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M. P. Francis

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M. P. Francis

NIWA
Private Bag 14901
Wellington 6241

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EXECUTIVE SUMMARY

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In the 23 years since rig and school shark Quota Management Area (QMA) boundaries were established, a significant amount of new, pertinent information has been accumulated. Fishery managers are currently making decisions that may have important sustainability and cost implications if QMA boundaries are inappropriate because they either encompass multiple biological stocks, or cover only part of a biological stock. It is therefore timely to review the existing QMA boundaries in order to determine whether they are appropriate. A fundamental principle is that QMAs should be matched to biological stock boundaries as closely as possible, unless other overriding considerations exist. This report re-analyses updated tagging datasets to assess the degree of inter-QMA movement of rig and school shark. Companion studies have examined a range of other measures or indicators that might provide information on stock range and boundaries. All these sources of information are reviewed in order to assess the match between the current QMA boundaries and biological stock boundaries.

Despite many caveats about using tagging data from inappropriate experimental designs to infer movement rates, it is possible to draw several robust conclusions from the tagging results.

- Male rig rarely moved outside the release QMA, even after more than 5 years at liberty.
- Female rig were more mobile than male rig, with about 30% moving beyond the release QMA boundaries within 2–5 years of release. The proportion moving beyond the release QMA increased steadily with time. However, few females moved more than one QMA away from the release point.
- Female school shark were slightly more mobile than males, with higher proportions of the former moving to non-adjacent QMAs and to Australia.
- About 30% of school sharks moved outside the release QMA within a year of release, and this was maintained in the second year after release. After 2–5 years at liberty about 60% of school sharks (both sexes) had moved outside the release QMA. After more than 5 years at liberty, 8% of males and 19% of females had moved to Australia.

Male rig move shorter distances than female rig, so a conservative management approach would be to set rig QMAs at a size appropriate for males. Tagging data indicate that male rig do not often move outside current QMA boundaries. A large proportion of tagged school sharks moved outside the QMA of release within 5 years, and a significant proportion eventually moved to Australia. From the tagging evidence, there is probably a single biological stock in the New Zealand EEZ.

Companion studies reviewed genetic, biological, and fishery information for evidence of separate stocks of rig and school shark in New Zealand. Little genetic variation was found that might indicate different stocks of either species. Some differences were found in CPUE trends at a small spatial scale, but stock separation at these small scales seems unlikely. The only persuasive evidence for a mismatch between existing QMA boundaries and biological stocks in these studies was the apparent lack of juvenile school shark nursery areas in SCH 4 and SCH 5, suggesting that these Fishstocks are not distinct, but are instead maintained by recruitment from other QMAs.

The existing QMAs are probably appropriate for rig stocks, although the boundaries between biological stocks are not clearly defined. School shark QMAs are much smaller than the ranges inhabited by the sharks. However, management of school shark in the current small QMAs is probably not having a detrimental effect on the stock. The relative importance of various breeding grounds around New Zealand (e.g., aggregations of breeding females in Kaipara Harbour) and whether females return to the area in which they were born are unknown. Therefore, the current stock management units may be a wise precautionary measure to spread fishing effort; amalgamation of all QMAs into one QMA for the whole country could create unacceptable risks to stock sustainability.

1. INTRODUCTION

Rig (*Mustelus lenticulatus*) and school shark (*Galeorhinus galeus*) are small to medium sized sharks that occur widely throughout New Zealand coastal waters, and may extend down to 500 m depth or more (Anderson et al. 1998). Both species commonly aggregate in inshore waters to breed during spring and summer, and then disperse across the shelf and upper slope during autumn–winter (Francis & Mace 1980). The inshore aggregations support locally important target fisheries for both species, which are also commonly taken as bycatch (Ministry of Fisheries 2008).

Five putative biological stocks of rig were proposed in October 1986 at the start of the Quota Management System (QMS) (Francis 1985; 1988a; Ministry of Fisheries 2008): northeast coast North Island (NECNI), southeast coast North Island (SECNI), east coast South Island, Southland, and Fiordland (ECSI), west coast South Island (WCSI), and west coast North Island (WCNI). The ECSI and WCSI stocks were determined from a tagging programme carried out in the early 1980s (Francis 1988b; 1989), NECNI and SECNI stocks were separated on the basis of different catch per unit effort (CPUE) trends before 1986 (Francis & Smith 1988), while the WCNI stock was arbitrarily defined to be similar in size to the South Island stocks.

Six Quota Management Areas (QMAs) were established for rig in October 1986 (Figure 1). Fishstocks SPO 2, SPO 3, and SPO 7 closely correspond with the SECNI, ECSI, and WCSI biological stocks respectively. SPO 1 includes the northern part of the WCNI stock and the NECNI stock, while SPO 8 comprises the southern portion of the WCNI stock. SPO 10 comprises the Kermadec Islands; however, Kermadec specimens of *Mustelus* are now known to represent a different undescribed species (C. Duffy and M. Francis, unpublished data). Whether true rig (*Mustelus lenticulatus*) occurs in SPO 10 is unknown.

School shark are considered to comprise one biological stock in New Zealand waters, based on tag return data (Ministry of Fisheries 2008). Although most tagged sharks were recovered from within the QMA of release, many moved large distances, including some that travelled 1700–5000 km to Australia (Coutin 1992; Hurst et al. 1999).

In the absence of evidence for school shark stock boundaries (Paul 1988), eight QMAs were established in 1986 (Figure 2). SCH 1 comprises the northwest coast North Island and northeast coast North Island, SCH 2 comprises the southeast coast North Island, SCH 3 comprises east coast South Island, SCH 4 includes the Chatham Rise and Chatham Islands, SCH 5 covers Southland, subantarctic waters, and the Stewart-Snares shelf, SCH 7 includes the west coast South Island, and SCH 8 includes the southwest coast North Island (Ministry of Fisheries 2008).

