Analysis of the stable isotopic composition of the otoliths of Goldband Snapper, *Pristipomoides multidens*, as an aid to the determination of stock structure

Dr S.J. Newman
Mr. R.A. Steckis
Dr. J.S. Edmonds
Ms J. Lloyd

FISHERIES
WESTERN AUSTRALIA

NORTHERN TERRITORY
DEPARTMENT OF PRIMARY INDUSTRY & FISHERIES

FISHERIES
RESEARCH &
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Objectives

To investigate the stock structure of Goldband Snapper (*Pristipomoides multidens*) across northern Australia using otolith stable isotopic composition in order to assist in the sustainable development of appropriate management plans for the deepwater snapper fisheries of the Northern Territory and Western Australia.

Non Technical Summary

Measurement of stable isotope ratios of oxygen (^{18}O:^{16}O) and carbon (^{13}C:^{12}C) in the earstone (sagittal otolith) carbonate from assemblages of goldband snapper, *Pristipomoides multidens*, from waters off northern and western Australia revealed location-specific signatures and indicated that fish from all sites sampled within Australia (Exmouth, Rankin Bank, Broome, Vulcan Shoals, Timor Sea, Arafura Sea), Indonesia (Kupang) and Papua New Guinea (Pommern Bay) were different.

The significant differences in the isotopic signatures of goldband snapper demonstrated that there is unlikely to be substantial movement of fish among these distinct adult assemblages. The stable isotopic signatures for the fish from the different locations was persistent through time, and therefore it could be concluded that they comprise separate stocks for many of the purposes of fisheries management.

The ratios of the stable oxygen isotopes in goldband snapper were significantly related to sea surface temperatures (r^2 = 0.797) and latitude (r^2 = 0.783). This study has provided further evidence that measurement of the stable isotope ratios in teleost earstone (sagittal otolith) carbonate can be a valuable tool in the delineation of fishable

stocks, or fishery management units, of vulnerable age classes where the range of distribution of the species in question covers waters with different temperature regimes.

KEYWORDS: Goldband snapper, *Pristipomoides multidens*, Stock structure, Stable isotopes, Otoliths, Fisheries management.

Project Contact

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Principal Investigator Dr Stephen Newman

Details
Fisheries Research Division
Fisheries Western Australia
PO Box 20
North Beach WA 6020
AUSTRALIA
Telephone: 08 9246 8444
Fax: 08 9447 3062

Background

The goldband snapper, *Pristipomoides multidens* (Day), is widely distributed throughout the tropical Indo-Pacific Ocean region from Samoa in the Central Pacific to the Red Sea in the western Indian Ocean and from southern Japan south to Australia (Allen 1985). Within north-western Australia, goldband snapper are found as far south as Cape Pasley (34°S) in Western Australia and are landed in commercial quantities from the Ningaloo Reef area (23°30'S) northwards to the Gulf of Carpentaria (Kailola et al. 1993, Newman unpublished data). Goldband snapper inhabit hard-bottom areas and areas of vertical relief and large epibenthos from depths of 60 to at least 180 metres and are concentrated in depths from 80 to 150 metres (Allen 1985, Newman unpublished data).

Goldband snapper is a commercially important species throughout much of its range forming an important component of the landed catch in both artisanal and developed fisheries (Dalzell and Preston 1992, Newman unpublished data). In Australia, goldband snapper and related species are fished throughout all the northern states. This highly valued fish is marketed whole, usually fresh on ice, and is transported from regional centres to markets in most capital cities and is occasionally exported. The landed catch of goldband snapper in the five year period from 1994 to 1998 has ranged from 303 to 453 tonnes $year^{-1}$ in Western Australia and from 201 to 255 tonnes $year^{-1}$ in the Northern Territory. The current catch from all the tropical finfish fisheries in north-western and northern Australia is valued in excess of $20 million annually. This increase in catch has corresponded with a significant

increase in fishing effort, especially in the deeper regions, targeting goldband snapper and related species.

Goldband snapper are presently managed across north-western Australia by two State-based fishery management agencies which have separate management arrangements with regional segregation of the demersal finfish fisheries within these two states. Both these states support highly valuable mixed gear commercial fisheries for the goldband snapper and therefore the identity of individual component stocks is important. Current management arrangements make no allowance for migratory fish or overlapping stocks across either State or intra-State fishery boundaries. Furthermore, foreign (Indonesian) fishing grounds lie adjacent to the territorial waters of north-western Australia. Consequently, there is a need to identify stocks within these areas in order to assess the impacts of fishing in each area should competitive fishing practices develop.

To ensure the development of effective management strategies for the sustainable exploitation of goldband snapper stocks off north-western Australia at both a national and international level, there is a need to know whether the widespread distribution of this species may be regarded as a single stock or whether there are a number of smaller, essentially non-mixing population units. The concept of a stock is fundamental to fishery management. The management of demersal finfish stocks across broad geographic areas is greatly facilitated by the delineation of stock structure as it allows specific zones or areas to be managed separately as discrete units. Thus, for both fisheries managers and stock assessment biologists it is important to determine if adjacent populations of fish are either sufficiently intermixing to be regarded as a single stock or adequately autonomous (no intermixing) to be regarded as distinct stocks.

Fish stocks have been variously defined, ranging from a stock definition of a single interbreeding population to a unit capable of independent exploitation or management and containing as much of an interbreeding unit or as few reproductively isolated units as possible. Ihssen et al. (1981) defined a stock as “an intra-specific group of randomly mating individuals with temporal or spatial integrity”. This definition is used as the basis for the interpretation of stock structure in this study. Therefore, in this report, a fish ‘stock’ refers to groups of post-juvenile fish that remain separate and non-mixing (ie. with either spatial or temporal integrity) and therefore comprise a management unit capable of independent exploitation. This definition does not imply that such groups of fish or management units comprise separate breeding stocks (although this may be so).

