AN EVALUATION OF ICHTHYOPLANKTON MONITORING AT IMOS NATIONAL REFERENCE STATIONS

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Abbreviations

NIMO: National Ichthyoplankton Monitoring and Observing (this monitoring program)
IMOS: Integrated Marine Observing System
NRS: National Reference Station
NSI: North Stradbroke Island (QLD NRS)
PH: Port Hacking (NSW NRS)
MAI: Maria Island (TAS NRS)

NON-TECHNICAL SUMMARY

This report evaluates the value of long-term monitoring of ichthyoplankton at selected locations in the Integrated Marine Observing System (IMOS) National Reference Station (NRS) network, and assesses its potential for providing fishery-independent information relevant for marine fishes and their management. This report focused on 3 east coast NRS (North Stradbroke Island, Port Hacking, and Maria Island) due to the availability of comparable historical ichthyoplankton data for this region. Historical data from 8 surveys were used to provide a long-term context to help evaluate the value of long-term ichthyoplankton monitoring. In summary, this report found:

- **The NRS larval fish monitoring can detect changes in the spatial distribution of the spawning of species/taxa.** This requires a long time series of NRS data, and it is largely restricted to species 'appearing' or 'disappearing' from fixed NRS locations. Detecting this can also be achieved using a shorter time series of NRS data by comparing it to historical survey data (which was done here). There is evidence that the North Stradbroke Island (NSI), Port Hacking (PH), and Maria Island (MAI) NRS currently have different larval fish communities than what was historically present. In particular, MAI has become more similar to northern and mid latitudes (NSI, PH), and there was evidence from MAI of a southward shift in the spawning of some temperate fish taxa: namely the appearance of larval sardine and wrasse, and an increased abundance of anchovy. Such shifts in species composition may help interpret causes of changes in adult fish communities (such as distinguishing environmental and fisheries-related causes).

- **Larval fish communities show consistent differences over large spatial ranges, even in a short time series (1-2 years).** Despite the large variance in the abundance of larval fish, even among samples close in space and time, there was a latitudinal gradient in the larval fish communities along the east coast (including in the NRS data). The community composition of samples taken hours apart at a single location are often as different as samples taken days and many kilometres apart, suggesting that larval fish communities measured at an NRS may be representative of a larger region. However, measuring a *trend* in the community at a location requires a large community change (such as the mean MAI community becoming similar to the PH community) due to the large variation in the measured abundance of individual taxa.

- **It is possible to detect temporal trends in larval abundance of taxa with a long time series.** There were clear 'indicator species' across latitude along the east coast, including lutjanid snapper in the north of NSW and QLD, silver trevally and redfish (*C. affinis*) at mid latitudes of NSW, and jack mackerel near TAS. A power analysis revealed that a moderately declining trend in the annual larval abundance of common species requires at least 15 years of data (given current sampling effort). In the case of pilchard (sardine) a monthly time series from the PH NRS could detect a 7% annual decline in abundance with 15 years of monitoring, or a 3% annual decline with 25 years of monitoring. For jack mackerel in TAS, a time series from the MAI NRS may need to be ~43 years long to detect a 3% annual decline in its abundance due to large variation in its observed monthly abundance.

- **There are seasonal patterns in spawning, and an analysis of phenology may be possible by identifying spawning 'modes' in historical data.** Due to short duration (~ 2 y) of the current ichthyoplankton monitoring, and the temporal and spatial patchiness and methodological differences of the historical data, we could only do a preliminary evaluation of the value of these data for monitoring changes in the timing of spawning (phenology), which has been a fruitful use of ichthyoplankton data in other systems. A historical survey revealed strong evidence for seasonal spawning patterns, with 5 spawning 'modes' shared between the common taxa. Detecting this seasonality at the NRS, however, will likely require a longer time series (> 5 y). Combining taxa into spawning modes identified in historical data sets may increase the power of analyses of phenology in the NRS time series.

- **The power of the NRS monitoring would greatly improve with increased sampling effort.** The sampling of ichthyoplankton at NRS has great taxonomic resolution, but would benefit from increased temporal resolution to improve its ability to detect patterns in common taxa and the fish assemblage. The most pragmatic approach to increasing sampling effort is to increase the volume filtered (e.g. double the ~500 m^3 currently filtered per sample); and a more ambitious would be a transect of 4-5 stations at each NRS sampled monthly. There is evidence that increasing to 5 samples per month could increase the observed monthly diversity of taxa from ~14% to ~50%.

1. BACKGROUND

1.1. REPORT OBJECTIVES

This report evaluates the value of long-term monitoring of ichthyoplankton at selected locations in the Integrated Marine Observing System (IMOS) National Reference Station (NRS) network (Fig. 1). This monitoring began in late 2014, and is now ongoing at 5 NRS around Australia. At a workshop for this project in December 2015, this monitoring was named 'National Ichthyoplankton Monitoring and Observing' (NIMO). This report focuses on three East coast NRS (North Stradbroke Island, Port Hacking, and Maria Island) where ichthyoplankton monitoring was implemented, due to the availability of comparable historical data for these regions. To provide a long-term context to evaluate the value of long-term ichthyoplankton monitoring at NRS on Australia's east coast, we supplemented IMOS NIMO data (13-20 months) with historical data from 8 surveys (spanning 1983-2015).

Objectives for this project were to:

1. Develop an ongoing time series of larval fish abundance at NRS around Australia (Section 1.4);
2. Characterise patterns in larval fish off eastern Australia using historical surveys (Section 2.1);
3. Provide larval abundances and measures of variation for key species, from historical surveys and current NRS monitoring (Section 2.1; Table S1 in Appendix A);
4. Thereby assess the ability of larval fish monitoring at NRS to detect trends in abundance of key species, and in the larval fish community (Section 2.2);
5. Examine the feasibility of the collection and storage of larval fish samples for possible genetic analyses (Section 2.3);
6. Provide recommendations on the potential for NRS larval fish monitoring for providing management-relevant information (Section 3).

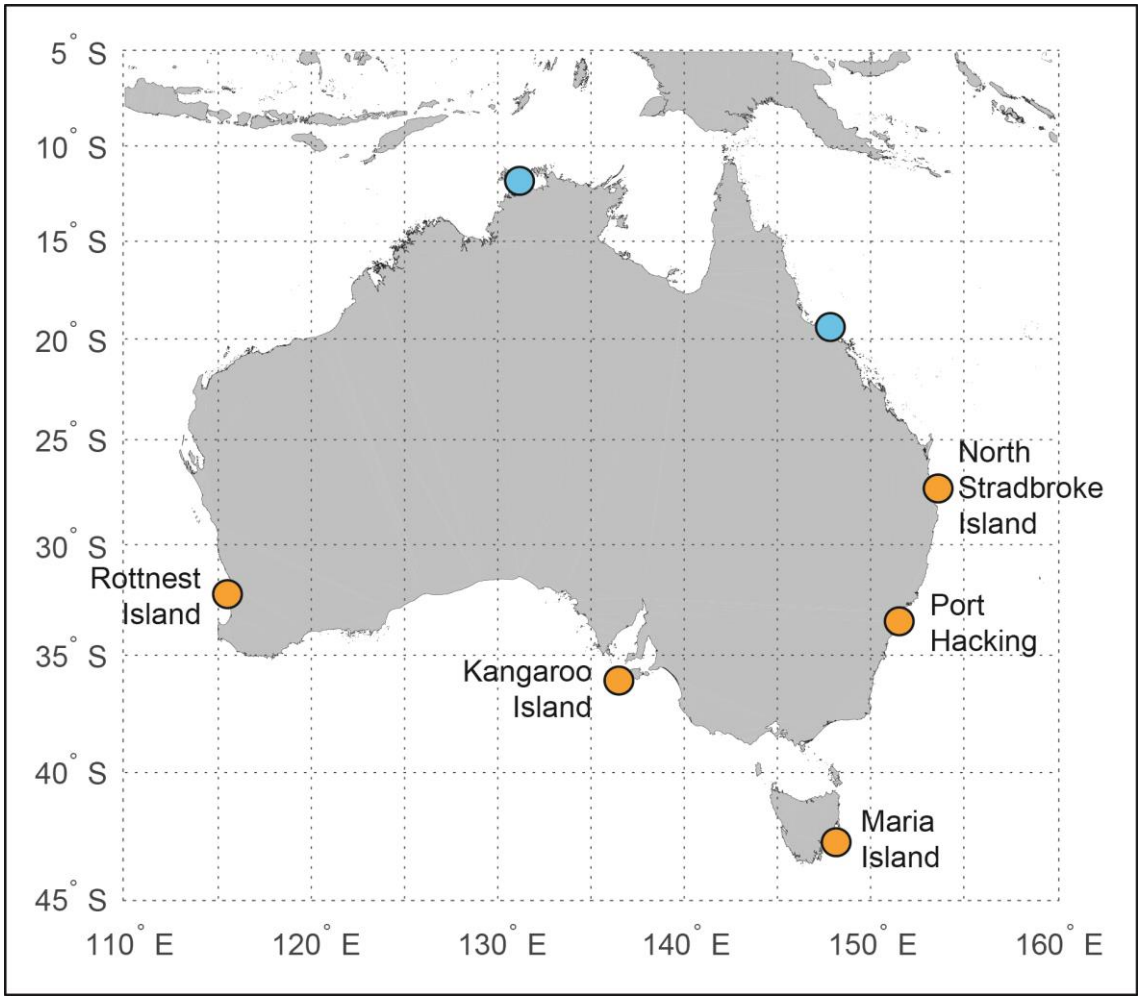

Figure 1. A map of the National Reference Stations (NRS) currently operating (orange and blue circles). Ichthyoplankton monitoring is underway at the 5 orange NRS. The three NRS considered in this report are North Stradbroke Island (NSI), Port Hacking (PH) and Maria Island (MAI).

1.2. THE VALUE OF ICHTHYOPLANKTON MONITORING

The need to include ecosystem analyses into fisheries management is increasingly accepted (Arkema *et al.* 2006). An important limitation for Australia to manage its marine estate effectively is the lack of adequate baseline information, and long-term observations (Litzow *et al.* 2016), to monitor ecosystem trends. To evaluate the ecosystem health of our oceans and the benefits and impacts of activities such as fishing, a monitoring system at a national scale is required (OPSAG 2013). Most fishes inhabit the upper water column during their early life history, and ichthyoplankton surveys provide a relatively low-cost, efficient means to monitor marine fish populations and communities (Koslow and Wright 2016). Ichthyoplankton monitoring is also valuable because larval fish are sensitive to environmental changes, with many oceanographic processes influencing their distribution, abundance and survival (Hsieh *et al.* 2006; Cowen *et al.* 2007; Keane and Neira 2008). Such monitoring has revealed dramatic declines in some coastal fish communities (Koslow *et al.* 2015), possibly driven by large-scale climatic and oceanographic factors. Most species have eggs and larvae that can be readily sampled with simple plankton nets in the upper 100 m of the water column resulting in a broad suite of fishes caught (Koslow and Couture 2013). Determining the trends followed by the chosen indicators requires the existence of baselines together with continuous long-term monitoring to assess the state of the ecosystem and implications for the fishing industry (Hsieh *et al.* 2005; Hsieh *et al.* 2006; Rochet and Trenkel 2009).

There are only a few programs worldwide that have monitored the whole marine ecosystem including larval fish over long time periods. The longest and best known is the California Cooperative Oceanic Fisheries Investigations (CalCOFI). This program has extensively sampled the upwelling system off southern California since 1951, and is unique in that it has used ichthyoplankton surveys (Moser *et al.* 2001) to follow trends in regional fish communities, endeavouring to monitor the oceans from ‘winds to whales’. The understanding of how the local ecosystem responds to El Niño cycle, decadal changes and climate change has only been achieved through its long-term monitoring program (Koslow and Couture 2013). A sub-sampling of the CalCOFI ichthyoplankton data set determined that even with as few as three stations the abundance time series for the most abundant 12 species is significantly correlated with the time series obtained from the full 51 station data set (Koslow and Wright 2016). These results, and work undertaken by Brodeur *et al.* (2008), demonstrate

that ichthyoplankton monitoring at limited sites can still deliver information relevant to tracking changes in the environment and in the fish community.

At the heart of the problem with ecological monitoring is that phytoplankton, zooplankton and micronekton (krill and small fish) are mostly examined on an ad hoc basis, despite comprising the bulk of ocean ecosystems (Koslow and Couture 2013; Koslow and Couture 2015). Monitoring has become particularly important with our marine systems already changing due to warming temperatures and mass mortalities from disease (Gruber 2011; Burge *et al.* 2014), ocean acidification and deoxygenation, and the need for sustainable fisheries. Australia's Integrated Marine Observing System (IMOS) aims to address this need for monitoring by providing a national oceanographic monitoring framework, although there are gaps in different parts of the ecological system, particularly fish larvae.

Of key importance to the long-term monitoring of Australia's marine environment are three coastal reference stations: Rottnest Island in WA, Maria Island in southeast TAS, and Port Hacking in NSW (Fig. 1). These three stations have been sampled since the 1940s for various physical and chemical oceanography parameters (Thompson *et al.* 2009) and provided the foundation for the IMOS National Reference Station (NRS) network. The NRS network currently has 7 NRS around Australia (Fig. 1) where physical, chemical and now biological (phyto- and zooplankton) observations are collected on a monthly basis. The 4 NRS sites added to the 3 long-term sites were selected based on the physical and biological features of Australia's coastline and include Darwin, Yongala, Kangaroo Island and North Stradbroke Island. Preliminary modelling indicated that the NRS are well situated to describe inter seasonal and inter annual variation for a variety of oceanographic parameters (e.g. sea surface temperature, velocity and elevation), and phyto- and zooplankton at national scales on the continental shelf (Oke and Sakov 2012; Lynch *et al.* 2014). While physico-chemical and some biological parameters are monitored at these sites, ichthyoplankton is not yet a dedicated component of the NRS sampling program.

1.3. HISTORY OF ICHTHYOPLANKTON DATA IN AUSTRALIA

Ichthyoplankton data in Australia have been collected since the 1930s, beginning with a survey of pilchard larvae (Dakin and Colefax 1934), and subsequent work by Blackburn on pilchard (Blackburn 1949) and anchovy (Blackburn 1950). Ichthyoplankton surveys became

more frequent during the 1980s onwards. Surveys of larval fish have typically been done as part of one-off projects, often with environment- or species-specific objectives: e.g. the deep ocean outfall monitoring of larval fish off Sydney (Gray *et al.* 1992), done to examine the effect of sewage plumes on near-surface larval fish; or the sampling of larval fish assemblages at the separation zone of the East Australian Current (Syahailatua *et al.* 2011b), done to explore the role of 'water mass' on larval fish. The FRDC report (98/103), titled 'A synthesis of existing data on the early life history of southern Australian finfish' (Bruce and Bradford 2002), consolidated much of the larval fish survey data collected between 1983-2003, for 44 common commercial fish species. There were ~113 cruises and > 5000 samples of these species from eastern and southern Australia; however these data are generally only a subset of the available data from each cruise.

Although these surveys have collected larval fish data, they have generally been conducted independently with differences in: locations surveyed, months or seasons surveyed, taxonomic resolution, gear types used, or time of day and depths surveyed. This makes comparative analyses, especially through time, challenging. Sporadic and methodologically disparate surveys cannot deliver the data required for long-term monitoring. What is required is a dedicated larval fish monitoring program that is repeated in space and time with standardized collection and identification protocols.

1.4. CURRENT ICHTHYOPLANKTON MONITORING AT NRS

To create a standard larval fish monitoring program, ichthyoplankton was incorporated into regular bio-physical monitoring by the Integrated Monitoring and Observing System (IMOS) at the National Reference Stations (NRS). Leveraging off this existing monitoring program was the most cost-effective way to initiate regular, sustained and consistent ichthyoplankton monitoring in Australia. The monitoring of larval fish begun in late 2014 at select NRS around Australia, and is now ongoing at 5 NRS (North Stradbroke Island, Port Hacking, Maria Island, Kangaroo Island, Rottnest Island; Fig. 1). Although there is sampling for zooplankton at the NRS, larval fish are much rarer than other zooplankton such as copepods (by several orders of magnitude) and thus require a dedicated net of larger size and mesh to increase the volume of water sampled.

1.4.1 Species List and Collection Protocol

The IMOS NIMO project created a standardised collection, identification, and storage protocol for larval fish monitoring. Many of these protocols were developed during a 3-day meeting from 7-9th December 2015 at the University of Tasmania in Hobart, Tasmania. One of the outcomes of this meeting was a species list for this monitoring program, which forms the standard taxonomic resolution for all NRS monitoring and provides the necessary taxonomic resolution for comparable historical survey data. This species list comprises 208 taxa or groups, from 142 families, with 114 of these taxa identified to genus or species (this list and a summary of abundances are in Table S1 in the Appendix). The standard collection protocol is included as an appendix (Appendix B) in this report, and is now part of the IMOS NRS biogeochemical operations manual.

1.4.2 Storage of Data and Samples

A goal of this project was to make the NRS ichthyoplankton monitoring data publically available, along with the validated historical data used in this report. All data used in this report are stored on CSIRO's Data Access Portal ('National Ichthyoplankton Monitoring and Observing (NIMO) - Monitoring data from select National Reference Stations and cruises 1983 – 2016'; http://doi.org/10.4225/08/5840deac23e10), and will be publically available, and uploaded to the Australian Ocean Data Network (AODN), in early 2017. This is the first time many of these data will be publically available.

To ensure long-term value of the IMOS NIMO data, and to ensure ichthyoplankton samples are available for possible genetic analyses and questions of stock structure, part of this project was to ensure ichthyoplankton samples were stored long-term. Funds from this project have been transferred to the Australian Museum to archive samples from the IMOS NIMO project, including historical sampling and the NRS monitoring. Over the past year this involved consolidation of archived ichthyoplankton samples from the Marine National Facility (historical surveys), and the transfer of these samples to the Australian Museum has begun. Samples from the NRS monitoring in 2014-15 are being transferred to the Australian Museum in December 2016, and 2016 samples transferred by mid-2017.

1.4.3 Sampling Extent

The monitoring of ichthyoplankton begun in late 2014 at select NRS around Australia, and is now ongoing at 5 NRS (North Stradbroke Island - NSI, Port Hacking - PH, Maria Island - MAI, Kangaroo Island, Rottnest Island; Fig. 1). Samples have been sorted up until early or mid-2016 for the three east coast NRS (NSI, PH, MAI; Figures 2 and 3), comprising 92 samples and 6098 larval fish. The taxonomic breakdown of the ichthyoplankton at these three NRS is summarised in Table 1 and detailed further in Table S1. To date, the number of larval fish taxa observed at each NRS is 80 (NSI), 71 (PH), and 38 (MAI). Yellowtail scad (*Trachurus novaezelandiae*) was the most abundant taxa at both the NSI and PH NRS, with jack mackerel (*Trachurus declivus*) the most abundant at the MAI NRS (Table 1). A single ichthyoplankton sample per month from each NRS was analysed in this report, but a second sample from a second location has been collected from early 2016. The importance of this increase in sampling effort for the power of the IMOS NIMO data to detect trends in abundance and species composition can only be addressed after more samples have been collected and processed.

Table 1. Summary of the relative abundance (as a % of total abundance per m^3) of the 15 most common larval fish taxa observed at each NRS. Highlighted in blue are some AFMA-managed taxa. Numbers (#) are the IMOS NIMO taxa numbers (see Table S1 in Appendix A for all taxa).

NSI NRS				PH NRS				MAI NRS			
#	**Family**	**Taxon**	**%**	**#**	**Family**	**Taxon**	**%**	**#**	**Family**	**Taxon**	**%**
26.2	Carangidae	Yellowtail scad	29.3	26.2	Carangidae	Yellowtail scad	21.2	26.4	Carangidae	Jack mackerel	30.1
120 120.1	Scombridae	Tuna	6.7	108 108.1	Platycephalidae	Flathead	13.3	19	Bothidae	Flatfish	21.8
42.4	Clupeidae	Pilchard	6.6	42.4	Clupeidae	Pilchard	10.6	50	Engraulidae	Anchovy	8.9
73	Labridae	Wrasse	6.3	126.3 126.4	Sillaginidae	Whiting	7.1	42.4	Clupeidae	Pilchard	8.2
124	Serraninae	Wirrahs	4.2	19.3	Bothidae	Flatfish	5.7	139.2	Triglidae	Spiny gurnard	7.5
80	Lutjanidae	Snapper	4.1	26.5	Carangidae	Silver trevally	5.3	126.4	Sillaginidae	Eastern school whiting	6.7
24	Callionymidae	Dragonets	3.5	94	Myctophidae	Lanternfish	5.0	108	Platycephalidae	Flathead	2.7
122	Scorpaenidae	Scorpenids	3.4	89	Monacanthidae	Leatherjacket	3.8	139, 139.1	Triglidae	Gurnard	1.7
120.2	Scombridae	Blue mackerel	2.7	81	Macroramphosidae	Bellowsfish	3.2	92	Mugilidae	Mullet	1.5
59	Gobidae	Goby	2.6	11.1	Arripidae	Australian salmon	1.8	89	Monacanthidae	Leatherjacket	1.4
93	Mullidae	Goatfish	2.5	120.2	Scombridae	Blue mackerel	1.8	35.2	Cheilodactylidae	Jackass morwong	0.8
19.4	Bothidae	Flatfish	2.5	102	Paralichthyidae	Large tooth flounder	1.3	73	Labridae	Wrasse	0.8
139.1	Triglidae	Gurnard	2.2	59	Gobidae	Goby	1.3	122	Scorpaenidae	Scorpenids	0.8
108	Platycephalidae	Flathead	1.8	52	Epinephelinae	Grouper	1.3	40	Clinidae	Weedfishes	0.7
94	Myctophidae	Lanternfish	1.6	73	Labridae	Wrasse	1.1	136.2	Trachichthyidae	Roughy	0.6
		Other	19.9			Other	16.2			Other	5.8

2. EVALUATION OF ICHTHYOPLANKTON MONITORING AT NRS: CONTEXT, TRENDS, AND POWER

2.1. GENERAL PATTERNS IN ICHTHYOPLANKTON IN EASTERN AUSTRALIA

The current ichthyoplankton monitoring at the National Reference Stations (NRS) has only recently started, and has thus insufficient samples for a robust analysis of existing patterns and its ability to detect trends. To address this, a subset of historical surveys for the same region was used to provide context for this study (Table 2, Fig. 2). In particular, these historical surveys were used to identify trends and variation in larval fish abundance and community composition across space and time. This information was essential to enable a more robust evaluation of the ability of an ichthyoplankton time series at fixed location (i.e. the current IMOS NIMO program) to detect trends. This evaluation included exploring whether single monthly estimates of the larval fish community at a fixed location are likely to be representative of the larval fish community at meaningful temporal and spatial scales. The temporal span of these historical surveys is over decades, but they lack the temporal continuity of the current NRS monitoring (Fig. 3), which limited the possible analyses. This highlights the value of a dedicated long-term monitoring program.

To compare the historical data with the NRS monitoring, it was necessary to align the taxonomic resolution of the historical data with the IMOS NIMO data. This was a time-consuming process and required considerable data manipulation and advice from larval fish taxonomists. This meant that only a subset of all available historical data could be used in this report. However, the value of aligning all data to the (high) taxonomic resolution of IMOS NIMO is that analysis of the historical data is more relevant to the NRS monitoring being evaluated.

The following sub-sections outline the results of patterns in the historical and IMOS NIMO data, and the likely power of this NRS monitoring to detect trends in taxa or the community.

The results of Section 2.1 can be summarized as:

- Total larval fish abundance and species richness were generally higher at more equatorial latitudes (Fig. 4, Fig. 5).
- Total larval fish abundance generally decreased with sampling depth, although it may peak at 20-30 m (Fig. 6).

- There were indicator taxa at various spatial scales from single latitudinal bands (hundreds of km) to multiple bands (thousands of km), suggesting a strong latitudinal pattern in species composition (Fig. 7).
- A multivariate GLM showed that the larval fish community caught in a sample depends on: latitude, the depth of the sample, calendar month, and whether the sample is on or off the continental shelf (Table 3).
- There is considerable variation in the larval fish assemblages measured at the NRS, even when compared to the total variation observed across all historical surveys (Fig. 8); however, there is a strong latitudinal signal (Fig. 9), showing that the fish community can change predictably across a large latitudinal gradient.
- There is evidence in the NRS monitoring of a southward shift in the spawning of some temperate fish taxa: namely the appearance of larval sardine, and an increased abundance of larval anchovy, at the MAI NRS (Fig 10, 11).
- The latitudinal pattern in larval fish community composition is probably persistent across months/seasons (Fig. 12, 13).
- The large variation in the measured larval fish community at the NRS can be put in context by comparing it to the variation in the zooplankton community at these same sites – there is much greater variation between monthly samples of the larval fish community than the zooplankton community, and much of this may be due to the comparatively low sampled abundance of larval fish at the NRS (Fig. 14).

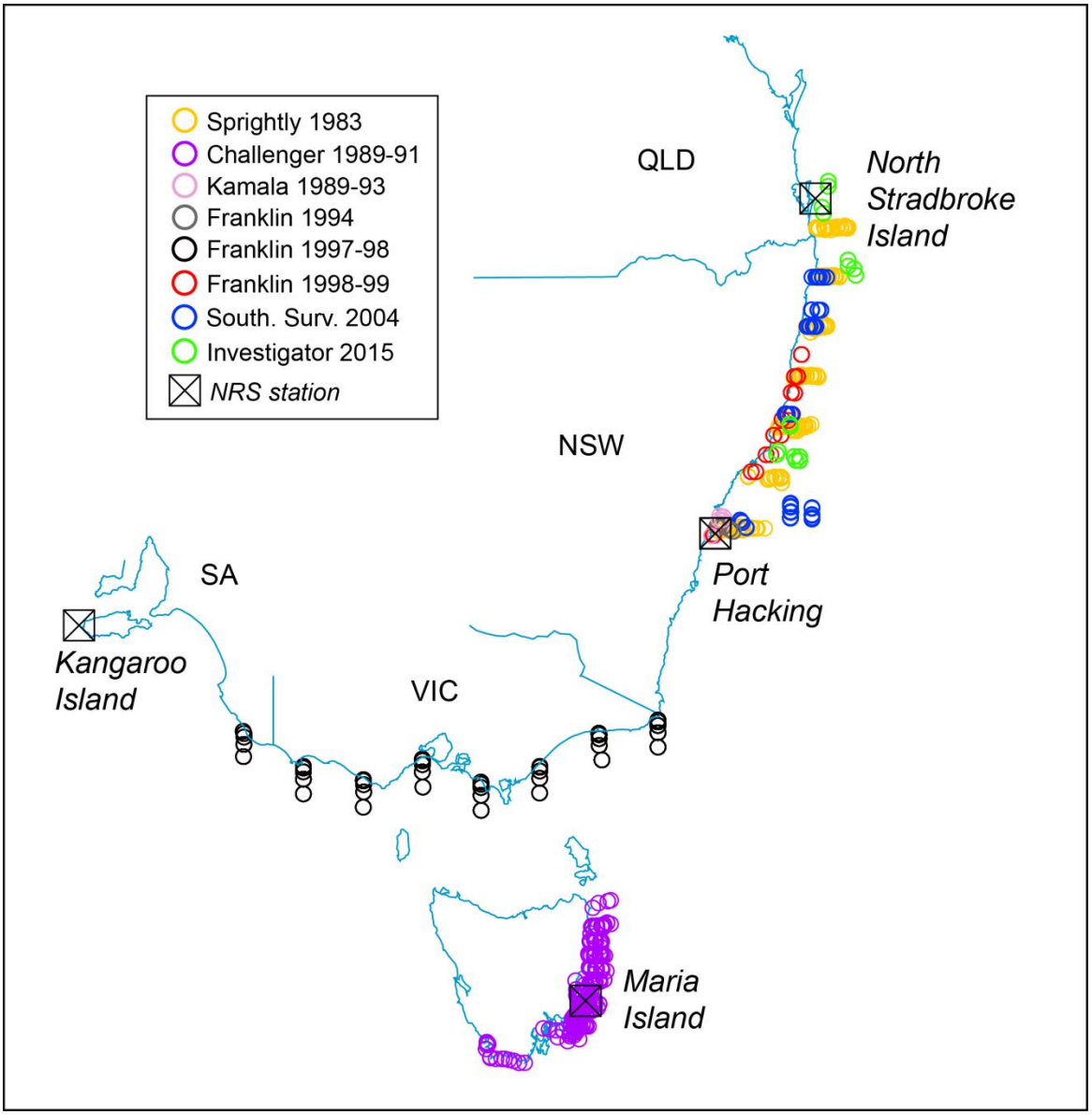

Figure 2. Map of the historical larval fish surveys used in this report. Each circle identifies locations of individual samples, and crosses indicate the location of four National Reference Station (NRS; data from Kangaroo Island was not used in this report). To maintain a focus on an East coast analysis only the 3 most eastern transects from 'Franklin 1997-98' were used in most analyses.