In the 23 years since rig and school shark QMA boundaries were established, a significant amount of new, pertinent information has been accumulated. Fishery managers are currently making decisions that may have important sustainability and cost implications if QMA boundaries are inappropriate because they either encompass multiple biological stocks, or cover only part of a biological stock. It is therefore timely to review the existing QMA boundaries in order to determine whether they are appropriate.

Understanding fish stock ranges and boundaries is fundamental to accurate and sustainable fisheries management. A mismatch between the spatial range of biological stocks and management areas could lead to undesirable management consequences. In extreme cases, significant ‘leakage’ of fish across management boundaries could produce severe overfishing. For example if a management area includes the boundary of two adjacent stocks A and B in which stock density is markedly different, Total Allowable Catches (TACs) set at levels appropriate for the higher density stock may be too high to be sustainable in the lower density stock.

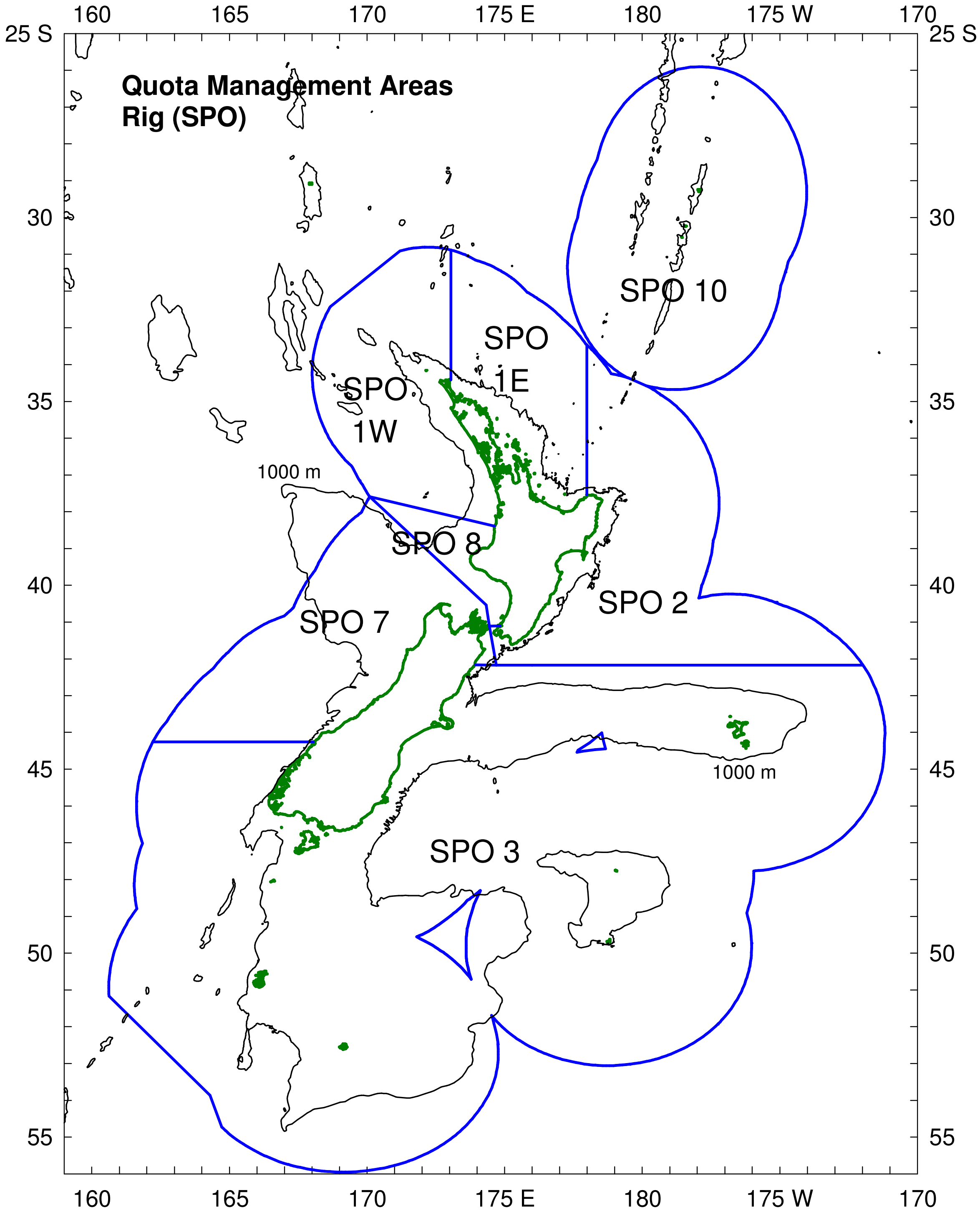

Figure 1: Rig Quota Management Areas. SPO 1 was subdivided into east (SPO 1E) and west (SPO 1W) subareas for analyses in the present study.