A range of methods have been developed to deduce stock structure (e.g. Ihssen et al. 1981, Pawson and Jennings 1996) and include analysis of the elemental and stable isotopic composition of teleost otoliths (e.g. Campana et al. 1994, Edmonds et al. 1991, 1992, 1995, Kalish et al. 1996, Edmonds and Fletcher 1997, Edmonds et al. 1999). Measurement of the stable isotope ratios of oxygen and carbon in the sagittal otolith carbonate involves the analysis of the main structural constituent of the otoliths and avoids possible biases associated with the determination of trace elements (e.g. sample contamination). As the whole otolith is used in the analysis, its isotopic signature represents the entire ontogenetic history and has the potential to reflect the home range of each individual fish.

Previous studies have examined the relationship between the isotopic composition of teleost otolith carbonate and environmental variables. The $^{18}O/^{16}O$ ratio in sagittal otolith carbonate is deposited close to oxygen isotopic equilibrium with the

surrounding water (Kalish 1991a, 1991b, Iacumin et al. 1992, Thorrold et al. 1997). Edmonds and Fletcher (1997) showed that differences in sea surface temperature provided the basis for different oxygen isotope signatures in the otolith carbonate of the pilchard *Sardinops sagax* from south-western Australia and hence demonstrated separation of stocks of adult fish. Variation in the water temperatures to which groups of fish are exposed (as measured by sea surface temperatures) is therefore likely to provide the basis for any differences in oxygen isotopic signatures.

Stable carbon isotope ratios ($^{13}C/^{12}C$) in sagittal otolith carbonate are not deposited in equilibrium with the surrounding water (Mulcahy et al. 1979, Kalish 1991b). Thorrold et al. (1997) demonstrated that metabolic effects apparently generate large isotopic disequilibria in $\delta^{13}C$ values. Recent studies suggest that variations in $\delta^{13}C$ may result from changes in metabolic rate as fish mature as well as changes driven by the environment and/or long term changes in the behaviour of the fish such as dietary shifts which may be associated with changes in habitat or nutrient sources as fish age (see Schwarcz et al. 1998). However, there is still uncertainty in defining all the factors which govern the stable carbon isotope composition of sagittal otolith carbonate.

The delineation of stock structure from analysis of the stable isotopic composition of teleost otoliths assumes that geographically distinct stocks possess a characteristic isotopic signature that reflects the isotopic composition of the water body in which the fish is resident. However, as has been discussed in earlier works (Edmonds and Fletcher 1997, Edmonds et al. 1999), knowledge of the causal mechanisms responsible for the stable isotopic composition of teleost otolith carbonate is not necessary for any measured differences to be used as an aid in delineating stock structure.

Given the philopatric nature of demersal reef fish, the objective of this study was to determine if a multi-stock complex of goldband snapper was present across northern and western Australia. If a multi-stock complex of goldband snapper were to be identified, then a measurable difference in the oxygen isotope ratios of the goldband snapper among locations would be expected, *a priori*, because of the substantial variation in sea surface temperatures (largely due to the latitudinal variation) across the geographical range of this species. This study was also designed to determine whether any differences in the isotopic signatures of the sagittal otolith carbonate of goldband snapper among locations was persistent through time. If any spatial or temporal differentiation in isotopic signatures was evident for any or all of the locations sampled, they could be assumed to comprise separate management units capable of independent exploitation for fishery management purposes.

Need

The Northern Territory Fisheries Division and Fisheries Western Australia are currently formulating management plans for the demersal fisheries resources off their respective coastlines and are concerned about current levels of exploitation and the potential for over-exploitation. A key issue in the formulation of these plans is whether there is a single shared stock between WA and NT or distinct isolated stocks. Under a single stock assumption, overfishing in any one sector of the fishery could directly lead to depleted catches in other sectors. There is presently little information on the stock structure of *Pristipomoides multidens* across northern Australia, nor is there any information on migration patterns within the

region (genetic differences have been investigated in FRDC Project 96/131). This important issue needs to be resolved before appropriate management plans can be determined.

Furthermore, the resolution of stock structure between WA and NT will allow informed decisions on the likelihood of shared demersal fishery resources with Indonesia across international maritime boundaries.

Objectives

To investigate the stock structure of Goldband Snapper (*Pristipomoides multidens*) across northern Australia using otolith stable isotopic composition in order to assist in the sustainable development of appropriate management plans for the deepwater snapper fisheries of the Northern Territory and Western Australia.

Methods

Sampling design - Sagittal otolith samples from goldband snapper were collected across the distributional range of the commercial catches of this species within north-western Australia. Six locations were sampled within Australia (Fig. 1), four in Western Australia (Exmouth, Rankin Bank, Broome, Vulcan Shoals) and two in the Northern Territory (Timor Sea, Arafura Sea). Additional samples were also opportunistically obtained from Kupang, Indonesia and Pommern Bay in northern Papua New Guinea (Fig. 1).

Samples were collected on two separate occasions a minimum of 6 months apart from each of the regions sampled. This temporal sampling was required to ensure that any observed differences were not due to seasonal variation in water composition. Edmonds et al. (1995) found that differences in some concentrations of trace elements in Pink Snapper (*Pagrus auratus*) in Shark Bay might have been due to seasonal variation in water composition. Otoliths were collected from approximately 40 fish (20 females and 20 males) from each of the sample sites listed above on each sampling date (Table 1).

Otolith removal and preparation - The sagittal otoliths were removed by opening the otic bulla from under the operculum. Otoliths were then washed in freshwater, allowed to dry and stored in envelopes prior to processing. One sagitta from each otolith pair was selected at random and cleaned by scrubbing with a nylon brush under high purity (Milli-Q) water, air dried (50°C) and powdered. Powdered sagittal otoliths were deproteinated by treatment with hydrogen peroxide and analysed for $^{18}O/^{16}O$ and $^{13}C/^{12}C$ ratios by standard mass spectrometric techniques (CSIRO Division of Water Resources, Perth) after the carbonate was decomposed to CO_2 with 100% phosphoric acid. Values are reported in standard δ notation relative to the PDB-1 standard (Epstein et al. 1953).