Table 2. Description of the historical ichthyoplankton surveys used in this report. Samples are distinguished as surface (surf.) or oblique/sub-surface (obl.) tows.

Ship	Years	Location (see Fig. 2)	Samples	Survey details
RV Sprightly	1983	QLD and NSW	184 (obl.) 186 (surf.)	3 cruises: Jan. 1983, Mar. 1983, May 1983; includes sampling close to Port Hacking NRS; predominantly off the continental shelf; ring net 500 um mesh
RV Challenger	1989-91	Eastern and southern TAS	403 (obl.)	3 summer cruises; multiple stations sampled repeatedly; predominantly on the continental shelf; bongo net 500 um mesh (obl.); (Jordan *et al.* 1995)
FRV Kamala	1989-93	Sydney, NSW	555 (obl.) 543 (surf.)	14 cruises; repeated measurements at 6 sites and multiple depths close to the coast, monitoring Sydney's deep ocean sewage outfall; ring net 500 um mesh; (Gray *et al.* 1992; Gray and Miskiewicz 2000)
ORV Franklin	1994	Sydney, NSW	147 (obl.) 76 (surf.)	5 stations sampled repeatedly in Jan 1994 and again in April 1994; both on and off continental shelf; includes sampling close to Port Hacking NRS; EZ net 333 um mesh (obl.), neuston net 500 um mesh (surf.); (Smith *et al.* 1999; Smith and Suthers 1999)
ORV Franklin	1997-98	VIC and SA	318 (obl.) 126 (surf.)	4 cruises: Jan. 1997, Dec. 1997, June 1998, July 1998; sampled 8 transects repeatedly; 4 depth strata in oblique tows; ~40% of samples were in the 3 eastern most transects (Fig. 1); EZ net and bongo net 500 um mesh (obl.), neuston 500 um net (surf.); (Neira *et al.* 1998)
ORV Franklin	1998-99	NSW	49 (obl.) 83 (surf.)	Sampled 9 'locations' over 2 cruises: Nov. 1998, Jan. 1999; all on continental shelf; includes sampling close to Port Hacking NRS; EZ net 500 um mesh (obl.), neuston net 500 um mesh (surf.); (Uehara *et al.* 2005; Syahailatua *et al.* 2011b; Syahailatua *et al.* 2011a)
RV Southern Surveyor	2004	NSW	48 (obl.) 60 (surf.)	Sampled multiple water bodies (EAC, mixed, coast, front); single cruise in Sept. 2004; both on and off continental shelf; RMT net 1000 um mesh (obl.), neuston net 500 um mesh (surf.); (Mullaney *et al.* 2011)
RV Investigator	2015	QLD and NSW	63 (obl.) 30 (surf.)	Sampled two water types: 'coast' and 'eddy'; single cruise in June 2015; both on and off continental shelf; EZ net 500 um mesh (obl.), neuston net 500 um mesh (surf.)

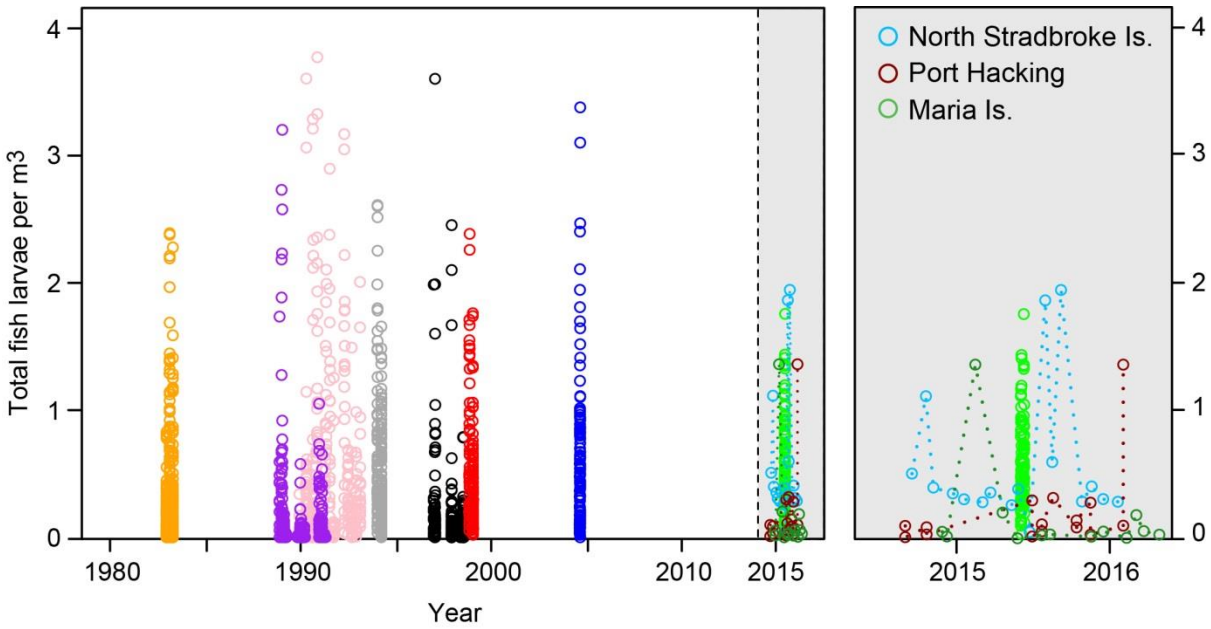

Figure 3. Timeline of the 8 historical surveys and ichthyoplankton monitoring at the 3 NRS included in this report, and the total abundance of fish larvae (per m^3) observed in every sample. Recent monitoring has been expanded for clarity. See Fig. 2 for colour scheme of historical surveys.

2.1.1. Patterns in Total Abundance and Species Richness

Trends in total larval fish abundance and the number of species were evaluated in the historical and IMOS NIMO data. This was done to provide a baseline to interpret patterns in the NRS data, and to investigate any broad differences between the NRS samples and historical surveys. The occurrence, mean abundance, and coefficient of variation (SD/mean) for all 208 taxa and groups identified in the NRS data is summarized in Table S1 (Appendix A).

There was a strong latitudinal pattern in both total larval fish abundance (Fig. 4) and in species richness (Fig. 5; this is number of NRS taxa – see Table S1 for full list of taxa). There was generally higher abundance and more species at the more northern latitudes, although fitted generalized additive models (GAMs) suggest that there is generally little difference between 27°S and 34°S. There was also a pattern in total larval fish abundance with sampling depth (Fig. 6). Total abundance generally decreased with sampling depth, although abundance may peak at 20-30 m depth. A GAM was also fitted to this data.

The generalized additive models (GAMs) fitted penalized regression splines, and were done using the R (R Core Team 2016) package ‘mgcv’ (Wood 2006; Wood 2011). Total abundance and species richness were dependent variables, but were visualized on the x-axis for convenience. To standardize for some of the variation between surveys in the historical data, GAMs including both depth and latitude were fitted for abundance and species richness, but the fitted splines were similar to those illustrated in Fig. 4-6, so the single-variable models are illustrated for simplicity.

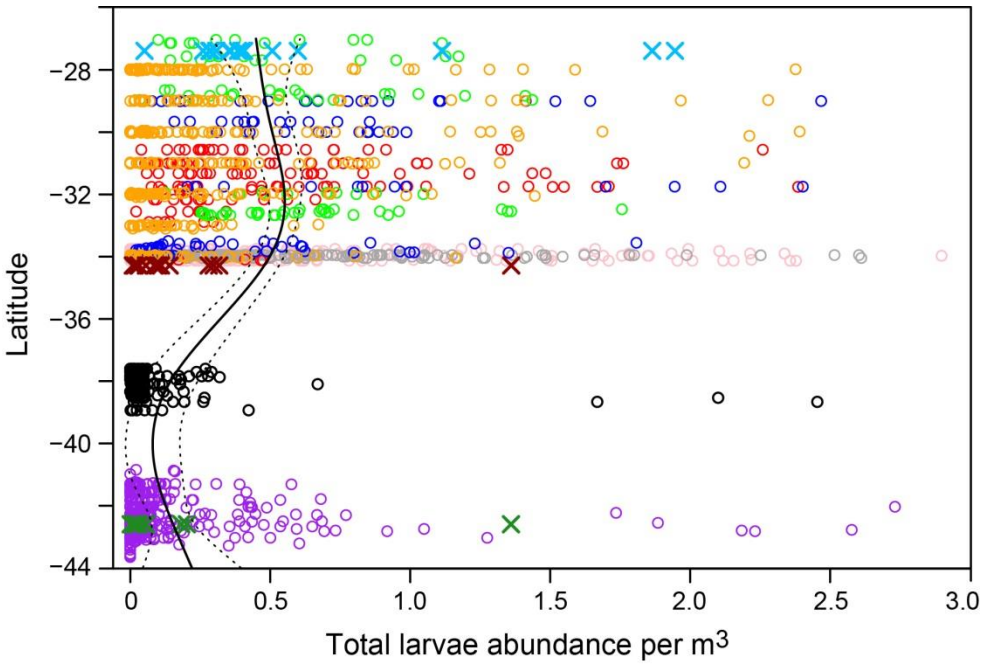

Figure 4. Total larval fish abundance (per m^3) against latitude. Each point is one sample and each colour is one survey (see Fig. 1 and Fig. 2 for colour schemes). Samples from the three NRS sites (North Stradbroke Island, Port Hacking, Maria Island) are indicated by crosses. The black line is a penalized regression spline fitted in a GAM, and dotted lines are 95% confidence intervals for the mean fit.

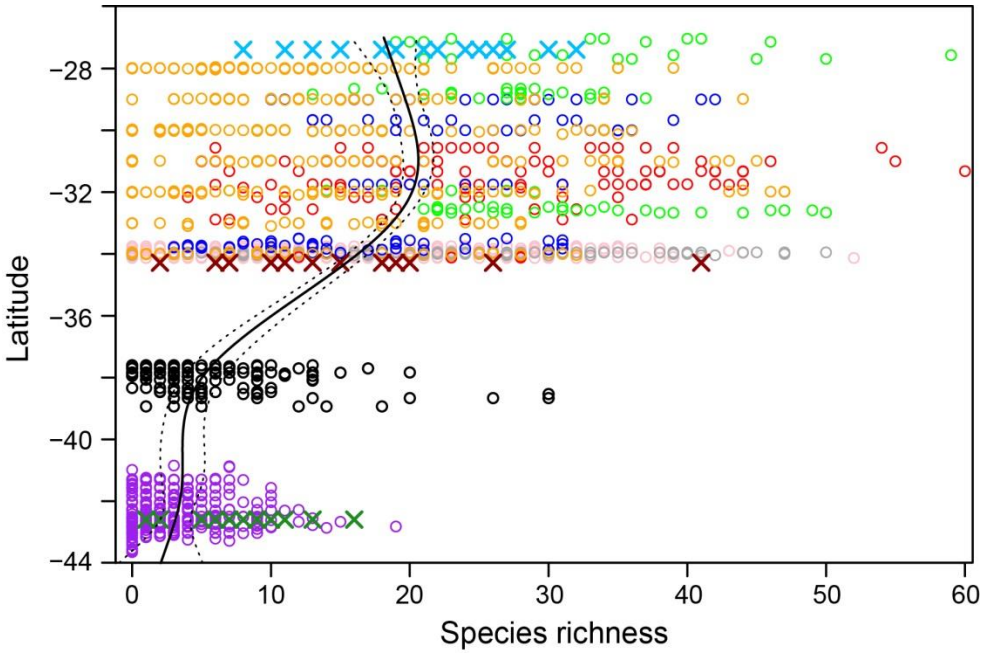

Figure 5. Species richness against latitude. See Fig. 4 caption for more information.

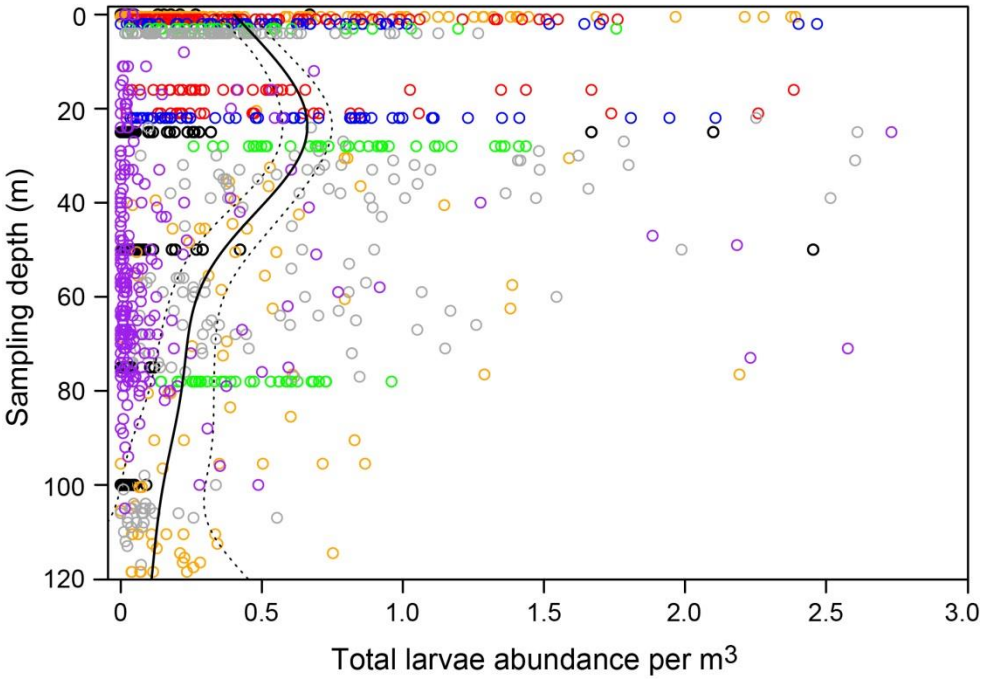

Figure 6. Total larval abundance (per m^3) against sampling depth for the historical surveys. Each point is one sample and each colour is one survey (see Fig. 1 for colour scheme). The black line is a penalized regression spline fitted in a GAM, and dotted lines are 95% confidence intervals for the mean fit. The surface points (depth = 0) have been jittered vertically for clarity.

2.1.2. Indicator Taxa

We combined the historical surveys and IMOS NIMO to examine latitudinal patterns in the abundance of specific taxa. This was done using an 'indicator species analysis' (Dufrêne and Legendre 1997). This analysis identifies indicator taxa by combining the relative abundance and frequency of occurrence of taxa to characterise a pre-determined group of sites (Dufrêne and Legendre 1997; De Cáceres and Legendre 2009). Identifying taxa that are indicators of sites (i.e. are significantly more likely to be detected at those sites) is a useful approach for exploring taxa-specific spatial patterns, and for identifying key taxa for subsequent analyses. In this case, 'sites' were 5 latitudinal regions (Fig. 7), which were selected based on geographic knowledge but also on the distribution of available data. This analysis was done using the R package 'indicspecies' (De Cáceres and Legendre 2009), which identified statistically-significant taxa that were characteristic of one or more regions. Those taxa with the strongest associations (based on the reported indicator statistic) are illustrated in Fig. 7.

We see that some taxa are statistically more abundant in single regions, such as blue mackerel (*Scomber australasicus*) in Region 1, redfish (*Centroberyx affinis*) in Region 3, and jack mackerel (*Trachurus declivis*) in Region 5. Other taxa are characteristic over larger areas, such as maray (*Etrumeus teres*) in Regions 1-2, the family labridae (wrasse) in Regions 1-3, and pilchard (*Sardinops sagax*) in Regions 1-4 (Fig. 7). These taxa are those that are relatively common and show a latitudinal pattern in their abundance, so make good candidates for monitoring change along the east coast of Australia (as we do in Section 2.1.3.2 for pilchard). However, these same species may not be ideal candidates elsewhere around Australia (including at other NRS), so their value as 'indicators' depends on the ecological and spatial dimensions of the pattern of interest. We therefore caution against using these indicator taxa to limit the type of data collected at NRS, given that uncommon or cosmopolitan species may not be indicator species but help dand believe that the highest taxonomic resolution possible (and feasible) should be maintained in any long-term monitoring.

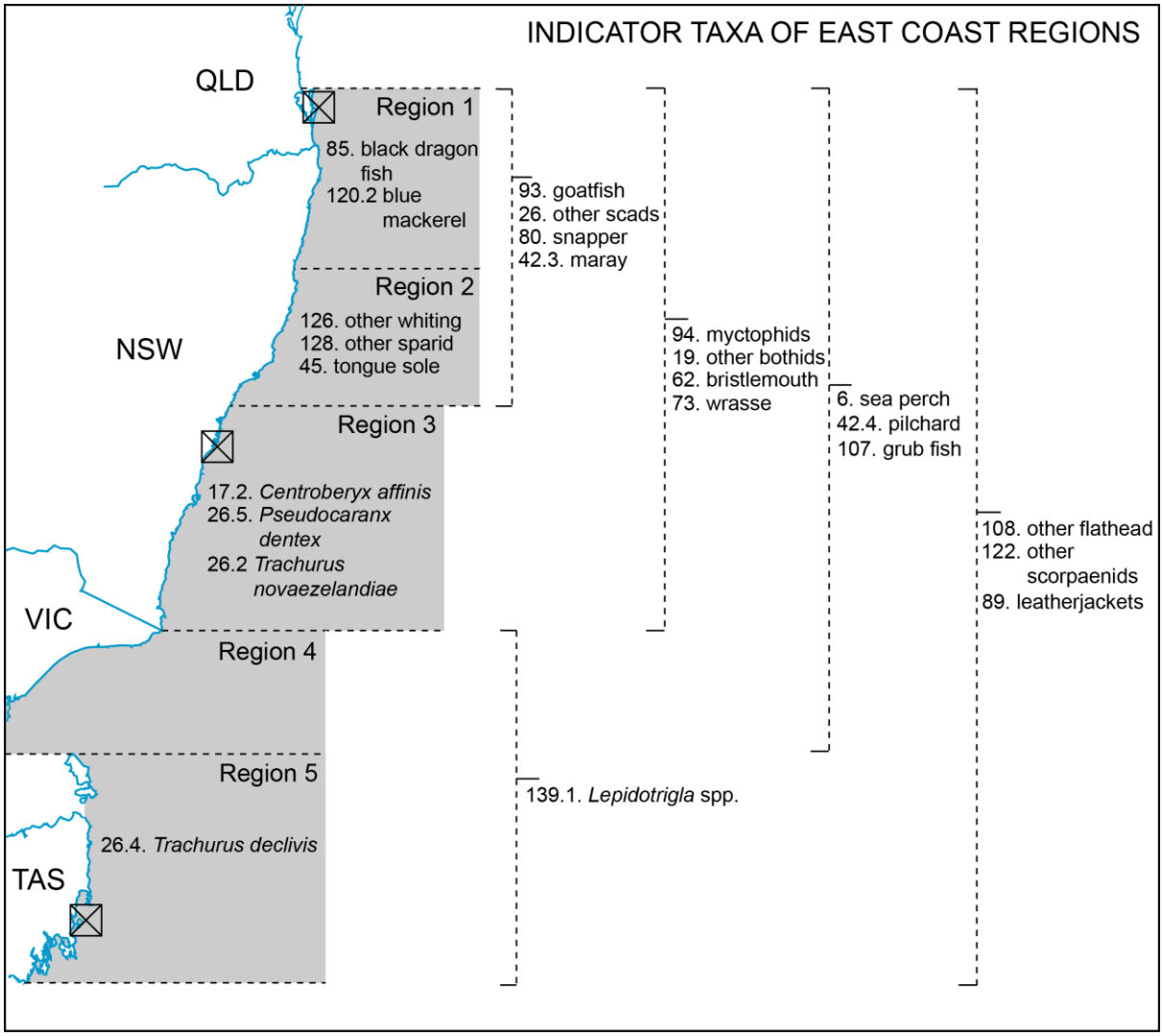

Figure 7. Key indicator taxa identified in the 'indicator species analysis'. Indicator taxa are those with a strong association (combining relative abundance and occurrence) with one or more regions. Those taxa with the strongest associations are shown here, based on the historical survey and NRS data. 'Other flathead', 'other scorpaenids', and 'leatherjackets' are taxa that occur approximately equally in all regions so are not (by definition) indicator taxa. Numbers are the IMOS NIMO taxa ID numbers (see Table S1 in Appendix A).

2.1.3. Trends in the Larval Fish Community

Larval fish abundance can be useful for identifying ecological and environmental patterns or change (Genner *et al.* 2010; Asch 2015), but, due to the often high diversity and variability of larval fish communities (Cyr *et al.* 1992), identifying these environmental signals can be difficult at the level of individual taxa. Instead, abundance data is frequently examined at the community-level by means of multivariate analyses. Distance-based ordination and classification is frequently used for this purpose in larval fish research (Brodeur *et al.* 2008; Richardson *et al.* 2010), including principal components analysis (Koslow *et al.* 2013; Asch 2015). Another approach to this type of data is a model-based analysis (multivariate generalised linear models) which allows for community-level inference using resampling based hypothesis testing (Wang *et al.* 2012), and has the advantage of providing statistical significance for effects in a more robust statistical framework. We used both of these approaches in this report to explore the general patterns in the larval fish community in response to predominantly latitude, but also in response to sampling depth, calendar month, and location relative to the continental shelf. These analyses provide valuable context for interpreting patterns observed in the larval fish community in the long-term NRS monitoring. In addition, the distance-based ordination allowed us to explore the variation that can be expected in the larval fish community (i.e. in an index that correlates with variation in the community), which can be used to infer the likelihood of observing a change in that community (see section 2.1.3.2).

In this report we used principal coordinates analysis (PCO), which differs from classic principal components analysis (PCA) by allowing for a non-Euclidean similarity measure. This is ideal for abundance data, for which 'Bray-Curtis' similarity is one of the most preferred metrics (Clarke and Warwick 2001). We also used cluster analysis (Anderson *et al.* 2008) to help explain the similarity between monthly samples at the NRS.

2.1.3.1. Response to environmental factors

The multivariate generalized linear model (MGLM) analysis provides a statistical analysis of the effects of environment variables on the larval fish community. This was done for all historical surveys except for the FRV Kamala survey, which was excluded to avoid a bias to the Sydney area. The variables analysed were 'Latitude' (continuous), 'Depth' (depth of sampling; continuous), 'Month' (calendar month of sampling; categorical), and 'Shelf'

(location of sampling relative to continental shelf; categorical as 'on' or 'off' shelf). The value of this MGLM is that we can also identify the number of taxa that respond to each of these covariates (i.e. the results used to make community-level inferences), after accounting for multiple testing (Wang *et al.* 2012).

We can see that there are strong effects of all variables on the community observed in samples, with the number of taxa (from 86 tested) responding individually to the covariates ranging from 24 to 86 (Table 3). This means that the mean larval fish community caught in a sample depends on: latitude, the depth of the sample, calendar month, and whether the sample is on or off the continental shelf (which correlates with distance to coast and bottom depth). The latitude effect is unsurprising given the strong latitudinal patterns observed in total abundance (Fig. 4) and species richness (Fig. 5), and also the strong pattern we observed in the PCO (see Section 2.1.3.2; Fig. 9). The strong effect of month suggests large temporal variation in the community composition, and it is likely that at least some of this variation is due to the seasonality of spawning (discussed further in Section 2.2.3).

The MGLM was done on counts data, using a Poisson family (to account for overdispersion). A log-linear offset for sample volume (m^3) was used to standardise counts to volume sampled. The MGLM was done using the 'manyglm' function in the R package 'mvabund' (Wang *et al.* 2012). There were 1214 samples and 86 taxa used in the MGLM (due to the computational burden of this analysis, only the most common 86 taxa were included).

Table 3. Results of the multivariate GLM using historical survey data. A significant P-value indicates a community-level response to a covariate. The number of taxa (from the 86 most common) responding significantly to each variable is also reported.

	Df	Residual Df	P	Number of taxa
Intercept		1214		
Latitude	1	1213	< 0.001	61
Depth	1	1212	< 0.001	53
Month	9	1203	< 0.001	86
Shelf	1	1202	< 0.001	24

2.1.3.2. Latitudinal trends in the larval fish community (PCOs)

The principal coordinates analysis (PCO) showed there is generally a strong separation between the 7 historical surveys, but there can be considerable overlap between the Port Hacking and Maria Island NRS samples (Fig. 8). There was generally poor explanatory power, however, with the first two principal components explaining only 22.5% of the variation. This suggests that there are a large number of factors contributing to the variation in larval fish composition between samples – more than can be explained by these two 'latent' principal components. However, even the NRS samples, which control for many factors such as depth and location, show considerable dissimilarity between them, suggesting that larval fish assemblages can be extremely variable, even at fixed locations.

When the points are coloured according to the latitude at which each sample was taken, we see a clear latitudinal gradient along principal component 1 (PCO1; Fig. 9a). Given the results of the MGLM (Table 3), we then restricted these data to only those samples on the continental shelf (which is most relevant to the NRS monitoring), and the latitudinal gradient in the larval fish community remains clear along PCO1 (Fig. 9b).

If we examine the relationship between PCO1 and latitude (Fig. 10), we see the strong gradient observed in Fig. 9b, with a particularly strong change between Sydney (34°S) and the more southern latitudes. If we compare the trend in PCO1 (i.e. an index of community composition) in the historical data (black line, Fig. 10) with the trend in the recent NRS data (blue line, Fig. 10), we see a possible shift in the latitudinal trend. The community at each NRS appears to somewhat different to what was historically evident at those latitudes, and the most southern latitude (MAI) is now more similar to northern and mid latitudes (NSI, PH).

One reason for this is a change in the species composition. A difference between MAI NRS samples and the historical Tasmanian samples in this analysis was that the MAI samples had a high occurrence of pilchard and anchovy, which were much less common or absent in the historical data. Larval pilchard, in particular, has been historically absent from Tasmania (Fig. 11), but has been observed in 60% of MAI samples (Table S1, Appendix A). These taxa were identified as 'indicators' of warmer temperate regions (Fig. 7), so evidence for them in the MAI samples could be evidence of the known southward redistribution of fish species due

to a warming climate (Last *et al.* 2011). Another contributor to this clear difference could be methodological differences between the NRS and historical sampling; namely sample volume, net type, and depths sampled (NRS are typically shallower than most historical surveys). Due to the currently short time-scale of the NRS data, this difference between the NRS and historical survey data should be interpreted cautiously, but does provide some evidence of a southward shift in the spawning of some warm-temperate fish taxa.

Due to the sporadic collection of the historical survey data, and the short time-scale of the NRS data, it was difficult to evaluate the seasonality of trends in community composition in this report. However, we examined the few months that had sufficient data and there is evidence that the latitudinal gradient in the community composition is persistent across months for the historical survey data (Fig. 12) and NRS data (Fig. 13). So although the community composition is likely to vary across months (Table 3), there are year-round differences in the community across this large latitudinal gradient. Seasonality in the abundance of individual taxa, and how this relates to our power to detect trends, is explored in Section 2.2.3.

The ordinations (Fig. 8-9) were based on square-root transformed Bray-Curtis similarities of abundance data (number per m^3). Samples with few taxa observed (< 5) were removed, as were taxa with few occurrences in all historical surveys combined (< 5 occurrences), as these samples and taxa contained little information. Only sub-surface tows were included, as these were deemed the most similar to the current NRS sampling method, and a single 'replicate' per site was used from the Kamala cruises to avoid issues of pseudo-replication. This led to the removal of ~58% of samples (mostly from Tasmania and Bass Strait), and 31 taxa (of 208). 'Unidentified', 'damaged' and 'other' groups (see Table S1 in Appendix) were also excluded as these groups were inconsistently used between surveys. Thus, the full PCO included 789 samples from the 8 historical cruises and the 3 NRS locations, and 174 taxa (Fig. 8, 9a). The shelf-only PCO (Fig. 9b) was further reduced to 560 samples and 164 taxa, by including only those samples located on the continental shelf, and only the three most eastern Franklin 1997-98 transects (Fig. 2). The PCO (and the cluster analysis in Section 2.1.3.3) were done using PRIMER-E with Permanova+ software (v6.1.11; Plymouth, UK).