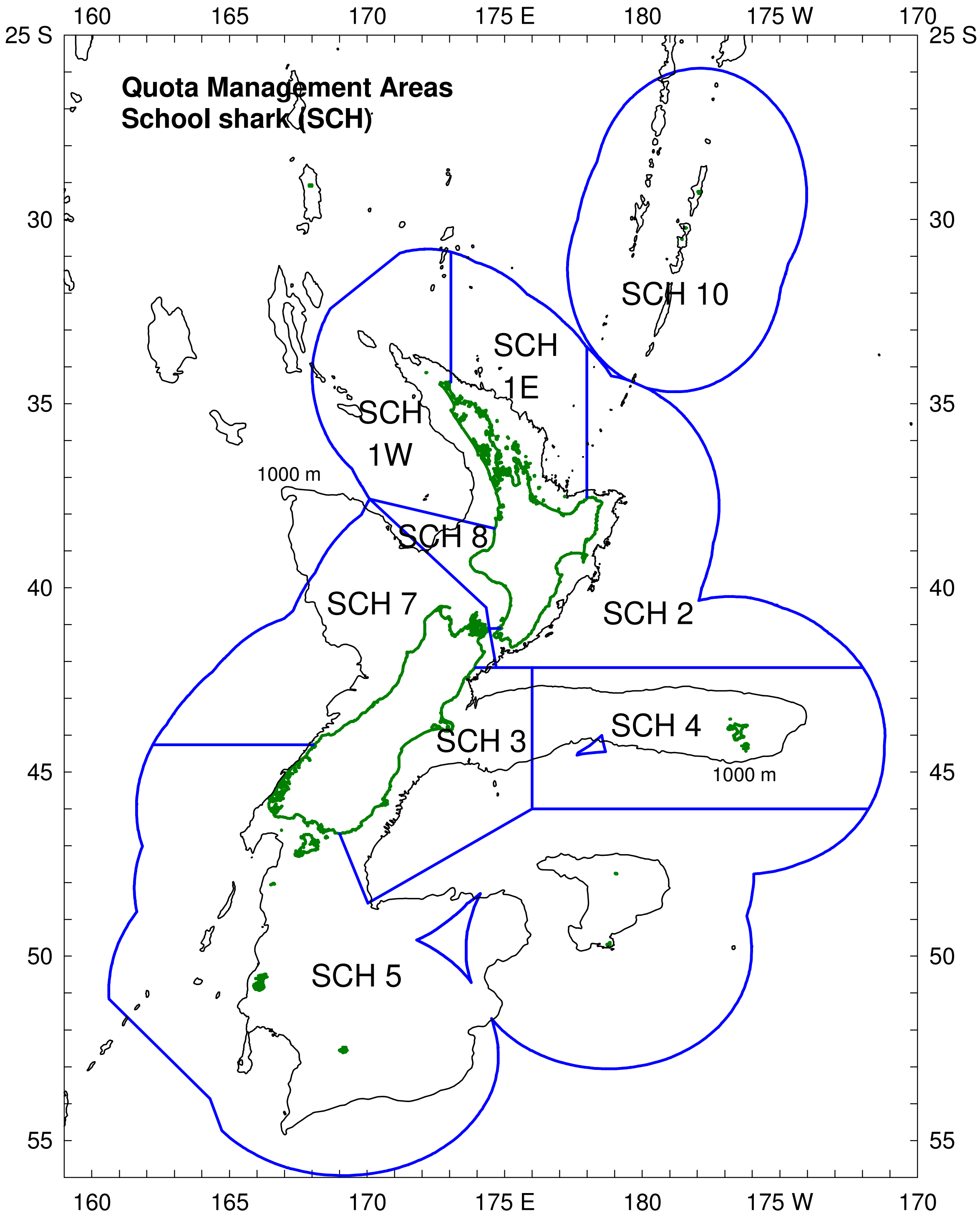

Figure 2: School shark Quota Management Areas. SCH 1 was subdivided into east (SCH 1E) and west (SCH 1W) subareas for analyses in the present study.

Modification of management boundaries could lead to improvements in sustainability, increases in catch, improved catching efficiency for industry, simpler and cheaper quota trading, and reduced research, assessment, and management costs (especially if small QMAs are amalgamated into larger units). A fundamental principle is that QMAs should be matched to biological stock boundaries as closely as possible, unless other overriding considerations exist.

This report re-analyses updated tagging datasets to assess the degree of inter-QMA movement of rig and school shark. The results will help to determine whether the number and size of existing QMAs are appropriate for management. The related question of whether QMA boundaries are in the right place is not considered here because existing tagging data have limited utility for identifying fine scale movement patterns. Companion studies have examined a range of other measures or indicators that might provide information on stock range and boundaries, including length and age at maturity, size composition, sex ratio, spatial variation in CPUE trends, trends in relative biomass as determined from trawl surveys, and population genetic composition (Smith 2009; Blackwell & Francis 2010). All these sources of information are reviewed here in order to assess the match between the current QMA boundaries, and biological stock boundaries.

2. METHODS

A rig tagging programme was carried out by the Ministry of Agriculture and Fisheries between 1978 and 1988, with most sharks being tagged in 1982–84. The tagging methodology, and results up to 1985, were reported by Francis (1988b). Rig were tagged mainly around the South Island from research surveys and commercial set net vessels, with smaller numbers being tagged around North Island. Data from this tagging programme were extracted from an Excel file maintained and held by M. Francis (NIWA). Since 2007, small numbers of rig have been tagged opportunistically during research trawl surveys around the South Island. An extract from the MFish *tag* database on 20 August 2009 revealed 69 tag releases post-1988 and two recaptures. Because of the very small number of recaptures, these recent tag releases were omitted from the present study.

A school shark tagging programme carried out by the Ministry of Agriculture and Fisheries (and subsequently NIWA) has been underway since 1985. The tagging methodology, and results up to 1997, were reported by Hurst et al. (1999). Sharks were tagged opportunistically, mainly during research trawl surveys. Most releases were made around the South Island. Since the analysis by Hurst et al., about 120 additional school shark tags have been returned, providing a considerable amount of new data for analysis. An extract of all school shark tag releases and recaptures under project identification code SCH_TAG was made from the *tag* database on 19 June 2009. The numbers of school sharks tagged annually varied greatly, with over 800 being tagged in each of 1986 and 1990, but fewer than 300 tagged per year in most other years. This dataset will be referred to here as 'School shark (NIWA)'.

School sharks have also been tagged by game fishers over many years. Tagging methods and results have been reported in a series of reports, the latest by Holdsworth & Saul (2008). However, school shark was not a target species of the programme and the number of releases and recaptures has been low. Consequently results for school shark were not presented separately, but were combined with a variety of other minor shark species (Holdsworth & Saul 2008). For the present study, John Holdsworth (Blue Water Marine Research) provided an extract dated 13 July 2009 of all released and recaptured school sharks. The vast majority of school sharks were tagged around northern North Island (SCH 1E and 1W). This dataset will be referred to here as 'School shark (GAME)'.