Statistical analysis - Analysis of covariance (ANCOVA) of the stable isotope values of $\delta^{18}O$ and $\delta^{13}C$ were undertaken using otolith weight as a covariate. The two factors in the analysis were location and sampling date. Location and sampling date were treated as fixed and orthogonal factors in the analysis. Otolith weight is considered to be a

proxy for age and therefore was used as a covariate in analyses to take into account different otolith mass. Type III sums of squares was used to test the hypothesis of differences in the population means. *A posteriori* multiple comparison of means (α = 0.05) were conducted using Tukey's honestly significant difference (HSD) method (Day & Quinn 1989). Initial analyses were carried out on all the data collected with the exception of those from Papua New Guinea, due to the small sample size from that location. For improvement of homogeneity and normality and to make treatment effects additive a subsequent analysis was undertaken on data from each location with a similar otolith weight and presumably age distribution. The otolith weight range selected was from 350 to 650 mg. Analyses were carried out in the same manner as described above.

An overall mean $\delta^{18}O$ value was calculated for each location and plotted against the mean annual sea surface temperature for the 10 year period from 1989 to 1998 for each location. The annual sea surface temperature (SST) for the years 1989 to 1998 were the average of the 12 monthly means in each of the 10 years and were obtained by the method described by Reynolds and Smith (1994).

Results

Locations sampled, sample numbers, collection dates and results of the $\delta^{18}O$ and $\delta^{13}C$ analyses of the otolith carbonate are summarised in Table 1 and Figs. 2 to 6. ANCOVA of the $\delta^{18}O$ values from all the fish samples (except PNG) showed that the location effect was significant (Table 2, Fig. 5). Tukey's (HSD) results: EX > RB > (BR = KU) > VS > TS > AS. Location differences alone account for a very high proportion of the variability in the $\delta^{18}O$ values, explaining 66% of the sum of squares. Otolith

weight and the location × date interaction effects were significant also, but explained only 4% of the sum of squares (Table 2). ANCOVA of the $\delta^{18}O$ values from all fish in the selected otolith weight range showed that the location effect was highly significant (Table 3, Fig. 6). Tukey's (HSD) results: EX > (RB = KU) > BR > VS > TS > AS. Location differences alone account for a very high proportion of the variability in the $\delta^{18}O$ values, explaining 79% of the sum of squares. Otolith weight and the location × date interaction effects were significant also, but explained only 3% of the sum of squares (see Table 3). The results of the ANCOVA from the analysis of fish in the selected otolith weight range were a reflection of the ANCOVA results from all the fish sampled. Variation was evident only in fish sampled from Kupang. Separation of locations along the north-west Australian coastline were unchanged (compare Figs. 5, 6). The date of sampling in each analysis was not significant, accounting for less than 0.01% of the sum of squares in each case thereby providing no evidence of any temporal variability in $\delta^{18}O$ values.

ANCOVA of the $\delta^{13}C$ values from all the fish samples (except PNG) showed that the location effect was significant (Table 4, Fig. 5). Tukey's (HSD) results: KU > (EX = BR = TS = AS) > (RB = VS). Location differences account for a high proportion of the variability in the $\delta^{13}C$ values, explaining 29% of the sum of squares. Otolith weight and the location × date interaction effects were significant also, explaining 31% of the sum of squares (Table 4). ANCOVA of the $\delta^{13}C$ values from all fish in the selected otolith weight range showed that the location effect was significant (Table 5, Fig. 6). Tukey's (HSD) results: KU > TS > (BR = AS) > (RB = VS = EX). Location differences alone account for a high proportion of the variability in the $\delta^{13}C$ values, explaining 31% of the sum of squares. Otolith weight and the location × date interaction

effects were significant also, but explained only 12% of the sum of squares (Table 5). The results of the ANCOVA from the analysis of fish in the selected otolith weight range were a reflection of the ANCOVA results from all the fish sampled, however, there was more differentiation evident in the data from the restricted otolith weight range. The most significant result was that fish sampled from Kupang were different to all other locations in each analysis (see Figs. 5, 6). In each analysis, the date of sampling was not significant, accounting for less than 0.01% of the sum of squares in each case thereby providing no evidence of any temporal variability in $\delta^{13}C$ values.

While only a small number of samples were obtained from PNG, they were much more variable in $\delta^{13}C$ and $\delta^{18}O$ values than for any other location sampled (Fig. 5). This variability in stable isotope values alone indicates that fish sampled from PNG are likely to different from all other locations sampled.

ANCOVA results of oxygen and carbon isotope values (see also Figs. 5, 6) for all regions indicate that location is the most important source of variation between the measured values. Therefore, based on these results we propose the following distinct assemblages or stocks of adult fish; (1) Exmouth; (2) Rankin Bank; (3) Broome; (4) Vulcan Shoals; (5) Timor Sea; (6) Arafura Sea; (7) Kupang, Indonesia and (8) Pommern Bay, Papua New Guinea.

Mean $\delta^{18}O$ values for each location were plotted against the mean of the annual sea surface temperatures from 1989 to 1998 (obtained using the methods of Reynolds and Smith 1994) for each location (Fig. 7), $r^2 = 0.797$ (excluding the small sample obtained from PNG). Mean $\delta^{18}O$ values for each location were also plotted against latitude (Fig. 8), $r^2 = 0.783$ (excluding the small sample obtained from PNG).

Table 1: Summary of all sampling data and results from stable isotope analyses of the sagittal otolith carbonate of *Pristipomoides multidens* (SST = mean annual sea surface temperature [average of the 12 monthly means from 1989-1998; Reynolds and Smith, 1994]).

