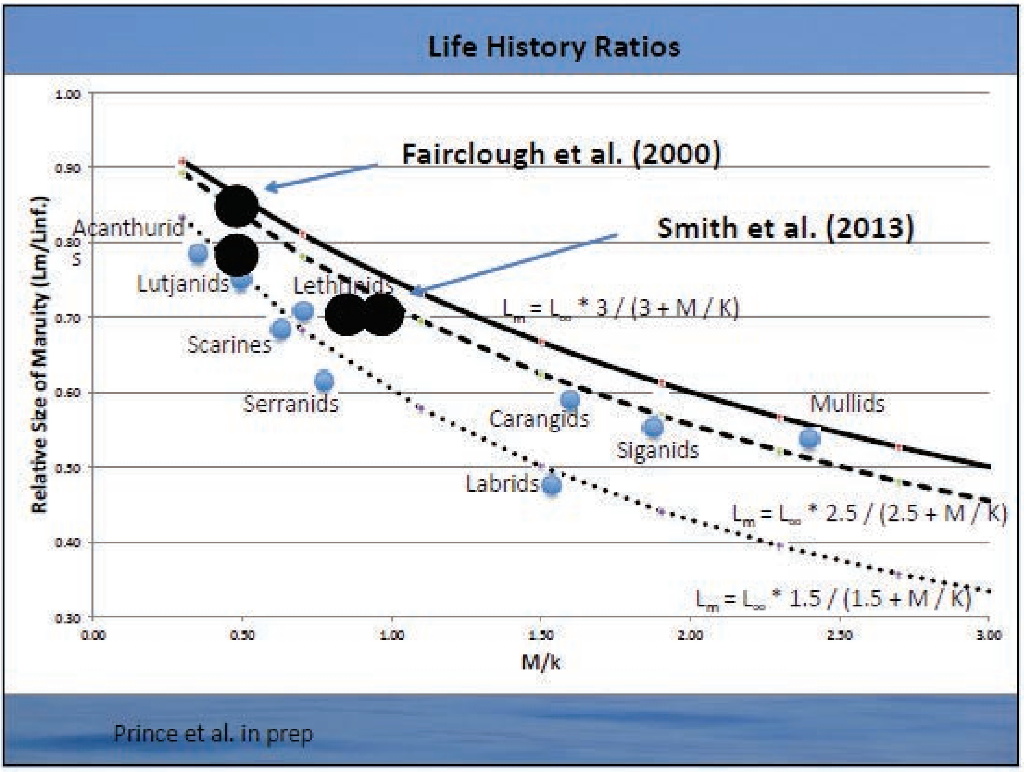


Figure 5.15. von Bertalanffy growth curves fitted to length-at-age data collected in 2008–11 for female and male Australian herring by Bioregion.

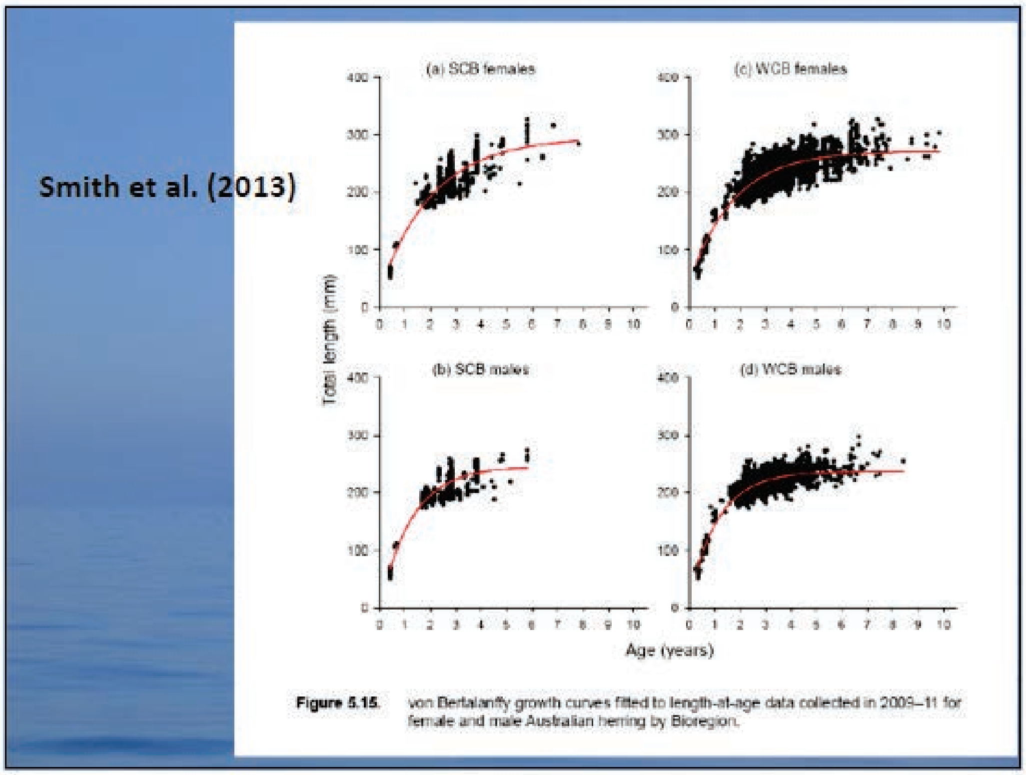
Parameters

Table 2 The biological parameters for the female Australian herring in the South Coast Bioregion and the West Coast Bioregion from two different time periods. All parameters from Smith et al. (2013).

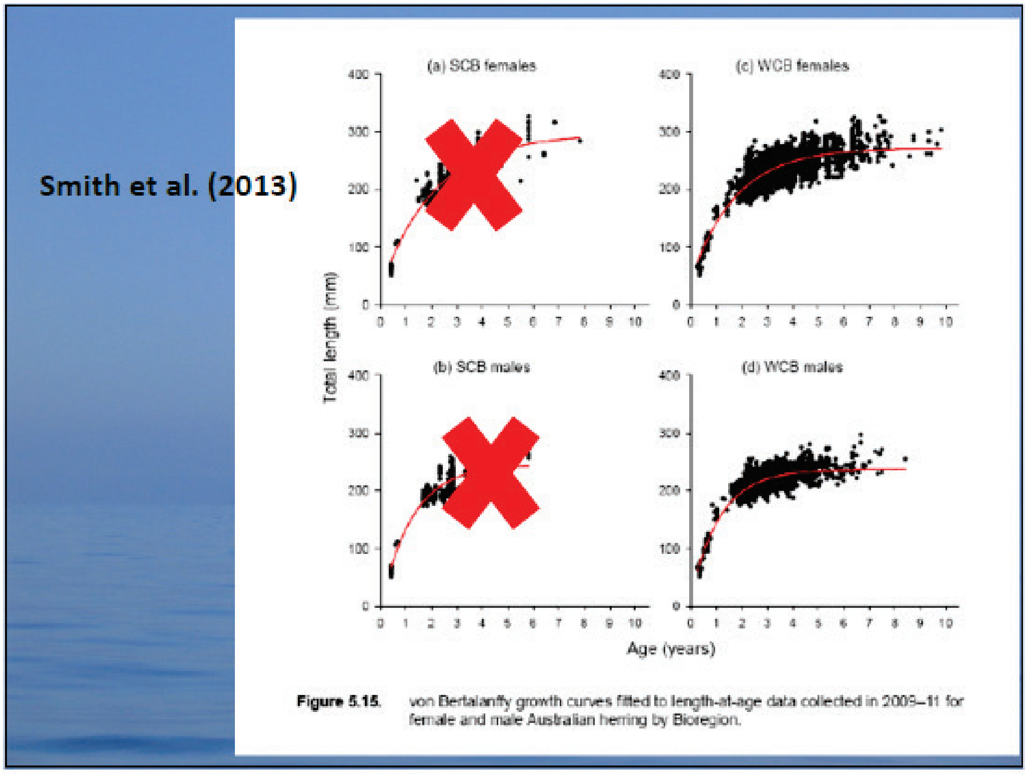
Year	Bioregion	L_∞	k	L_{50}	L_{95}	M	M/k	L_m/L_∞
1996-98	WCB	262.8	0.82	202.6	233.2	0.42	0.51	0.77
	SCB	266.2	0.78	228.3	255.7	0.42	0.53	0.85
2009-11	WCB	271.5	0.57	194.1	250.8	0.42	0.73	0.71
	SCB	295.8	0.48	219.6	265.3	0.42	0.875	0.74



Life History Ratios
Fairclough et al. (2000)
Smith et al. (2013)
Acanthurids
Lutjanids
Lethrinids
Scarines
Serranids
Carangids
Siganids
Mullids
Labrids
Lm = L∞ * 3 / (3 + M / K)
Lm = L∞ * 2.5 / (2.5 + M / K)
Lm = L∞ * 1.5 / (1.5 + M / K)
Relative Size of Maruity (Lm/Linf.)
M/k
Prince et al. in prep



Smith et al. (2013)
(a) SCB females
(c) WCB females
(b) SCB males
(d) WCB males
Total length (mm)
Age (years)
Figure 5.15 von Bertalanffy growth curves fitted to length-at-age data collected in 2009–11 for female and male Australian herring by Bioregion.