The rig and school shark datasets were groomed where possible, paying particular attention to release and recapture locations[1]. Release and recapture QMAs were determined from recorded latitudes and longitudes, or occasionally statistical areas. QMA 1 releases and recaptures were assigned to one of two subareas: 1 East (1E) or 1 West (1W); these subareas were divided at a north-south line centred on North Cape (i.e., the boundary between Fisheries Management Areas 1 and 9) (see Figures 1 & 2).

[1] Because of missing data, particularly for recaptures, sample sizes vary among analyses, figures and tables.

This was done because a major biogeographic boundary at North Cape might act as a biological stock boundary for either species.

3. RESULTS

3.1 Rig

The temporal distribution of tag releases (2386) and recaptures (437) is shown in Table 1 and Figure 3. Most releases (90%) were made in 1982–84. Recaptures generally followed the same pattern as releases, with 90% being recaptured in 1982–86. Most recaptures (81%) occurred within 2 years of tagging, with very few recaptures after 7 years. The maximum period at liberty was 13.8 years (Figure 4). More males were tagged than females (sex ratio 1.8:1) (Figure 5). The length-frequency distribution of released rig was strongly unimodal with a peak at 75–105 cm total length (TL) (Figure 5). Most released females would have been immature, but most males would have been mature (based on estimated lengths at maturity; see Figure 5). Cumulative length-frequency plots were flatter for females than males, indicating that a higher proportion of small and large females was tagged compared with males, which were dominated by intermediate-sized sharks (Figure 6). Rig that were small at release had a low recapture rate – few rig smaller than 70 cm TL at tagging were recaptured, and the percentage recaptured increased steadily for both sexes from about 10% at 70–80 cm to peak at about 30% at 95–105 cm (Figure 5 & 6). Most rig (87%) were released around the South Island in SPO 3 and SPO 7; smaller numbers were released in SPO 1E, 1W and 8 (Table 2).

Table 1: Rig tag releases and recaptures by year of release.

Year	Releases	Recaptures
1978	22	
1979	50	6
1980		4
1981	83	2
1982	1036	59
1983	766	132
1984	356	116
1985	31	57
1986	20	29
1987	13	2
1988	9	12
1989		6
1990		5
1991		2
1992		
1993		1
1994		1
1995		
1996		1
Unknown		2
Total	2386	437

A very high proportion (91%) of recaptured rig were caught in the same QMA that they were released in (release QMA). This pattern was consistent across QMAs, though only SPO 3 and 7 had large sample sizes (Table 3). Movements away from the release QMA were usually to adjacent QMAs. Division of the recaptures into subsets based on period at liberty did not change this pattern (Table 3): after more than 2 years at liberty, 84% of recaptured rig were still caught in the release QMA.

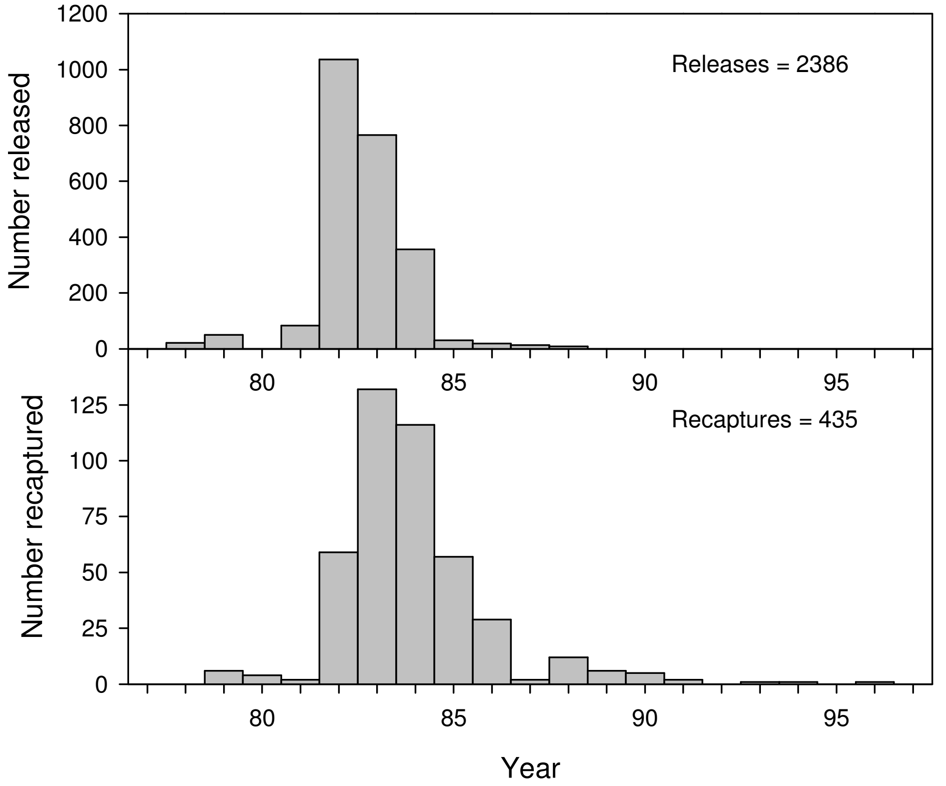

Figure 3: Number of rig tag releases and recaptures by year.