Location (code)	Position (latitude, longitude)	Date of Sampling	N	Length Range (FL, mm) mean (range)	Otolith weight (mg) mean (range)	$\delta^{18}O$ (‰ PDB) mean (range)	$\delta^{13}C$ (‰ PDB) mean (range)	SST (°C)
Exmouth (EX)	23°30'S, 113°15'E	July 1996	40	656 (515-742)	649 (313-931)	0.34 (-0.16 to 0.60)	-3.71 (-4.16 to -3.16)	24.15
		Mar. 1997	40	676 (446-845)	720 (228-1508)	0.48 (-0.04 to 1.02)	-3.70 (-4.72 to -2.72)	
Rankin Bank (RB)	19°45'S, 116°00'E	July 1996	40	470 (385-523)	315 (198-439)	-0.33 (-0.71 to -0.06)	-4.26 (-4.63 to -3.74)	26.37
		July 1997	40	493 (411-586)	346 (239-472)	-0.19 (-0.49 to 0.14)	-4.07 (-4.57 to -3.58)	
Broome (BR)	17°55'S, 120°26'E	June 1996	40	522 (310-629)	349 (109-494)	-0.43 (-0.69 to -0.17)	-3.91 (-4.63 to -3.26)	27.42
		Mar. 1998	40	492 (358-564)	545 (228-973)	-0.46 (-0.76 to -0.22)	-3.70 (-4.63 to -2.87)	
Vulcan Shoals (VS)	12°45'S, 124°26'E	June 1996	40	509 (383-615)	300 (164-408)	-0.61 (-0.97 to -0.14)	-4.24 (-5.02 to -3.52)	28.44
		Mar. 1998	40	514 (342-613)	538 (203-942)	-0.69 (-1.03 to -0.26)	-3.85 (-4.82 to -3.20)	
Timor Sea (TS)	10°15'S, 129°48'E	June 1996	40	514 (357-603)	494 (237-840)	-0.78 (-1.17 to -0.40)	-3.52 (-4.26 to -2.90)	28.42
		Jan. 1997	40	437 (307-607)	336 (171-817)	-0.71 (-1.17 to -0.37)	-3.85 (-4.71 to -3.02)	
Arafura Sea (AS)	9°56'S, 135°30'E	July 1996	45	481 (280-567)	489 (143-945)	-0.87 (-1.23 to -0.65)	-3.90 (-4.71 to -3.13)	27.72
		May 1997	22	484 (276-596)	482 (138-820)	-1.06 (-1.68 to -0.76)	-3.66 (-4.33 to -3.12)	
Kupang (KU)	10°20'S, 123°52'E	Apr. 1998	17	355 (210-620)	185 (64-593)	-0.65 (-1.01 to -0.33)	-3.59 (-4.70 to -2.60)	28.39
		Feb. 1999	27	505 (310-660)	373 (160-680)	-0.35 (-0.68 to 0.03)	-3.26 (-3.88 to -2.67)	
Pommern Bay (PNG)	5°32'S, 146°07'E	May 1998	9	571 (335-810)	444 (128-1088)	-0.02 (-0.79 to 0.72)	-3.45 (-4.38 to -1.92)	28.84

Table 2: ANCOVA of the $\delta^{18}O$ values of the sagittal otolith carbonate of *Pristipomoides multidens* (all raw data, excluding PNG).

Source	df	SS	MS	F	p
Location	6	69.0042	11.5007	441.706	< 0.0001
Date	1	0.0432	0.04325	1.6611	0.198
Location × date	6	2.8292	0.47153	18.1099	< 0.0001
Otolith weight	1	1.6984	1.69838	65.2295	< 0.0001
Residual (Error)	501	13.0445	0.02604		
Total	515	104.9133			

Table 3: ANCOVA of the $\delta^{18}O$ values of the sagittal otolith carbonate of *Pristipomoides multidens* (selected data: otolith weight range from 350 to 650 mg, excluding PNG).

Source	df	SS	MS	F	p
Location	6	35.9972	5.9995	267.087	< 0.0001
Date	1	0.0059	0.0059	0.2636	0.608
Location × date	6	1.4424	0.2404	10.7018	< 0.0001
Otolith weight	1	0.1777	0.1777	7.9089	< 0.01
Residual (Error)	223	5.0092	0.0225		
Total	237	45.7339			

Table 4: ANCOVA of the $\delta^{13}C$ values of the sagittal otolith carbonate of *Pristipomoides multidens* (all raw data, excluding PNG).

Source	df	SS	MS	F	p
Location	6	27.4837	4.58062	66.4341	< 0.0001
Date	1	0.04259	0.04259	0.6177	0.432
Location × date	6	1.81527	0.30255	4.3879	< 0.0001
Otolith weight	1	28.1482	28.1482	408.2425	< 0.01
Residual (Error)	501	34.5439	0.06895		
Total	515	95.8702			

Table 5: ANCOVA of the $\delta^{13}C$ values of the sagittal otolith carbonate of *Pristipomoides multidens* (selected data: otolith weight range from 350 to 650 mg, excluding PNG).

Source	df	SS	MS	F	p
Location	6	10.8490	1.8082	27.3585	< 0.0001
Date	1	0.00097	0.00097	0.01466	0.904
Location × date	6	1.13859	0.18977	2.87124	0.010
Otolith weight	1	2.83895	2.83895	42.9548	< 0.0001
Residual (Error)	223	14.7384	0.06609		
Total	237	34.6010			

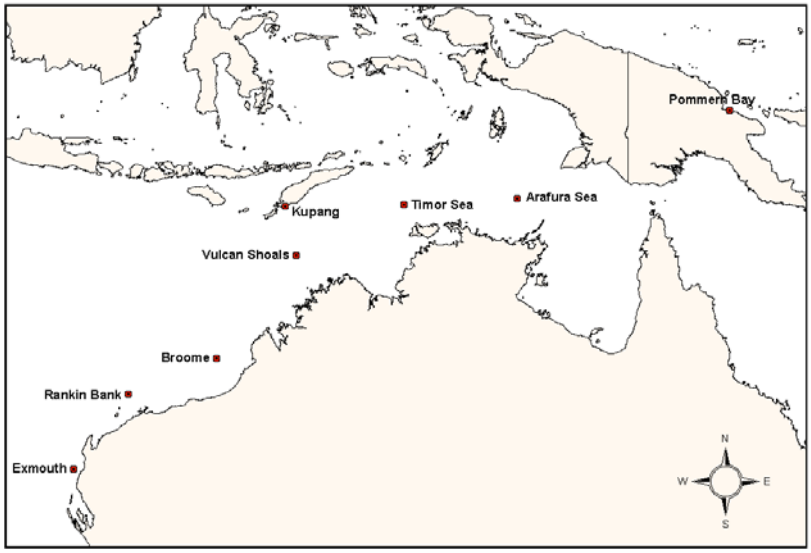

Figure 1: Sampling locations of the goldband snapper, *Pristipomoides multidens* from north-western Australia, Indonesia and Papua New Guinea.