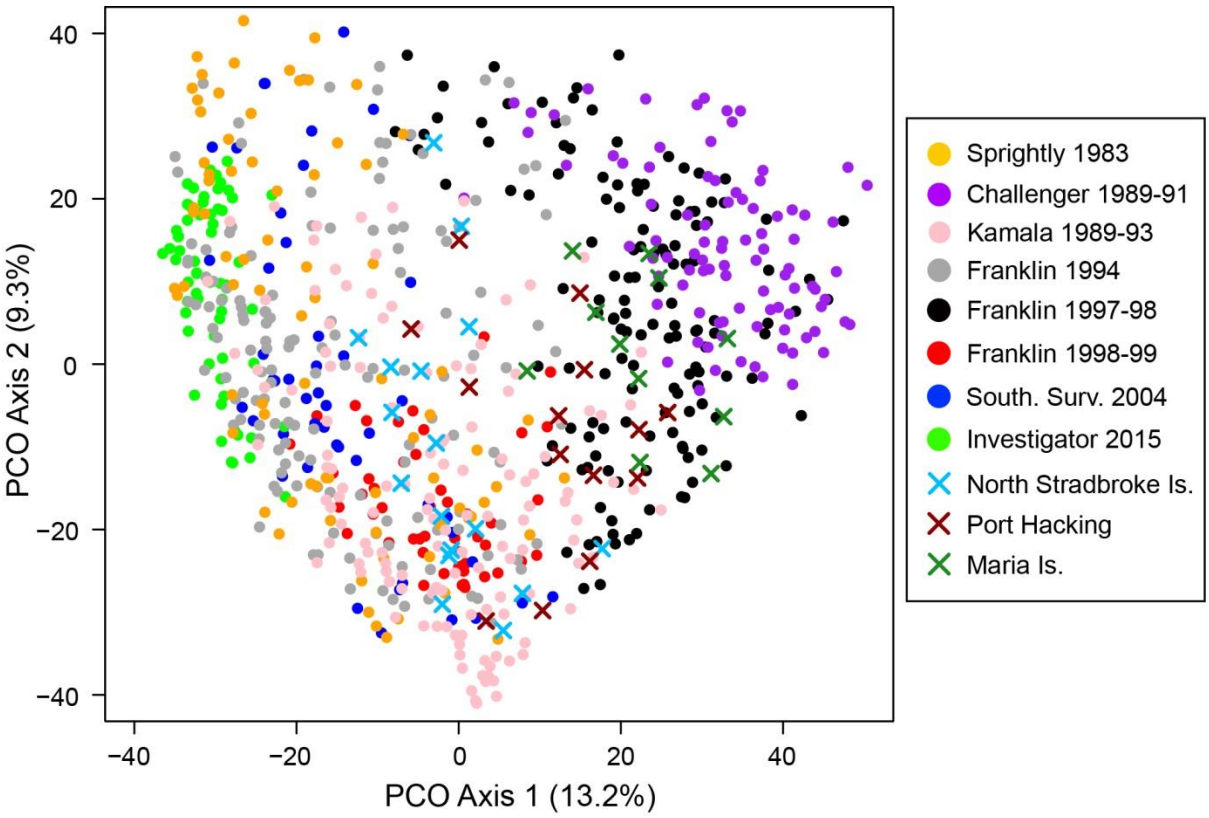

Figure 8. Principal coordinates analysis (PCO) of historical surveys and NRS monitoring data. Each survey is a different colour, and each dot is a sample. The NRS are indicated by crosses.

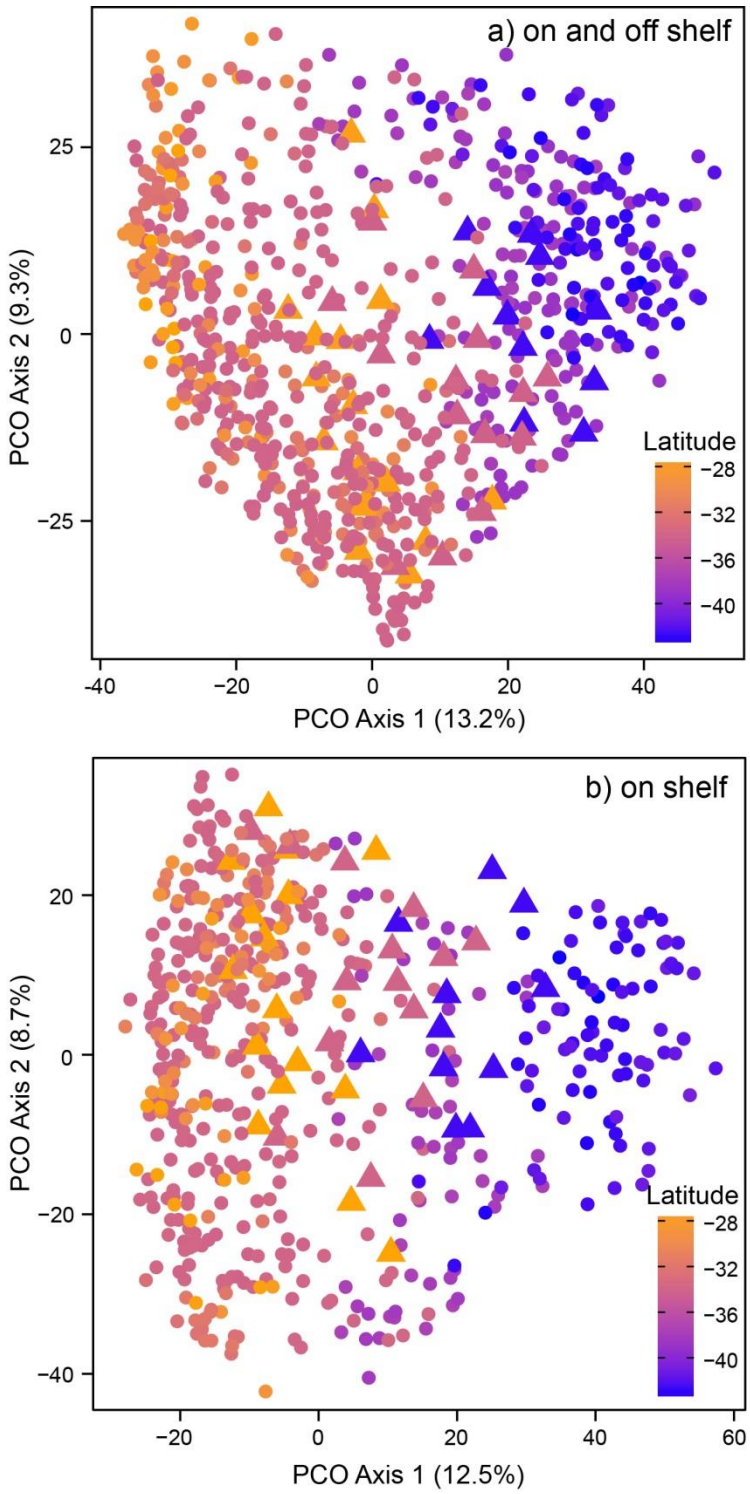

Figure 9a-b. Principal coordinates analysis (PCO) of historical surveys and IMOS NIMO data. Each dot is a sample, and colour is the latitude at which that sample was taken. The NIMO samples are indicated by triangles. In a) both on- and off-shelf samples were included (as in Fig. 8), and in b) only on-shelf samples were included. On-shelf samples are those most likely to match the current IMOS NIMO sampling.

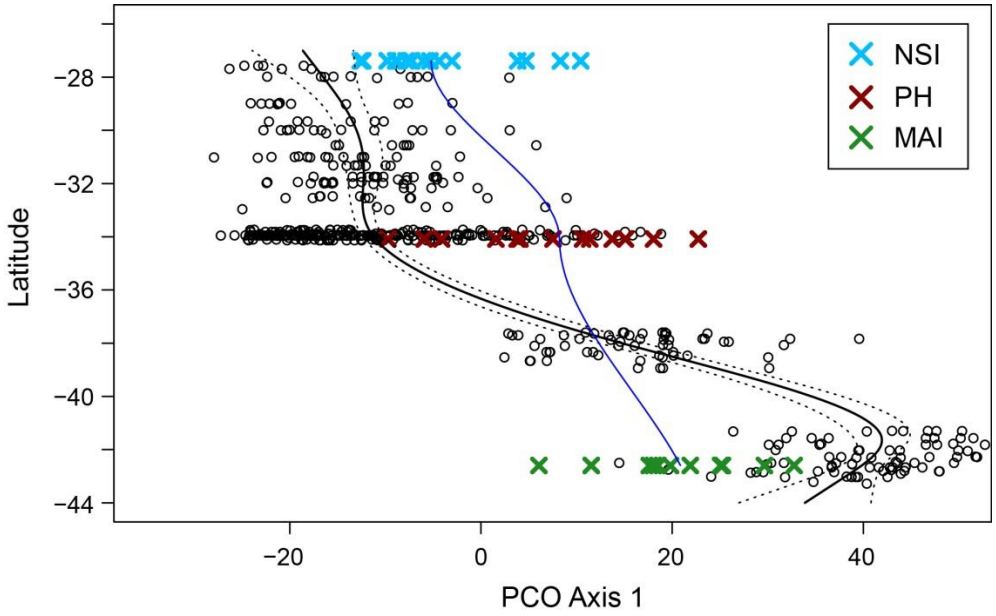

Figure 10. The PCO1 loadings (from Fig. 9b) from each sample plotted against latitude. A GAM (black line with 95% confidence intervals) is fitted to the historical survey data (black circles), and a loess smoother (blue line) is fitted to the IMOS NIMO data (NSI, PH, and MAI crosses). We can see a possible shift from the historical data to the recent NRS data, whereby the latitudinal gradient in the ichthyoplankton community is less distinct, particularly mid latitudes (PH) and high latitudes (MAI).

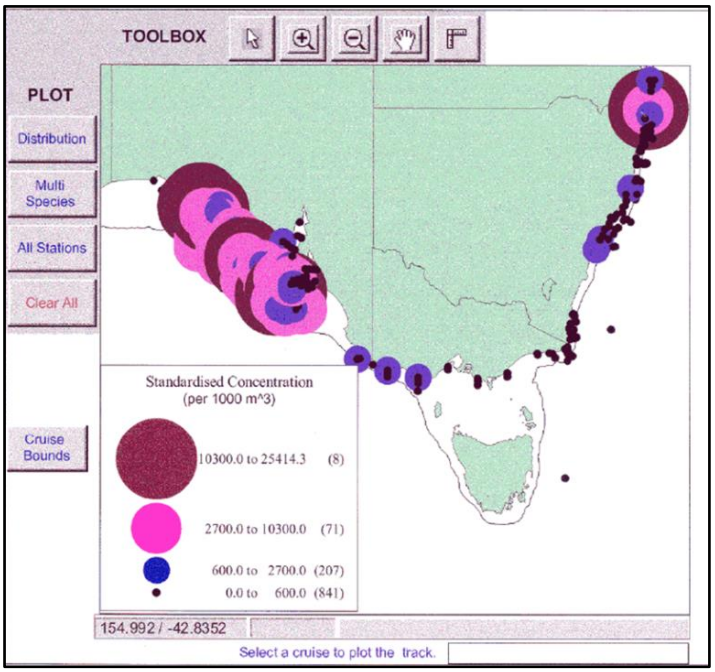

Figure 11. Historical distribution of larval pilchard (Bruce and Bradford 2002), showing the low historical abundance in Tasmanian waters.

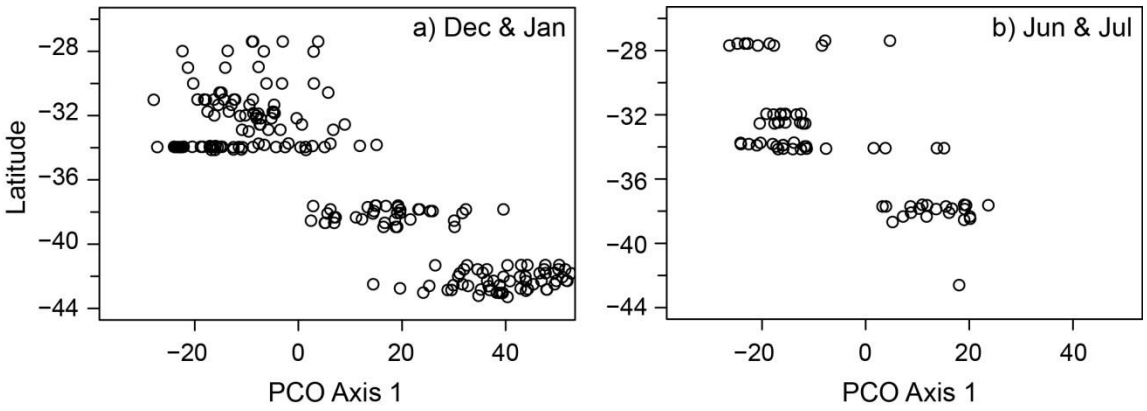

Figure 12a-b. Possible seasonal persistence of the PCO1 trend in historical survey data (same data as Fig. 10).

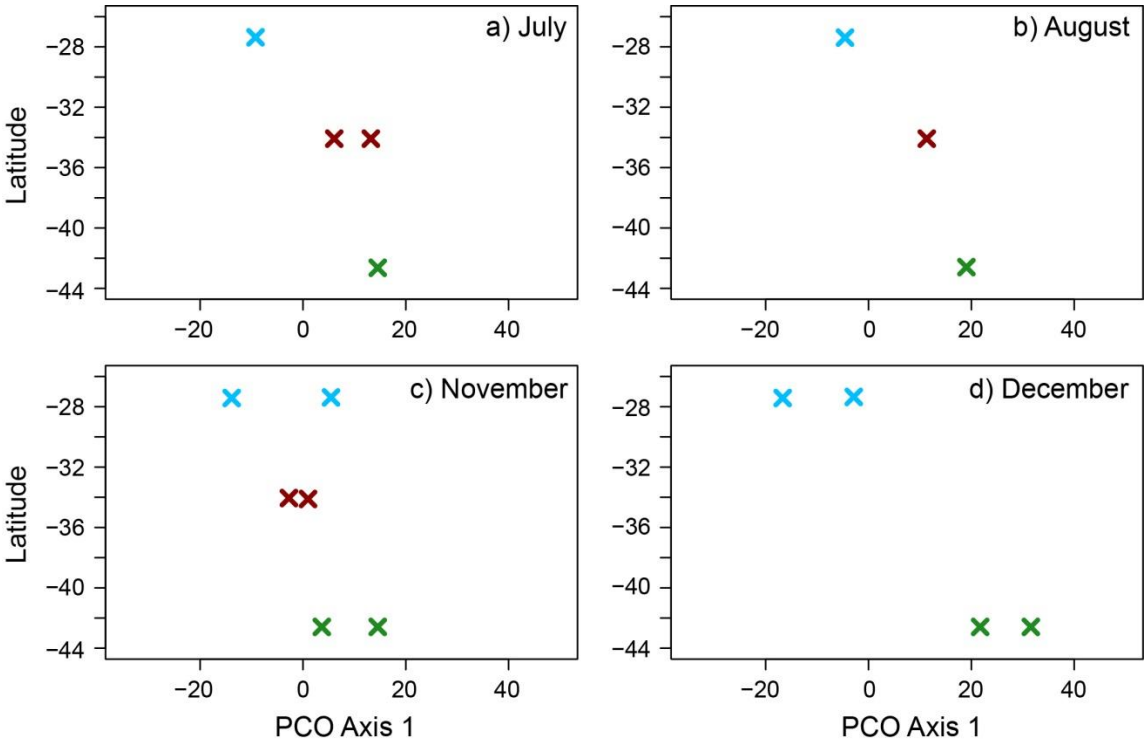

Fig. 13a-d. Possible seasonal persistency of the PCO1 trend in IMOS NIMO data (same data as Fig. 10). See Fig. 10 for NRS colours.

2.1.3.3. Comparison between larval fish and zooplankton communities

There is a large amount of variation in the larval fish community among samples taken at the NRS, even compared to the total variation observed in the historic survey data across a large range of years, months, and sampling depths (Fig. 8). Due to the nature of the NRS sampling program, it is possible to compare the variation among samples as the NRS between larval fish and zooplankton, for the same sampling days. This allows us to compare the power of these time series for detecting trends. The zooplankton data was diverse with > 300 taxa (reduced to 210 in the analysis below), comprising all mesozooplankton observed, including crustaceans, cnidarians, and echinoderms.

Figure 14 shows a PCO of the NRS larval fish data and a PCO of the zooplankton data from the exact same sampling days. There is greater separation of the NRS in the zooplankton community (Fig. 14b) than the larval fish community (Fig. 14a), especially between MAI and PH. Most obvious is the greater similarity (measured with a cluster analysis) among samples at an NRS in the zooplankton community than the larval fish community. The clusters (of 40% similarity) for the larval fish community are more often around single or small numbers of samples, rather than groups of samples (or even an entire NRS, in the case of NSI) for the zooplankton community.

It is likely that much of this variation in the larval fish community between NRS samples is due to the patchiness of larval fish, driven by their generally low abundance. In the zooplankton samples at the NRS there was an average of ~2500 individuals per m^3, whereas there was an average of 0.4 fish per m^3 in the larval fish samples. This inherent disparity in sampled abundance reflects the disparity in the ability to accurately measure a diverse community, and likely explains much of the difference we see between larval fish and zooplankton in Fig. 14. Even given IMOS NIMO's ~500 m^3 net tows, there are still orders of magnitude fewer larval fish than zooplankton per sample. It could also be, however, that larval fish respond differently to the environment than zooplankton (to temperature for example), and more variation between samples should be expected. In either case, this result suggests that it can be more difficult to detect signals in the environment (at temporal and spatial scales relevant to the current NRS sampling program) with larval fish than it is with zooplankton.

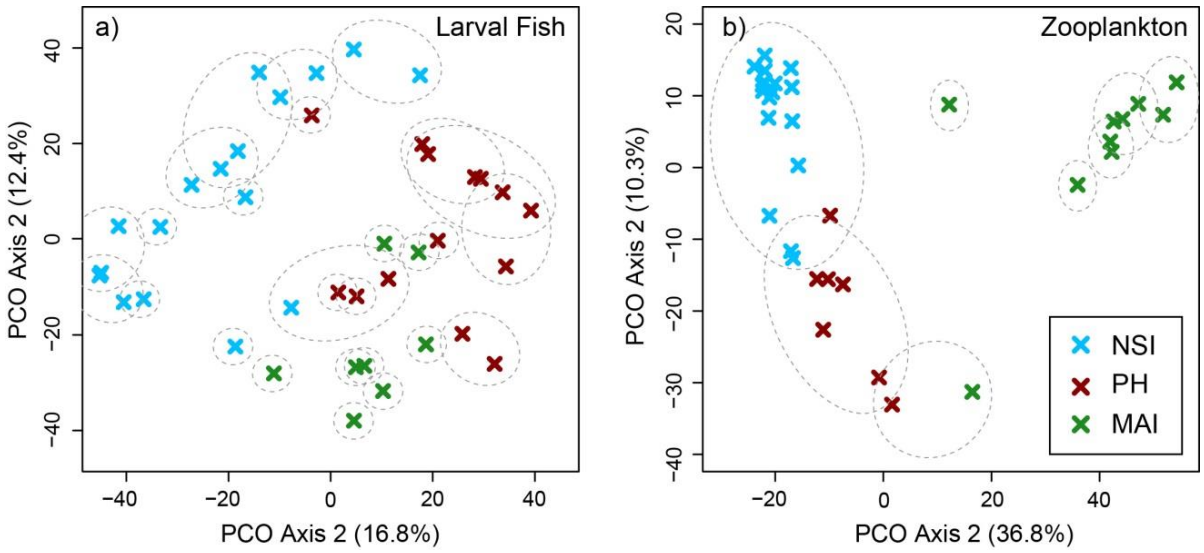

Figure 14a-b. A comparison of the larval fish communities (using PCO) at the 3 NRS locations in this report and the zooplankton communities at the same sites and same sampling dates. Grey lines show 40% similarity between sampling events (using 'complete linkage' cluster analysis). The larval fish data included the most common 181 taxa, and the zooplankton data the most common 210 taxa.

2.2. STATISTICAL POWER OF ICHTHYOPLANKTON MONITORING AT NRS

The goal of this section is to comment on the value of the NRS ichthyoplankton sampling for monitoring larval fish, in terms of the amount of data required for detecting trends and their magnitude in both individual taxa and the community. We did this by evaluating the power of the current NRS ichthyoplankton monitoring to detect trends in larval fish abundance. 'Statistical power' refers to the probability that a statistical test will correctly reject a null hypothesis. However, 'power' can be generally interpreted as the ability to detect a result with or without statistical significance, and in this section we calculate statistical power for detecting trends in species abundance (using traditional regression methods), and infer power for detecting changes in community composition (using distance-based similarity methods).

The analysis in this section is preliminary. The short time-scale of the NRS monitoring, and the poor temporal coverage of the historical surveys across months, meant that only a preliminary analysis of seasonality in the historical data could be done. It is important to do so, because seasonality can be accounted for in trend analyses (e.g. Rohner *et al.* 2013) to reduce the variation in mean abundance among years. The short time-scale of the NRS monitoring also meant we were unable to evaluate the power of this monitoring for addressing questions of phenology, such as a shift in the timing of spawning (Genner *et al.* 2010; Asch 2015). The IMOS NIMO sampling design was updated in early 2016 to include a second sample each month (at a second location) at each NRS, but it is too early to evaluate the benefit of this increased sampling effort. A more robust analysis of statistical power that 1) incorporates seasonality at the NRS, and 2) includes the second monthly sample, will require a longer time series of NRS monitoring, probably > 5 years.

The following sub-sections outline the results of the evaluation of power to detect trends in individual taxa or the community of larval fish, including an evaluation of how variation between samples varies across time and space. **The results of Section 2.2 can be summarized as:**

- Taxa with sufficient power for detecting a moderate decline in mean annual abundance are lutjanid snapper at the NSI NRS (Fig. 15), and pilchard at the PH NRS (Fig. 17); however, some species, like jack mackerel at the MAI NRS (Fig. 19) have low power due to large variance in their abundance.

- The estimated length of an NRS time-series (based on one sample per month) required for detecting moderate/severe declines in abundance varied between 15-50 years for common taxa (Table 4).
- An analysis of species accumulation showed that only ~14% of taxa present in a month are likely to be detected with 1 sample per month, but this increases to ~50% of monthly taxa with 5 samples per month (Fig. 20).
- The monitoring duration required to detect a moderate 3% per annum decline in pilchard abundance at the PH NRS is ~24 years with 1 sample per month (Table 4), but this duration declines to ~19 years with 2 samples per month (Fig. 21).
- There was evidence for strong seasonal abundance in the abundance of most taxa, with five spawning categories identified (Fig. 22); however detecting this seasonality for specific taxa at the NRS will require a longer time series (> 5 y).
- The variation in community composition of ichthyoplankton samples is high, and largely independent of the duration or distance between them (Fig. 23-25); this suggests that a single monthly sample is unlikely to accurately estimate the mean monthly community composition, which makes trend detection difficult.
- Weak evidence suggests that samples should be > 2 hours apart to ensure independence (Fig. 25d, Fig 26).
- Community-level analyses may be poor at detecting declines in even large numbers of taxa, so are not a substitute for monitoring and evaluating individual taxa (Fig. 27).

2.2.1. Power of Detecting Annual Trends in Common Taxa

There is always a relationship between the number of samples collected, the effect size (i.e. the strength of the trend), the significance level (typically $\alpha = 0.05$), and statistical power ($1-\beta = 0.8$, by convention). A traditional power analysis works by assuming the value of three of these variables and estimating the fourth (Quinn and Keough 2002).

For trend detection in a time series, there is a fifth parameter – the rate of change of the quantity being measured – meaning that we distinguish between the effect size and our precision in estimating it (Gerrodette 1987). The power of detecting temporal trends is often done with a regression approach (Gerrodette 1987) of so-called ‘exponential growth models’ (Humbert *et al.* 2009). This approach typically considers an evenly-spaced time series of non-

zero abundance data, and approximates the statistical power for detecting a specified change in that abundance over a given duration, based on the variation in the measured abundance.

This approach was employed in this report for numerous common taxa. We evaluated the statistical power of detecting a range of effect sizes (the magnitude of the trend in mean annual abundance), over 10 and 20 year time series. The precision to estimate abundance was estimated using the 'proportional standard error' (PSE; Nelson 2015), which was calculated as the ratio of the standard error and mean of monthly abundance. Thus PSE represents the uncertainty in our estimate of the mean annual abundance, and the greater the number of samples to estimate this mean the more likely a real trend in annual abundance will be detected. This analysis was done using the 'powertrend' function in the R package 'fishmethods' (Nelson 2015), which is based on the approach of Gerrodette (1987), and used the exponential model to apply change to abundance at a constant annual rate. The taxa selected for this analysis were those common at NRS, and thus likely to have the most accurate estimate of their PSE. PSE was estimated using the available NRS monitoring data (due to this data being less spatially and methodologically confounded than the historical survey data), but, due to the short time-scale of NRS data, the PSE were evaluated against available historical data to ensure they were realistic of a larger data set.

The traditional analytic approach (Gerrodette 1987) can be poorly suited to some abundance data (such as the NRS ichthyoplankton data), because it typically does not deal with zeroes (Humbert *et al.* 2009) or unequal intervals between sampling events (Gerrodette 1987; Staples *et al.* 2004). Thus this approach is often complemented by a simulation approach (Gibbs *et al.* 1998; LaCommare *et al.* 2012), whereby data are simulated with the estimated mean and variance structure and analysed for a specified trend. This approach is ideal for the NRS larval fish data, particularly if evaluating seasonal variation within years. Although we were unable to conduct a seasonal analysis (due to a lack of data), we nonetheless used a simulation approach to complement the analytic power analysis.

For the simulation, we generated abundance data from a negative binomial distribution, with a specified declining trend in mean annual abundance (similar to the approach in LaCommare *et al*. 2012). We estimated the overdispersion parameter 'theta' for this distribution from the raw NRS data, using a maximum likelihood method in the R package 'MASS' (Venables and Ripley 2002). Given the nature of the negative binomial distribution, abundance data were

generated for 20 years, with 12 samples per year. These counts were converted back to densities for comparison with the observed data. The trend (specified as a 50% decline in abundance) was then analysed for significance using linear regression. This simulation was iterated 50 times, each iteration randomly generating data from our specified distribution, and the proportion of iterations in which the trend was detected with significance ($P < 0.05$) was interpreted as statistical power.

The analytic and simulation approaches were focused on identifying the statistical power for detecting a trend over a 10 or 20-year time series, but of great interest to a monitoring program is the required length of a time series to make statistically-robust inferences about trends in abundance. This 'longitudinal' power analysis was also done using 'powertrend', but iterated the length of the time series until it could detect, with sufficient power (0.8), a specified rate of decline in annual abundance (3%, 5%, 7% per year). This again used 12 samples per year (to estimate mean annual abundance), and was done for the 10 most common taxa in each of 3 regions, corresponding to the three NRS.

These analyses showed that the power to detect a trend in mean annual abundance in common taxa varies among taxa. *Lutjanid snapper* had high occurrence at the NSI NRS (Fig. 15a), and there was sufficient statistical power (0.8) to detect a ~50% decline in abundance in a 20-year time series, or a ~70% decline in abundance in a 10 year time series (Fig. 15b). A 20 year time series of 6 samples per year had approximately the same power as a 10 year time series with 12 samples per year (Fig. 15b). The simulation showed a similar result, with simulated data approximating well the observed densities (Fig. 15c), and with almost all iterations showing a significant declining trend (which agrees with Fig. 15a). *Myctophids* at the NSI NRS were also common, but showed less power (Fig. 16), meaning that a 20 year time series is only able to detect trends more severe than a 60-70% decline in mean annual abundance. At the PH NRS, *pilchard* (*S. sagax*) had comparatively good power for detecting a trend in annual abundance (Fig. 17), but *flathead* had low power (Fig. 18), due to the high variance in observed abundance (Fig. 18a). At the MAI NRS, only *jack mackerel* (*T. declivis*) was investigated, due to generally low occurrence of taxa, and the variance in abundance was evaluated against the Challenger 1989-91 historical data. This species showed sporadic and large peaks in abundance (e.g. Fig 19a), which meant that there was low power for detecting a trend in annual abundance with current NRS sampling (Fig 19).