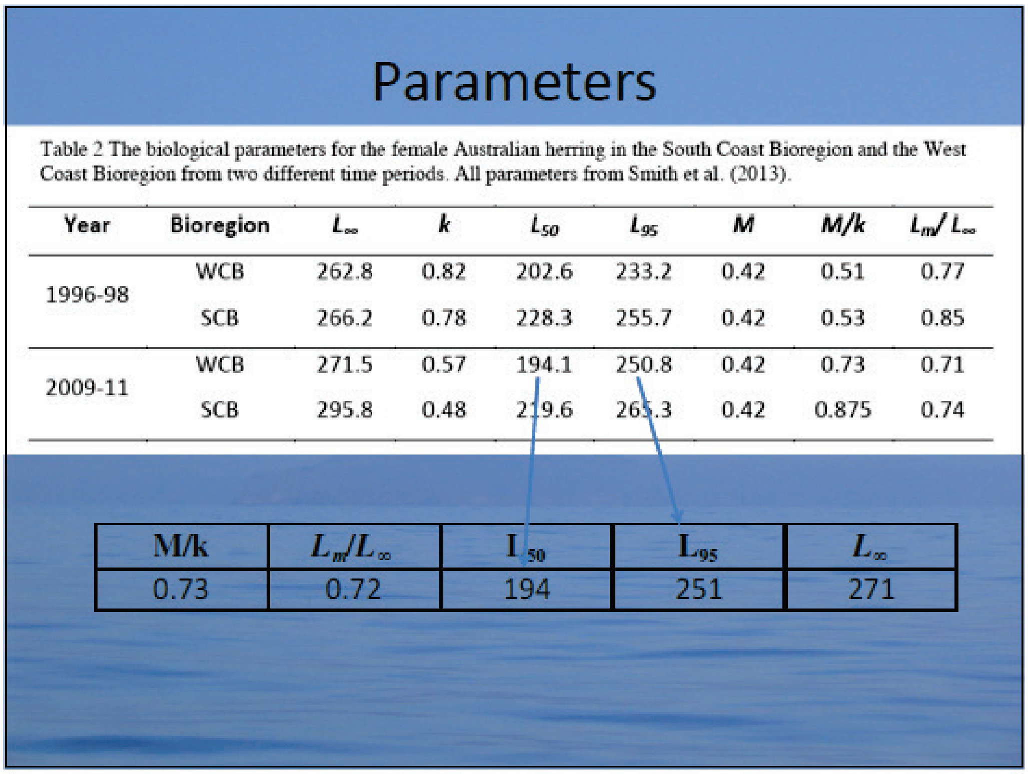


Parameters

Table 2 The biological parameters for the female Australian herring in the South Coast Bioregion and the West Coast Bioregion from two different time periods. All parameters from Smith et al. (2013).

Year	Bioregion	L_∞	k	L_{50}	L_{95}	M	M/k	L_m/L_∞
1996-98	WCB	262.8	0.82	202.6	233.2	0.42	0.51	0.77
	SCB	266.2	0.78	228.3	255.7	0.42	0.53	0.85
2009-11	WCB	271.5	0.57	194.1	250.8	0.42	0.73	0.71
	SCB	295.8	0.48	219.6	265.3	0.42	0.875	0.74

M/k	L_m/L_∞	L_{50}	L_{95}	L_∞
0.73	0.72	194	251	271

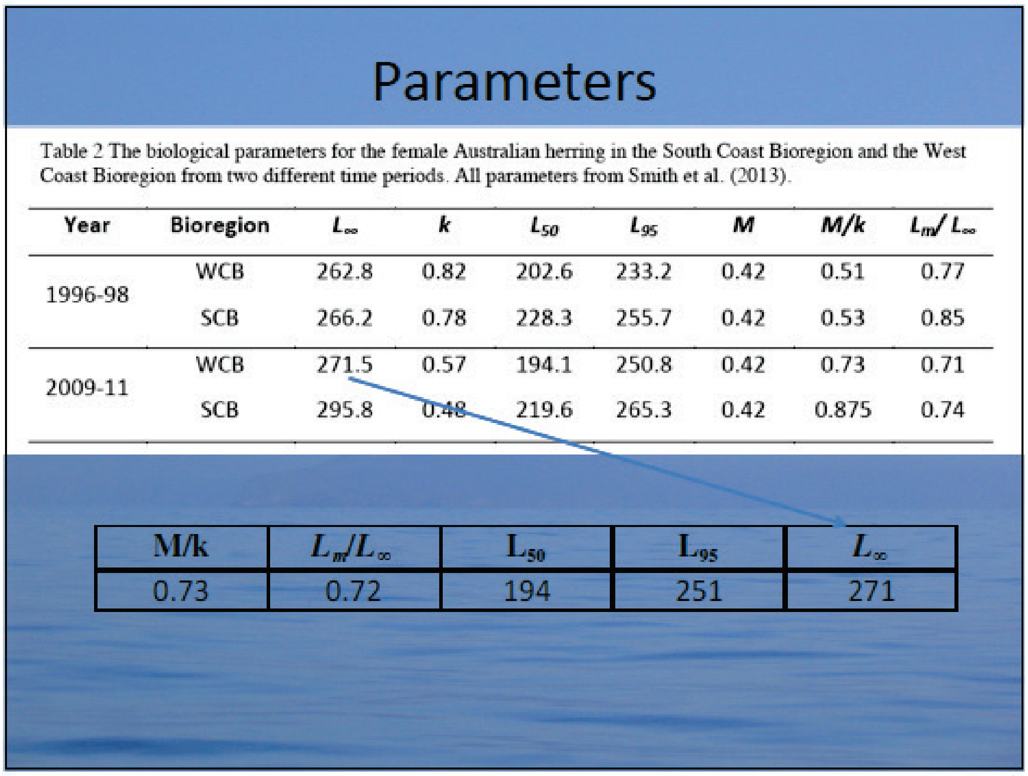


Parameters

Table 2 The biological parameters for the female Australian herring in the South Coast Bioregion and the West Coast Bioregion from two different time periods. All parameters from Smith et al. (2013).

Year	Bioregion	L_∞	k	L_{50}	L_{95}	M	M/k	L_m/L_∞
1996-98	WCB	262.8	0.82	202.6	233.2	0.42	0.51	0.77
	SCB	266.2	0.78	228.3	255.7	0.42	0.53	0.85
2009-11	WCB	271.5	0.57	194.1	250.8	0.42	0.73	0.71
	SCB	295.8	0.48	219.6	265.3	0.42	0.875	0.74