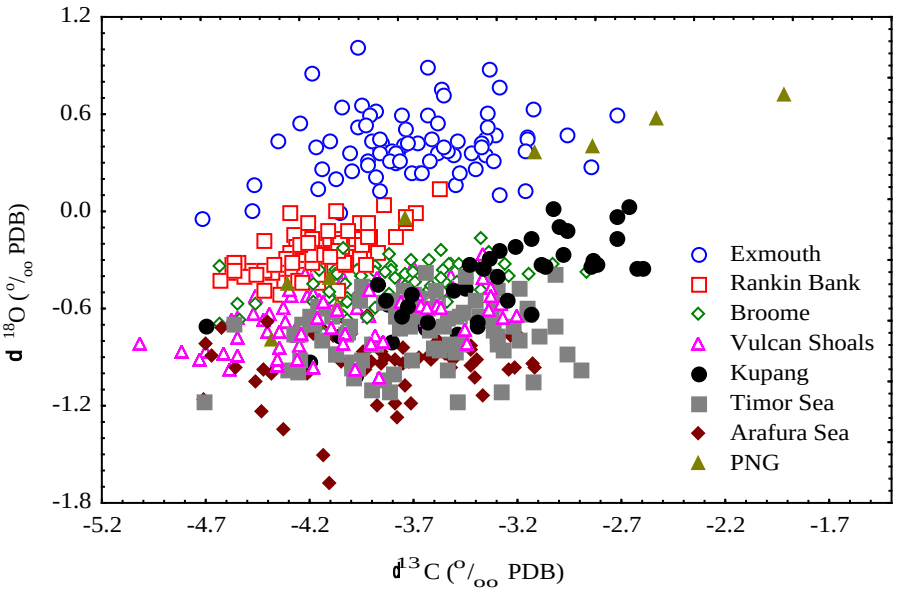

Figure 2: $\delta^{18}O$ values versus $\delta^{13}C$ values of goldband snapper sagittal otolith carbonate for each location for all data.

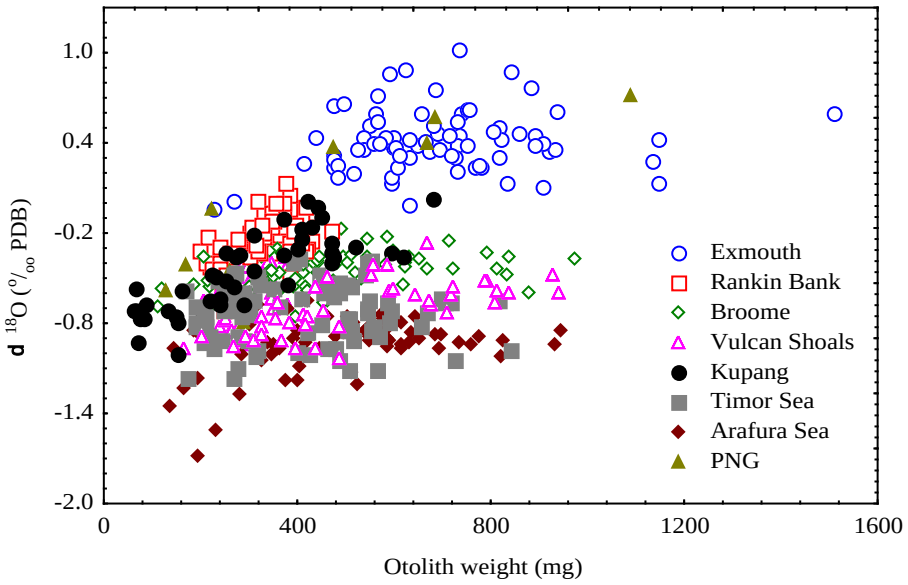

Figure 3: $\delta^{18}O$ values of goldband snapper sagittal otolith carbonate versus otolith weight for each location for all data.

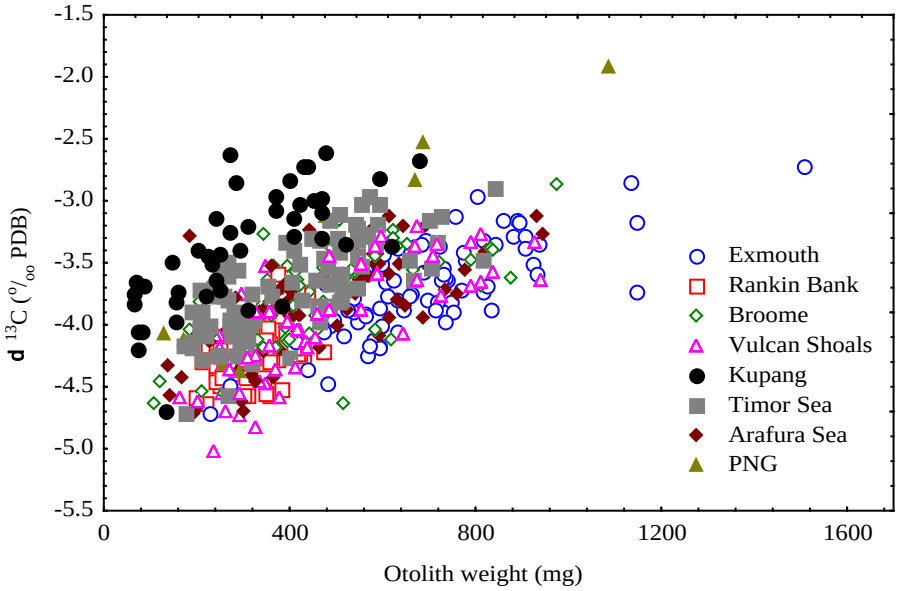

Figure 4: $\delta^{13}C$ values of goldband snapper sagittal otolith carbonate versus otolith weight for each location for all data.