The length of NRS time series required to detect moderate/severe declines in abundance (3%, 5%, 7% per year) with sufficient statistical power ranged from 15 years to ~50 years (Table 4). The required length of the time series also depended on the NRS, with NSI showing the least variation in abundance and thus required generally shorter time series. For some of these taxa, the decline was detected only after abundance had declined by a large amount (75% threshold indicated in Table 4).

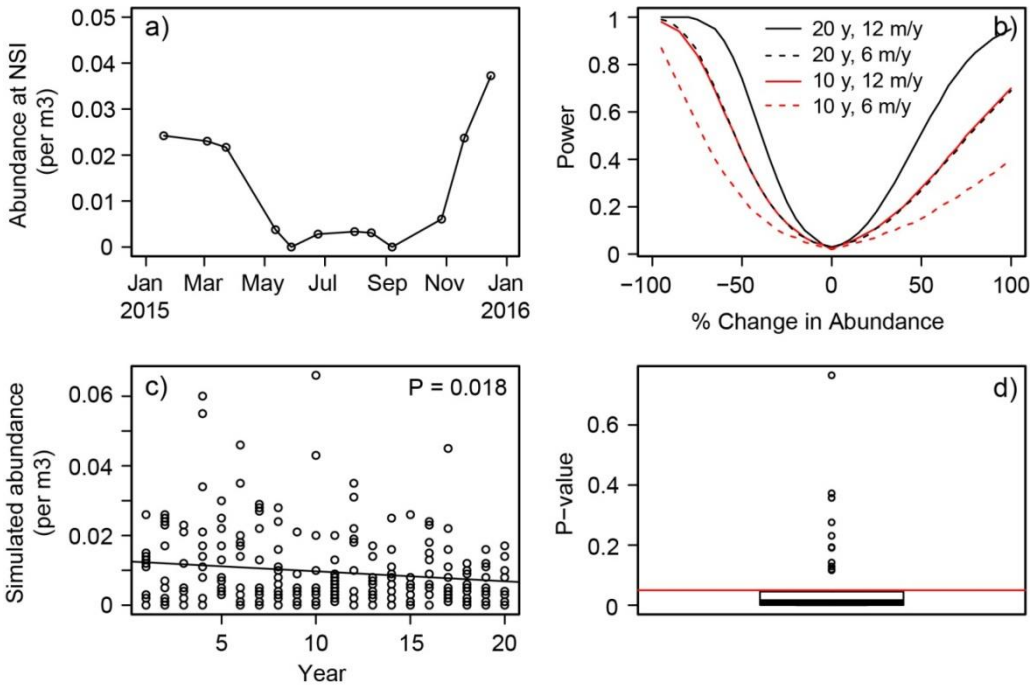

Figure 15a-d. Abundance and statistical power detecting a change in mean annual abundance for **lutjanid snapper** (taxa number 80, Table S1). The mean and variance of abundance was estimated from monitoring at the *North Stradbroke Island* (NSI) NRS. Reported is: a) the abundance measured during monitoring; b) the statistical power of detecting a trend (% change in abundance) over 10 or 20 years of data if samples are collected 12 months in the year, or just 6 months of the year; c) simulated data and declining trend, and a fitted linear model with P-value for one iteration; and d) P-values for 50 iterations of the simulation shown in c).

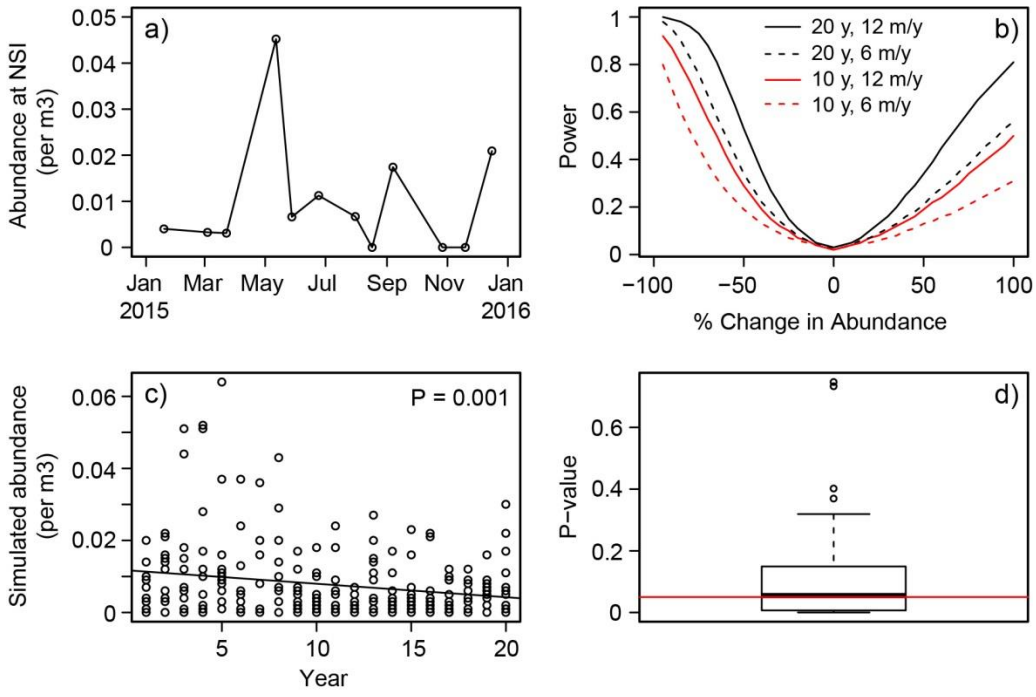

Figure 16a-d. Abundance and statistical power detecting a change in mean annual abundance for **Myctophidae** (taxa number 94, Table S1). The mean and variance of abundance was estimated from monitoring at the *North Stradbroke Island* (NSI) NRS. See Fig. 15 caption for more information.

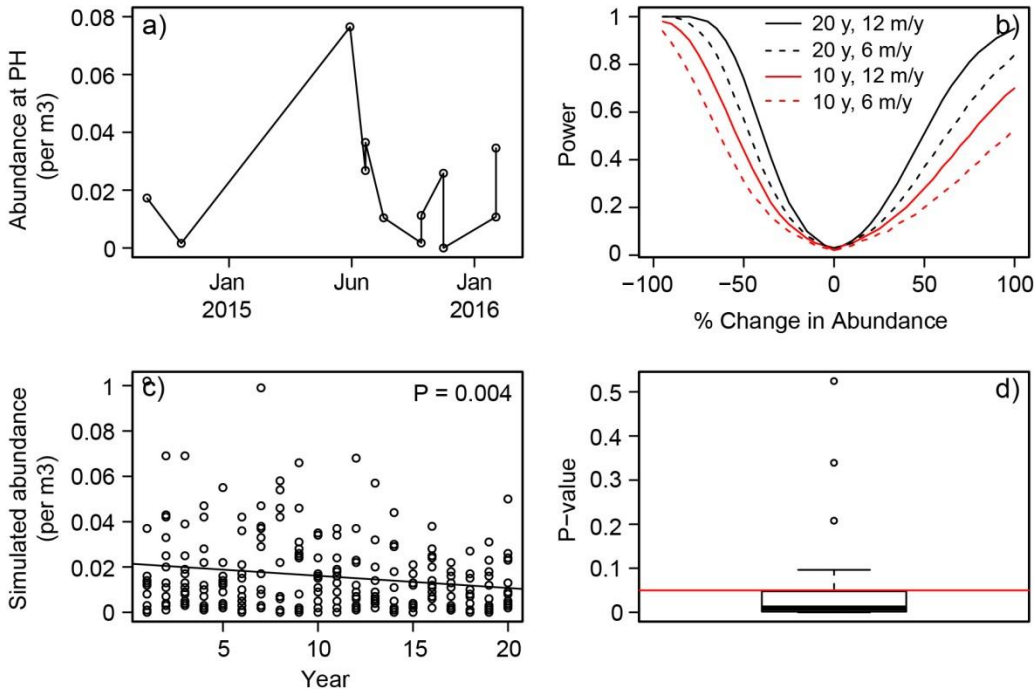

Figure 17a-d. Abundance and statistical power detecting a change in mean annual abundance for **pilchard** (*S. sagax*; taxa number 42.4, Table S1). The mean and variance of abundance was estimated from monitoring at the *Port Hacking* (PH) NRS. See Fig. 15 caption for more information.

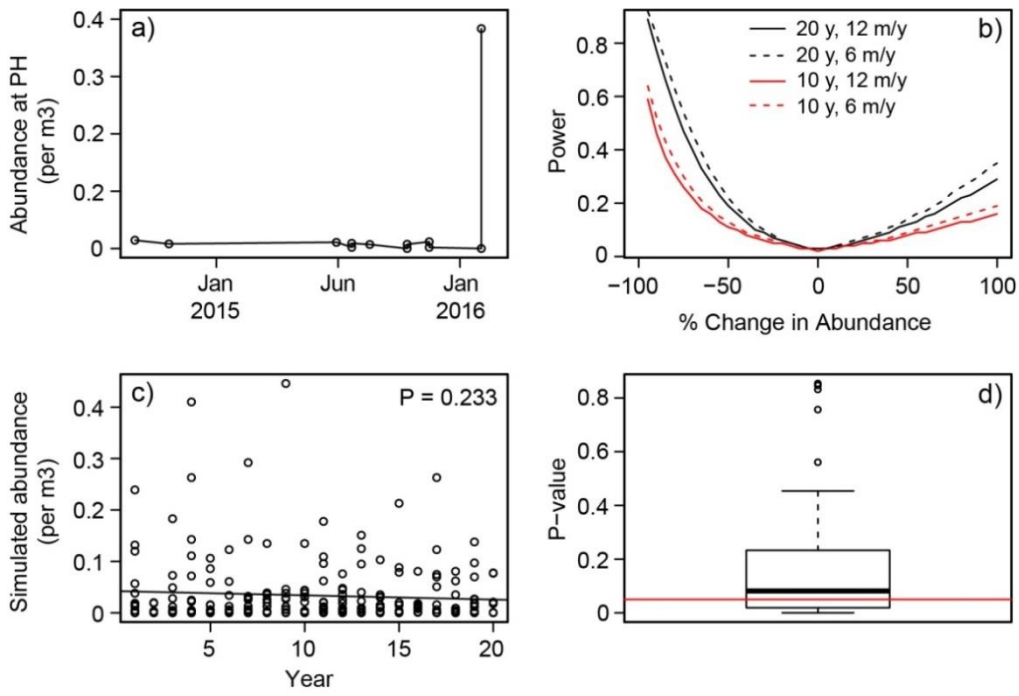

Figure 18a-d. Abundance and statistical power detecting a change in mean annual abundance for **other flathead** (taxa number 108, Table S1). The mean and variance of abundance was estimated from monitoring at the *Port Hacking* (PH) NRS. See Fig. 15 caption for more information.

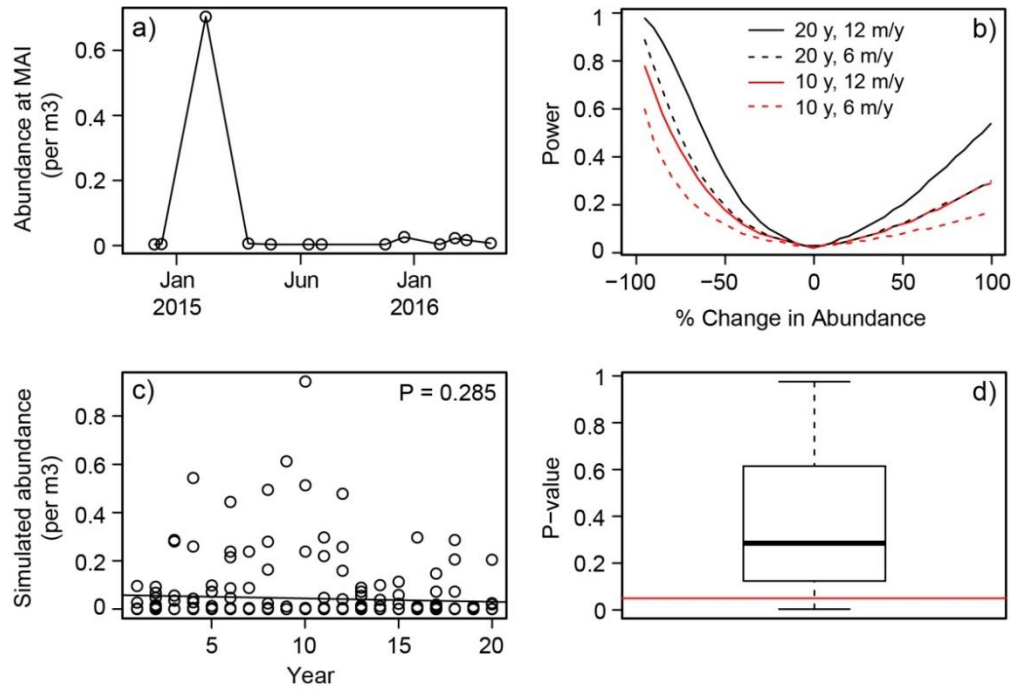

Figure 19a-d. Abundance and statistical power detecting a change in mean annual abundance for **jack mackerel** (*T. declivis*; taxa number 26.4, Table S1). The mean and variance of abundance was estimated from monitoring at the *Maria Island* (MAI) NRS. See Fig. 15 caption for more information.

Table 4. Approximate duration (**years**) of a time series required to detect (with power = 0.8) each of three rates of decline in annual larval fish abundance, using 12 samples per year, for common taxa at three regions corresponding approximately to the three NRS locations (NSI, PH, MAI). The three rates of decline are 3%, 5%, and 7% per year, which correspond to a 50% decline in abundance after ~25 y, ~15 y, and ~10 y, respectively. Values highlighted in grey indicate a time series in which the original abundance has declined by more than 75%, which we consider severe. Some AFMA managed species are highlighted in blue. **Note:** these results are based on preliminary abundance data, and may change as monitoring is continued at these NRS.

QLD (~NSI)				NSW (~PH)				TAS (~MAI)			
Taxa	Rate of decline			Taxa	Rate of decline			Taxa	Rate of decline		
	3%	5%	7%		3%	5%	7%		3%	5%	7%
78. Emperor (*Lethrinus* sp.)	24	18	15	42.4. Pilchard (*Sardinops sagax*)	24	18	15	122. Scorpaenidae (other)	33	24	20
26. Carangidae (other)	25	19	15	19.3. Bothidae (*Lophonectes gallus*)	25	19	15	89. Monacanthidae (leatherjacket)	36	27	22
94. Myctophidae (lanternfish)	28	20	17	73. Labridae (wrasse)	29	21	17	139.1. Gurnard (*Lepidotrigla* spp.)	38	30	25
62. Gonostomatidae (bristlemouth)	27	19	17	108. Platycephalidae (other)	30	23	20	108. Platycephalidae (other)	44	33	26
73. Labridae (wrasse)	28	21	17	126.4. Eastern school whiting (*S. flindersi*)	31	23	19	94. Myctophidae (lanternfish)	42	31	26
19. Bothidae (other)	30	21	18	24. Callionymidae (dragonets)	32	23	19	26.4. Jack mackerel (*Trachurus declivus*)	43	31	26
42.3 Maray (*Etrumeus teres*)	29	21	17	89. Monacanthidae (leatherjacket)	33	25	18	19.3. Bothidae (*Lophonectes gallus*)	43	31	26
95. Nemipteridae (threadfin bream)	31	22	19	26.2. Scad (*Trachurus novaezelandiae*)	33	25	20	56.3. Barracouda (*Thyrsites atun*)	44	33	27
93. Mullidae (goatfish)	31	23	19	94. Myctophidae (lanternfish)	33	25	21	24. Callionymidae (dragonets)	44	34	28
50. Anchovy (*Engraulis australis*)	33	25	21	26.5. Silver trevally (*Pseudocaranx dentex*)	39	30	24	143. Zeidae (Dory)	48	35	27

2.2.2. Evaluating Sampling Effort

Determining the optimum sampling design of a larval fish monitoring program (which would vary with objectives of end-users, taxa of interest, and monitoring location) is outside the objectives of this report. However, we evaluate briefly here the benefit of increasing the sampling effort for enhancing the value of the IMOS NIMO data. We note that from early 2016 an extra station was added at the NSI and MAI NRS, and having two samples per month at these NRS may improve power (provided that these two stations sample the same water masses), but this cannot yet be evaluated.

Effort can be increased by increasing the number of sites/stations, and/or by increasing the sampling effort at existing sites. Given that IMOS has strategically determined the number and locations of the NRS, we focused this evaluation of sampling effort on increasing sampling effort at the existing locations. This could be done by either increasing the volume per sample, or by increasing the number of samples per month. Doubling the volume of a sample is likely to improve power in a similar way as taking a second sample per month – both methods will improve the detection of taxa and more accurately estimate their abundance. Two approaches of evaluating the value of increasing sampling effort per month are to look at: 1) the accumulation of taxa with increased sampling; and 2) the increase in statistical power to detect trends in abundance with increased sampling. By doing so, we can evaluate how more samples per month alter our ability to ask questions of temporal patterns in species composition, and of trends in abundance of specific taxa.

To achieve the first approach, a species accumulation analysis was done on the Kamala 1989-93 surveys (see Table 2). These surveys were used because they contained a large number of samples within each month (a mean of 61 samples per month), and were thus likely to give good approximation of true monthly taxonomic diversity in a restricted spatial location. A species accumulation curve was produced for each of the 18 unique calendar months surveyed (using random permutation of the data), and was done using the 'vegan' R package. The 18 species accumulation curves are plotted in Fig. 20, and show that taxa accumulate quickly with the number of samples per month. Five samples per month were sufficient to observe an average 48% of the larval fish taxa observed with further sampling (a mean of 61 samples per month). One sample per month detected on average only 14% of the monthly taxa. This illustrates that questions focusing on the species composition of the larval fish

community (or the presence of uncommon or rare species) would benefit greatly from more samples per month, because this improves the detection of taxa and the characterisation of the community. An upper target for increased sampling effort would be 5 samples per month as this corresponds to ~50% of the taxonomic richness achieved with much greater sampling effort.

To achieve the second approach, an analysis of statistical power was done for one common taxa using simulated NRS larval fish data. This was done for pilchard (*S. sagax*) at the Port Hacking (PH) NRS, using the data shown in Fig. 17, including the simulated data shown in Fig. 17c. Using the same approach to the 'longitudinal' power analysis reported in Table 4, we calculated the duration of a time series required to detect a 3% per annum decline in abundance of pilchard at the PH NRS, and how this duration declined with increased sampling effort (samples per year). This was done for a single taxon only to illustrate the approximate relationship between statistical power and number of samples, and we stress that this relationship will vary between taxa and survey locations.

The current level of variation between monthly samples means that a time series of ~24 years is required to detect a 3% per annum decline in mean annual abundance for pilchard at the PH NRS (Fig. 21b, Table 4). If sampling effort is doubled, for example by taking 24 samples per year rather than the current 12 (Fig 21a), the proportional standard error (i.e. the variation) declines which reduces the length of the required time series from 24 years to ~19 years (Fig. 21b). The improvement in power by doubling monthly sampling effort would be proportionally even larger for less common species.

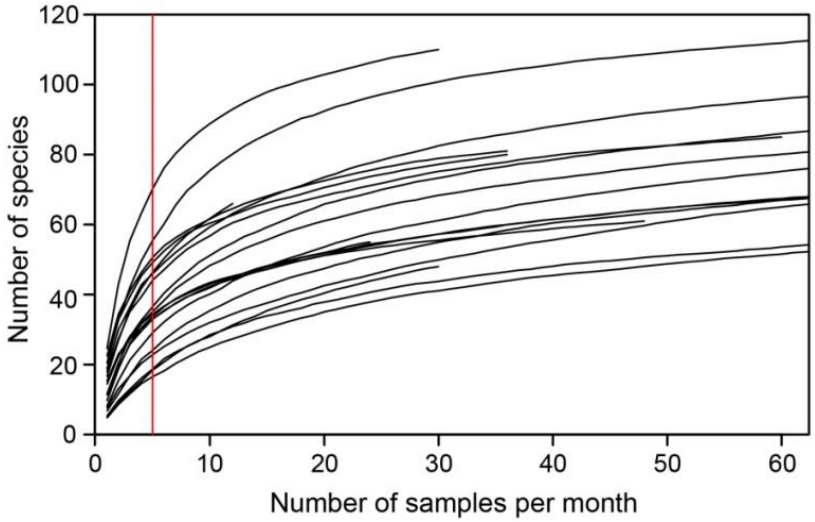

Figure 20. Species accumulation curves for Kamala 1989-93 data, examining how taxa observed in 18 unique surveyed months accumulated with number of sampling events in that month (the number of samples differed between months). The mean percentage of taxa observed in five samples (red line) compared to the total observed in each month was ~48%.

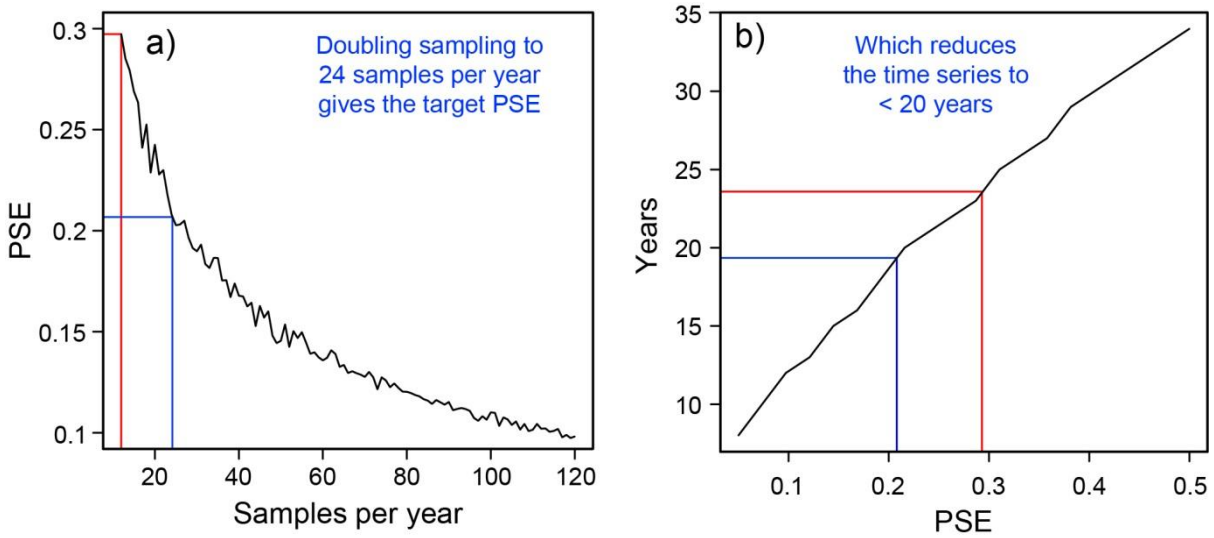

Figure 21a-b. a) The estimated relationship between number of samples per year and the proportional standard error (PSE) of abundance (per m^3) of pilchard (*S. sagax*); and b) the relationship between PSE and duration (years) of a time series required to detect a 3% per annum decline in pilchard abundance. Doubling sampling effort from 12 to 24 samples per year reduces the PSE (a), which corresponds to a decline in time series length from ~24 years to ~19 years (b).

2.2.3. Preliminary Analysis of Seasonality

An analysis of the historical data showed that 'month' influenced species composition (Table 3), but in order to establish this as seasonality of larval fish abundance requires disentangling the temporal component (month or season) from spatial components (latitude, depth etc). As already stated, this was not possible with the majority of available data because they were collected sporadically. The data set that was collected in a restricted spatial domain over the longest duration were FRV Kamala 1989-93 (done on the Sydney coast; Table 2). These data did allow for an analysis of seasonality in the abundance of common larval fish taxa, although we consider this preliminary as there were only 3 replicates of each season. Identifying whether there is seasonality is useful for interpreting trends in abundance, and accounting for season (e.g. Rohner *et al.* 2013) can increase the power for detecting temporal trends in abundance.

This preliminary analysis of spawning seasonality was done using cluster analysis on the larval fish abundance data from the Kamala 1989-93 surveys. To avoid issues from pseudoreplication or possible depth biases only a single replicate from samples at the 60 m isobaths were included (168 samples). The abundances (per m^3) of the 59 most common taxa (excluding taxa with < 10 occurrences) were averaged within calendar seasons, and this data was used in the group-average cluster analysis on a Bray-Curtis similarity matrix of square-root transformed data. Significant clusters were identified with a SIMPROF (similarity profile) analysis (Clarke *et al.* 2008). This analysis was done using PRIMER-E with Permanova+ software (v6.1.11; Plymouth, UK). The seasonality of each cluster was visualised by calculating the average abundance of all taxa in that cluster.

The cluster analysis identified five distinct clusters of taxa (Fig. 22a), which corresponded to peaks in spawning in specific seasons (Fig. 22b). The trevallas (*Seriolella* spp., taxa no. 28) were the only common taxa that spawned in winter in the surveyed area (Fig. 22b). The largest cluster of taxa (cluster 5, Fig. 22a) appeared to spawn mostly in autumn (Fig. 22b).

There is insufficient data to evaluate seasonality in the IMOS NIMO data. Although strong seasonality was detected in 3 years of data in the Kamala 1989-93 surveys, those data contained an average 14 samples per season – more than the 3 samples per season at each NRS. We thus consider it likely that *at least* 5 years of IMOS NIMO data will be required

before seasonality can be evaluated. Detecting seasonality will be of great benefit to the value of the IMOS NIMO program, as it will allow for improved trend detection in the abundance of common taxa or groups of taxa sharing season spawning patterns, as well as promote analyses of phenology by comparing IMOS NIMO data with historical data. Given the comparatively poor sampling of taxonomic richness with 1 sample per month (Fig. 20), increasing the sampling effort of IMOS NIMO will be of great benefit to the characterization of seasonality at the NRS.