M/k	L_m/L_∞	L_{50}	L_{95}	L_∞
0.73	0.72	194	251	271

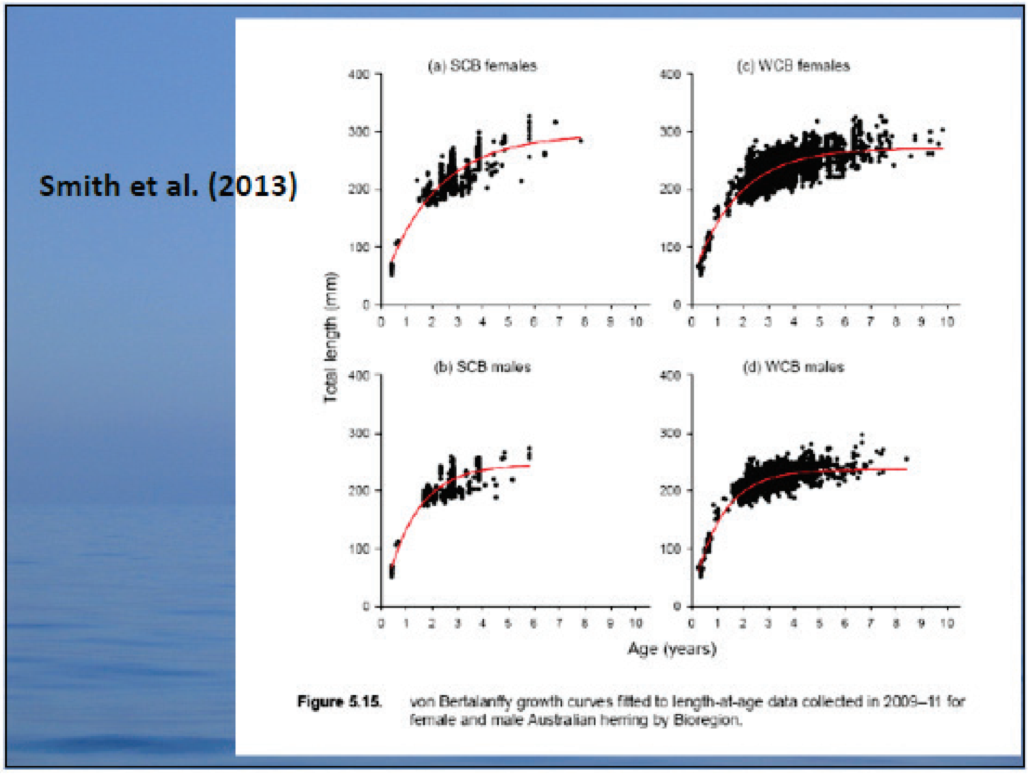


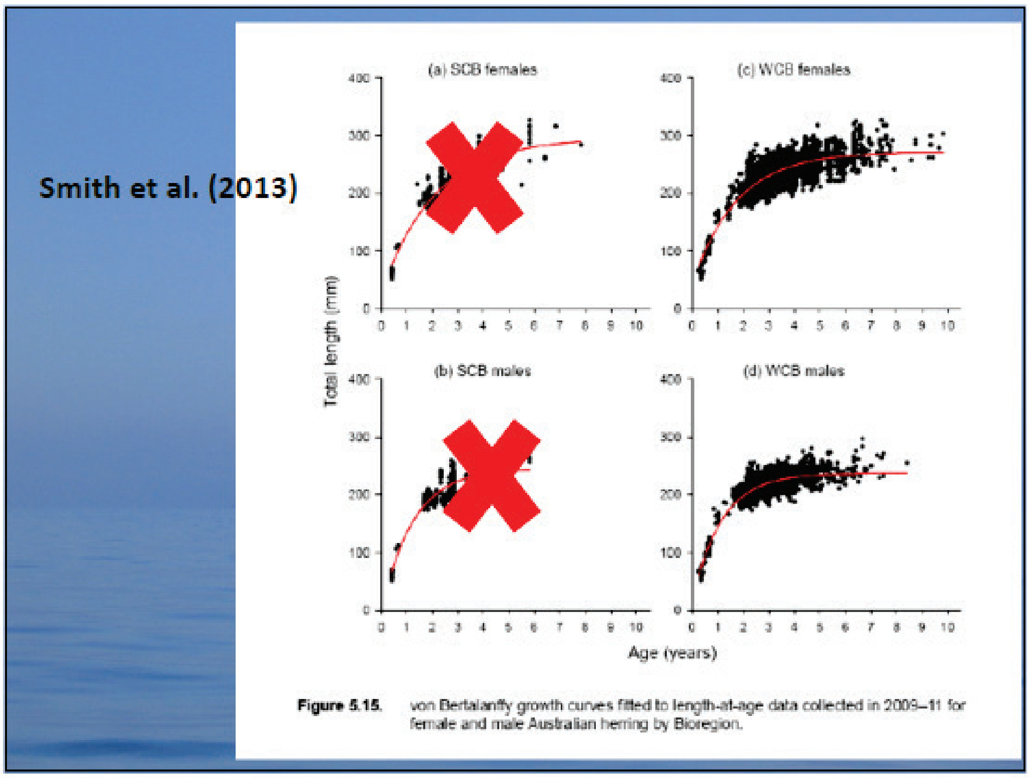
Parameters

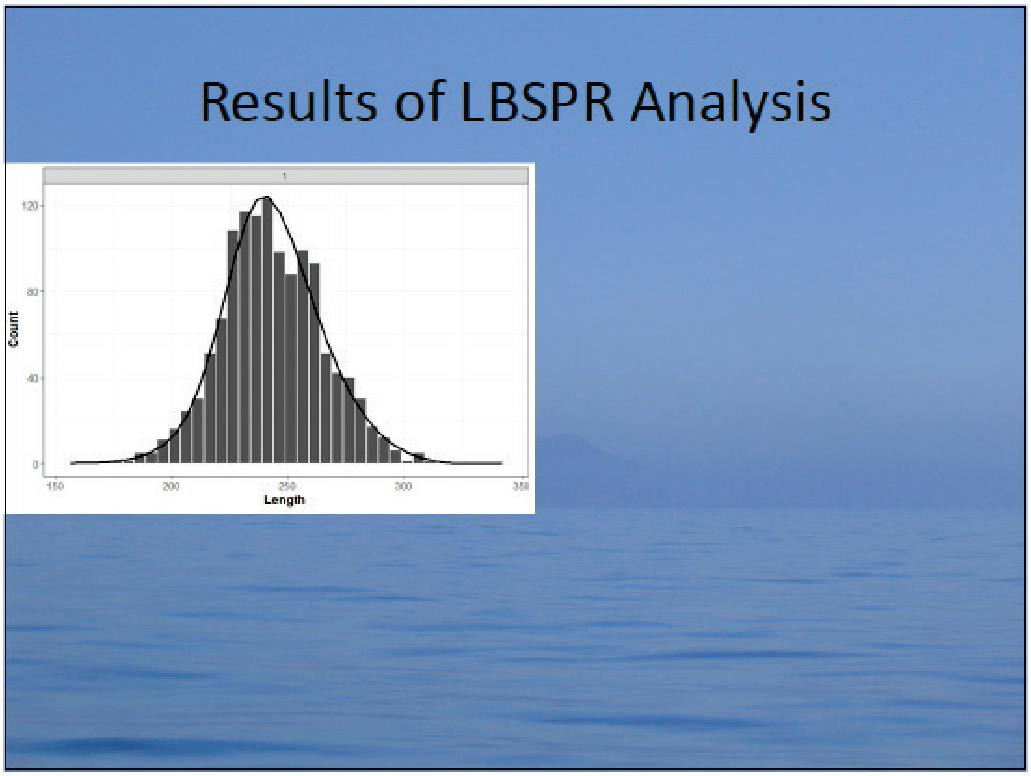
Table 2 The biological parameters for the female Australian herring in the South Coast Bioregion and the West Coast Bioregion from two different time periods. All parameters from Smith et al. (2013).

Year	Bioregion	L_∞	k	L_{50}	L_{95}	M	M/k	L_m/L_∞
1996-98	WCB	262.8	0.82	202.6	233.2	0.42	0.51	0.77
	SCB	266.2	0.78	228.3	255.7	0.42	0.53	0.85
2009-11	WCB	271.5	0.57	194.1	250.8	0.42	0.73	0.71
	SCB	295.8	0.48	219.6	265.3	0.42	0.875	0.74