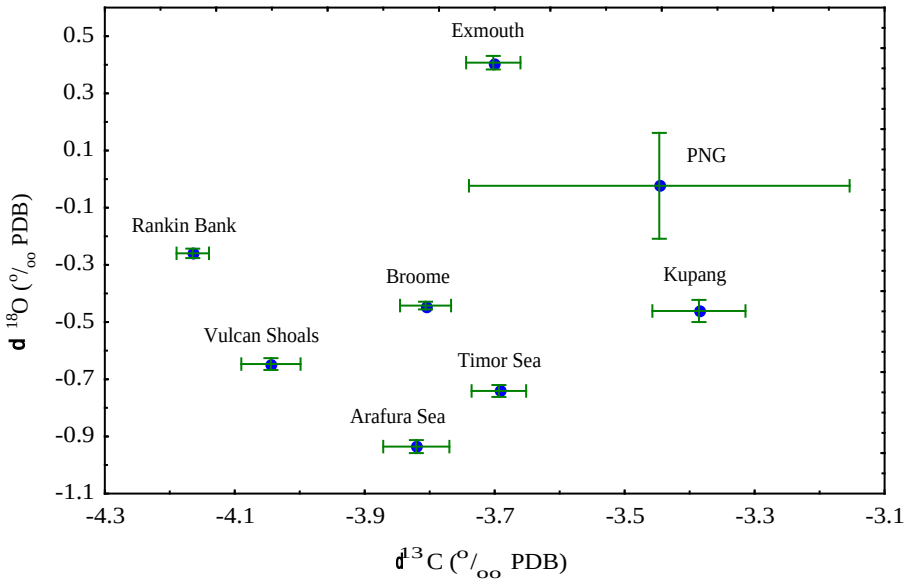

Figure 5: Mean $\delta^{18}O$ values (± standard error) versus mean $\delta^{13}C$ values (± standard error) of goldband snapper sagittal otolith carbonate for each location for all data.

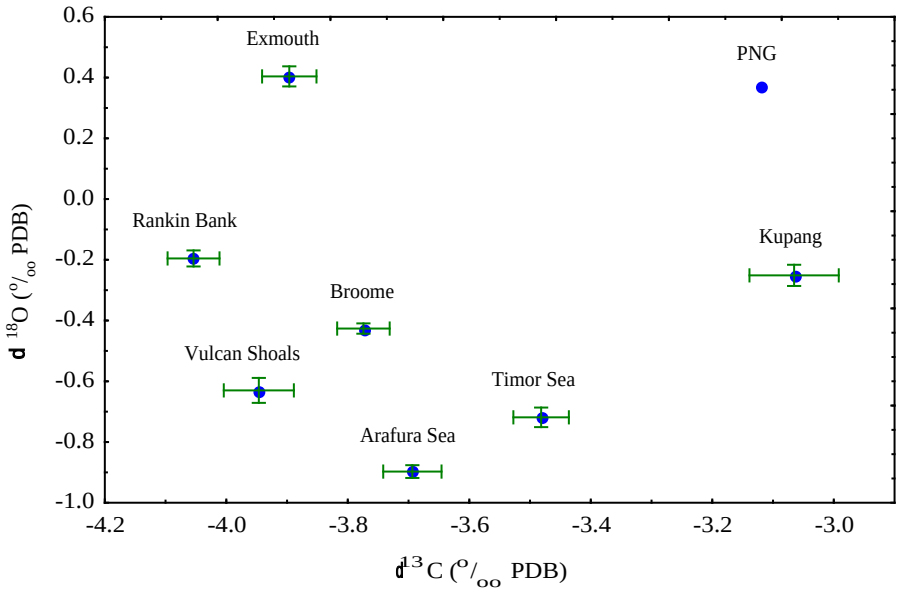

Figure 6: Mean $\delta^{18}O$ values (± standard error) versus mean $\delta^{13}C$ values (± standard error) of goldband snapper sagittal otolith carbonate for each location for selected data (otolith weight range from 350 to 650 mg only).

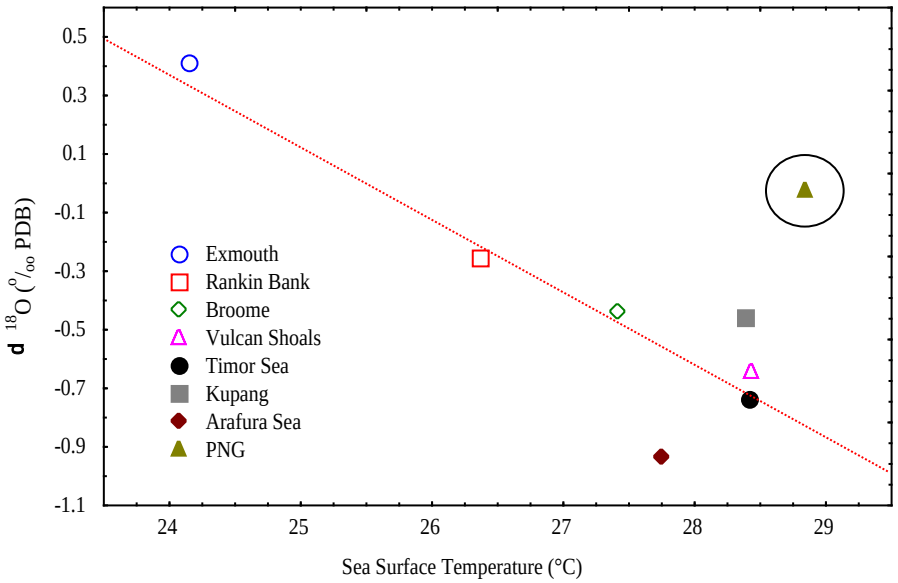

Figure 7: Mean $\delta^{18}O$ values of goldband snapper sagittal otolith carbonate for each location for all data versus mean sea surface temperatures from 1989 to 1998 (derived from the average monthly sea surface temperatures from 1989 and 1998; see Reynolds and Smith 1994) for each location.