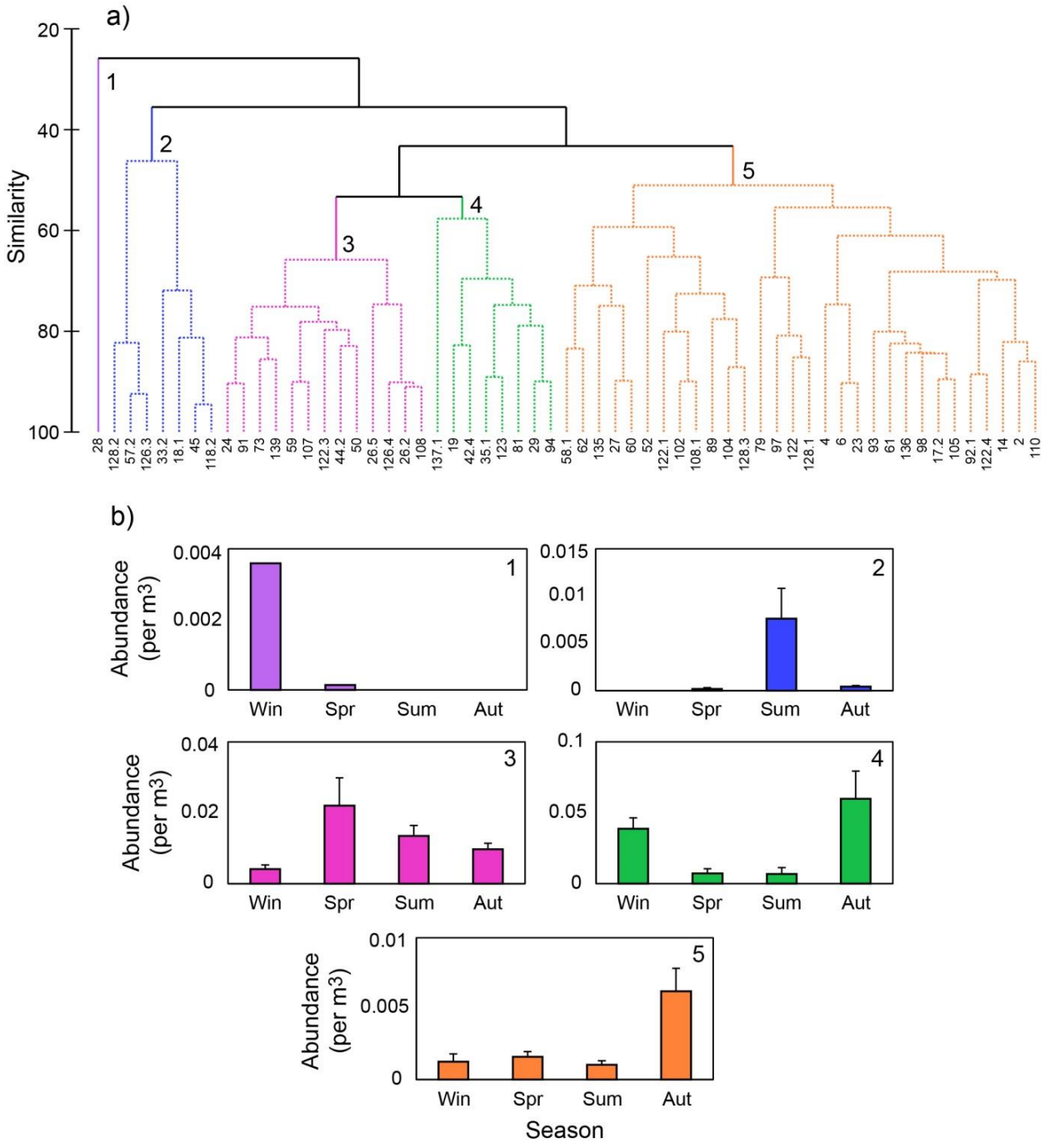

Figure 22a-b. a) Results of a cluster analysis of seasonal abundance of the 59 most common taxa in the Kamala 1989-93 data; distinct clusters were identified with a SIMPROF analysis. b) The mean (± s.e.) abundance of the taxa within each of the five significant clusters shown in a), and illustrates the patterns of seasonality by taxa within each cluster (e.g. taxa in cluster 2 were most abundant in summer). The end branch numbers in a) are the IMOS NIMO taxa numbers, and are defined in Table S1 in the Appendix.

2.2.4. Community Differences Across Space and Time

An important part of evaluating the power of the NRS sampling is understanding how representative single monthly samples at a fixed location are of the larval fish community over broader temporal and spatial scales. If these single samples are poor measures of mean abundance and community composition in the surrounding environment, then any trends observed in these data (regardless of their statistical power) will have little ecological value. This can be measured by examining the variation between individual samples across time and space.

We selected 3 historical surveys and calculated the community similarity between samples as these samples became further apart in time and space. Time and space are typically correlated in these cruises, so it can be difficult to distinguish their effects. But by plotting both variables together, it is possible to explore whether samples closer together (in time and space) are more similar than those further apart. Two of these surveys covered hundreds of kilometers and numerous oceanographic features, so it would be expected that samples close in time (and space) for these surveys would be much more similar than more distant samples.

It was observed that the similarity (or dissimilarity) between samples was generally independent of how far apart those samples were in time and space (at a scale of hundreds of kilometers, and one week). This was true for the *Franklin 1998-99* survey (Fig. 23a), the *Southern Surveyor 2004* survey (Fig. 24a) and the *Franklin 1994* survey (Fig. 25a). In these plots, the Bray-Curtis similarity does not obviously decrease as samples become further apart. If these results are examined at finer temporal and spatial scales, we again see that sample similarity is independent of duration and distance between samples, even at scales of days and within 10-50 km (Fig. 23b-d, Fig. 24b-d, Fig 25b-d). The exception is *Franklin 1994* survey for sub-daily duration between samples (Fig. 25d), which shows that samples may be more similar if they are within 10 km and a few hours of each other.

This lack of correlation between samples does suggest that samples at a single point can be indicative of a much larger temporal and spatial scale, but the large *variation* of between-sample similarity, even on short time scales (e.g. Fig. 23b-d, Fig. 24b-d, Fig 25b-d), shows that accurately estimating the mean monthly community composition is likely to require multiple samples per month.

A similar analysis can be done for the IMOS NIMO data, which has the advantage of removing 'distance between samples' from the analysis. Until Nov 2015, two ichthyoplankton samples were taken at each NRS, 10-20 minutes apart. Due to a concern about non-independence, these have been changed to a single longer tow. These initial samples, however, allow us to investigate the similarity between samples across a very short time frame at the same location. We see that there was more similarity between consecutive samples at the NSI NRS (minutes apart) than samples taken months apart, however this is less obvious at the PH and MAI NRS (Fig. 26). Maria has generally the lowest similarity between the 'same day' samples, which may be because this NRS generally samples the lowest larval fish abundance (Fig. 4).

So generally we see that there is large variation in the ichthyoplankton community between samples, and it is often the case that samples within hours and kilometers of each other are as similar as samples taken months and hundreds of km apart. This does not mean there are no consistent spatial or temporal patterns in the community (this analysis only measured relative similarity), and we know that there is a difference in the community across a large spatial gradient (Fig. 10), apparent even with only 12-18 months of NRS data. But this result does mean that a single sample per month is unlikely to accurately estimate the mean monthly community composition in the surrounding environment. In terms of a time-series, this means that the time series will need to be longer to detect a trend (or the trend will need to have a large effect size, e.g. Fig, 10), due to the uncertainty of the point estimates of mean abundance and community composition. This echoes statements in trend analysis research that states that it is preferable to have more samples within a temporal unit of interest (here, 'month') to accurately estimate the mean, and have fewer months sampled (or even missed years) than to have lots of low precision sampling (Gibbs *et al.* 1998; Humbert *et al.* 2009).

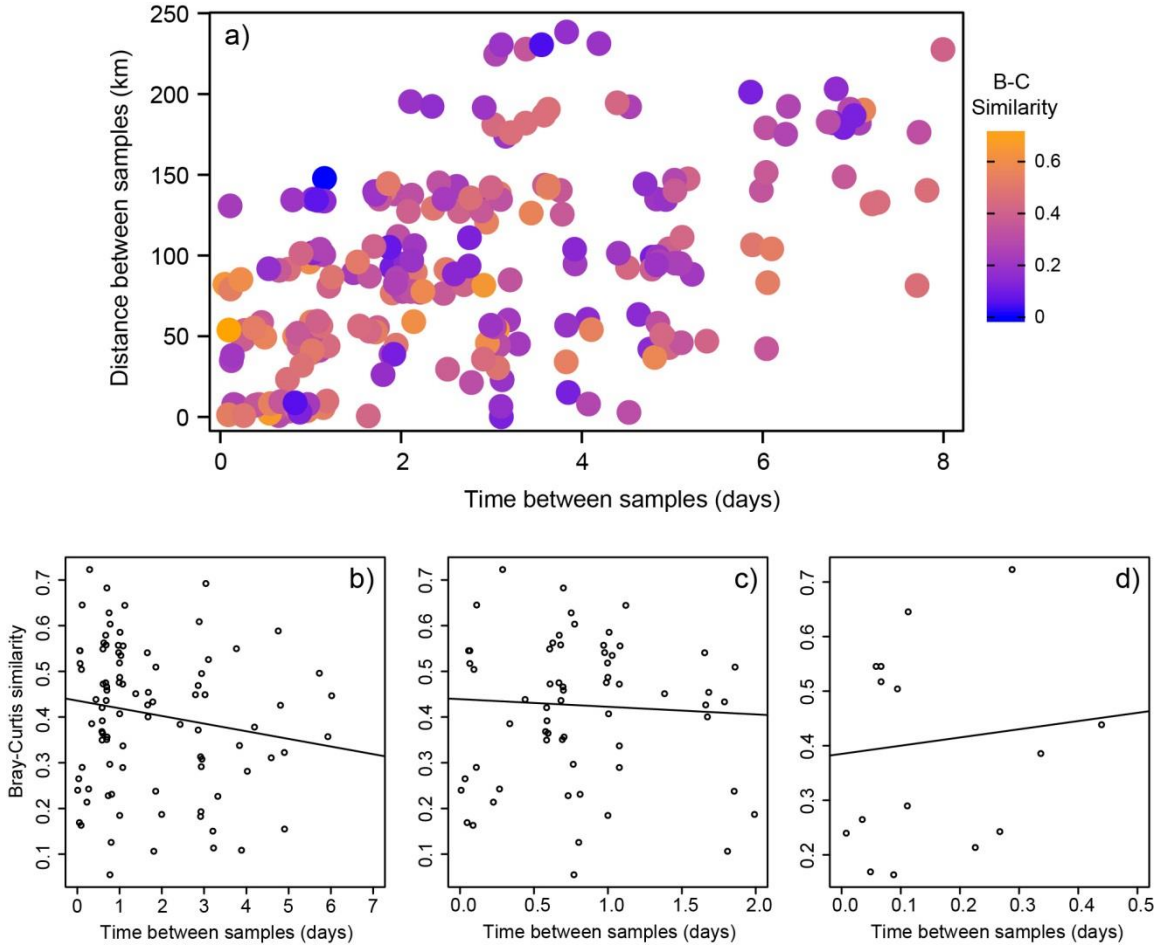

Figure 23a-d. a) The variation in the larval fish community between pairs of samples for the Franklin 1998-99 survey, as a function of the time between samples (days) and the distance between the samples (km). Point colour is the Bray-Curtis similarity of square-root transformed abundance data (number per m^3). An orange dot represents a pair of samples that had similar species composition. Note that points have been jittered for clarity. b-d) If we explore finer time scales (and restrict the distance between samples to within 50 km of each other), we see no significant relationship (of a linear regression) between sample similarity and: b) a 7-day time scale (P = 0.10), c) a 2-day time scale (P = 0.65), or d) a 12-hour time scale (P = 0.68).

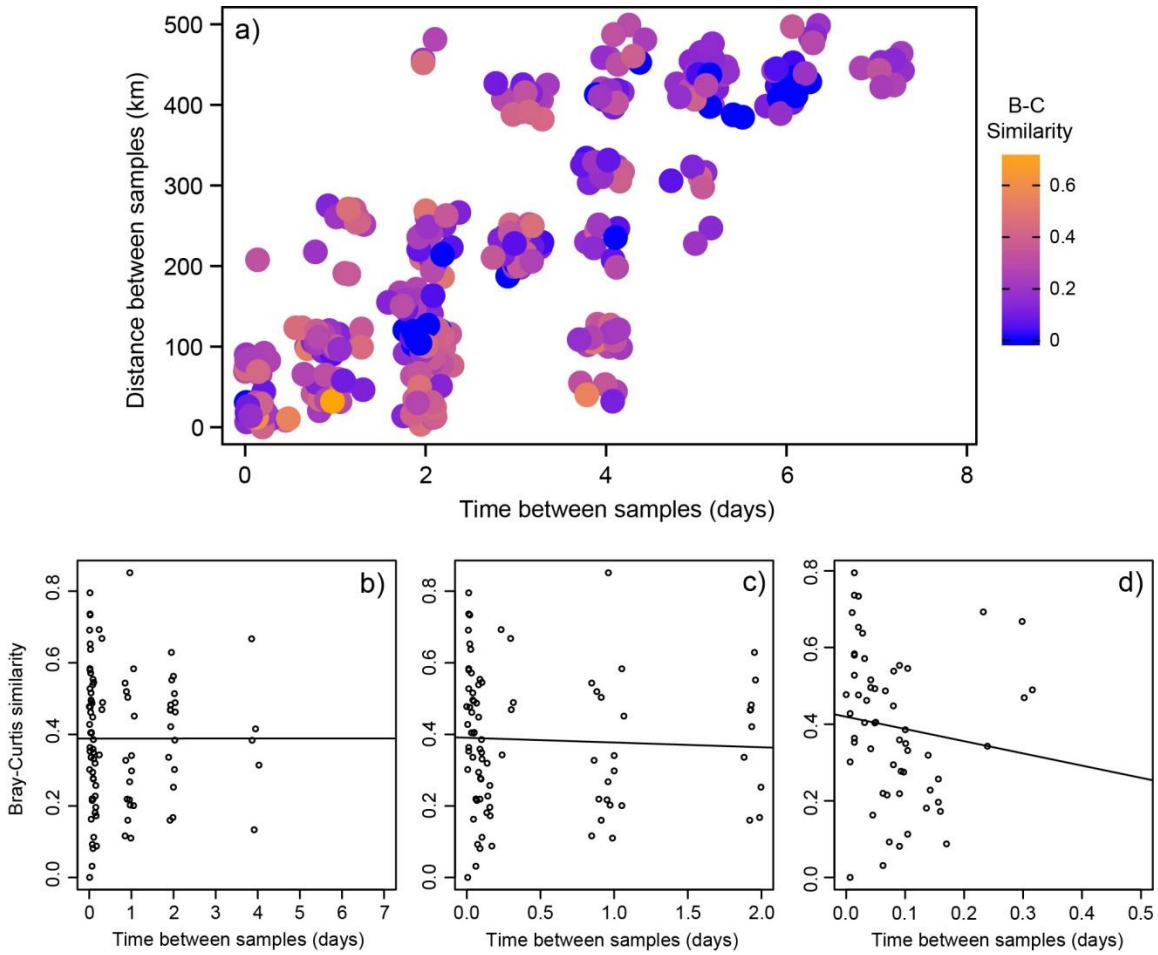

Figure 24a-d. a) The variation in the larval fish community between pairs of samples for the Southern Surveyor 2004 survey, as a function of the time between samples (days) and the distance between the samples (km). Point colour is the Bray-Curtis similarity of square-root transformed abundance data (number per m^3). An orange dot represents a pair of samples that had similar species composition. Note that points have been jittered for clarity. b-d) If we explore finer time scales (and restrict the distance between samples to within 50 km of each other), we see no significant relationship (of a linear regression) between sample similarity and: b) a 7-day time scale (P = 0.99), c) a 2-day time scale (P = 0.68), or d) a 12-hour time scale (P = 0.34).

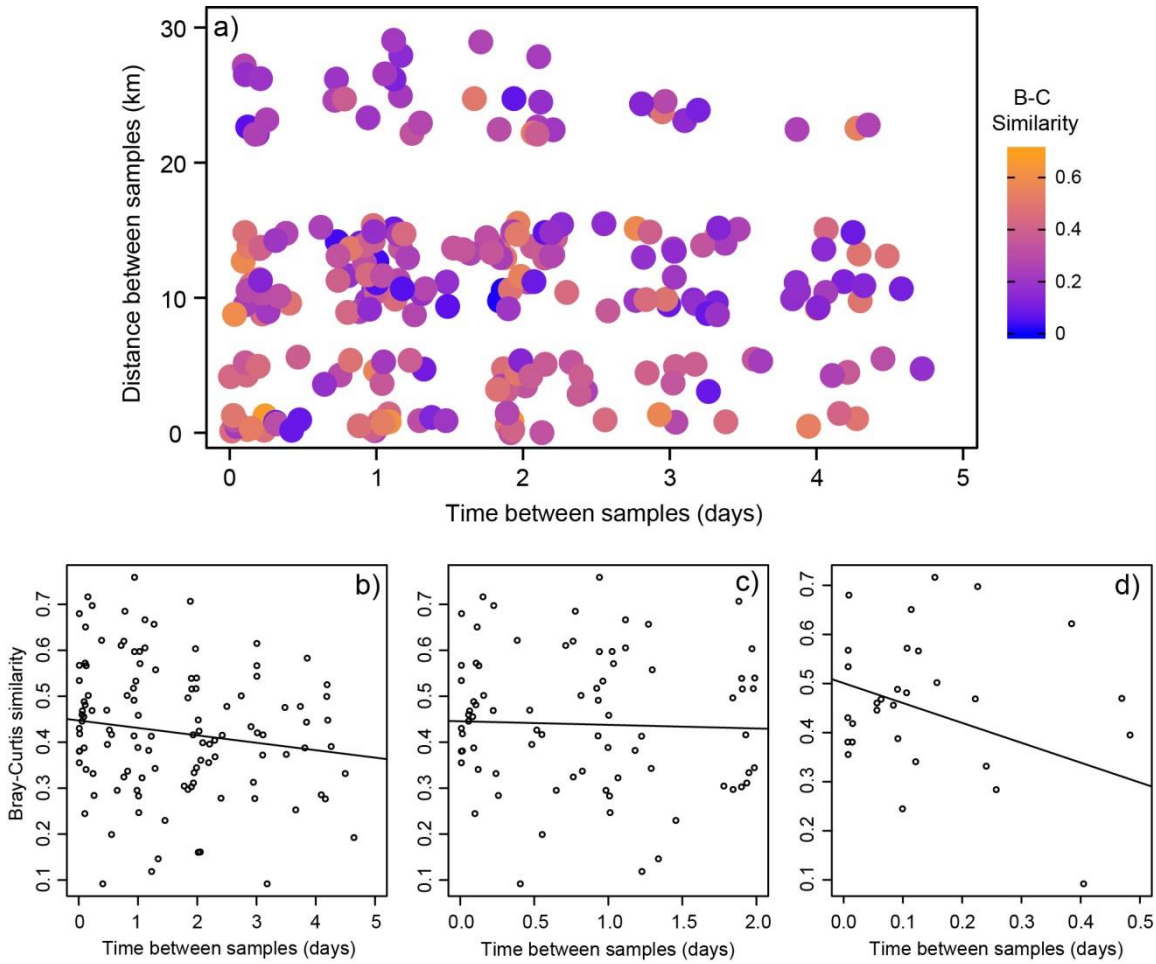

Figure 25a-d. a) The variation in the larval fish community between pairs of samples for the Franklin 1994 survey, as a function of the time between samples (days) and the distance between the samples (km). Point colour is the Bray-Curtis similarity of square-root transformed abundance data (number per m^3). An orange dot represents a pair of samples that had similar species composition. Note that points have been jittered for clarity. b-d) If we explore finer time scales (and restrict the distance between samples to within 10 km of each other), we see no significant relationship (of a linear regression) between sample similarity and: b) a 7-day time scale (P = 0.11), c) a 2-day time scale (P = 0.77), but we do see a significant decline in sample similarity on d) a 12-hour time scale (P = 0.03).

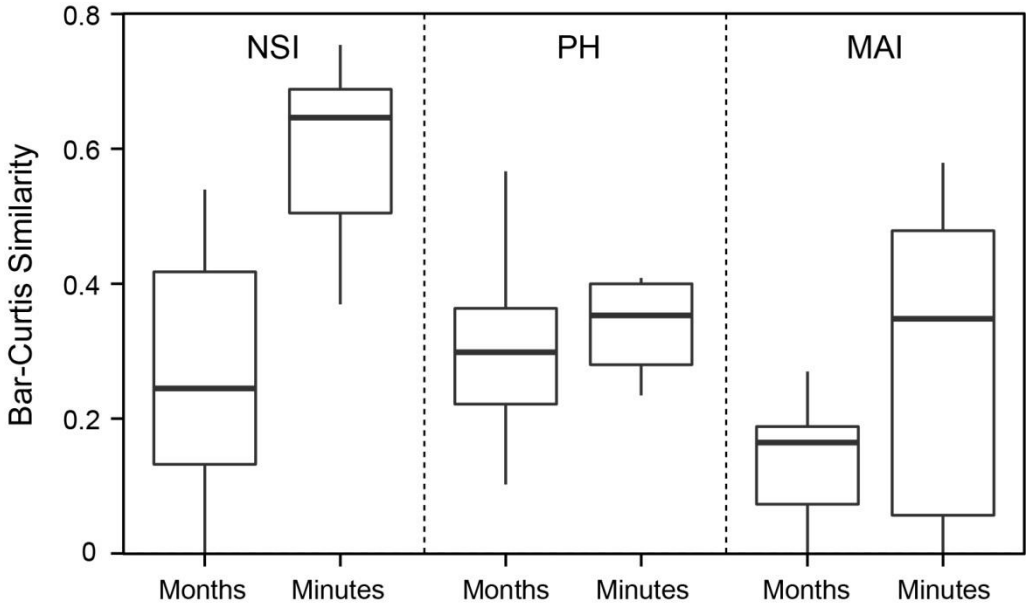

Figure 26. Bray-Curtis similarity of square-root transformed abundance data (larvae per m^3) between pairs of samples at each NRS taken 10-20 minutes apart ('minutes') or months apart ('months').

2.2.5. The Importance of Monitoring Individual Taxa

There are numerous reasons why individual larval fish taxa would be monitored, but given the move towards 'ecosystem-based' approaches to fisheries management (Pikitch *et al.* 2004; Scandol *et al.* 2005; Smith *et al.* 2007) there may be an incentive to monitor fish communities for change, rather than individual taxa. An analysis was done here to evaluate whether changes in individual taxa were also likely to be detected in community-level analyses.

This analysis was a simulation in which real larval fish abundance data was altered so that an increasing number of taxa declined at an increasing rate, and we measured the ability of a community-level analysis to detect this. We used a multivariate GLM (Wang *et al.* 2012) as the community-level analysis. The simulation involved simulating three levels of decline in abundance (30, 50, 80%) in an increasing number of taxa (from 10 to 50 taxa, out of a total of 61 common taxa), using the NSI NRS data. The multivariate GLM was of the same form as that used in Section 2.1.3.1. Using a negative binomial family meant that counts needed to be simulated. Counts were typically rounded after calculating the decline, but for low counts this would lead to considerable rounding errors, so declines in counts for low numbers of larvae (5 or fewer) were estimated probabilistically – e.g. a 50% decline for a taxon with a count of 1 was done by changing this to 0 for ~half the iterations.

This simulation showed that not until a 50% decline in most larval fish taxa (or an 80% decline in half the taxa) does the analysis report a statistically different community (Fig. 27). A 30% decline in most taxa was barely detected at all. This analysis relies on significance derived from a modern resampling-based inference (Wang *et al.* 2012), and distance-based methods such as PCO (e.g. Fig. 8) might show a more gradual separation of the community with increased decline in abundance. However, distance-based methods also tend to transform abundance data to reduce the importance of a few highly abundant taxa, so may also be prone to underestimating the effect of declining abundance in numerous taxa. Community analyses and metrics are extremely valuable, but are not a substitute for monitoring species of interest, as a declining abundance in one or even many taxa is not a strong community-level change, and may not be easily detected in community-level analyses.

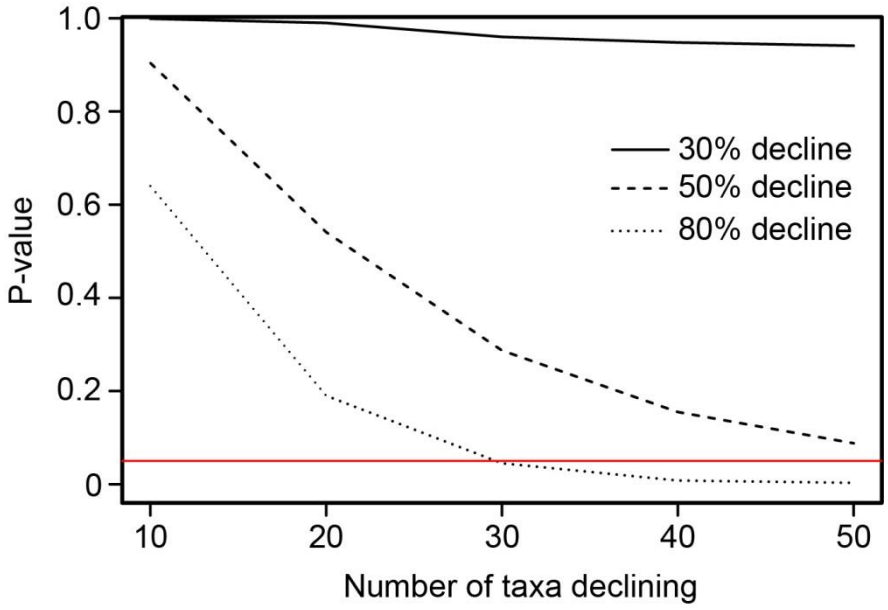

Figure 27. The ability to detect declining species abundance in community analyses; not until we see a decline of more than 50% abundance in most taxa (here the NSI NRS, with a total 61 common taxa) will a community level analysis (here, MGLM) consider it a different community. This highlights the variation we see in NSI NRS, but also shows that the power we see in the historical data is due to the addition and loss of species, not just changes in abundance. Thus, we need to monitor individual species and other metrics (like phenology) to understand changes at a highly variable site, not just community-level analyses. The red line indicates P = 0.05.

2.3. GENETIC ANALYSIS OF ICHTHYOPLANKTON

The rationale for collecting larval fish for genetic analysis is for the potential to: 1) conduct a population analysis, 2) create a reference library for future 'genetic ID methods'.

A population analysis based on the genetics of larval fish (1) would likely be based on Bravington *et al.* (2014), and could be done to measure adult stock size, relatedness between individuals (stock structure), or relatedness at different sites (migration). However, at the December 2015 larval fish monitoring meeting in Hobart, Campbell Davies and Mark Bravington (CSIRO) cautioned that extracting genetic material from larval fish of high quality for close-kin type analysis needs to be confirmed. They also cautioned that the number of individuals to test can be large: $10 \times (\text{adult population})^{0.5}$, meaning that 10,000 larval fish would need to be tested to estimate the stock size for 1,000,000 adults. We thus consider this type of analysis unlikely, given that a single sample at the NRS collects a mean of 130 larvae per sample, and a mean of 9.6 larvae per observed taxa per sample (although tests of stock structure or connectivity may require fewer samples). It is possible that stored samples could be subject to a future genetic analysis of changes in reproductive stocks at an NRS, but this would also require a large number of individuals. It would also require high level taxonomic expertise to sort all samples (12 per year) and extract the taxa of interest.

Creating a genetic reference library for larval fish (2) would be valuable, and could aid in future metabarcoding or 'bulk' taxonomic methods (Taberlet *et al.* 2012; de Vargas *et al.* 2015) for identifying species in ichthyoplankton samples. These methods are much less reliant on the (rare) high-level ichthyoplankton taxonomic expertise. This genetic reference library wouldn't need to be created from larval fish necessarily, but ichthyoplankton samples make a ready source of numerous taxa, and would provide the taxa most likely to be observed in the future ichthyoplankton samples to be analysed. This is a more realistic use for collected ichthyoplankton samples, and preliminary reports from the CalCOFI ichthyoplankton monitoring suggest that larval fish can provide genetic material when properly stored.

Given that the collection of these samples is already underway, it would be prudent to continue to store monthly samples from each NRS in ethanol for the preservation of genetic material, with a vision for accumulating a reference library for common taxa. However, the costs of sample maintenance require consideration.

3. CONCLUSIONS AND RECOMMENDATIONS

Objective 1. Develop an ongoing time series of larval fish abundance at multiple National Reference Stations (NRS) around Australia

- IMOS NIMO monthly sampling is ongoing since late 2014 at 3 IMOS National Reference Stations (North Stradbroke Island, Port Hacking, Maria Island) and has now started at 2 more (Kangaroo Island and Rottnest Island).
- For the first time for fish larval monitoring in Australia, a sampling program has developed and used a standardised sampling methodology, consistent taxonomy (208 taxa with 114 identified to genus or species), a curated archive, a common database, and made their data open access.

Objective 2. Characterise patterns in larval fish off eastern Australia using historical surveys

- Larval fish communities show consistent differences over large spatially, identifiable even over the 18 months of sampling so far. Using fish larval data from IMOS NIMO and historical surveys, there is an 80% decline in diversity and a 50% decline in abundance from the subtropics off Brisbane to temperate waters off Tasmania.
- Based on the most extensive monthly fish larval data in Australia from the 1980s, we identified 5 distinct seasonal cycles in spawning patterns for the 59 most abundant taxa: 1. Summer; 2. Winter; 3. Autumn; 4. Spring and Summer; and 5. Autumn and Winter. This historical information will form the basis for IMOS NIMO to assess whether species have changed their spawning seasons.