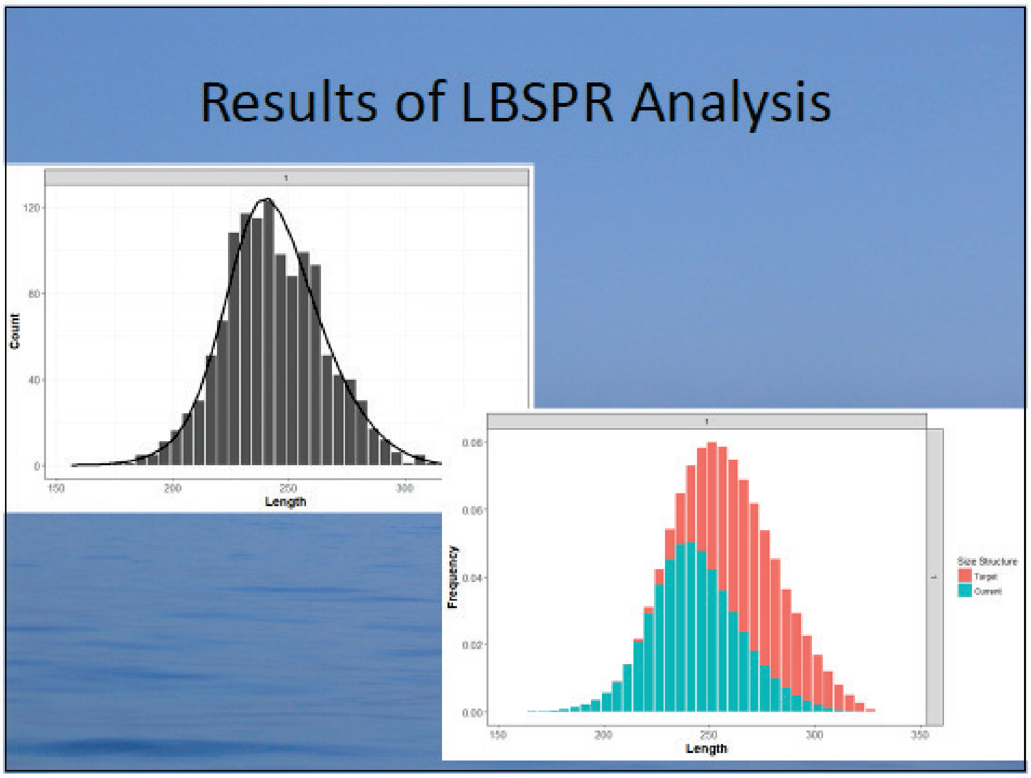
M/k	L_m/L_∞	L_{50}	L_{95}	L_∞
0.73	0.72	194	251	271


Smith et al. (2013)
(a) SCB females
(c) WCB females
(b) SCB males
(d) WCB males
Total length (mm)
Age (years)
Figure 5.15. von Bertalanffy growth curves fitted to length-at-age data collected in 2009–11 for female and male Australian herring by Bioregion.

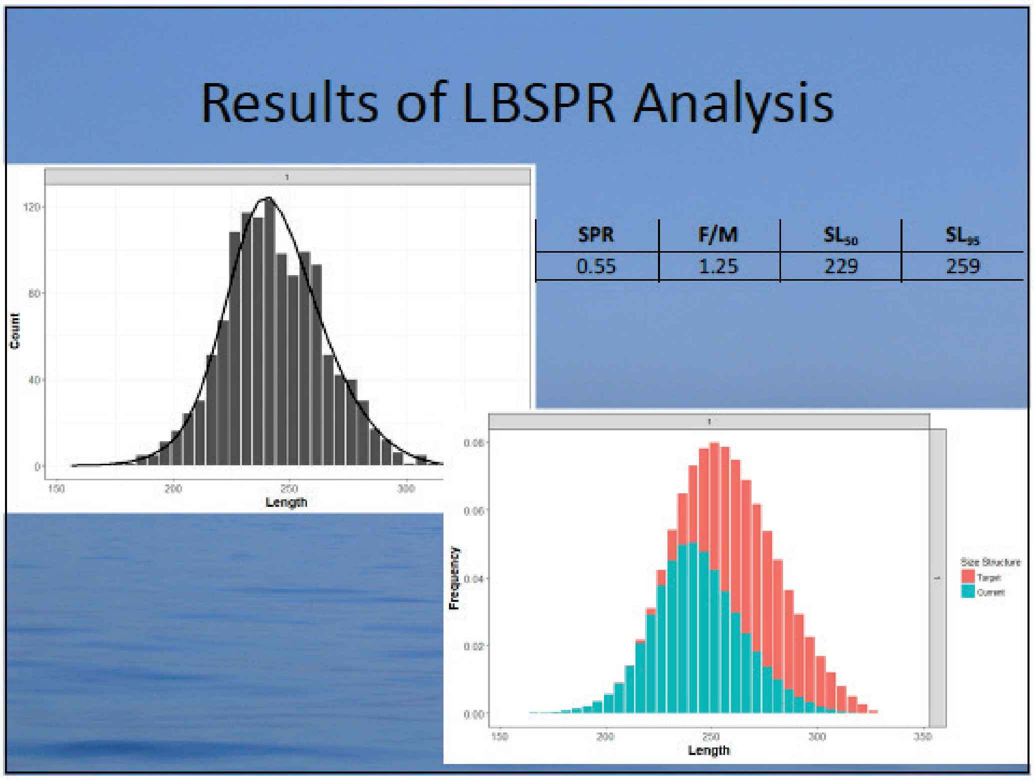

Smith et al. (2013)
(a) SCB females
(c) WCB females
(b) SCB males
(d) WCB males
Total length (mm)
Age (years)
Figure 5.15. von Bertalanffy growth curves fitted to length-at-age data collected in 2009–11 for female and male Australian herring by Bioregion.