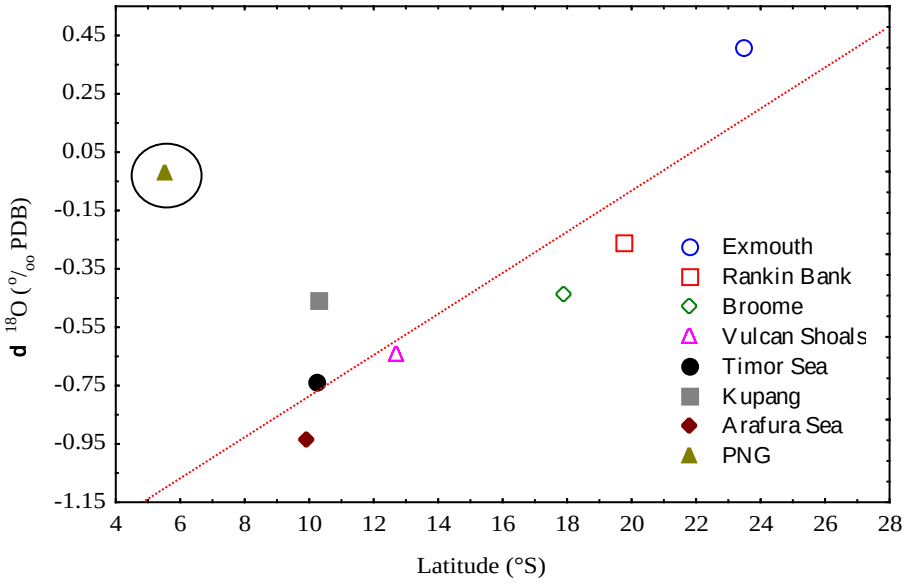

Figure 8: Mean $\delta^{18}O$ values of goldband snapper sagittal otolith carbonate for each location for all data versus latitude of each location.

Discussion

Oxygen isotopes in sagittal otolith carbonate have been reported to be deposited close to equilibrium with ambient sea-water (Kalish 1991a, 1991b; Iacumin et al. 1992). Hence, the oxygen isotope ratios in the sagittal otolith carbonate are a function of the water temperature in which the fish are resident if it is assumed the isotopic composition of the sea-water does not vary across the whole area of interest. It was therefore hypothesised that differences in the oxygen isotope values for each location could be explained by the relative differences in water temperature (which are dependent upon latitude) across northern Australia. The observed pattern of differences in oxygen isotope ratios supported this hypothesis, with the lowest oxygen isotope values, indicating the highest mean water temperatures being found in fish from the Vulcan Shoals, Timor Sea and Arafura Sea (see Fig. 7). Conversely, the highest oxygen isotope values, indicating the lowest mean water temperatures were found in fish from Exmouth (Fig. 7). Hence, the relationship between both sea surface temperature and latitude with $\delta^{18}O$ values was linear (Figs. 7, 8).

The $\delta^{18}O$ values obtained from the analysis of carbonate from whole powdered sagittal otoliths represent a mean value integrated over the entire ontogenetic life history of each individual fish. These fish may range in age from 3 to possibly 30 years (Newman unpublished data). In this study, the oxygen isotope signatures for each of the locations are significantly different and reflect different environmental conditions indicating that the adult fish have remained resident in the one location for most of their lives, with the bulk of the otolith carbonate laid down in a spatially distinct environment with its own characteristic temperature regime. If the adult fish were mixing among locations then the isotopic signatures for each location

would be similar with the adult fish having been exposed to a variety of environmental conditions and temperature regimes as was demonstrated by Edmonds et al. (1999) for tailor (*Pomatomus saltatrix*) in mid-western Australia. The oxygen isotope signatures of the goldband snapper across north-western Australia therefore present strong evidence that the adult fish are spatially distinct and non-mixing and hence, can be considered as independent management units, or stocks, for the purposes of fisheries management.

The $\delta^{18}O$ and $\delta^{13}C$ values obtained from the sagittal otolith carbonate of goldband snapper collected from PNG were much more variable when compared to those collected from any other location. This variability alone was considered to be indicative of separation of the adult fish in this area, from elsewhere and hence these fish were considered to be a separate stock. Values for $\delta^{18}O$ otolith carbonate from the small number of fish sampled from PNG was higher than was expected from considerations of water temperature alone (see Fig. 7). This indicated that the fish (captured from 100 to 200 metres water depth) were resident in colder waters below the thermocline separating such waters from the lens of warm surface water influenced by the isotopically light rainfall typical of equatorial regions (Gagan, pers. comm.). Furthermore, temperature profiles with depth for different latitudes indicate that low latitudes possess the largest variation in temperature with water depth (Millero and Sohn, 1989). This, then, provides the potential for the variations in isotopic composition of otoliths from PNG fish that were observed in this study.