Objective 3. Provide larval abundances and measures of variation for key species, from historical surveys and current NRS monitoring

- The IMOS NIMO program can detect changes in the spatial distribution of the spawning of key species/taxa. By combining the fish larval community data from IMOS NIMO and historical surveys predominantly from the 1980s and 1990s, we show that the North Stradbroke Island (QLD), Port Hacking (NSW), and Maria Island (TAS) National Reference Stations have different larval fish communities than were historically present. Specifically, Maria Island has become more similar to northern and mid latitudes at North Stradbroke Island and Port Hacking. There was evidence from Maria Island of a

southward shift in the spawning of larval sardine, and increased anchovy abundance. This is consistent with a southward movement of some species with climate change and recent homogenisation of larval fish communities. Such information on shifts in species composition can provide insights into causes of changes in adult fish communities such as potentially distinguishing environmental and fisheries-related causes.

- Using an indicator species analysis, we identified larval species with region-specific affinities, including blue mackerel (*Scomber australasicus*) in southern QLD and northern NSW, maray (*Etrumeus teres*) in southern QLD to central NSW, pilchard (*Sardinops sagax*) in southern QLD to VIC, and jack mackerel (*Trachurus declivis*) off TAS. Being indicative of regions, these sentinel species will inform IMOS NIMO analyses on shifting larval distributions with climate change.

Objective 4. Thereby assess the ability of larval fish monitoring at NRS to detect trends in abundance of key species, and in the larval fish community

- Preliminary analysis of the length of time series needed suggests that between 15-50 years of data are need to identify moderate/severe declines in fish larval abundance. These power analyses should be taken as an upper limit, as no seasonality has been considered, and thus the unexplained variance associated with each species is overestimated.
- At least 5 years of IMOS NIMO sampling will be needed to estimate seasonality and thus robustly estimate how long time series will need to be to detect trends. Once seasonality is included, estimates of time series length required to detect trends are likely to reduce.

Objective 5. Examine the feasibility of the collection and storage of larval fish samples for possible genetic analyses

- Some replicate samples are currently stored in ethanol for possible DNA 'metabarcoding' analysis to aid taxonomic identification. This will be a valuable archive into the future.

Objective 6. Provide recommendations on the potential for NRS larval fish monitoring for providing management-relevant information

- The IMOS NIMO sampling program provides unique monthly data on fish larvae and insights into fish spawning from key locations around Australia. This information is not routinely available from fisheries dependent data sources, and no fisheries management

agency currently has a monthly monitoring program for fish larvae. Legacy data on fish larvae from historical surveys provide IMOS NIMO with a longer-term context and is already delivering insights into how communities and spawning patterns might have responded to climate change.

  - RECOMMENDATION 1: *We recommend further work to unearth historical fish larval data – already collected at considerable expense but not in the public domain; this will provide IMOS NIMO time series with a longer-term perspective while they are still relative short*

- IMOS NIMO can provide estimates of trends in larval abundance of key taxa, but preliminary analysis – that does not consider seasonality of spawning because of the short time series – suggests decades are needed to detect significant trends. With 5 years of data hopefully enabling the description of typical seasonal cycles, it is likely that shorter time series will be needed to detect significant trends for common taxa.
  - RECOMMENDATION 2: *We recommend that IMOS NIMO be continued for another 3 years (till 2020) to evaluate more robustly its ability to provide estimates of trends in larval abundance*

- The power of IMOS NIMO to detect trends in fish larval abundance would greatly improve with increased samples per month. However, it will be difficult logistically and financially to sample IMOS National Reference Stations more frequently than once a month, and evidence suggests that samples taken within 1-2 hours are not independent.
  - RECOMMENDATION 3: *We thus recommend the most pragmatic way to improve representation of the larval community in IMOS NIMO samples is to collect a larger volume of water, even if this is done by combining two consecutive tows of ~500 m^3 at each NRS each month*

- The creation of a genetic reference library for larval fish would be a valuable resource which could aid in future metabarcoding or 'bulk' taxonomic methods.
  - RECOMMENDATION 4: *That storage of larval fish samples in ethanol continues (to enable genetic analyses); and that a project evaluating the value of DNA 'metabarcoding' for streamlining the identification process be considered (as is being done in the CalCOFI program)*

- By basing NIMO at the IMOS National Reference Stations that are sampled monthly, there is considerable added value provided by the physical, chemical and biological data on temperature, salinity, pH, nutrients, microbes, phytoplankton and zooplankton. IMOS NIMO has already expanded from 3 National Reference Stations to 5, but there are no time series currently in tropical Australia.
    - RECOMMENDATION 5: *We recommend that NIMO sampling start at the other two National Reference Stations – Darwin and Townsville – as funding allows*

4. A FINAL WORD

There are numerous questions that can be asked of the current NRS ichthyoplankton monitoring (Table 5). Not all can be addressed with precision over fine temporal or spatial scales, due to the large spatio-temporal variation in larval fish abundance, and due to the large distances between the NRS. Thus, **the immediate value IMOS NIMO is for observing large spatial shifts in spawning, and this is best done by comparison with independent/historical surveys**. An area that has been fruitful using other ichthyoplankton data (Genner *et al.* 2010) has been monitoring changes in phenology, and IMOS NIMO will become increasingly useful for examining temporal shifts in spawning as monitoring continues. There are multiple groups of taxa with common patterns in phenology (Fig. 22), and detecting this seasonality at the NRS is a priority of the next few years. We should not underestimate the value of long-term monitoring of larval fish, even given the decades it often takes to detect trends in biological time series – there is much to be gained from the array of independent ichthyoplankton surveys (Table 2) by having a regular 'baseline' available to provide a broader temporal and spatial context for interpreting these surveys.

Using IMOS NIMO to address questions of change in abundance and community composition in the short-term requires more sampling effort. This can be done by sampling more water volume per sample (at least doubling), or by sampling additional days per month or additional stations per sampling day. We showed that samples taken hours apart are often as dissimilar as samples taken days and many kilometres apart (Section 2.2.4), so increased sampling within a single day is a viable option provided samples are > 2 hours apart and/or separated in space. Larval fish and other biological data are often surveyed using transects, e.g. the CalCOFI program, and the Franklin 1997-98 surveys used in this report (Figure 2). It has been demonstrated in the California Current system that a few stations along a single transect can provide larval fish time series useful for observing changing patterns in common species as well as assemblages (Koslow and Wright 2016). Although not essential to provide useful data, **an ambitious IMOS NIMO sampling design is a single transect of 4-5 stations sampled monthly at each NRS**. Of course, the costs of collecting, sorting, and especially identifying these increased number of samples must be considered, and a **1.0 FTE taxonomist would be essential**. And although there are currently few people in Australia with the expertise to sort these samples at the required taxonomic resolution, we consider IMOS NIMO a vehicle to encourage Australia's retention of this taxonomic expertise.

Table 5. Key questions that can be asked of larval fish abundance data, and the suitability of the NRS monitoring data for addressing these questions.

Question	Ability to Answer	Issues and Comments
Is there a temporal trend in *community composition*?	Possible; changes at an NRS will need to be large	Although there is considerable noise in abundances of individual taxa, larval fish communities can show consistent differences over large spatial ranges – even in a short time series (1-2 years); but measuring community change at a location would require a large change in the community (such as the mean MAI community becoming like the mean PH community)
Is there a temporal trend in larval abundance of a fish *functional group*?	Possible; groupings should be done 'a priori'	By combining fish into groups based on an aspect of their life history, some power to detect trends is gained by reducing the variance of individual taxa; taxa can be combined using 'indicator species analysis', but this should be done 'a priori' to avoid biasing results by clumping species using the trend being measured
Is there a temporal trend in larval abundance of a single fish *species/taxa*?	Possible; requires > 15 years of NRS time series, and often a severe trend	There is generally very high variance in abundance of larval fish, even between samples close in space and time; for numerous taxa there is consistent variation in abundance across large spatial ranges, which shows that abundance estimates at a point may be representative of a region, but the high variance makes it difficult to estimate abundance accurately
Is there a change in the *seasonality* of larval fish abundances (i.e. phenology)?	Possible; likely to require more NRS sampling effort for all but the most common taxa	Investigating seasonal trends in abundance can show if certain taxa are changing the timing of spawning (to follow cues from ocean temperature, for example); evidence from the Kamala 1989-93 surveys show that many taxa do show seasonality, but detecting this seasonality for individual taxa at the NRS has yet to be demonstrated; grouping taxa by 'seasonality mode' may aid analysis of phenology
Is there a change in the *spatial distribution* of a species/taxa?	Possible; restricted to NRS locations	This is possible, but requires a long time series of NRS data, and is restricted to species 'appearing' or 'disappearing' from a fixed NRS location; can be done using a short time series of NRS data when compared to historical survey data (as we did in Section 2.1.3.2), but may detect the appearance of uncommon species with current sampling effort
Do larval fish provide evidence of a marine ecosystem '*regime shift*'	Unlikely; but may contribute to a meta-analysis of time series	Evidence of regime shifts has been observed in larval fish time series (Brodeur *et al.* 2008), but this is unlikely solely with NIMO due to the large variability of the region (Litzow *et al.* 2016); NIMO may be valuable as one of the ~30 biological time series required to ask these ecosystem-scale questions (Litzow *et al.* 2016)

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6. APPENDIX A

Summary Table of Occurrence and Abundance

This appendix contains a table (Table S1) of the standard ‘species’ list used in the IMOS NIMO project, and the one used for the 8 historical cruises used in this report (see Table 2). Each set of taxa was split over two pages to communicate the data for all 11 data sets (8 historical cruises and 3 NRS).

Table S1. Summary of fish taxa caught in the 8 cruises and 3 NRS in this report. Each taxa's % occurrence, average abundance (N) per 1000 m^3, and abundance coefficient of variation (CV; SD/mean) is reported. Surface and oblique samples are pooled. Franklin 1997-98 includes only the 3 most eastern transects (see Fig. 2). The 20 most common taxa in each cruise are shaded grey; highlighted in blue are some AFMA-managed taxa.

Taxa #	Family	Common	Species	Sprightly 1983			Challenger 89-91			Kamala 1989-93			Franklin 1994			Franklin 1997-98			Franklin 1998-99		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
1	Acanthuridae	Surgeonfish		12.8	0.36	4.54	0	0	0	0.9	0.03	10.6	2.7	0.26	7.64	0	0	0	26.5	2.03	2.34
2	Acropomatidae	Threespine cardinalfish	Apogonops anomalus	10.4	1.33	5.52	0	0	0	13.8	4.31	4.43	19.7	1.14	2.96	0	0	0	7.6	0.27	4.08
3	Ammodytidae	Sand lance		0.8	0.02	13.9	0	0	0	0.3	0.01	18.3	0	0	0	0	0	0	29.5	1.43	2.67
4	Anguilliformes	Order of eels		44.7	5.66	3.26	8.4	0.91	3.72	18	6.64	4.31	57.4	19	2.04	1.7	0.03	7.74	34.8	2.98	3.15
5	Antennariidae	Anglerfish		0.8	0.01	11.5	0	0	0	1.5	0.08	8.64	3.6	0.12	5.34	0	0	0	0	0	0
6	Anthiinae	Sea perch		16.3	2.11	5.4	0	0	0	36.8	9.38	3.56	40.4	21.4	2.32	10.5	3.57	7	47	3.01	1.64
7	Aploactinidae	Velvetfish	Matsubarichthys inusitatus	1.4	0.03	10.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Aplodactylidae	Sea carp	Aplodactylus sp.	0	0	0	0	0	0	1.8	0.1	9.47	0.9	0.03	10.6	2.8	0.15	6.58	0	0	0
9	Apogonidae	Cardinal fish		8.2	0.41	7.57	0	0	0	2.7	0.1	6.39	4.9	0.16	4.65	2.2	0.41	8.24	39.4	2.82	2.62
10	Argentinidae	Herring smelt		0.3	0.39	19.2	0	0	0	1.2	0.05	10.4	10.8	0.62	4.49	9.9	0.76	5.99	2.3	0.04	6.59
11.1	Arripidae	Australian salmon	Arripis trutta	1.4	0.03	9.14	0	0	0	0.6	0.05	15.3	7.2	0.68	5.69	1.1	0.07	11.2	21.2	1.7	4.9
11	Arripidae	Australian salmon	other arripidae	4.6	0.06	6.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Astronesthidae	Dragonfish		8.4	1.02	8.94	0	0	0	3.3	0.15	5.93	6.7	0.29	4.77	0	0	0	0	0	0
13	Atherinidae	Hardyhead		0.3	0.01	19.2	0	0	0	1.8	0.14	9.32	0	0	0	0.6	0.04	13.4	2.3	0.2	7.78
14	Aulopidae	Sergeant Baker	Hime spp.	2.5	0.11	8.12	0	0	0	24	3.4	3.38	37.7	2.41	2.09	1.7	0.05	8.72	0	0	0
15	Balistidae	Triggerfish		3	0.05	6.76	0	0	0	0	0	0	0	0	0	0	0	0	13.6	0.47	3.45
16	Bathylaginae	Deepsea smelt		4.1	0.13	5.95	0.5	0.04	13.8	1.5	0.04	8.15	1.8	0.04	8.06	0	0	0	0	0	0
17.2	Berycidae	Redfish	Centroberyx affinis	8.7	0.24	4.98	0	0	0	7.2	1.05	5.27	55.6	31	2.14	0	0	0	0	0	0
17.1	Berycidae	Redfish	Beryx sp.	3.5	0.06	6.04	0	0	0	0	0	0	0.4	0.02	14.9	0	0	0	0	0	0
17	Berycidae	Redfish	other berycid	0	0	0	0	0	0	0	0	0	0.4	0.01	14.9	0.6	0.01	13.4	7.6	0.22	4.05
18.4	Blennidae	Blenny	Plagiotremus sp.	3.5	0.06	7.35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.3	Blennidae	Blenny	Petroscirtes lupus	5.7	0.23	6.1	0	0	0	0.9	0.1	12.7	0	0	0	0	0	0	0	0	0
18.2	Blennidae	Blenny	Omobranchus anolius	0.5	0.01	13.6	0	0	0	6	0.58	6.09	0	0	0	0	0	0	0	0	0
18.1	Blennidae	Blenny	Parablennius spp.	0.8	0.02	12.3	0	0	0	6.3	0.51	6.38	0	0	0	1.1	0.06	10.4	0	0	0
18	Blennidae	Blenny	other blennies	0.5	0.01	13.7	1.6	0.18	8.63	0	0	0	4.5	0.11	5.09	0	0	0	40.9	2.08	2.06

Table S1 (cont.). The three NRS are North Stradbroke Island (NSI), Port Hacking (PH), and Maria Island (MAI).

Taxa #	Family	Common	Species	South. Surv. 2004			Investigator 2015			NSI NRS			PH NRS			MAI NRS		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
1	Acanthuridae	Surgeonfish		0	0	0	9.7	0.24	3.37	11.8	2.82	3.09	0	0	0	0	0	0
2	Acropomatidae	Threespine cardinalfish	Apogonops anomalus	17.6	3.88	3.31	37.6	15.4	2.26	0	0	0	0	0	0	7.7	0.09	3.61
3	Ammodytidae	Sand lance		24.1	7.69	2.61	15.1	0.34	2.86	0	0	0	0	0	0	7.7	0.14	3.61
4	Anguilliformes	Order of eels		36.1	1.4	1.99	77.4	4.57	1.04	5.9	0.14	4.12	13.3	0.68	3.3	0	0	0
5	Antennariidae	Anglerfish		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Anthiinae	Sea perch		53.7	10.5	2.43	67.7	10.8	1.6	17.6	0.62	2.37	6.7	0.19	3.87	0	0	0
7	Aploactinidae	Velvetfish	Matsubarichthys inusitatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Aplodactylidae	Sea carp	Aplodactylus sp.	15.7	0.6	2.71	0	0	0	0	0	0	0	0	0	0	0	0
9	Apogonidae	Cardinal fish		6.5	0.09	3.97	18.3	0.34	2.44	35.3	1.33	1.61	6.7	0.38	3.87	0	0	0
10	Argentinidae	Herring smelt		0	0	0	54.8	2.26	1.45	0	0	0	0	0	0	0	0	0
11.1	Arripidae	Australian salmon	Arripis trutta	0	0	0	0	0	0	0	0	0	26.7	3.17	2.41	0	0	0
11	Arripidae	Australian salmon	other arripidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Astronesthidae	Dragonfish		28.7	0.77	1.85	0	0	0	0	0	0	0	0	0	0	0	0
13	Atherinidae	Hardyhead		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Aulopidae	Sergeant Baker	Hime spp.	8.3	0.2	3.65	30.1	0.71	2	0	0	0	6.7	0.13	3.87	0	0	0
15	Balistidae	Triggerfish		0	0	0	0	0	0	11.8	0.73	2.83	0	0	0	0	0	0
16	Bathylaginae	Deepsea smelt		2.8	0.1	6.24	26.9	0.75	2.61	0	0	0	0	0	0	0	0	0
17.2	Berycidae	Redfish	Centroberyx affinis	0	0	0	0	0	0	0	0	0	6.7	0.51	3.87	0	0	0
17.1	Berycidae	Redfish	Beryx sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Berycidae	Redfish	other berycid	0	0	0	4.3	0.06	4.75	0	0	0	0	0	0	0	0	0
18.4	Blennidae	Blenny	Plagiotremus sp.	0	0	0	6.5	0.1	3.88	17.6	0.53	2.31	0	0	0	0	0	0
18.3	Blennidae	Blenny	Petroscirtes lupus	0	0	0	1.1	0.05	9.64	5.9	0.2	4.12	6.7	0.19	3.87	0	0	0
18.2	Blennidae	Blenny	Omobranchus anolius	0	0	0	0	0	0	0	0	0	6.7	0.19	3.87	0	0	0
18.1	Blennidae	Blenny	Parablennius spp.	0	0	0	1.1	0.01	9.64	0	0	0	0	0	0	0	0	0
18	Blennidae	Blenny	other blennies	2.8	0.05	7.36	0	0	0	0	0	0	0	0	0	0	0	0

Table S1 (cont.).

Taxa #	Family	Common	Species	Sprightly 1983			Challenger 89-91			Kamala 1989-93			Franklin 1994			Franklin 1997-98			Franklin 1998-99		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
19.6	Bothidae	Flatfish	Crossorhombus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.5	Bothidae	Flatfish	Engyprosopon sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.4	Bothidae	Flatfish	Gramatobothus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.3	Bothidae	Flatfish	Lophonectes gallus	0	0	0	18.2	5	3.17	0	0	0	0	0	0	0	0	0	0	0	0
19.2	Bothidae	Flatfish	Arnoglossus sp.	0	0	0	0	0	0	0	0	0	0	0	0	16	0.63	3.92	0	0	0
19.1	Bothidae	Flatfish	Asterorhombus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Bothidae	Flatfish	other bothids	49.9	9.16	2.99	0	0	0	47.3	44.7	2.88	54.3	8.02	2.01	2.2	0.13	8.04	78	16.8	1.46
20.2	Bovichthidae	Thornfishes	Bovichthus augustifrons	0	0	0	0	0	0	0.6	0.09	12.9	0	0	0	1.1	0.05	10.7	0	0	0
20.1	Bovichthidae	Thornfishes	Pseudaphritis urvilli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Bramidae	Pomfret	Brama sp.	2.5	0.03	6.71	0	0	0	1.2	0.04	9.12	3.6	0.08	5.66	0	0	0	3.8	0.51	6.16
22	Bregmacerotidae	Codlets	Bregmaceros spp.	10.9	0.45	4.67	0	0	0	4.8	0.22	5.35	12.6	0.61	4.21	0	0	0	3.8	0.14	7.09
23	Callanthidae	Splendid perch	Callanthias australis	2.7	0.08	9.41	0	0	0	23.1	7.6	4.03	6.7	0.15	4.09	1.1	0.01	9.49	1.5	0.04	8.32
24	Callionymidae	Dragonets		33.5	3.7	3.04	12.9	1.52	3.33	40.1	7.32	2.07	50.7	9.43	3.34	21.5	0.77	2.58	74.2	27.3	2.54
25	Caproidae	Boarfishes	Antigonia sp.	1.6	0.03	8.71	0	0	0	0	0	0	5.4	0.16	5.2	0	0	0	6.8	0.33	4.58
26.5	Carangidae	Scad	Pseudocaranx dentex	0	0	0	0	0	0	18	79.6	5.9	18.8	17.6	6.06	5	0.4	6.26	0	0	0
26.4	Carangidae	Jack mackerel	Trachurus declivus	0	0	0	30.3	73.4	4.93	0	0	0	0	0	0	11.6	1.19	5.44	0	0	0
26.3	Carangidae	Scad	Decapterus spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.2	Carangidae	Yellowtail	Trachurus novaezelandiae	0	0	0	0	0	0	33.2	27.4	4.87	35.4	57.7	5.61	0	0	0	0	0	0
26.1	Carangidae	Kingfish	Seriola sp.	5.4	0.14	5.52	0	0	0	2.7	0.49	10.2	2.2	0.1	9.69	0.6	0.01	13.4	0	0	0
26	Carangidae	Scad	other scads	25.6	14.3	7.83	0	0	0	1.2	0.04	9.1	31.4	14.5	3.11	0	0	0	90.9	64.1	2.56
27	Carapidae	Pearlfish		7.6	0.1	3.79	1.6	0.13	7.96	8.1	0.31	3.9	17	0.53	2.77	5.5	0.14	5.41	2.3	0.04	6.87
28	Centrolophidae	Trevallas	Seriolella spp.	0	0	0	0	0	0	8.4	1.68	9.07	0	0	0	15.5	1.25	4.6	10.6	0.42	4.15
29	Cepolidae	Bandfish	Cepola australis	16.3	1.09	5.08	0	0	0	35.9	13.9	3.22	27.8	9.83	4.58	6.1	0.13	6.35	9.1	0.76	6.72
30	Cetomimidae	Whalefish		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	Chaetodontidae	Butterfly fish		13.4	0.64	4.14	0	0	0	2.1	0.07	7.17	2.2	0.05	7.26	0	0	0	25	1.93	3.07
32	Champsodontidae	Gapers		7.1	0.1	4.44	0	0	0	3	0.14	6.7	8.1	0.2	4.65	0	0	0	1.5	0.13	8.13

Table S1 (cont.).

Taxa #	Family	Common	Species	South. Surv. 2004			Investigator 2015			NSI NRS			PH NRS			MAI NRS		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
19.6	Bothidae	Flatfish	Crossorhombus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.5	Bothidae	Flatfish	Engyprosopon sp.	0	0	0	0	0	0	17.6	2.42	3.4	13.3	0.31	2.69	0	0	0
19.4	Bothidae	Flatfish	Gramatobothus sp.	0	0	0	0	0	0	29.4	13.6	2.25	0	0	0	0	0	0
19.3	Bothidae	Flatfish	Lophonectes gallus	0	0	0	0	0	0	0	0	0	66.7	8.7	1.21	0	0	0
19.2	Bothidae	Flatfish	Arnoglossus sp.	0	0	0	0	0	0	0	0	0	6.7	0.11	3.87	0	0	0
19.1	Bothidae	Flatfish	Asterorhombus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Bothidae	Flatfish	other bothids	75	22.7	2.24	88.2	7.99	1.28	17.6	2.27	2.49	0	0	0	38.5	2.39	1.75
20.2	Bovichthidae	Thornfishes	Bovichthus augustifrons	0	0	0	0	0	0	0	0	0	0	0	0	7.7	1.12	3.61
20.1	Bovichthidae	Thornfishes	Pseudaphritis urvilli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Bramidae	Pomfret	Brama sp.	22.2	1.11	2.73	21.5	0.52	2.16	5.9	0.2	4.12	6.7	0.12	3.87	0	0	0
22	Bregmacerotidae	Codlets	Bregmaceros spp.	17.6	0.51	2.76	64.5	5.01	1.7	17.6	0.95	2.53	0	0	0	0	0	0
23	Callanthidae	Splendid perch	Callanthias australis	21.3	1.02	2.76	1.1	0.02	9.64	5.9	0.34	4.12	0	0	0	0	0	0
24	Callionymidae	Dragonets		25.9	1.19	2.74	75.3	4.62	1.08	70.6	20.2	1.12	33.3	2.16	2.73	0	0	0
25	Caproidae	Boarfishes	Antigonia sp.	0	0	0	12.9	0.28	3.33	17.6	1.07	2.33	6.7	0.11	3.87	0	0	0
26.5	Carangidae	Scad	Pseudocaranx dentex	3.7	0.15	5.21	11.8	0.36	4.43	11.8	0.64	2.91	46.7	8.26	2.49	0	0	0
26.4	Carangidae	Jack mackerel	Trachurus declivus	0	0	0	0	0	0	0	0	0	6.7	0.22	3.87	53.8	58.7	3.29
26.3	Carangidae	Scad	Decapterus spp.	0	0	0	0	0	0	5.9	0.48	4.12	0	0	0	0	0	0
26.2	Carangidae	Yellowtail	Trachurus novaezelandiae	0	0	0	43	10.1	2.23	58.8	167	1.96	80	42	1.87	0	0	0
26.1	Carangidae	Kingfish	Seriola sp.	1.9	0.07	7.33	17.2	1.01	3.3	0	0	0	6.7	0.87	3.87	0	0	0
26	Carangidae	Scad	other scads	73.1	102	1.54	0	0	0	41.2	4.5	1.71	6.7	0.2	3.87	0	0	0
27	Carapidae	Pearlfish		0.9	0.01	10.4	12.9	0.22	2.99	5.9	0.2	4.12	0	0	0	0	0	0
28	Centrolophidae	Trevallas	Seriolella spp.	7.4	0.13	3.95	1.1	0.02	9.64	0	0	0	0	0	0	15.4	0.46	2.76
29	Cepolidae	Bandfish	Cepola australis	8.3	0.56	5.54	14	0.43	2.94	0	0	0	13.3	0.79	2.64	0	0	0
30	Cetomimidae	Whalefish		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	Chaetodontidae	Butterfly fish		4.6	0.09	5.01	16.1	0.54	3.22	52.9	4.05	1.4	0	0	0	0	0	0
32	Champsodontidae	Gapers		13	0.29	3.33	21.5	1.46	3.15	0	0	0	0	0	0	0	0	0

Table S1 (cont.).