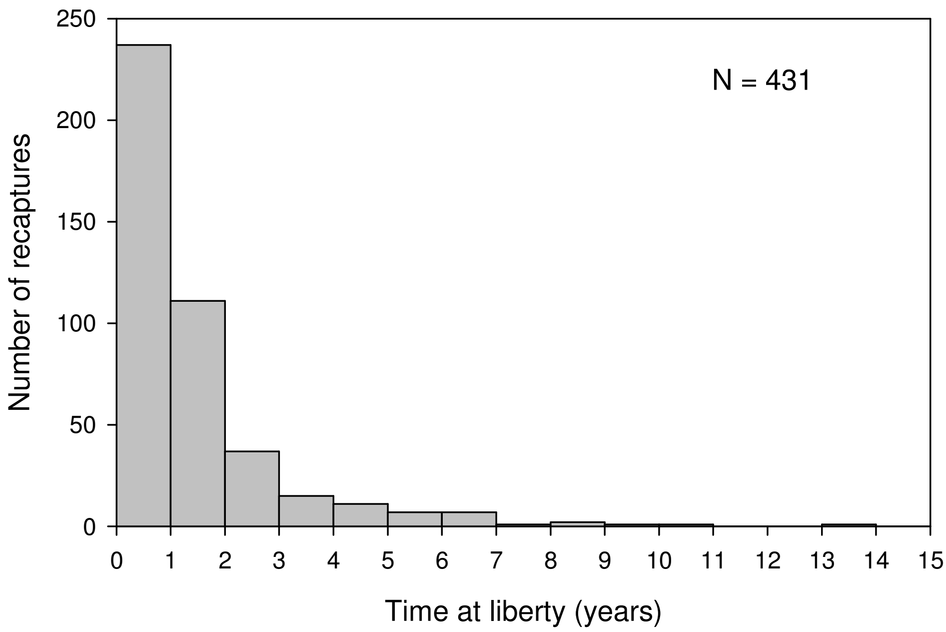

Figure 4: Frequency distribution of time at liberty for rig recaptures.

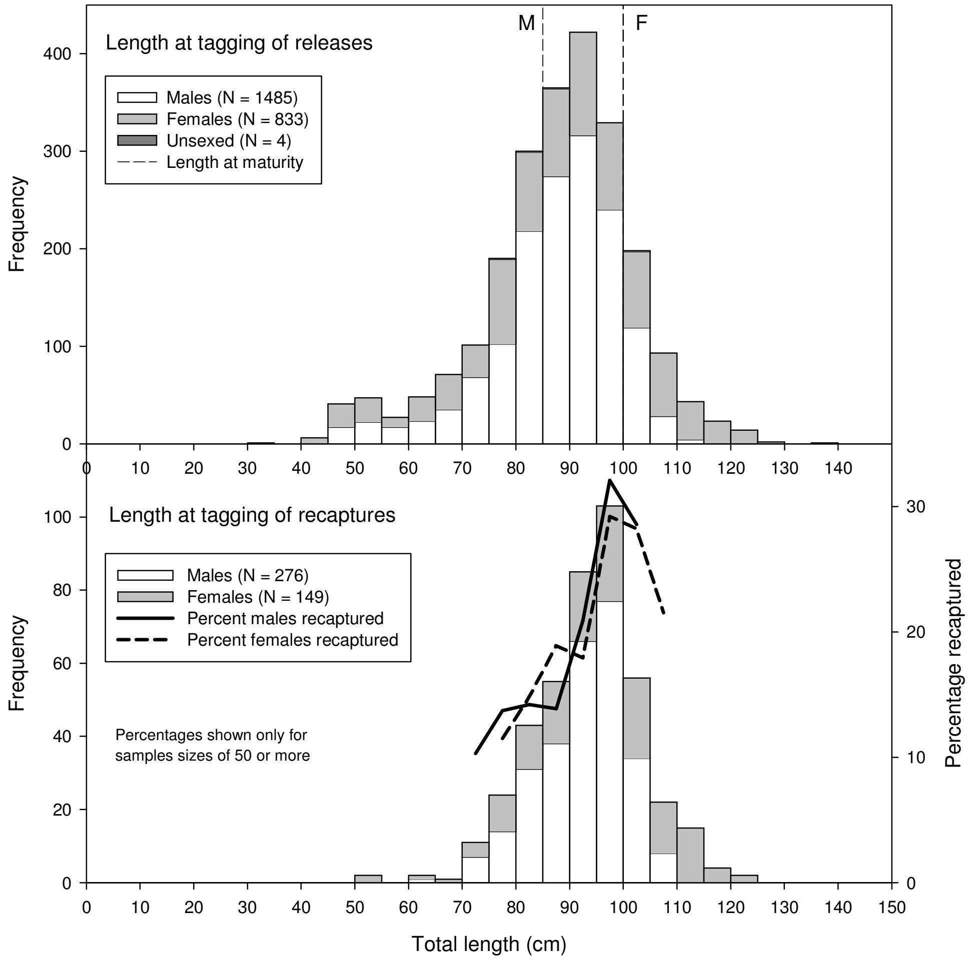

Figure 5: Length frequency distribution of released and recaptured rig (both at time of release) by sex. The percentage of rig recaptured by 5 cm length class and sex is shown in the bottom panel.

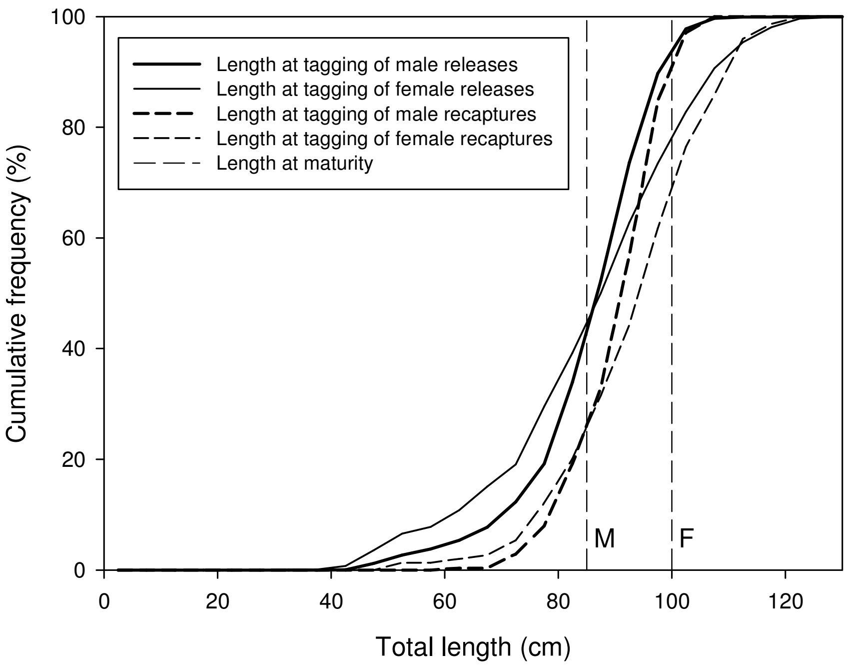

Figure 6: Cumulative length frequency distributions of released and recaptured rig (both at time of release) by sex.