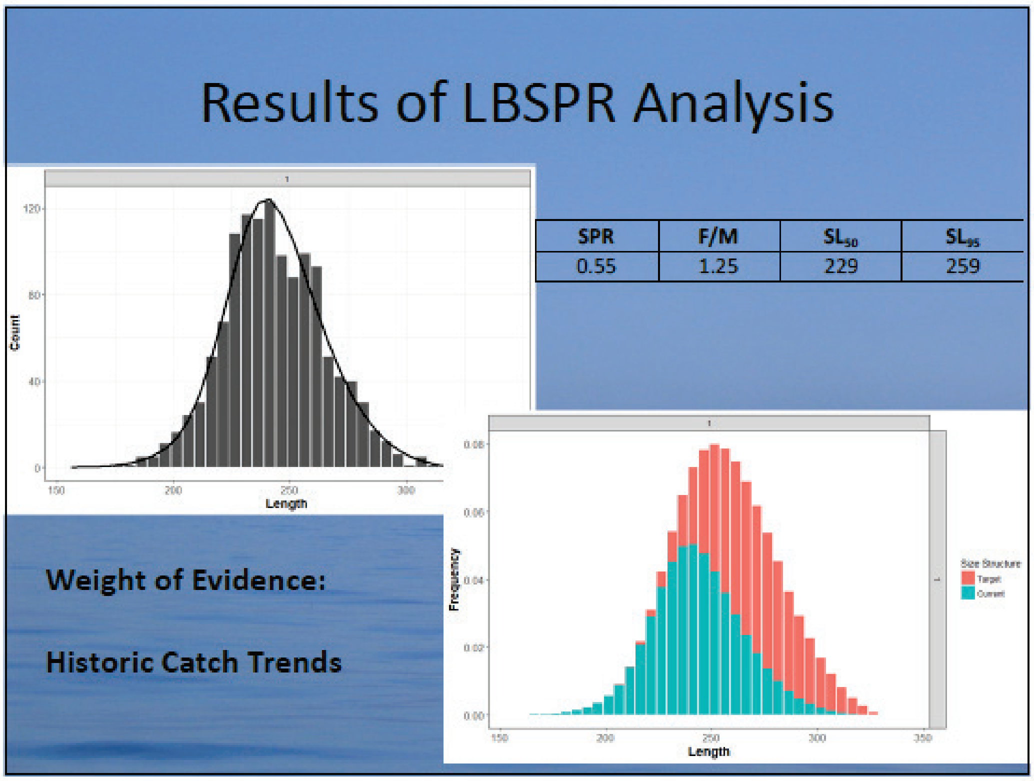


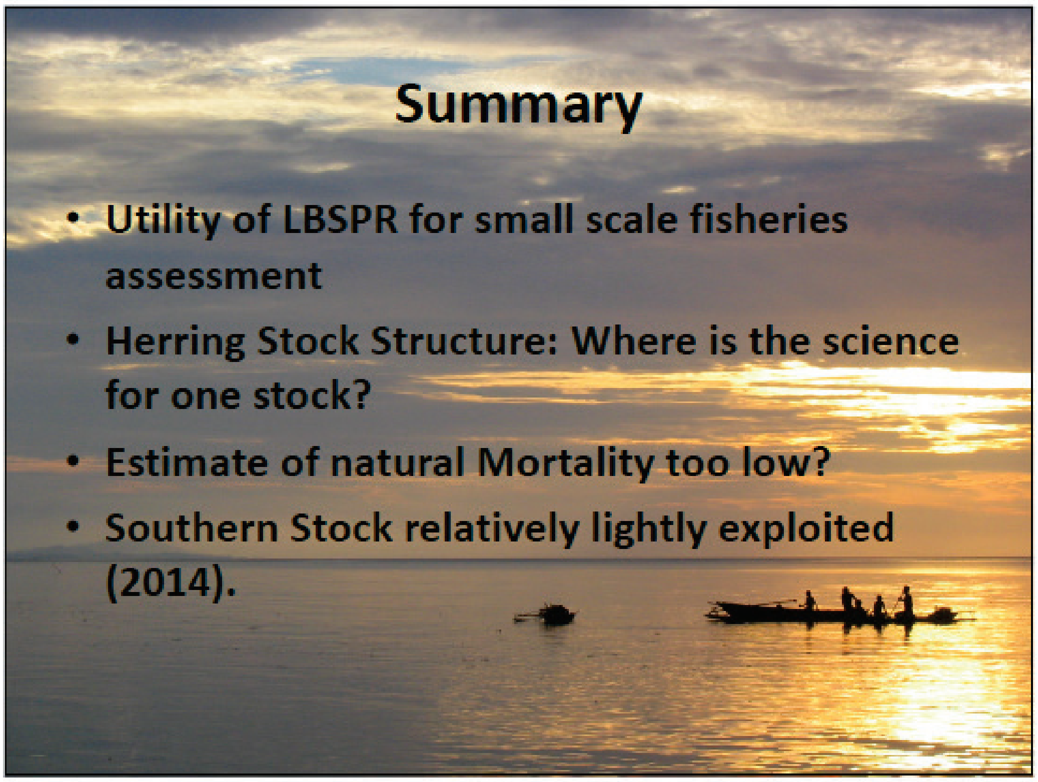
Results of LBSPR Analysis
Count
Length



Results of LBSPR Analysis
Count
Length
Frequency
Length


Results of LBSPR Analysis
SPR | F/M | SL50 | SL95
0.55 | 1.25 | 229 | 259
Count
Length
Frequency
Length
Size Structure
Target
Current


Results of LBSPR Analysis
SPR | F/M | SL50 | SL95
0.55 | 1.25 | 229 | 259
Weight of Evidence:
Historic Catch Trends
Count
Length
Frequency
Length
Size Structure
Target
Current



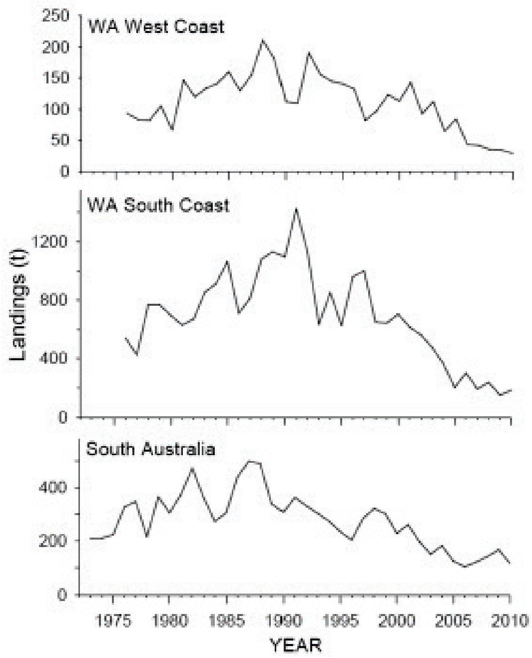
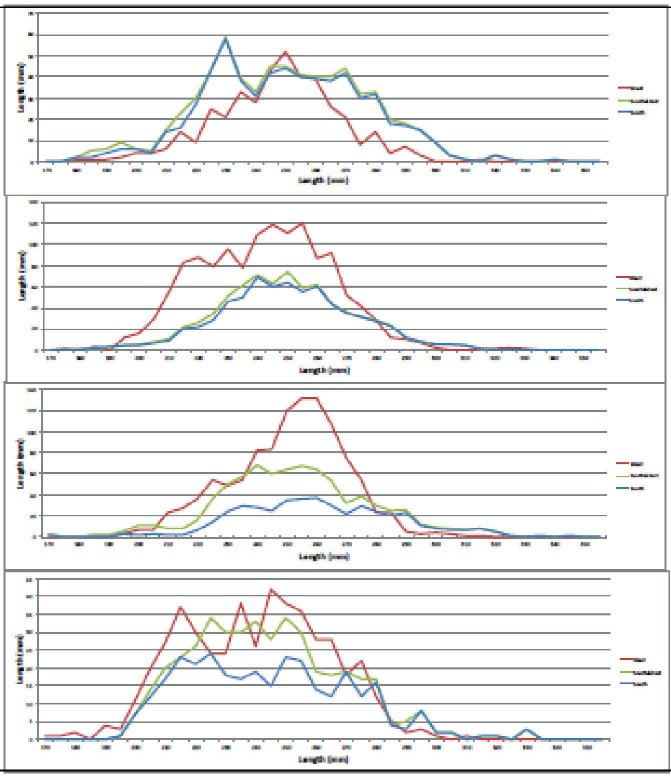


Figure 3.3. Total annual commercial landings of Australian herring in the main fishery regions, 1976 to 2010 in Western Australia (WA), 1973/74 to 2009/10 in South Australia.



Parameters Used

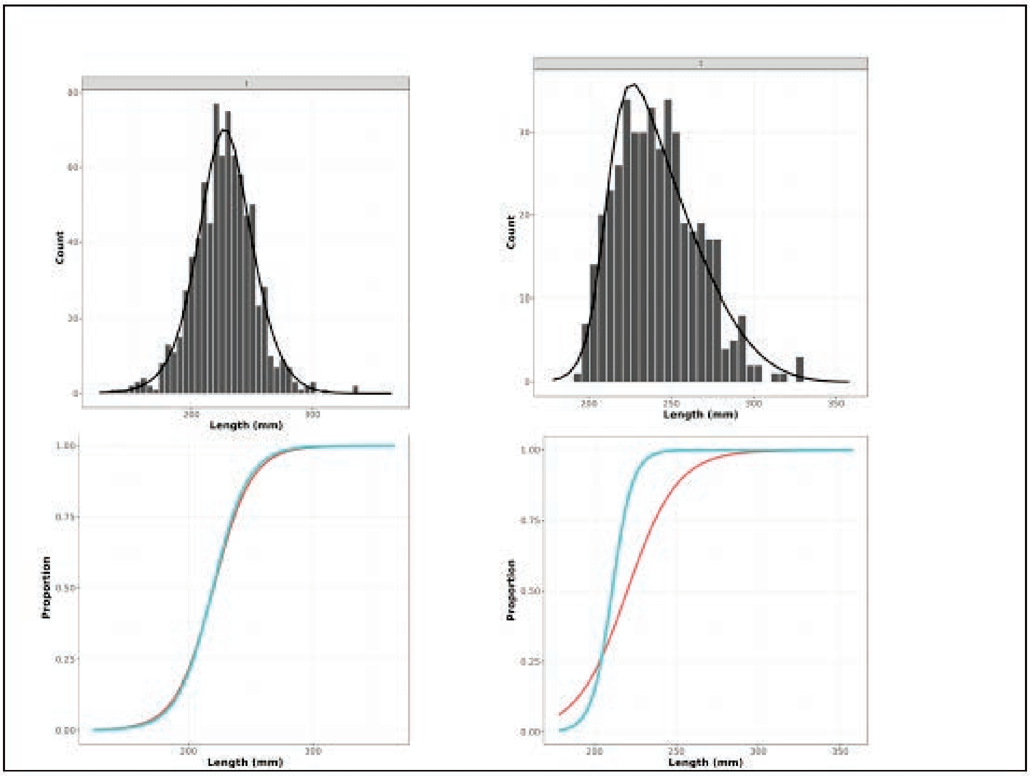
Region	M/k	L_{50}	M	k	L_{95}	L_{∞}
SC	0.88	220	0.42	0.48	265	296
SC	0.73	220	0.38	0.52	265	296
WC	0.88	194	0.42	0.48	251	271
WC	0.73	194	0.38	0.52	251	271