Taxa #	Family	Common	Species	Sprightly 1983			Challenger 89-91			Kamala 1989-93			Franklin 1994			Franklin 1997-98			Franklin 1998-99		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
33.2	Chandidae	Port Jackson perchlet	Ambassis jacksoniensis	1.4	0.06	10.9	0	0	0	9.6	1.74	5.39	6.3	0.46	6.15	0.6	0.01	13.4	27.3	1.28	3.09
33.1	Chandidae	Estuary perchlet	Ambassis marianus	0.5	0.01	15.7	0	0	0	1.5	0.27	11.6	0	0	0	0	0	0	0	0	0
34	Chauliodontidae	Viperfish		4.4	0.04	4.97	0	0	0	0.3	0.01	18.3	1.3	0.03	9.03	0	0	0	0	0	0
35.2	Cheilodactylidae	Jackass morwong	Nemadactylus macropterus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35.1	Cheilodactylidae	Morwong	Cheilodactylus sp.	2.2	0.53	12.3	7.4	1.2	5.08	18.6	7.52	5.36	27.4	3.1	2.41	5	0.3	6.14	3.8	0.11	6.01
36	Chiasmodontidae	Swallowers		27.2	0.75	2.61	0	0	0	4.2	0.36	7.54	11.2	0.4	3.92	0.6	0.01	13.4	0	0	0
37	Chironemidae	Marblefish	Chironemus sp.	0	0	0	0	0	0	0	0	0	0	0	0	2.2	0.03	6.68	4.5	0.15	5.55
38	Chloropthalmidae	Greeneyes	Chloropthalmus sp	1.9	0.02	7.59	0	0	0	3.3	0.12	5.65	0.4	0.03	14.9	4.4	0.15	5.09	0	0	0
39	Cirrhitidae	Hawkfish		8.2	0.38	4.95	0	0	0	0.9	0.03	10.7	1.8	0.12	9.08	0	0	0	3.8	0.19	7.52
40	Clinidae	Weedfishes		0	0	0	2.6	0.36	7.07	3	0.15	6.71	0	0	0	5	0.61	8.46	0	0	0
42.4	Clupeidae	Pilchard	Sardinops sagax	28.9	18.6	4.49	0	0	0	35.6	67.4	4.07	11.2	3.81	5.11	11.6	10.7	5.85	0	0	0
42.3	Clupeidae	Maray	Etrumeus teres	33.2	15	3.74	0	0	0	3.3	0.11	5.63	10.3	0.52	3.61	0	0	0	0	0	0
42.2	Clupeidae	Sandy sprat	Hyperlophus vittatus	0.5	0.03	16.2	0	0	0	12.3	2.81	6.55	7.2	5.88	13.6	0.6	0.01	13.4	0	0	0
42.1	Clupeidae	Blue sprat	Spartelloides robustus	0	0	0	0	0	0	0.3	0.01	18.3	0	0	0	0	0	0	0	0	0
42	Clupeidae	Herring	other herrings	0	0	0	7.9	1.26	4.33	0	0	0	7.6	0.73	5.67	0	0	0	76.5	102	2.18
43	Coryphaenidae	Dolphin fish	Coryphena sp.	7.6	0.16	4.37	0	0	0	0.3	0.01	18.3	5.8	0.29	4.47	0	0	0	9.1	0.73	3.68
44.2	Creediidae	Sand burrower	Creedia sp.	0.8	0.02	11.2	0	0	0	26.9	7.99	3.55	0	0	0	7.2	0.32	5.15	9.8	0.31	4.69
44.1	Creediidae	Sand burrower	Limnichthys sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	Creediidae	Sand burrower	other creedid	1.6	0.15	10.2	0	0	0	0	0	0	27.4	4.87	3.29	0	0	0	6.8	0.27	4.61
45	Cynoglossidae	Tongue sole		2.5	0.04	8.86	0	0	0	5.1	0.26	5.09	21.1	1.19	3.06	3.9	0.2	6.67	66.7	12.1	1.68
46	Dactylopteridae	Flying gurnard	Dactyloptena sp.	9.3	0.41	5.82	0	0	0	0.6	0.02	13.3	6.3	0.27	4.46	0	0	0	36.4	3.17	2.51
47	Dinolestidae	Long fin pike	Dinolestis lewini	0	0	0	0	0	0	6	0.57	5.49	0	0	0	0	0	0	0	0	0
48	Diretmidae	Discfish	Diretmus sp.	1.9	0.03	7.71	0	0	0	0.3	0.01	18.3	0	0	0	0	0	0	0	0	0
49	Emmelichthys	Redbait	Emmelichthys nitidatus	0	0	0	0	0	0	0.3	0.06	18.3	0	0	0	0.6	0.01	13.4	0	0	0
50	Engraulidae	Anchovy	Engraulis australis	37.1	16.9	5.21	1.1	0.27	10	21.6	5.13	4.21	18.4	5.15	5.62	9.4	3.12	4.61	42.4	3.41	2.81

Table S1 (cont.).

Taxa #	Family	Common	Species	South. Surv. 2004			Investigator 2015			NSI NRS			PH NRS			MAI NRS		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
33.2	Chandidae	Port Jackson perchlet	Ambassis jacksoniensis	0	0	0	0	0	0	0	0	0	6.7	0.38	3.87	0	0	0
33.1	Chandidae	Estuary perchlet	Ambassis marianus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	Chauliodontidae	Viperfish		0.9	0.03	10.4	7.5	0.14	3.89	0	0	0	0	0	0	0	0	0
35.2	Cheilodactylidae	Jackass morwong	Nemadactylus macropterus	0	0	0	0	0	0	0	0	0	0	0	0	7.7	1.63	3.61
35.1	Cheilodactylidae	Morwong	Cheilodactylus sp.	5.6	0.29	5.37	26.9	3.38	2.48	0	0	0	6.7	0.1	3.87	7.7	1.26	3.61
36	Chiasmodontidae	Swallowers		9.3	0.23	3.89	2.2	0.03	6.9	0	0	0	0	0	0	0	0	0
37	Chironemidae	Marblefish	Chironemus sp.	18.5	0.58	2.85	0	0	0	0	0	0	0	0	0	0	0	0
38	Chloropthalmidae	Greeneyes	Chloropthalmus sp	0	0	0	2.2	0.07	6.84	5.9	0.11	4.12	0	0	0	0	0	0
39	Cirrhitidae	Hawkfish		3.7	0.08	5.77	18.3	0.69	2.49	5.9	0.2	4.12	0	0	0	0	0	0
40	Clinidae	Weedfishes		0	0	0	0	0	0	0	0	0	0	0	0	7.7	0.13	3.61
42.4	Clupeidae	Pilchard	Sardinops sagax	75.9	113	2.67	9.7	0.27	3.47	41.2	35.9	2.19	86.7	17.4	1.18	61.5	16.5	2.39
42.3	Clupeidae	Maray	Etrumeus teres	49.1	20	2.23	50.5	6.39	2.24	23.5	1.23	2.1	13.3	0.29	2.74	0	0	0
42.2	Clupeidae	Sandy sprat	Hyperlophus vittatus	10.2	1.56	4.84	0	0	0	0	0	0	0	0	0	0	0	0
42.1	Clupeidae	Blue sprat	Spartelloides robustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	Clupeidae	Herring	other herrings	10.2	1.8	3.72	0	0	0	0	0	0	0	0	0	0	0	0
43	Coryphaenidae	Dolphin fish	Coryphena sp.	0.9	0.02	10.4	11.8	0.34	3.3	11.8	0.84	2.84	0	0	0	0	0	0
44.2	Creediidae	Sand burrower	Creedia sp.	0	0	0	0	0	0	5.9	0.55	4.12	13.3	0.54	2.9	0	0	0
44.1	Creediidae	Sand burrower	Limnichthys sp.	0	0	0	0	0	0	5.9	0.18	4.12	0	0	0	0	0	0
44	Creediidae	Sand burrower	other creedid	0.9	0.01	10.4	2.2	0.03	6.78	0	0	0	0	0	0	0	0	0
45	Cynoglossidae	Tongue sole		22.2	0.95	2.54	28	0.85	2.09	17.6	3.2	3.1	6.7	0.77	3.87	0	0	0
46	Dactylopteridae	Flying gurnard	Dactyloptena sp.	0	0	0	3.2	0.1	5.86	23.5	1.44	2.24	6.7	0.19	3.87	0	0	0
47	Dinolestidae	Long fin pike	Dinolestis lewini	0	0	0	0	0	0	0	0	0	0	0	0	7.7	0.21	3.61
48	Diretmidae	Discfish	Diretmus sp.	0.9	0.01	10.4	9.7	0.17	3.44	0	0	0	0	0	0	0	0	0
49	Emmelichthys	Redbait	Emmelichthys nitidatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	Engraulidae	Anchovy	Engraulis australis	57.4	19.4	2.04	50.5	5.93	57.4	41.2	7.06	2.12	26.7	2.32	2.61	23.1	17.7	3.17

Table S1 (cont.).

Taxa #	Family	Common	Species	Sprightly 1983			Challenger 89-91			Kamala 1989-93			Franklin 1994			Franklin 1997-98			Franklin 1998-99		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
51	Enoplosidae	Old wife	Enoplosus armatus	0	0	0	0	0	0	2.1	0.11	7.64	0	0	0	0.6	0.01	13.4	11.4	0.6	4.88
52	Epinephelinae	Grouper		9.8	0.57	5.13	0	0	0	6	2.75	8.84	1.3	0.07	9.13	0	0	0	0	0	0
53	Evermannellidae	Sabretooth		3.3	0.07	7	0	0	0	2.1	0.09	7.25	0.9	0.02	11.8	0	0	0	0	0	0
54	Exocetidae	flying fish		10.1	0.35	5.61	0	0	0	1.5	0.09	9.2	1.8	0.06	7.47	2.8	0.13	6.72	22.7	1.64	2.88
55	Fistulariidae	Flutemouth		0	0	0	0	0	0	1.5	0.06	9.38	1.3	0.11	9.36	0	0	0	1.5	0.03	8.78
56.3	Gempylidae	Barracouda	Thyrsites atun	0.5	0.01	15.4	10	1.8	4.19	0	0	0	0	0	0	11	3.04	6.41	0	0	0
56.2	Gempylidae	Gemfish	Rexea solandri	0	0	0	0	0	0	0.6	0.02	12.9	0	0	0	0.6	0.01	13.4	0	0	0
56.1	Gempylidae	Snake mackeral	Gempylus serpens	2.5	0.02	6.57	0	0	0	0.3	0.01	18.3	0	0	0	0	0	0	0	0	0
56	Gempylidae		other gempylid	3	0.05	9.38	0	0	0	1.5	0.14	10.2	6.7	0.26	4.74	0.6	0.02	13.4	3	0.09	7.87
57.2	Gerreidae	Silver belly	Gerres subfasciatus	6.3	0.39	7.63	0	0	0	7.8	4.57	5.62	7.6	1.5	6.1	0	0	0	25.8	1.42	2.57
57.1	Gerreidae	Silver belly	Parequula melbournensis	1.6	0.03	8.63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58.1	Girellidae	Luderick	Girella tricuspidata	1.4	0.16	16.1	0	0	0	3.6	0.53	8.08	3.1	0.29	7.39	2.2	0.31	8.62	10.6	0.52	4.64
58	Girellidae	Luderick	other girellids	0.3	0	19.2	0	0	0	0.9	0.06	10.6	0.9	0.14	13.8	0	0	0	0	0	0
59	Gobidae	Goby		34.6	7.66	3.9	2.6	0.5	8.87	39.5	10.3	2.76	51.1	5.2	1.8	12.7	1.29	5.74	84.8	40	1.59
60.1	Gobiesocidae	Clingfish	Alabes sp.	0	0	0	0	0	0	0.3	0.02	18.3	3.6	0.25	6.62	2.8	0.2	6.87	0	0	0
60	Gobiesocidae	Clingfish	other clingfish	0.3	0.09	19.2	0	0	0	16.2	2.17	4.55	0.9	0.05	11.8	0.6	0.01	13.4	14.4	0.5	4.49
61	Gonorhynchidae	Beak salmon	Gonorhynchus greyi	27.8	55.5	8.8	0	0	0	6	17.2	12.8	43.9	34.8	3.04	0	0	0	20.5	1.69	4.4
62	Gonostomatidae	Bristlemouth		52.3	13.3	2.12	0.5	0.04	13.8	25.4	1.8	2.32	74.9	79.4	5.87	2.2	0.04	6.83	2.3	0.05	6.96
63	Grammistidae	Soapfish		0.8	0.01	11.6	0	0	0	0.3	0.01	18.3	0	0	0	0	0	0	0	0	0
64	Haemulidae	Sweetlips		0.8	0.03	14.6	0	0	0	0.9	0.03	10.8	0	0	0	0	0	0	9.8	0.29	3.64
65	Hemiramphidae	Garfish	Hemiramphus spp.	9.8	0.32	4.72	0	0	0	0.9	0.03	10.9	0	0	0	0.6	0.01	13.4	7.6	0.32	4.17
66	Holocentridae	Squirell fish		15.3	0.42	3.83	0	0	0	0	0	0	0.9	0.03	10.6	0	0	0	15.9	1.24	3.83
67	Hoplichthyidae	Ghost flathead	Hoplichthys sp.	0.3	0	19.2	0	0	0	3.6	0.18	6.13	0.4	0.01	14.9	0	0	0	0	0	0
68	Howellidae	Pelagic bass	Howella sp.	5.2	0.44	6.42	0	0	0	4.2	0.46	7.56	18.4	1.74	4.26	1.1	0.02	9.56	0	0	0
69	Idiacanthidae	Black dragonfish	Idiacanthus sp.	6.8	0.34	6.55	0	0	0	0.6	0.02	13.6	0.9	0.02	10.8	1.1	0.04	9.56	0	0	0
70	Ipnopidae	Tripodfish		0.3	0	19.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table S1 (cont.).

Taxa #	Family	Common	Species	South. Surv. 2004			Investigator 2015			NSI NRS			PH NRS			MAI NRS		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
51	Enoplosidae	Old wife	Enoplosus armatus	0	0	0	0	0	0	0	0	0	6.7	0.38	3.87	0	0	0
52	Epinephelinae	Grouper		0.9	0.01	10.4	0	0	0.9	17.6	0.67	2.24	13.3	1.75	2.8	0	0	0
53	Evermannellidae	Sabretooth		3.7	0.05	5.29	38.7	1.95	3.7	0	0	0	0	0	0	0	0	0
54	Exocetidae	flying fish		13.9	1.5	3.76	4.3	0.08	13.9	0	0	0	0	0	0	0	0	0
55	Fistulariidae	Flutemouth		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56.3	Gempylidae	Barracouda	Thyrsites atun	0	0	0	0	0	0	0	0	0	0	0	0	15.4	0.55	3.13
56.2	Gempylidae	Gemfish	Rexea solandri	11.1	0.43	3.05	0	0	11.1	0	0	0	6.7	0.12	3.87	0	0	0
56.1	Gempylidae	Snake mackeral	Gempylus serpens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	Gempylidae		other gempylid	18.5	0.63	2.7	80.6	4.8	18.5	11.8	0.74	2.83	0	0	0	0	0	0
57.2	Gerreidae	Silver belly	Gerres subfasciatus	0	0	0	0	0	0	11.8	0.77	3.09	0	0	0	0	0	0
57.1	Gerreidae	Silver belly	Parequula melbournensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58.1	Girellidae	Luderick	Girella tricuspidata	3.7	0.81	7.95	0	0	3.7	0	0	0	20	0.65	2.23	0	0	0
58	Girellidae	Luderick	other girellids	2.8	0.08	5.96	0	0	2.8	0	0	0	6.7	0.22	3.87	0	0	0
59	Gobidae	Goby		28.7	1.49	2.56	78.5	7.05	28.7	70.6	15.8	1.47	26.7	3.4	3.05	7.7	0.14	3.61
60.1	Gobiesocidae	Clingfish	Alabes sp.	0	0	0	0	0	0	0	0	0	6.7	0.19	3.87	0	0	0
60	Gobiesocidae	Clingfish	other clingfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	Gonorhynchidae	Beak salmon	Gonorhynchus greyi	9.3	0.52	6.17	53.8	14.5	9.3	0	0	0	0	0	0	0	0	0
62	Gonostomatidae	Bristlemouth		60.2	5.23	1.32	75.3	8.33	60.2	47.1	3.95	1.44	26.7	0.84	2.07	7.7	0.07	3.61
63	Grammistidae	Soapfish		0	0	0	2.2	0.03	0	0	0	0	0	0	0	0	0	0
64	Haemulidae	Sweetlips		0	0	0	22.6	0.91	0	11.8	0.4	2.84	0	0	0	0	0	0
65	Hemiramphidae	Garfish	Hemiramphus spp.	3.7	0.14	5.14	1.1	0.02	3.7	0	0	0	0	0	0	0	0	0
66	Holocentridae	Squirell fish		0	0	0	1.1	0.03	0	23.5	3.44	2.63	0	0	0	0	0	0
67	Hoplichthyidae	Ghost flathead	Hoplichthys sp.	0.9	0.01	10.4	1.1	0.01	0.9	0	0	0	0	0	0	0	0	0
68	Howellidae	Pelagic bass	Howella sp.	33.3	1.33	1.95	78.5	13.9	33.3	0	0	0	0	0	0	0	0	0
69	Idiacanthidae	Black dragonfish	Idiacanthus sp.	0.9	0.01	10.4	9.7	0.14	3.43	0	0	0	0	0	0	0	0	0
70	Ipnopidae	Tripodfish		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table S1 (cont.).

Taxa #	Family	Common	Species	Sprightly 1983			Challenger 89-91			Kamala 1989-93			Franklin 1994			Franklin 1997-98			Franklin 1998-99		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
71	Istiophoridae	Marlin		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	Kyphosidae	Drummer	Kyphosus sp.	1.4	0.04	14.9	0	0	0	5.1	0.38	4.74	4	0.4	6.97	0	0	0	31.1	1.71	2.12
73	Labridae	Wrasse		43.9	10.6	3.09	0	0	0	40.1	17.1	3.99	46.6	5.31	2.36	7.2	0.79	5.89	80.3	21	1.4
74	Lampridiformes	Ribbonfish		4.4	0.07	6.9	0	0	0	0	0	0	5.8	0.19	5.08	1.7	0.03	7.92	0	0	0
75.1	Latridae	Trumpeter	Latris lineata	0	0	0	0	0	0	0	0	0	0	0	0	0.6	0.01	13.4	0	0	0
75	Latridae	Trumpeter	other latrids	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	Leiognathidae	Ponyfish		0	0	0	0	0	0	1.5	0.05	8.22	0	0	0	0	0	0	5.3	0.18	6.23
77	Leptoscopid	Sandfish		0.3	0	19.2	0	0	0	1.2	0.04	9.16	0.4	0.01	14.9	1.1	0.04	10.4	1.5	0.04	8.56
78	Lethrinidae	Emperor	Lethrinus sp.	24.3	2.96	3.6	0	0	0	0.3	0.01	18.3	0.9	0.02	11.5	0	0	0	47	5.43	1.8
79	Lophiformes	Anglerfish		14.7	0.3	3.12	0	0	0	5.7	0.32	4.52	18.8	0.71	2.57	0	0	0	1.5	0.03	8.2
80	Lutjanidae	Snapper		31.3	3.31	3.32	0	0	0	1.2	0.04	9.38	3.1	0.07	5.93	0	0	0	69.7	14.2	1.47
81	Macroramphosidae	Bellowsfish	Macroramphosus sp.	6.3	2.16	12.1	0	0	0	34.1	20	2.66	34.1	5.15	2.57	4.4	0.15	5.46	0.8	0.01	11.5
82	Macrouridae	Rattail		0.5	0.01	13.9	0	0	0	0.3	0.02	18.3	17.5	1.22	2.98	0	0	0	2.3	0.04	6.8
83.2	Malacanthidae	Tilefish	Branchiostegus sp	3.8	0.06	6.32	0	0	0	3.3	0.27	6.64	4.5	0.11	5.35	0	0	0	0.8	0.01	11.5
83.1	Malacanthidae	Blanquillo	Malacanthus sp.	1.1	0.01	11.5	0	0	0	0.3	0.01	18.3	0	0	0	0	0	0	0	0	0
84	Melamphaidae	Bigscale		7.6	0.56	5.48	0	0	0	2.4	0.51	11.3	16.1	0.94	3.35	1.1	0.02	9.81	1.5	0.02	8.1
85	Melanostomiidae	Black dragonfish		18	0.99	4.71	0	0	0	6.3	0.4	6.36	11.7	0.41	3.64	0	0	0	0	0	0
86.2	Microcanthidae	Mado	Atypichthys strigatus	0	0	0	0	0	0	4.2	0.22	5.54	6.3	0.18	4.62	2.8	0.18	7.35	31.8	15.9	4.5
86.1	Microcanthidae	Stripey	Microcanthus strigatus	0	0	0	0	0	0	0.3	0.01	18.3	0	0	0	0	0	0	0	0	0
87	Microdesmidae	Wormfish		1.4	0.04	12.4	0	0	0	0	0	0	0.4	0.02	14.9	0	0	0	28.8	3.52	2.78
88	Molidae	Sunfish		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	Monacanthidae	Leatherjacket		5.4	1.63	11.4	22.1	4.62	3.71	17.4	1.74	3.21	17.5	0.69	3.16	21	14.2	6.52	47	2.51	2.18
90.2	Monodactylidae	Diamondfish	Monodactylus sp.	0.3	0.01	19.2	0	0	0	0.3	0.02	18.3	0.4	0.03	14.9	0	0	0	0	0	0
90.1	Monodactylidae	Pomfred	Schuetta sp.	6	1.05	8.46	0	0	0	2.4	0.19	7.93	5.8	0.82	7.09	0	0	0	1.5	0.06	9.83
91	Moridae	Beardies		3.5	0.08	5.87	6.6	0.95	5.72	31.4	7.61	2.72	23.3	1.49	4.37	39.2	5.09	3.07	0	0	0
92.1	Mugilidae	Mullet	Liza argentea	2.2	0.03	8.25	0	0	0	26.6	3.35	3.17	4.9	0.41	5.81	0	0	0	0	0	0
92	Mugilidae	Mullet	other mullet	2.2	0.07	11.5	4.7	0.63	5.56	1.2	0.06	10.3	17.5	1.23	5.27	4.4	0.18	6.36	9.1	0.4	4.4

Table S1 (cont.).

Taxa #	Family	Common	Species	South. Surv. 2004			Investigator 2015			NSI NRS			PH NRS			MAI NRS		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
71	Istiophoridae	Marlin		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	Kyphosidae	Drummer	Kyphosus sp.	0	0	0	0	0	0	0	0	0	6.7	0.38	3.87	0	0	0
73	Labridae	Wrasse		55.6	9.95	3.72	93.5	19.9	1.33	76.5	34.4	1.9	40	2.58	2.84	15.4	1.55	3.32
74	Lampridiformes	Ribbonfish		0.9	0.01	10.4	3.2	0.05	5.71	0	0	0	6.7	0.11	3.87	0	0	0
75.1	Latridae	Trumpeter	Latris lineata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	Latridae	Trumpeter	other latrids	0.9	0.02	10.4	0	0	0	0	0	0	0	0	0	0	0	0
76	Leiognathidae	Ponyfish		2.8	0.26	6.14	2.2	0.06	7.84	0	0	0	0	0	0	0	0	0
77	Leptoscopid	Sandfish		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	Lethrinidae	Emperor	Lethrinus sp.	25	1.63	2.85	23.7	2.09	2.89	64.7	9.35	2.3	6.7	0.16	3.87	0	0	0
79	Lophiformes	Anglerfish		2.8	0.06	6.44	43	0.95	1.62	0	0	0	0	0	0	0	0	0
80	Lutjanidae	Snapper		10.2	0.32	3.95	15.1	0.34	3.08	82.4	23.5	1.67	6.7	0.16	3.87	0	0	0
81	Macroramphosidae	Bellowsfish	Macroramphosus sp.	38	9.43	2.91	16.1	0.32	2.99	23.5	6.59	2.87	26.7	4.77	2.64	0	0	0
82	Macrouridae	Rattail		0	0	0	0	0	0	11.8	0.61	2.94	0	0	0	0	0	0
83.2	Malacanthidae	Tilefish	Branchiostegus sp.	0	0	0	10.8	0.26	3.25	0	0	0	0	0	0	0	0	0
83.1	Malacanthidae	Blanquillo	Malacanthus sp.	0	0	0	4.3	0.05	4.75	0	0	0	0	0	0	0	0	0
84	Melamphaidae	Bigscale		1.9	0.07	8.93	20.4	0.4	2.42	0	0	0	0	0	0	0	0	0
85	Melanostomiidae	Black dragonfish		12	0.4	3.41	62.4	4.75	1.91	0	0	0	0	0	0	0	0	0
86.2	Microcanthidae	Mado	Atypichthys strigatus	33.3	5.73	2.94	14	0.34	3.16	5.9	0.2	4.12	6.7	0.13	3.87	0	0	0
86.1	Microcanthidae	Stripey	Microcanthus strigatus	7.4	0.44	5.5	1.1	0.02	9.64	0	0	0	0	0	0	0	0	0
87	Microdesmidae	Wormfish		0	0	0	2.2	0.03	6.79	23.5	1.49	2.02	0	0	0	0	0	0
88	Molidae	Sunfish		0	0	0	1.1	0.03	9.64	0	0	0	0	0	0	0	0	0
89	Monacanthidae	Leatherjacket		20.4	0.58	2.59	9.7	0.16	3.2	35.3	1.86	1.71	33.3	5.91	2.41	38.5	3.03	1.94
90.2	Monodactylidae	Diamondfish	Monodactylus sp.	0	0	0	0	0	0	0	0	0	6.7	0.11	3.87	0	0	0
90.1	Monodactylidae	Pomfred	Schuetta sp.	0	0	0	0	0	0	0	0	0	6.7	1.54	3.87	0	0	0
91	Moridae	Beardies		8.3	0.23	4.43	5.4	0.09	4.45	0	0	0	0	0	0	7.7	0.23	3.61
92.1	Mugilidae	Mullet	Liza argentea	0	0	0	1.1	0.01	9.64	11.8	0.42	2.83	13.3	2.51	3.55	0	0	0
92	Mugilidae	Mullet	other mullet	2.8	0.13	6.65	16.1	0.34	3.11	0	0	0	6.7	0.15	3.87	23.1	3.07	3.19

Table S1 (cont.).

Taxa #	Family	Common	Species	Sprightly 1983			Challenger 89-91			Kamala 1989-93			Franklin 1994			Franklin 1997-98			Franklin 1998-99		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
93	Mullidae	Goatfish		37.9	17.9	4.14	0	0	0	8.7	2.26	9.92	40.8	3.3	2.12	7.2	1.1	5.96	43.2	12.9	3.74
94	Myctophidae	Lanternfish		64.6	58.6	1.96	21.8	3.15	3.24	50.9	25.6	2.3	86.1	202	2.76	25.4	4.29	3.84	43.2	31.5	4.65
95	Nemipteridae	Threadfin bream		28.9	14.4	6.13	0	0	0	6.6	0.29	4.94	3.6	0.07	5.4	0	0	0	50.8	4.77	1.77
96	Nomeidae	Driftfish		11.4	0.28	5.44	1.6	2.71	11	4.5	0.16	5.04	8.1	0.44	4.41	0	0	0	0.8	0.03	11.5
97	Notosudidae	Paperbones		24	3.77	3.59	0	0	0	7.8	0.68	5.74	17.5	0.71	2.92	0.6	0.02	13.4	8.3	0.83	6.44
98	Odacidae	Rock cale		0	0	0	0	0	0	15.3	1.79	3.81	7.2	0.26	4.65	2.8	0.12	7.84	37.9	1.73	1.86
99.1	Ophidiidae	Ling	Genyptrus sp.	0	0	0	0	0	0	2.4	0.09	6.92	2.2	0.04	6.88	2.2	0.09	9.34	0	0	0
99	Ophidiidae	Ling	other ling	2.5	0.03	7.42	0.3	0.02	19.5	0	0	0	4	0.12	5.79	1.1	0.01	9.5	9.1	0.24	3.89
100	Ostraciidae	Cowfish		11.4	0.33	4.12	0	0	0	1.2	0.03	9.12	3.6	0.17	6.11	0	0	0	15.9	0.94	3.19
101	Paralepidae	Barracudinas		24.8	0.69	3.02	0.5	0.04	13.8	3.3	0.29	7.24	19.3	2.67	6.68	3.3	0.05	5.82	4.5	0.08	5.08
102	Paralichthyidae	Large tooth flounder	Pseudorhombus sp.	0.8	0.2	14.5	0	0	0	15.6	1.82	4.23	21.5	1.64	2.94	2.2	0.07	7.11	25	1.43	2.55
103	Pegasidae	Sea moth	Pegasus sp.	3.8	0.13	7.81	0	0	0	1.5	0.05	8.16	0.4	0.01	14.9	7.7	1.43	6.33	8.3	0.21	4.33
104	Pempheridae	Bullseye	Pempheris sp.	3.3	0.14	7.92	5.3	0.71	6.02	19.8	2.2	3.35	6.7	0.48	6.72	1.7	0.48	11.3	6.8	0.17	4.48
105	Percophidae	Duckbills		0	0	0	0	0	0	15.6	2.09	3.63	38.6	5.84	2.48	2.8	0.12	8.6	8.3	0.37	4.79
106	Phosicthyidae	Lightfishes		0	0	0	0	0	0	0	0	0	0	0	0	12.7	1.83	5.32	0	0	0
107	Pinguipedidae	Grub fish		21	1.7	3.25	0	0	0	27.5	4.75	2.79	25.6	3.39	2.82	9.9	2.12	5.05	43.9	2.85	1.75
108.1	Platycephalidae	Flathead	Platycephalus fuscus	15	1.09	5.08	0	0	0	12.6	1.29	5.38	0	0	0	2.2	2.11	9.6	0	0	0
108	Platycephalidae	Flathead	other flathead	16.3	2.74	4.54	17.6	10.4	4.57	38	22.6	4.4	39.9	11.2	3.35	9.4	2.35	6.16	61.4	12.6	1.86
109.1	Pleuronectidae	Flounder	Rhombosolea sp.	0	0	0	0	0	0	0	0	0	0	0	0	3.9	0.3	6.5	0	0	0
109	Pleuronectidae	Flounder	other flounder	1.9	0.05	8.34	0	0	0	0	0	0	0.9	0.03	10.6	2.8	0.18	7.06	9.1	0.21	3.6
110	Pomacentridae	Damselfish		12.8	0.95	6.52	0	0	0	28.7	7.49	2.64	43.5	12.1	4.09	4.4	1.66	7.82	46.2	4.44	1.92
111	Pomatomidae	Tailor	Pomatomus saltatrix	8.4	1.12	6.06	0	0	0	0.9	0.05	11	0	0	0	0	0	0	22.7	0.78	2.47
112	Priacanthidae	Bigeyes		12	0	0	0	0	0	1.8	0.09	9.09	0	0	0	0	0	0	15.9	0.56	3.72
113	Pseudochromidae	Dottyback		4.4	0.17	6.11	0	0	0	2.1	0.08	7.49	1.3	0.02	8.6	0	0	0	5.3	0.27	5.48
114	Rhombosoleidae	Flounder	Ammotretis sp.	0	0	0	0	0	0	0	0	0	0	0	0	3.9	0.77	7.1	0	0	0
115	Samaridae	Flatfish		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.12	6.01
116	Scaridae	Parrotfish		18.8	0.87	4.55	0	0	0	1.8	0.05	7.47	16.6	0.57	2.76	0.6	0.01	13.4	13.6	0.63	3.53

Table S1 (cont.).