Table 2: Release QMAs for tagged rig.

QMA	Number released	Percentage of releases
SPO 1E	107	4.5
SPO 1W	75	3.1
SPO 2	6	0.3
SPO 3	1037	43.5
SPO 7	1029	43.1
SPO 8	132	5.5
Total	2386	100.0

Table 3: Classification of recaptured rig by release QMA and recapture QMA. The number of recaptures is expressed as a percentage of all recaptured rig released in the release QMA. The first panel shows all recaptures, and the next three panels show recaptures classified by period at liberty. Shading is used to emphasise high percentages (see legend).

Legend

11-25%	26-50%	> 50 %

Release QMA	Recapture QMA (percentage of rig released in release QMA)							Sample size
	SPO 1E	SPO 1W	SPO 2	SPO 3	SPO 7	SPO 8	Total	
All recaptures								
SPO 1E	100.0						100	4
SPO 1W		75.0				25.0	100	4
SPO 2								0
SPO 3		0.8	0.4	94.7	1.9	2.3	100	265
SPO 7	0.7	1.4		6.2	84.8	6.9	100	145
SPO 8				5.3		94.7	100	19
Total	1.1	1.6	0.2	59.7	29.3	8.0	100	437
0-0.99 years								
SPO 1E	100.0						100	3
SPO 1W		100.0					100	2
SPO 2								0
SPO 3				97.1	1.4	1.4	100	140
SPO 7				6.3	90.0	3.8	100	80
SPO 8						100.0	100	12
Total	1.3	0.8		59.5	31.2	7.2	100	237
1-1.99 years								
SPO 1E	100.0						100	1
SPO 1W						100.0	100	1
SPO 2								0
SPO 3			1.5	98.5			100	68
SPO 7		6.3		6.3	71.9	15.6	100	32
SPO 8				16.7		83.3	100	6
Total	0.9			64.8	21.3	10.2	100	108
2-14 years								
SPO 1E								0
SPO 1W		100.0					100	1
SPO 2								0
SPO 3		3.5		84.2	5.3	7.0	100	57
SPO 7	3.7			7.4	81.5	7.4	100	27
SPO 8						100.0	100	1
Total	1.2			58.1	29.1	8.1	100	86

Movement patterns were explored in more detail by dividing the data by sex, and calculating the percentages of sharks recaptured in the release, adjacent, and non-adjacent QMAs by period at liberty. Non-adjacent QMAs were defined as QMAs that were separated from the release QMA by at least one intervening QMA. Male rig showed very low movement among QMAs, with more than 95% being recaptured in the release QMA regardless of the period at liberty (Figure 7). The males that did move beyond the release QMA were caught in the adjacent QMA. Females showed little movement during the first year at liberty, but the percentage recaptured in the release QMA declined steadily to 38% after 5–14 years at liberty (though the sample size was very low). The percentages of females recaptured in an adjacent QMA or a non-adjacent QMA increased correspondingly to 50% and 13% respectively after 5–14 years at liberty. Thus most female recaptures were made within the release or adjacent QMAs (88%) even after more than 5 years at liberty.