South Coast

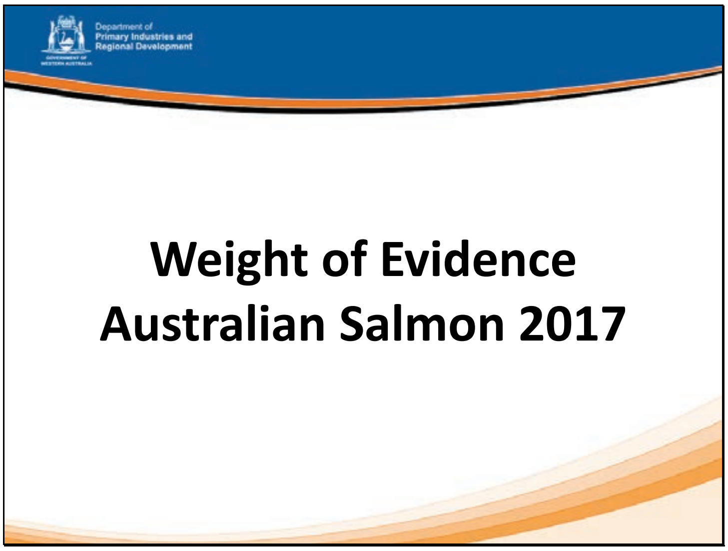
Gear	Year	Reg.	M/k	SPR	SPR 95%	F/M	F/M 95%	SL_{50}	95% SL_{50}	SL_{95}	95% SL_{95}
Rec. Rod & Line	2017	SC	0.88	**0.39**	0.31-0.47	**1.08**	0.73-1.43	211	205-216	229	218-240
Rec. Rod & Line	2017	SC	0.73	0.32	0.25-0.38	1.45	1.04-1.86	211	205-216	229	218-239
Rec. Rod & Line	2016	SC	0.88	**0.44**	0.39-0.50	**1.33**	0.98-1.68	234	229-239	269	260-278
Rec. Rod & Line	2016	SC	0.73	0.37	0.32-0.42	1.74	1.32-2.16	234	228-239	269	261-278
Rec. Rod & Line	2015	SC	0.88	**0.35**	0.30-0.40	**2.16**	1.60-2.72	234	229-240	268	259-277
Rec. Rod & Line	2015	SC	0.73	0.29	0.25-0.34	2.73	2.06-3.40	234	229-240	268	259-277
Rec. Rod & Line	2014	SC	0.88	**0.43**	0.35-0.50	**1.21**	0.79-1.63	226	217-234	262	249-276
Rec. Rod & Line	2014	SC	0.73	0.35	0.29-0.42	1.6	1.10-2.10	225	217-234	262	249-276
Trap Net Only	2012/13	SC	0.73	**0.3**	0.25-0.34	**3.92**	2.68-4.96	242	237-246	264	257-272
Trap Net Only	2012/13	SC	0.88	0.35	0.30-0.40	3.12	2.27-3.97	242	237-246	264	257-272
All gears	1996/97	SC	0.73	**0.17**	0.14-0.21	**4.5**	3.53-5.47	229	222-235	280	271-235
All gears	1996/97	SC	0.88	0.22	0.18-0.25	3.6	2.8-4.4	229	223-235	279	270-288
Comm Only	1996/97	SC	0.73	**0.23**	0.17-0.30	**3.77**	2.42-5.12	240	230-251	303	287-318
Comm Only	1996/97	SC	0.88	0.28	0.21-0.36	2.99	1.87-4.11	240	230-251	301	287-316
Rec Only	1996/97	SC	0.73	**0.15**	0.12-0.18	**4.28**	3.35-5.21	220	214-226	261	252-270
Rec Only	1996/97	SC	0.88	0.19	0.15-0.22	3.42	2.65-4.19	220	214-226	261	252-270

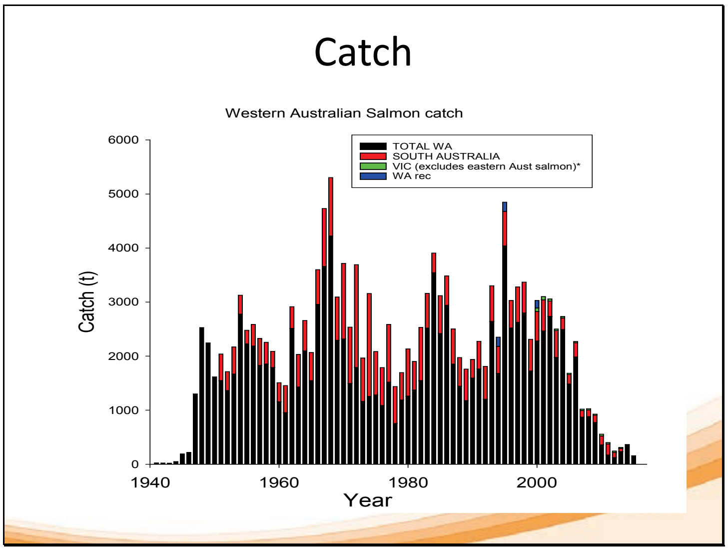
West Coast

Gear	Year	Reg.	M/k	SPR	SPR 95%	F/M	F/M 95%	SL_{50}	95% SL_{50}	SL_{95}	95% SL_{95}
Rec. Rod & Line	2017	WC	0.88	**0.66**	0.48-0.83	**0.58**	0.58-1.11	215	200-230	246	222-230
Rec. Rod & Line	2017	WC	0.73	0.56	0.41-0.72	0.84	0.20-1.48	214	199-229	247	221-272
Rec. Rod & Line	2016	WC	0.88	**0.61**	0.56-0.66	**2.87**	2.08-3.66	257	252-261	294	288-3.67
Rec. Rod & Line	2016	WC	0.73	0.54	0.49-0.60	3.54	2.60-4.48	257	252-262	296	289-302
Rec. Rod & Line	2015	WC	0.88	**0.60**	0.53-0.67	**0.98**	0.60-1.36	226	219-233	258	247-233
Rec. Rod & Line	2015	WC	0.73	0.52	0.44-0.59	1.34	0.89-1.79	226	219-233	259	248-270
Rec. Rod & Line	2014	WC	0.88	**0.59**	0.50-0.67	**2.07**	1.09-3.05	246	237-255	282	270-294
Rec. Rod & Line	2014	WC	0.73	0.52	0.43-0.61	2.62	1.43-3.81	246	237-255	283	2.70-296
Rec. Rod & Line	2010	WC	0.73	**0.5**	0.46-0.54	**1.09**	0.87-1.31	213	210-216	236	230-241
Rec. Rod & Line	2010	WC	0.88	0.59	0.54-0.64	0.77	0.59-0.95	213	210-241	236	230-241
Haul net	2010	WC	0.73	**0.29**	0.28-0.33	**3.87**	3.06-4.68	219	215-224	249	242-256
Haul net	2010	WC	0.88	0.35	0.31-0.39	3.09	2.42-3.76	219	215-224	249	242-256
Rec. Only	1997 & 98	WC	0.73	**0.58**	0.49-0.66	**0.81**	0.48-1.14	217	207-226	271	257-284
Rec. Only	1997 & 98	WC	0.88	0.65	0.56-0.75	0.6	0.31-0.89	217	208-2227	271	257-284
Comm Only	1997 & 98	WC	0.73	**0.43**	0.24-0.62	**1.17**	0.32-2.02	209	163-255	356	295-417
Comm Only	1997 & 98	WC	0.88	0.54	0.33-0.75	0.79	0.12-1.46	212	168-256	353	297-409


Count
Length (mm)
Proportion
Length (mm)
Count
Length (mm)
Proportion
Length (mm)

Appendix 5. West Australian Salmon Weight of Evidence, Stocks Status and Summary of Supporting Analyses.