Taxa #	Family	Common	Species	South. Surv. 2004			Investigator 2015			NSI NRS			PH NRS			MAI NRS		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
93	Mullidae	Goatfish		55.6	8.53	2.85	52.7	4.17	1.73	70.6	13.4	1.39	26.7	1.6	1.94	0	0	0
94	Myctophidae	Lanternfish		84.3	34.6	1.31	100	272	0.9	70.6	9.28	1.34	46.7	7.7	2.46	15.4	0.25	2.55
95	Nemipteridae	Threadfin bream		25.9	1.57	2.34	21.5	1.42	2.77	52.9	9.04	1.85	6.7	0.77	3.87	0	0	0
96	Nomeidae	Driftfish		18.5	0.42	2.52	66.7	3.12	1.43	11.8	0.39	3.08	0	0	0	0	0	0
97	Notosudidae	Paperbones		39.8	2.76	1.93	97.8	55.7	1.28	5.9	0.17	4.12	0	0	0	0	0	0
98	Odacidae	Rock cale		0.9	0.03	10.4	0	0	0	0	0	0	6.7	0.38	3.87	15.4	0.24	2.45
99.1	Ophidiidae	Ling	Genyptrus sp.	7.4	0.2	3.91	20.4	0.57	2.48	0	0	0	0	0	0	0	0	0
99	Ophidiidae	Ling	other ling	0	0	0	0	0	0	0	0	0	0	0	0	7.7	0.12	3.61
100	Ostraciidae	Cowfish		0	0	0	0	0	0	5.9	0.18	4.12	0	0	0	0	0	0
101	Paralepidae	Barracudinas		14.8	0.36	2.9	73.1	6.83	1.19	0	0	0	0	0	0	0	0	0
102	Paralichthyidae	Large tooth flounder	Pseudorhombus sp.	18.5	0.68	2.81	4.3	0.08	5.42	5.9	0.2	4.12	20	3.66	3.44	0	0	0
103	Pegasidae	Sea moth	Pegasus sp.	10.2	0.46	4.25	0	0	0	11.8	1.14	3.71	13.3	0.33	2.77	0	0	0
104	Pempheridae	Bullseye	Pempheris sp.	1.9	0.12	8.13	0	0	0	5.9	0.18	4.12	6.7	0.16	3.87	0	0	0
105	Percophidae	Duckbills		1.9	0.02	7.42	4.3	0.06	4.76	0	0	0	6.7	0.13	3.87	0	0	0
106	Phosicthyidae	Lightfishes		7.4	0.37	6.53	87.1	19.4	1.25	5.9	0.2	4.12	0	0	0	0	0	0
107	Pinguipedidae	Grub fish		5.6	0.18	4.99	45.2	1.61	1.62	11.8	0.39	2.85	0	0	0	0	0	0
108.1	Platycephalidae	Flathead	Platycephalus fuscus	2.8	0.16	7.45	6.5	0.2	4.14	0	0	0	6.7	4.04	3.87	0	0	0
108	Platycephalidae	Flathead	other flathead	30.6	7.22	3.52	30.1	2	2.51	47.1	9.78	1.97	73.3	31.1	3.14	23.1	5.71	3.5
109.1	Pleuronectidae	Flounder	Rhombosolea sp.	0	0	0	0	0	0	0	0	0	6.7	0.54	3.87	0	0	0
109	Pleuronectidae	Flounder	other flounder	0	0	0	0	0	0	0	0	0	0	0	0	15.4	0.25	2.45
110	Pomacentridae	Damselfish		17.6	0.44	2.84	51.6	3.39	2.28	47.1	4.73	1.75	33.3	1.51	1.91	0	0	0
111	Pomatomidae	Tailor	Pomatomus saltatrix	5.6	0.22	6.92	7.5	0.18	4	29.4	8.06	3.49	0	0	0	0	0	0
112	Priacanthidae	Bigeyes		0	0	0	2.2	0.03	6.8	23.5	2.88	2.08	0	0	0	0	0	0
113	Pseudochromidae	Dottyback		2.8	0.26	8.16	30.1	1.21	2.04	5.9	0.59	4.12	0	0	0	0	0	0
114	Rhombosoleidae	Flounder	Ammotretis sp.	0	0	0	0	0	0	0	0	0	0	0	0	7.7	0.11	3.61
115	Samaridae	Flatfish		0.9	0.01	10.4	7.5	0.11	3.65	0	0	0	0	0	0	0	0	0
116	Scaridae	Parrotfish		6.5	0.16	4.13	52.7	3.51	1.61	0	0	0	0	0	0	0	0	0

Table S1 (cont.).

Taxa #	Family	Common	Species	Sprightly 1983			Challenger 89-91			Kamala 1989-93			Franklin 1994			Franklin 1997-98			Franklin 1998-99		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
117	Schindleriidae	Floater	Schindleria sp.	9.5	0.27	4.53	0	0	0	2.4	0.07	6.57	6.3	0.22	4.7	0	0	0	28	2.46	3.8
118.2	Sciaenidae	Mulloway	Agyrosomus japonicus	2.5	0.41	13.1	0	0	0	4.8	0.33	5.4	13.5	1.01	5.99	0	0	0	0	0	0
118.1	Sciaenidae	Teraglin	Atractoscion aequidens	2.5	0.07	10.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
118	Sciaenidae		other sciaenid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27.3	2.18	3.01
119	Scomberesocidae	Saury	Scomberesox saurus	3.5	1.25	9.96	0	0	0	0.6	0.03	13.6	4.9	0.21	4.63	2.8	0.12	9	6.8	0.3	4.61
120.2	Scombridae	Blue mackerel	Scomber australasicus	1.9	0.07	7.91	0	0	0	3	0.32	6.88	0.9	0.02	10.5	1.7	0.16	9.44	0	0	0
120.1	Scombridae	Tuna	Auxis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
120	Scombridae	Tuna	other tuna	1.6	0.02	7.98	0	0	0	0	0	0	9	0.63	6.11	0	0	0	65.9	13.7	1.29
121	Scopelarchidae	Pearleyes		4.6	0.06	5.93	0	0	0	0.6	0.02	12.9	1.3	0.04	9.2	0.6	0.01	13.4	0	0	0
122.4	Scorpaenidae	Ocean perch	Helicolenus sp.	0	0	0	0	0	0	14.1	3.07	4.16	0.4	0.01	14.9	5.5	0.16	5.1	0	0	0
122.3	Scorpaenidae	Gurnard perch	Neosebastes sp.	7.9	1.59	6.82	0	0	0	19.8	4.57	3.52	8.5	0.54	5.4	11	0.67	4.52	0	0	0
122.2	Scorpaenidae	Cobbler	Gymnapistes marmoratus	0	0	0	0	0	0	0.3	0.04	18.3	0	0	0	4.4	1.11	8.02	0	0	0
122.1	Scorpaenidae	Fortescue	Centropogon australis	5.4	0.22	6.42	0	0	0	18.6	1.94	3.04	6.3	0.28	4.88	1.1	0.02	9.52	0	0	0
122	Scorpaenidae		other scorpenids	29.7	3.01	5.49	19.5	6.52	4.13	11.7	0.95	4.28	58.3	9.86	1.9	7.7	1.42	12	59.1	5.97	2.05
123	Scorpididae	Sweep	Scorpis sp.	1.4	0.08	12.6	0	0	0	26.9	13.4	3.98	1.8	0.16	9.9	3.3	0.31	7.18	13.6	0.62	4
124	Serraninae	Wirrahs	Acanthistius sp.	0	0	0	0	0	0	0	0	0	12.6	4.29	3.9	0.6	0.01	13.4	0	0	0
125	Siganidae	Rabbitfish	Siganus sp.	1.4	0.03	11.2	0	0	0	0	0	0	0.9	0.01	10.6	0	0	0	2.3	0.04	6.76
126.5	Sillaginidae	Stout whiting	Sillago robusta	20.4	5.66	5.52	0	0	0	2.4	0.1	6.83	0	0	0	0	0	0	0	0	0
126.4	Sillaginidae	Eastern school whiting	Sillago flindersi	7.4	1.13	6.66	0	0	0	33.2	22.4	4.24	14.8	8.64	4.42	2.8	0.71	10.6	0	0	0
126.3	Sillaginidae	Sand whiting	Sillago ciliata	4.6	0.79	13.2	0	0	0	5.7	5.11	6.51	0	0	0	0	0	0	0	0	0
126.2	Sillaginidae	Western school whiting	Sillago bassensis	0	0	0	0	0	0	0.9	0.06	11.4	0	0	0	1.1	0.26	9.83	0	0	0
126.1	Sillaginidae	King George whiting	Sillaginodes punctata	0	0	0	0	0	0	0.6	0.05	13.6	0	0	0	0	0	0	0	0	0
126	Sillaginidae	Whiting	other whiting	6	0.75	6.92	0	0	0	2.7	0.55	8.53	25.6	6.04	3.72	2.2	0.09	8.03	80.3	24.1	2.06
127	Soleidae	Sole		0.3	0	19.2	0	0	0	3.3	0.12	5.77	7.6	0.26	4.44	4.4	0.46	7	5.3	0.09	4.55

Table S1 (cont.).

Taxa #	Family	Common	Species	South. Surv. 2004			Investigator 2015			NSI NRS			PH NRS			MAI NRS		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
117	Schindleriidae	Floater	Schindleria sp.	2.8	0.04	6.46	34.4	0.77	1.79	0	0	0	0	0	0	0	0	0
118.2	Sciaenidae	Mulloway	Agyrosomus japonicus	0.9	0.02	10.4	0	0	0	0	0	0	6.7	1.35	3.87	0	0	0
118.1	Sciaenidae	Teraglin	Atractoscion aequidens	0	0	0	0	0	0	0	0	0	6.7	1.15	3.87	0	0	0
118	Sciaenidae		other sciaenid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
119	Scomberesocidae	Saury	Scomberesox saurus	50.9	49.9	2.31	30.1	6.52	3.47	0	0	0	0	0	0	0	0	0
120.2	Scombridae	Blue mackerel	Scomber australasicus	79.6	132	2.47	0	0	0	41.2	15.6	1.83	33.3	2.73	1.98	0	0	0
120.1	Scombridae	Tuna	Auxis sp.	0	0	0	0	0	0	11.8	20.1	3.67	0	0	0	0	0	0
120	Scombridae	Tuna	other tuna	0.9	0.03	10.4	1.1	0.05	9.64	41.2	19.8	1.75	6.7	0.1	3.87	0	0	0
121	Scopelarchidae	Pearleyes		3.7	0.05	5.69	8.6	0.17	4.29	0	0	0	0	0	0	0	0	0
122.4	Scorpaenidae	Ocean perch	Helicolenus sp.	3.7	0.19	5.34	0	0	0	0	0	0	0	0	0	15.4	0.34	2.45
122.3	Scorpaenidae	Gurnard perch	Neosebastes sp.	3.7	0.17	5.4	0	0	0	0	0	0	0	0	0	7.7	0.24	3.61
122.2	Scorpaenidae	Cobbler	Gymnapistes marmoratus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
122.1	Scorpaenidae	Fortescue	Centropogon australis	2.8	0.5	6.32	0	0	0	0	0	0	6.7	0.13	3.87	0	0	0
122	Scorpaenidae		other scorpenids	34.3	1.72	2.58	53.8	2.4	1.57	70.6	20.3	2.8	26.7	1.15	2.18	30.8	1.61	1.69
123	Scorpididae	Sweep	Scorpis sp.	21.3	1.06	3.32	15.1	0.69	3.27	0	0	0	33.3	1.17	2.06	0	0	0
124	Serraninae	Wirrahs	Acanthistius sp.	0	0	0	3.2	0.06	5.97	52.9	25.8	2.07	20	1.3	2.47	15.4	0.32	2.77
125	Siganidae	Rabbitfish	Siganus sp.	0	0	0	0	0	0	0	0	0	13.3	0.68	3.27	0	0	0
126.5	Sillaginidae	Stout whiting	Sillago robusta	2.8	0.19	7.45	0	0	0	5.9	0.18	4.12	0	0	0	0	0	0
126.4	Sillaginidae	Eastern school whiting	Sillago flindersi	2.8	1.02	6.75	0	0	0	29.4	1.54	1.71	53.3	5.2	1.68	15.4	13.3	3.57
126.3	Sillaginidae	Sand whiting	Sillago ciliata	0	0	0	0	0	0	0	0	0	13.3	11.4	3.84	0	0	0
126.2	Sillaginidae	Western school whiting	Sillago bassensis	0	0	0	0	0	0	0	0	0	6.7	0.58	3.87	15.4	0.28	2.51
126.1	Sillaginidae	King George whiting	Sillaginodes punctata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
126	Sillaginidae	Whiting	other whiting	9.3	0.65	5.78	25.8	1.19	2.56	0	0	0	0	0	0	0	0	0
127	Soleidae	Sole		0.9	0.01	10.4	0	0	0	0	0	0	6.7	0.38	3.87	0	0	0

Table S1 (cont.).

Taxa #	Family	Common	Species	Sprightly 1983			Challenger 89-91			Kamala 1989-93			Franklin 1994			Franklin 1997-98			Franklin 1998-99		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
128.3	Sparidae	Snapper	Pagrus auratus	5.2	0.12	8.88	0	0	0	15.3	2.74	4.62	6.3	0.15	4.28	4.4	0.72	9.06	0	0	0
128.2	Sparidae	Yellowfin bream	Acanthopagrus australis	3.8	0.12	6.25	0	0	0	14.1	4.73	6.42	4.5	0.19	7.4	0	0	0	0	0	0
128.1	Sparidae	Tarwhine	Rhabdosargus sarba	5.2	1.33	9.41	0	0	0	9.9	1.03	4.09	5.8	0.36	6.66	0	0	0	0	0	0
128	Sparidae		other sparid	0	0	0	0	0	0	0	0	0	1.3	0.03	9.14	0	0	0	72	15.3	2.02
129	Sphyraenidae	Barracudas	Sphyraena sp.	12.5	1.13	4.09	0	0	0	1.5	0.17	10.2	5.4	0.16	4.94	0	0	0	23.5	1.04	2.8
130	Sternoptychidae	Hatchet fish		1.6	0.02	9.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
131.1	Sygnathidae	Pipe fish	Stigmatopora nigra	0	0	0	0	0	0	0	0	0	0	0	0	9.9	0.44	4.73	0	0	0
131	Sygnathidae	Pipe fish	other pipefish	0.3	0	19.2	6.3	0.51	4.11	3.9	0.15	5.44	0.4	0.01	14.9	3.3	0.08	5.77	1.5	0.02	8.39
132	Synodontidae	Lizard fish		37.3	2.76	2.41	0	0	0	3.3	0.17	6.19	33.2	2.97	2.99	0.6	0.01	13.4	51.5	5.23	2.21
133	Terapontidae	Trumpeter	Pelates sp.	13.9	3.15	6.88	0	0	0	3	0.33	8.67	2.7	0.08	7.28	1.7	0.08	8.58	62.9	8.36	1.91
134	Tetragonuridae	Squaretail	Tetragonuris sp.	2.2	0.02	8.11	5.8	0.93	8.3	1.5	0.06	8.95	12.6	0.58	3.36	0	0	0	0	0	0
135	Tetraodontidae	Toadfish		13.9	0.3	3.58	0	0	0	5.7	0.21	4.31	22.9	1.04	2.35	1.7	0.03	7.92	6.8	0.11	3.9
136.2	Trachichthyidae	Roughy	Aulotrachichthys sp.	0	0	0	0	0	0	3.6	0.29	7.23	0.4	0.02	14.9	0	0	0	0	0	0
136.1	Trachichthyidae	Roughy	Sp2	0	0	0	0	0	0	0.3	0.01	18.3	0	0	0	0	0	0	0	0	0
136	Trachichthyidae	Roughy	other roughy	4.4	0.2	7.31	0	0	0	16.8	1.21	2.91	10.8	0.28	3.68	1.1	0.07	10.4	1.5	0.07	8.32
137.1	Trichiuridae	Frostfish	Lepidopus caudatus	0.3	0	19.2	0	0	0	20.4	6.9	4.07	0	0	0	0	0	0	0	0	0
137	Trichiuridae	Cutlassfish	other cutlassfish	3.5	0.04	6.26	0	0	0	0	0	0	2.2	0.03	6.69	0	0	0	4.5	0.1	5.76
138	Trichonotidae	Sanddivers	Trichonotus sp.	0.3	0.01	19.2	0	0	0	0	0	0	0	0	0	0	0	0	4.5	0.07	4.82
139.2	Triglidae	Gurnard	Lepidotrigla papilo	0	0	0	1.8	0.23	9.76	0	0	0	0	0	0	3.9	0.22	7.19	0	0	0
139.1	Triglidae	Gurnard	Lepidotrigla spp.	0	0	0	21.6	4.95	3.83	0	0	0	0	0	0	16	1.12	4.33	14.4	1.16	4.96
139	Triglidae	Gurnard	other gurnard	15.5	2.15	4.77	0.8	0.1	12.9	47.3	10.4	2.18	29.1	3.24	3.01	0	0	0	10.6	0.62	3.4
140	Tripterygiidae	Triplefins		0	0	0	0.5	0.06	14.7	13.8	2.27	4.15	0.4	0.02	14.9	0	0	0	2.3	0.1	9.28
141	Uranoscopidae	Stargazers		1.6	0.03	10.1	0	0	0	1.2	0.05	9.56	2.2	0.04	7.45	3.9	0.16	6.26	0.8	0.02	11.5
142	Xiphiidae	Swordfish	Xiphias sp.	0.5	0.01	13.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
143	Zeidae	Dory		0.3	0	19.2	10.3	1.16	3.63	0.9	0.04	10.6	0	0	0	0.6	0.01	13.4	0	0	0
144	unknown			0	0	0	43.7	23.3	2.44	17.4	1.26	2.87	50.7	9.32	2.42	23.8	2.29	4.2	0	0	0
145	damaged			0.3	0.01	19.2	0	0	0	10.8	0.63	3.59	19.3	2.22	3.05	0	0	0	0	0	0
146	other			5.2	0.2	12.1	0	0	0	10.2	0.59	3.75	42.6	8.77	2.03	10.5	0.32	3.65	56.1	3.46	1.41

Table S1 (cont.).

Taxa #	Family	Common	Species	South. Surv. 2004			Investigator 2015			NSI NRS			PH NRS			MAI NRS		
				% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N	% Occ	Av N	CV N
128.3	Sparidae	Snapper	Pagrus auratus	12	0.89	4.17	15.1	0.48	3.21	23.5	1.24	2.11	20	1.65	2.77	15.4	0.32	2.73
128.2	Sparidae	Yellowfin bream	Acanthopagrus australis	5.6	0.17	4.16	19.4	1.22	3.17	17.6	2.38	2.6	6.7	0.1	3.87	0	0	0
128.1	Sparidae	Tarwhine	Rhabdosargus sarba	4.6	0.57	5.42	0	0	0	0	0	0	0	0	0	0	0	0
128	Sparidae		other sparid	10.2	0.55	3.9	0	0	0	0	0	0	0	0	0	0	0	0
129	Sphyraenidae	Barracudas	Sphyraena sp.	0	0	0	11.8	0.29	3.74	35.3	1.62	1.57	0	0	0	0	0	0
130	Sternoptychidae	Hatchet fish		0.9	0.01	10.4	1.1	0.03	9.64	0	0	0	0	0	0	0	0	0
131.1	Sygnathidae	Pipe fish	Stigmatopora nigra	0	0	0	0	0	0	0	0	0	0	0	0	15.4	0.42	2.52
131	Sygnathidae	Pipe fish	other pipefish	0	0	0	1.1	0.04	9.64	0	0	0	0	0	0	15.4	0.16	2.45
132	Synodontidae	Lizard fish		25	1.77	3.12	53.8	2.3	1.44	17.6	1.4	2.49	6.7	0.2	3.87	0	0	0
133	Terapontidae	Trumpeter	Pelates sp.	17.6	1.76	4.02	0	0	0	23.5	3.06	2.4	26.7	0.63	1.81	0	0	0
134	Tetragonuridae	Squaretail	Tetragonuris sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
135	Tetraodontidae	Toadfish		16.7	0.33	2.57	24.7	0.57	2.28	11.8	1.55	2.93	0	0	0	7.7	0.24	3.61
136.2	Trachichthyidae	Roughy	Aulotrachichthys sp.	0	0	0	0	0	0	5.9	0.2	4.12	0	0	0	15.4	1.16	3.31
136.1	Trachichthyidae	Roughy	Sp2	0	0	0	0	0	0	0	0	0	0	0	0	7.7	0.36	3.61
136	Trachichthyidae	Roughy	other roughy	16.7	0.78	2.68	21.5	0.53	2.38	0	0	0	0	0	0	0	0	0
137.1	Trichiuridae	Frostfish	Lepidopus caudatus	9.3	0.21	3.83	0	0	0	0	0	0	0	0	0	0	0	0
137	Trichiuridae	Cutlassfish	other cutlassfish	0	0	0	12.9	0.29	3.17	0	0	0	0	0	0	0	0	0
138	Trichonotidae	Sanddivers	Trichonotus sp.	0	0	0	0	0	0	5.9	0.14	4.12	0	0	0	0	0	0
139.2	Triglidae	Gurnard	Lepidotrigla papilo	0	0	0	50.5	3.76	1.85	0	0	0	0	0	0	7.7	1.07	3.61
139.1	Triglidae	Gurnard	Lepidotrigla spp.	0	0	0	0	0	0	41.2	9.94	2.36	20	0.82	2.79	15.4	15	3.58
139	Triglidae	Gurnard	other gurnard	44.4	15	2.32	1.1	0.01	9.64	5.9	0.53	4.12	13.3	0.26	2.69	30.8	1.55	2.14
140	Tripterygiidae	Triplefins		0	0	0	0	0	0	0	0	0	0	0	0	7.7	0.22	3.61
141	Uranoscopidae	Stargazers		1.9	0.02	7.43	1.1	0.02	9.64	0	0	0	0	0	0	0	0	0
142	Xiphiidae	Swordfish	Xiphias sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
143	Zeidae	Dory		0	0	0	5.4	0.08	4.35	0	0	0	0	0	0	0	0	0
144	unknown			38	4.71	2.04	0	0	0	58.8	5.3	1.19	40	0.86	1.31	61.5	2.78	1.43
145	damaged			6.5	0.44	4.42	73.1	16.1	1.43	11.8	0.43	2.83	0	0	0	7.7	0.12	3.61
146	other			9.3	0.17	3.67	14	0.28	2.87	0	0	0	0	0	0	15.4	0.46	3.03

7. APPENDIX B

Sampling Protocol for the National Ichthyoplankton Monitoring and Observing (NIMO) Program

Version 15 December 2015, by Iain Suthers et al.

Summary of gear deployment:

- Deployments are meant to be simple, and uncomplicated for a variety of vessels (ie from 25 m Ngerin to a 7 m shark cat)
- Tow 1.5 m/s (~3 knots through the water), sampling an oblique tow from ~20 m depth to near-surface.
- Aim to sample at least 500 m^3 per tow (it should take ~12 minutes).
- Do not sample shallower than 2 m depth.
- 2-3 tows per trip: first tow at NRS stored in formalin (for processing); second tow stored in ethanol (for genetics); if there is time, a third tow can be done at spatially distant station and stored in formalin.

Sampling Procedure:

1) Launch Hobo temperature-depth logger
2) Fill in field log-sheet
3) Screw 1.2 L white sampling jar onto net
4) Vessel in gear and appropriate course for swell, wind (~1 knot)
5) Start clock, and deploy over side of boat at 3 knots through the water
6) Fully deploy all 30 m rope to start at depth while slow, and bring speed up to ~3 knots;
7) At ~6 minutes, reduce speed, to 1 knot or even neutral to allow net to sink, then return to 3 knots
8) Adjust this in future tows as necessary, depending on the depth profile from logger; the goal is a relatively even oblique from 20 to 2 m, twice. Note that the NIMO depressor is not heavy enough to sample 20 m at 3 knots.
9) At ~12 minutes reduce speed, or even into neutral to bring briskly on board.
10) With the ring and depressor on board, 'tea-bag' the cod end to wash contents into jar; inspect the mesh that it is clean. With the full cod jar still attached to the net, pour most of the content back out the mesh just above the clamp;
11) Splash or squirt the ichthyoplankton back into the jar, so that it is 50-90% full. Then allocate concentrated formaldehyde solution to make 5% solution (i.e. add 2.5 mL to 50 mL).
    a. For ethanol sample use minimal water; tap zooplankton back into jar and put in 95% ethanol; avoid dilution of ethanol as much as possible.
12) If necessary 'tea-bag' the open cod end to remove any residual slime. Fill in flow meter details, screw on a fresh jar, and prepare for next tow.

Field laboratory:

- Rinse out flow meter with fresh water and allow to dry
- Hobo temperature-depth logger: download logger, prepare depth profile and send to local scientist (I. Suthers or A. Lara-Lopez)
- Blast net with freshwater hose to prevent it getting fouled. If necessary soak in enzymatic detergent for 2 hours to remove dried slime.
- In ethanol stored samples, pour off ethanol from field within 1 day of capture and replace with fresh 95% ethanol. Unless this is done, a high proportion of the specimens will degrade and can't be genetically sequenced.

Description of gear:

1. GO flow meter:

The GO flow meter (pictured) has a 5 mm diameter hole carefully drilled out for the drainage hole (so that it partially floods with seawater, but then easily flushed out at end of day).

The following are instructions for estimating distance, speed, and volume filtered using **flow meter**:

4. Calculations

10 counts are equal to 1 rotor revolution on the graphic labels on all flowmeters. The cts/sec. Is "counts per second" and must not be used as revolutions per second for calculations.

ROTOR CONSTANTS: Standard Speed Rotor Constant = 26,873
Low Speed Rotor Constant R6 = 57,560
(R2) Low Speed Rotor Constant = 51,020
Speed Curve See Page 11

A. DISTANCE in meters = $\frac{\text{Difference in COUNTS (X) Rotor Constant}}{999999}$

(Example: Where the graph may indicate 100 cts/sec this is also equal to 10 revolutions/sec). Therefore please ensure the correct units are being used when measuring and calculating.

B. SPEED in cm/sec = $\frac{\text{Distance in meters (X) 100}}{\text{Time in seconds}}$

C. VOLUME cubic meters = $\frac{3.14 \text{ (X) (Net Diameter)}^2 \text{ (X) Distance}}{4}$

2. HOBO temperature-depth logger:

- To initiate the depth logger you must connect the depth logger to the USB base station and install then run the HOBO software (Set units to SI).
- You will then have to set the Logging Interval: to 1 second prior to deployment to get a good measure of what is going on during the tows.
- When downloading the data you will have to go to: Device>Read out> Plot Setup>
- Select series to Plot, then select 'None' on the same page 'Select Internal Logger events to plot' and also select 'None'
- Then below go to Data Assistants> Barometric Compensation Assistant> Process
- Set this to Fluid density: Saltwater and tick the Use a Reference Water Level box and set this to : 0.000 Meters
- On the bottom of this window then select 'Create New Series'. This will then return you to the previous window and you can the press 'Plot' here.

3. NIMO Ichthyoplankton net and depressor:

- We use a standard 85 cm diameter net with 500 um mesh, on a 5/8" stainless steel rod
- There is a 2-point bridle and 8 kg Scripps depressor attached to the bottom (image)