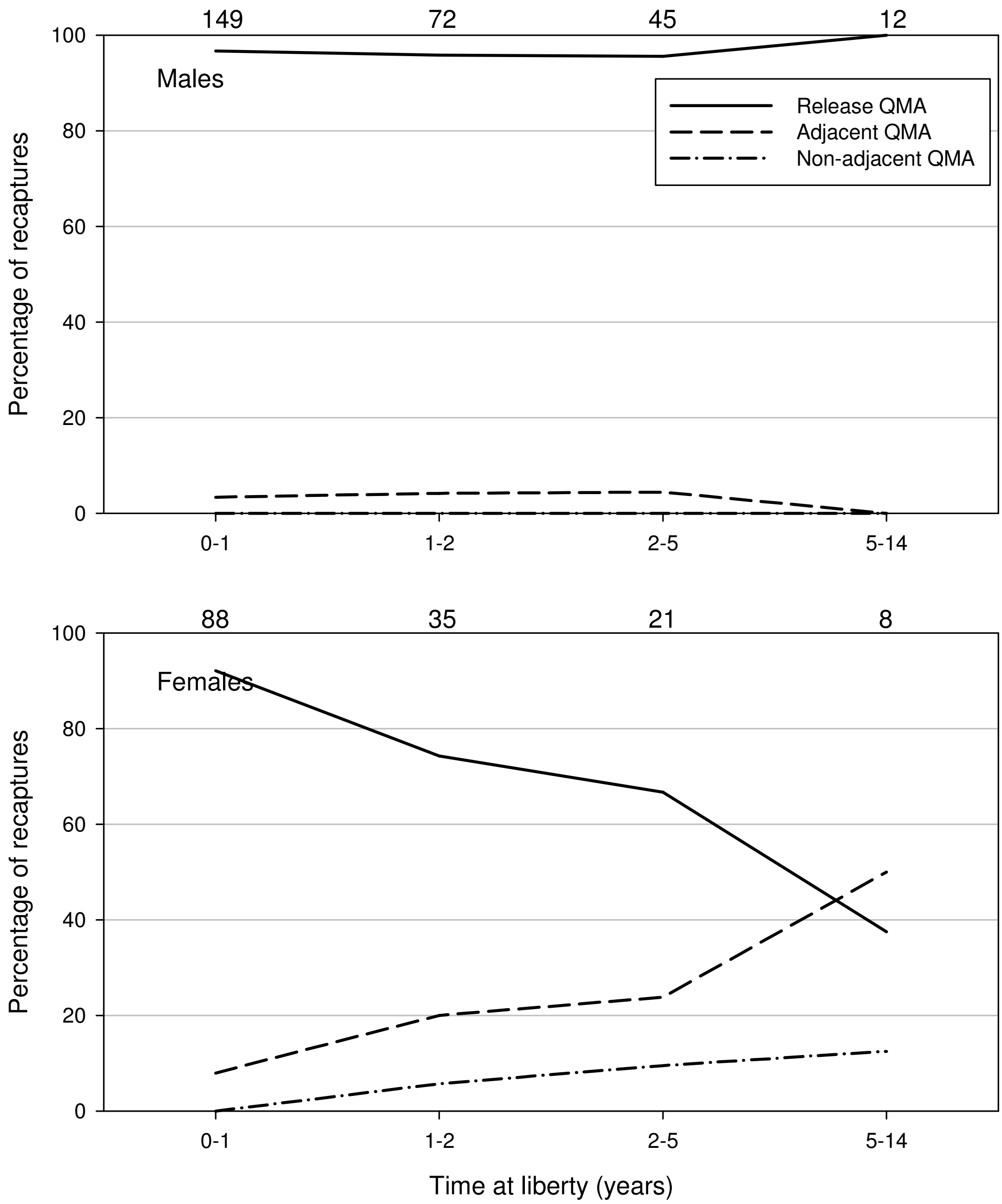

Figure 7: Percentage of male and female rig recaptures classified by recapture QMA and period at liberty. Sample sizes for each time period are shown at the top of each panel.

3.2 School shark

3.2.1 School shark (NIWA)

The temporal distribution of NIWA tag releases (4506) and recaptures (320) is shown in Table 4 and Figure 8. School sharks were tagged in most years between 1985 and 2008, with the notable exception of 1998–2002 when none were tagged. The numbers of sharks tagged per year varied greatly with peaks of 996 in 1986 and 879 in 1990, but most other years had fewer than 300 releases. Recaptures were spread throughout a 24-year period, but with greatest numbers being returned in the 1990s. Most recaptures (82%) occurred within 5 years of tagging, but a considerable number were at liberty for 5–11 years; the maximum period at liberty was 16.1 years (Figure 9). More males were tagged than females (sex ratio 1.4:1) (Figure 10). The length-frequency distribution of released school shark had a weak peak at 100–125 cm TL within a broad plateau at 65–155 cm (Figure 10). Most released school sharks would have been immature (based on estimated lengths at maturity; see Figure 10). A higher proportion of large males was released than large females (Figure 11). School shark that were small at release had a low recapture rate – the percentage recaptured increased steadily for both sexes from about 5% at 65–80 cm to peak at about 12% at 80–95 cm, followed by a slow decline (apart from a couple of spikes) (Figure 10). Most school shark (78%) were released around the South Island in SCH 3, 5, and 7; smaller numbers were released in SCH 1W, 2, 4, and 8 (Table 5).

Table 4: School shark tag releases and recaptures. Data are subdivided by tagging programme (School shark (NIWA) and School shark (GAME)).

Year	NIWA releases	NIWA recaptures	GAME releases	GAME recaptures
1984			1	
1985	256			
1986	996	5	14	4
1987	22	13	21	5
1988	28	10	4	1
1989	66	3	8	2
1990	879	21	13	5
1991	37	17	14	3
1992	270	11	10	3
1993	279	18	4	2
1994	254	18	2	1
1995	325	25		
1996	283	26	3	
1997	159	21		
1998		19		
1999		13	1	
2000		7	2	1
2001		9	2	1
2002		13	5	
2003	144	8	10	
2004		9	2	
2005	141	10	7	2
2006		4	7	
2007	283	6	2	
2008	80	16	1	
2009		4	1	
Unknown	4	14	3	3
Total	4506	320	137	33

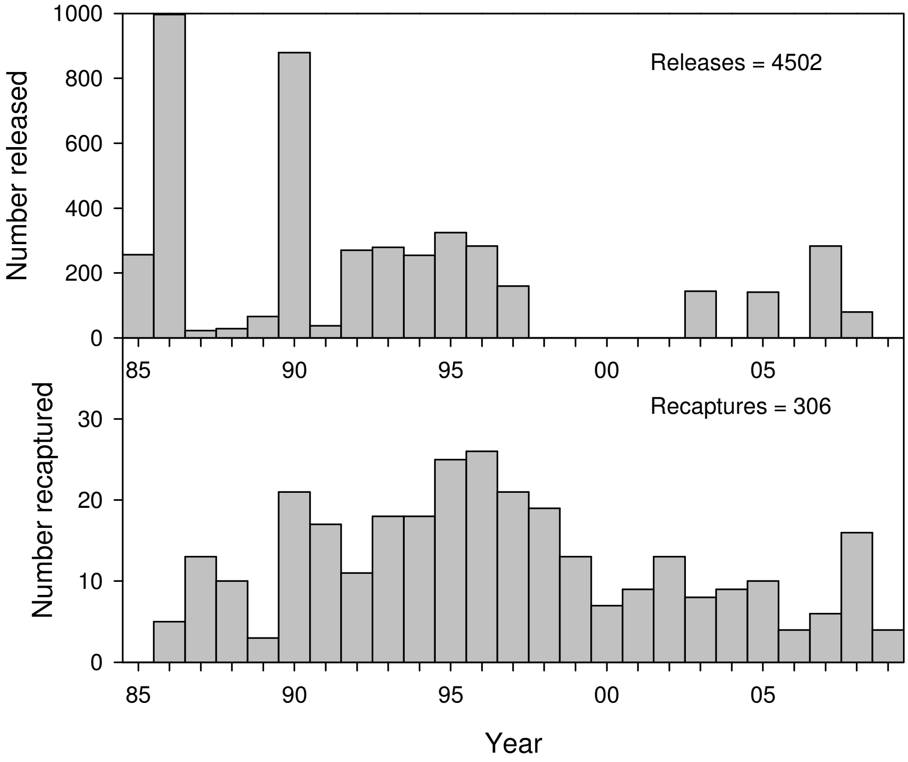

Figure 8: Number of school shark tag releases and recaptures by year (School shark (NIWA)).