Catch

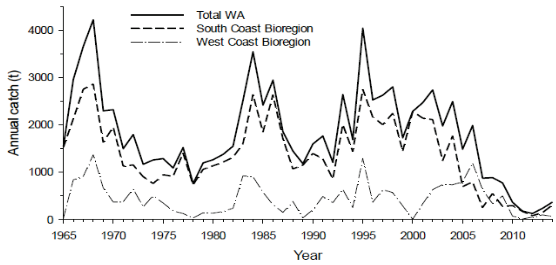


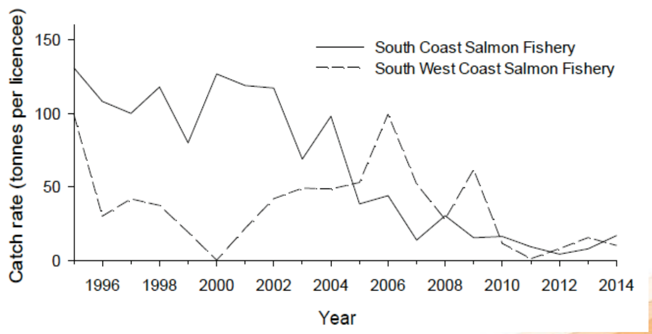
Table 1. Estimates of recreational catches of Australian salmon in WA.

Year	WA total Catch (t)	WCB catch (t)	SCB catch (t)	Rec catch share (%)	Source
1994	154.3	64	90.3	8%	Ayvazian *et al.* 1997
1995	183.4	55.4	128	4%	Ayvazian *et al.* 1997
1996/97	-	9.7 ± 3 (boat only)	-	-	Sumner & Williamson 1999
2000/01	136	-	-	5%	Henry & Lyle 2003
2011/12	-	negligible (boat only)	6.8 t ± 1.6 t (boat only)	-	Ryan *et al.* 2013
2013/14	-	negligible (boat only)	3.4 t ± 0.6 t (boat only)	-	Ryan *et al.* 2015

Catch Distribution

- Commercial - assigned beaches between Shoal Cape and Cape Beaufort; each team has access to a single nominated beach.
- Recreational fishers operate in all waters (estuarine, nearshore, etc.).

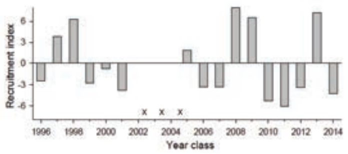
Catch rates

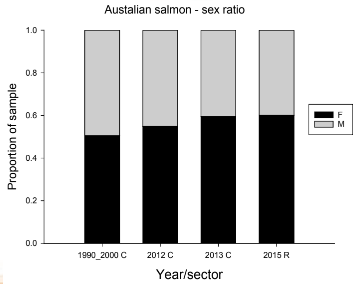


Vulnerability
(Productivity Susceptibility Analysis [PSA])

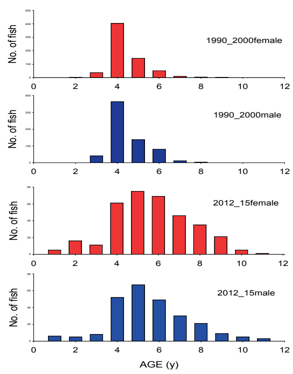
- Single biological stock from Kalbarri to SA, Vic and western Tas.
- Eggs and larvae dispersed by Leeuwin Current
- Grow and mature before moving back towards their spawning areas in the WC
- Max age: 12 years; Max size ~ 850 mm FL
- Highly productive

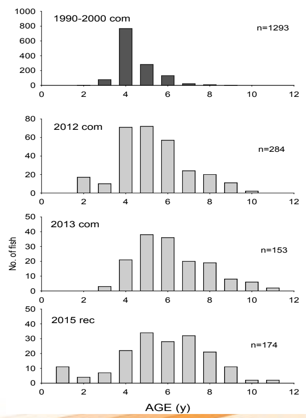
Vulnerability
(Productivity Susceptibility Analysis [PSA])





Age composition





Risk Assessment

Risk matrix					
Consequence (stock depletion) Level	Likelihood Level				Risk Score
	L1 Remote (<5%)	L2 Unlikely (5-20%)	L3 Possible (20-50%)	L4 Likely (>50%)	
C1 Minimal (above target)				X	4
C2 Moderate (above threshold)		X			4
C3 High (below threshold)	X				3
C4 Major (below limit)					N/A

Risk Assessment

- **C1 (Minimal Stock Depletion): L4.**

Catches have been less than 500 t for more than 7 years; productive stock. Age structure includes fish > 10 years.

- **C2 (Moderate Stock Depletion): L2. Risk - 4. (LOW)**

Catches have been less than 500 t but include catches exceeding 2- 3,000 t with subsequent declines, suggesting impacts could be possible. However, highly productive stock and age structure includes fish > 10 years suggesting full recovery.

- **C3 (High Stock Depletion): L1.**

High catches in mid 1990s followed by decline; may suggest over exploitation but remote given recent age structure and productivity.

- **C4 (Major Stock Depletion): Not plausible with available data**

Risk Score

	Consequence Level			
Likelihood Level	Minimal (1)	Moderate (2)	High (3)	Major (4)
Remote (1)	Negligible	Negligible	Low	Low
Unlikely (2)	Negligible	Low	Medium	Medium
Possible (3)	Low	Medium	High	High
Likely (4)	Low	Medium	Severe	Severe

Current Risk Status of the Stock

The current risk score was estimated to be **LOW** generated by the combination of **C2** and **L2**.

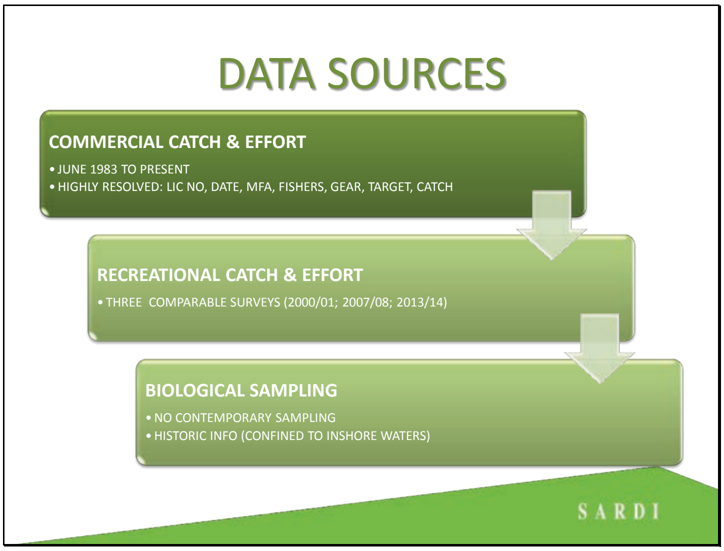
This **LOW risk** reflects that;

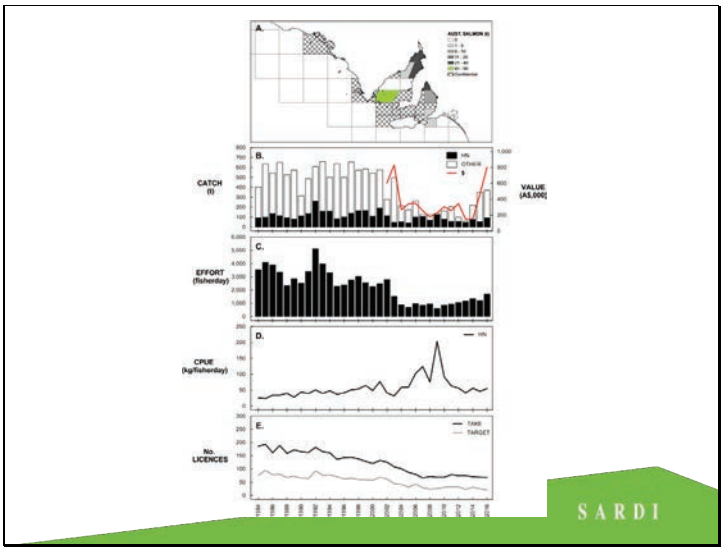
- Recent catches have been less than 500 t
- Historic catches exceeding 2- 3,000 t were followed by subsequent declines, suggest impacts are possible.
- However, highly productive stock
- Age structure includes fish > 10 years suggesting full recovery.