Variation in $\delta^{13}C$ values of all the goldband snapper sampled were more attributable to otolith weight than location of capture (Table 4). However, when the otolith weight range was restricted (Table 5), variation in $\delta^{13}C$ values of the goldband snapper were more attributable to location of capture than to otolith weight. This

result is consistent with the hypothesis of Kalish (1991b) that $\delta^{13}C$ values are dependent to a large degree on metabolic rate, with higher rates resulting in greater depletion of otolith $\delta^{13}C$. Hence, when the age range was restricted (otolith weight is considered a proxy for fish age), variation in $\delta^{13}C$ values of the goldband snapper were more attributable to the location of capture. The $\delta^{13}C$ data clearly demonstrated that the goldband snapper sampled from Kupang, Indonesia were distinctly different from all other locations sampled. The separation of the Kupang, Timor Island, Indonesia samples from the locations along the continental shelf of Australia is not surprising given that they are separated by the Timor Trench which is approximately 2000 metres deep. The Timor Trench is therefore an effective barrier to adult movement between the continental shelf waters of Australia and the islands of Indonesia.

This study has provided further evidence that the measurement of stable isotopes ratios in teleost sagittal otolith carbonate can be a valuable tool in the determination of discernible fishery management units of adult fish where the range of distribution of the species in question covers waters with different temperature regimes

Fishery management implications

Oxygen and carbon stable isotope values in this study have shown distinct location-specific isotope signatures which strongly support the hypothesis of a multi-stock complex of goldband snapper being present across north-western Australia. This multi-stock complex of goldband snapper persists through time and can be separated into a number of distinct stocks or management units. These stocks are: (1)

Exmouth; (2) Rankin Bank; (3) Broome; (4) Vulcan Shoals; (5) Timor Sea; (6) Arafura Sea; (7) Kupang [Indonesia] and (8) Pommern Bay [Papua New Guinea]. Further subdivision may have been revealed with a more closely spaced sampling regime. While these stocks of adult goldband snapper are effectively isolated from each other, recruitment to each of the stocks across north-western Australia may be derived from a common gene pool (if there is an absence of significant genetic variation among stocks). Westward and southward directed movement of eggs and larvae is highly probable under the influence of the Indonesian Throughflow and the Leeuwin Current and therefore stocks may be well mixed in the genetic sense. The extent of the gene flow between goldband snapper populations across northern Australia has been investigated as part of FRDC Project 96/131.

A high probability of connectivity or intermixing during the egg and larval stages across a multi-stock complex of separate and distinct adult stocks implies that the size of the total adult spawning stock (ie. the combined sum of each of the separate adult stocks) could impact recruitment. Thus, fishing on any one stock could impact fishing on any other stock, through subsequent recruitment (resulting from a reduced spawner biomass). However, direct impacts of fishing on one stock should not affect adjacent stocks (or any fishing impact should be negligible).

Recruitment in fish stocks is inherently variable and is usually dependent upon both the total spawner biomass and the prevailing oceanographic conditions at the time of spawning. Consequently, one stock may produce relatively high recruitment one year or over a series of years, while another stock suffers from poor recruitment. If fish stocks suffer from localised depletions (removal of spawners and hence older age classes) and local recruitment is poor (no juveniles available in subsequent years), then the recovery of the stock will be dependent on the rate of supply of external

recruits. Under these circumstances of adult residency shown in this study, it may be difficult for stocks to recover and the recovery cycle may be in the order of decades in long lived fishes such as goldband snapper. Given the need for external recruitment in the replenishment of local depletion events and an initial adult stock structure which consists of at least 20+ age classes (e.g. ages 5 to at least 25), then a serious local depletion event would require a minimum of 20 years for the stock to recover in terms of the both the spawner biomass and age structure.

Separation of stocks and the delineation of stock structure allows management units to be defined. The presence of a multi-stock complex of goldband snapper indicates that management can be applied separately to each of the stocks at the regional or location level along the north-western Australian coast. However, a more robust or cautionary approach to fisheries management is recommended whereby each State management agency should aim to maintain an adequate total spawner biomass within each of the fishable stocks and avoid localised depletion events. This cautionary approach to management applies to both State-based management agencies within Australia and also to cross-border management agencies within Indonesia given the adjacent nature of fishing grounds in northern Australian waters.

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Benefits

The results from this project directly benefit the commercial fishers of both Western Australia and the Northern Territory by enabling both the Northern Territory Fisheries Division and Fisheries Western Australia to formulate separate management regimes for the goldband snapper fishery resources in each

region. The resolution of stock structure also assists in our understanding of the dynamics of this important fishery resource.

Information gained from this study also have some relevance to *Pristipomoides* species elsewhere in Australia, eg. the Great Barrier Reef, Queensland.

Conclusion

This project has demonstrated that genetics alone are not a stock discrimination panacea (see Ovenden et al. 1999). Genetic analyses may identify differences that occur when gene flow is restricted. Genetic differences are useful if they provide understandable and significant differences in biological parameters, such as growth rates or distinctly different adjoining populations. However, only a small amount of gene flow (eg. from larval drift) is required for a population to be genetically homogeneous (ie. one stock in the genetic sense). While adult populations may represent one genetic stock, they may occur in discrete units. Otolith microchemistry may be used to resolve a genetically homogeneous population into discrete units of adult fish, should these exist based on the different chemical components within the otolith which reflect the environmental conditions in which the fish live. The resolution of these differences will provide useful information for predicting the effects of localised depletions on stock sustainability. In order to provide the best management advice it is important to utilise techniques that provide for robust separation of population units and hence resolution of stock structure.

It is advisable to use a range of methodologies when examining the stock structure of demersal fisheries resources, as different stock discrimination techniques all provide information on various aspects of the life history of teleost fish and each piece of information is important in resolving stock structure or separate population units for fishery management purposes.

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Appendix 1: Intellectual Property

Nil

Appendix 2: Staff

Dr. S. Newman	Fisheries WA
Dr. J. Edmonds	Fisheries WA
Ms J. Lloyd Dr.	NT Fisheries
T. Bastow Mr. R.	Fisheries WA
Steckis Mr. C.	Fisheries WA
Bryce Mr. I.	NT Fisheries
Dunk Mr. R.	Fisheries WA
Ashworth Mr. J.	Fisheries WA
Jenke Ms. M.	Fisheries WA
Brasseur Ms. A.	Fisheries WA
Kidd Ms. J.	Fisheries WA
Moore	Fisheries WA