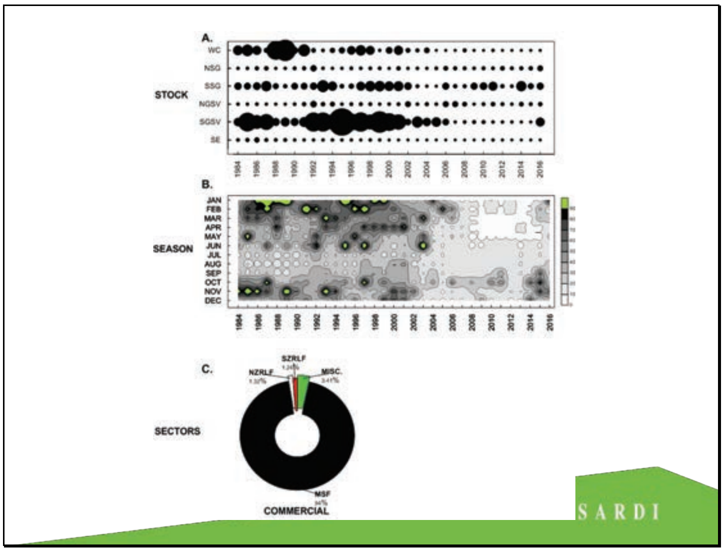
Management

Risk Category	Description	Likely Reporting Requirements	Likely Management Response
Negligible	Acceptable, not an issue	Minimal	Nil
Low	Acceptable; no specific control measures needed	Justification required	None specific
Medium	Acceptable; with current risk control measures in place (no new management required)	Full performance report	Specific management and/or monitoring required
High	Not desirable; continue strong management actions OR new and/or further risk control measures to be introduced in near future	Full performance report	Increases to management activities may be needed
Severe	Unacceptable; if not already introduced, major changes are required to management in immediate future	Full performance report	If increases to management activities likely to be needed urgently

Appendix 6. South Australian Presentation on West Australian Salmon (Mike Steer).




A.
B.
C.
D.
E.
CATCH (t)
EFFORT (fisherday)
CPUE (kg/fisherday)
No. LICENCES
VALUE (A$,000)
SARDI

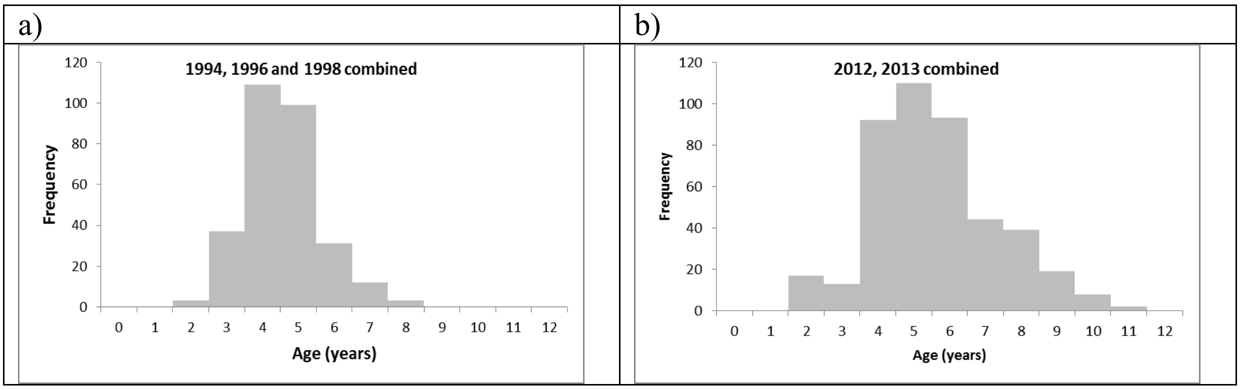

A.
STOCK
WC
NSG
SSG
NGSV
SGSV
SE
B.
SEASON
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
C.
SECTORS
SZRLF
NZRLF
MISC.
MSF
COMMERCIAL
SARDI


MARKET DEVELOPMENT
• BAIT
• INCREASED HUMAN CONSUMPTION
• IMPROVED PROCESSING
RECREATIONAL
• NO ALLOCATION
• EXCLUSIVE RIGHTS?
• NO NETTING
ABORIGINAL/TRADITIONAL
• DEVELOPMENT ACCESS/IMPORTANCE
FISHING PRACTICES
• PURSE SEINE (OFFSHORE ACCESS)
• FRDC EOI (WA/SA COLLABORATION). 'IMPROVING OUR UNDERSTANDING OF POPULATION DYNAMICS TO ENABLE QUANTITATIVE STOCK ASSESSMENT AND IMPROVED FISHERIES MANAGEMENT'.
SARDI

Appendix 7. West Australian salmon age composition data and analyses based on catch curves, a per recruit model, and an equilibrium age-structured model.

A set of “historical” age composition data for West Australian salmon, aged using otoliths, were pooled for 1994 (n=79), 1996 (n=91) and 1998 (n=124), as were samples from a more recent period in 2012 (n=284) and 2013 (n=153). The ages of West Australian salmon in the earlier years ranged between 2 and 8 years, with most (70%) being 4 or 5 years of age (Figure 1). In comparison, the maximum age of West Australian salmon in 2012/13 was 11 years, with 46% of fish being 4 or 5 years old, and 47% of fish being above 5 years old (Figure 1).

Estimates of fishing mortality (F) were produced using two catch curve models for each period, namely the Chapman-Robson (1960) mortality estimator, and a model assuming logistic age-based selectivity and that the age data conform to a multinomial distribution (these were a subset of the models applied to herring) (Table 1). Assuming a value for natural mortality (M) of 0.4 year-1 for West Australian salmon (as with the same type of analyses conducted for herring), the estimates of F for the early period (0.77 and 0.85 year-1) were substantially higher than those estimated for the more recent period (0.25 and 0.28 year-1). The ratio of fishing mortality to natural mortality (F/M) was thus also much higher (2.13) for the early period than the latter period (0.69). The estimates of selectivity derived from catch curve analysis were similar for the two periods (Table 2). Applying the assumed biological parameter values listed in Tables 2 and 3, the estimate of spawning potential ratio (SPR) was much lower for the historical period (0.34) than the more recent period (0.59). The estimates of relative biomass exhibited a similar trend, i.e. 0.29 vs 0.55. Thus, currently, the values for SPR and relative biomass both lay well above the target value of 0.4, suggesting that current exploitation on the stock is relatively low. The indication that exploitation in now much lower than in the past is consistent with the differences described in the age composition data for the two periods. Note that the catch curve analyses applied assumed that the stock is in equilibrium with respect to mortality and do not account for annual variations in recruitment, which could affect reliability of results.



Appendix 5. Figure 1. Pooled age composition data for West Australian salmon collected in a) 1994, 1996 and 1998 and b) 2012 and 2013.

Appendix 5. Table 1. Estimates of fishing mortality, and the ratio of fishing mortality to natural mortality, *F*/*M*, from catch curve analyses. 95% confidence limits are presented in brackets.

	Fishing mortality (*F*; year^{-1})		***F*/*M* (based on catch curve method 2)**
	Catch curve 1. Chapman-Robson	**Catch curve 2 Multinomial-selectivity**	
Years: 1994, 1996, 1998	0.77 (0.57-097)	0.85 (not calculated)	2.13
Years: 2012, 2013	0.25 (0.16-0.34)	0.28 (not calculated)	0.69

Appendix 5. Table 2. Estimates of age-based, logistic selectivity produced by catch curve analyses.

Years of data collection	**A_{50} selectivity**	**A_{95} selectivity**
1994, 1996, 1998	4.13	5.37
2012, 2013	4.67	6.14

Appendix 5. Table 3. Biological parameters used in per recruit analysis.

Parameter	**Value(s)**	**Comments / Source(s)**
Growth parameters		$L_t = L_\infty\{1 - \exp[-k(1 - t_0)]\}$
L_∞ (mm)	Both sexes 871.2	Re-analysis 2016.
k (year^{-1})	Both sexes 0.289	
t_0 (years)	Both sexes 0.001	
Maximum age (years)	12	
Natural mortality, M (year^{-1})	0.4	As for herring, with same maximum observed age.
Length-weight parameters		$lnW = a.ln(L) - b$
a	11.378	Re-analysis 2016.
b	3.000	
Maturity parameters		
A_{50} (years)	Both sexes 3.24	Re-analysis 2016.
A_{95} (years)	Both sexes 4.94	Re-analysis 2016.
Selectivity parameters	See below	
Sex ratio at birth	Parity	As for herring.
Steepness, *h*	0.75	As for herring.

Appendix 5. Table 4. Estimates of female spawning potential ratio (SPR) from per recruit analysis and relative spawning biomass from the equilibrium age-structured model assuming a Beverton-Holt stock recruitment relationship with steepness set to 0.75.

Years of data collection	SPR	Relative spawning biomass
1994,1996,1998	0.34	0.29
2012, 2013	0.59	0.55