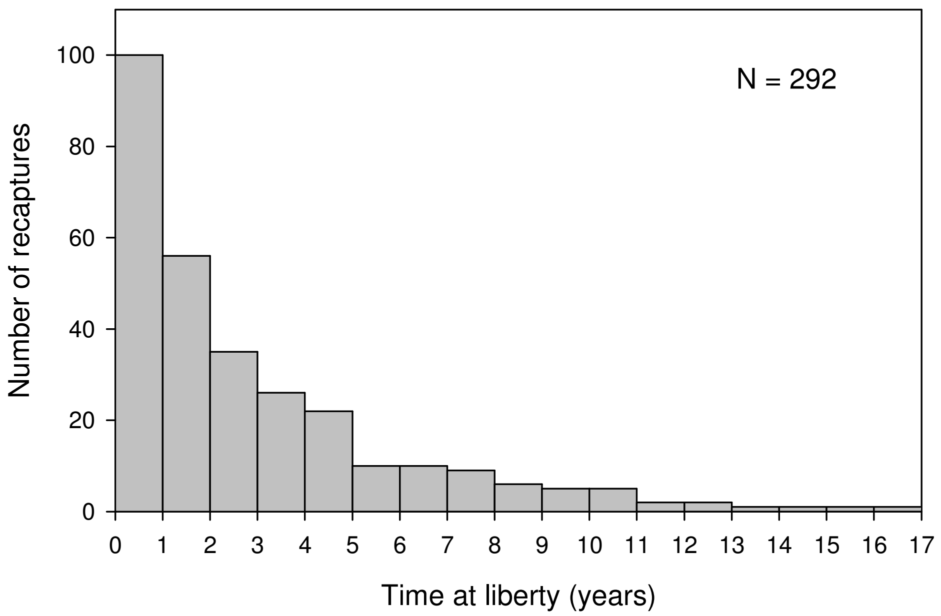

Figure 9: Frequency distribution of time at liberty (School shark (NIWA)).

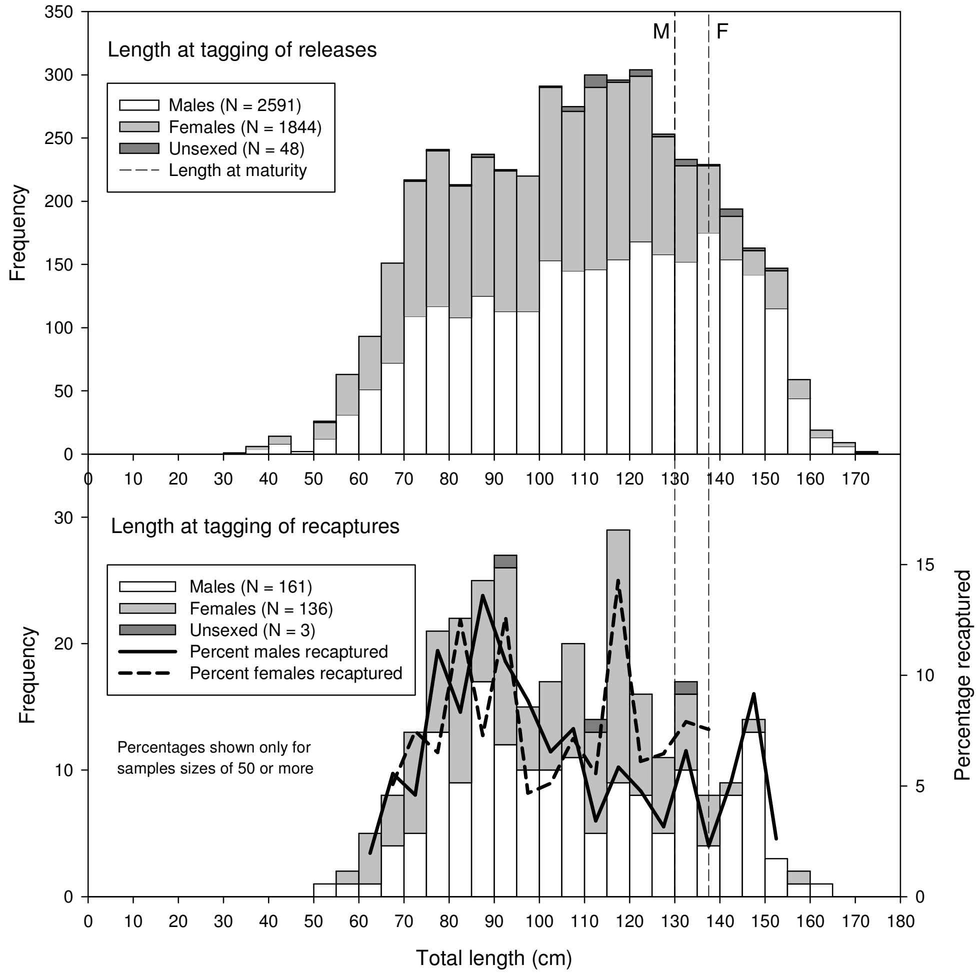

Figure 10: Length frequency distribution of released and recaptured school shark (both at time of release) by sex (School shark (NIWA)). The percentage of school shark recaptured by 5 cm length class and sex is shown in the bottom panel.

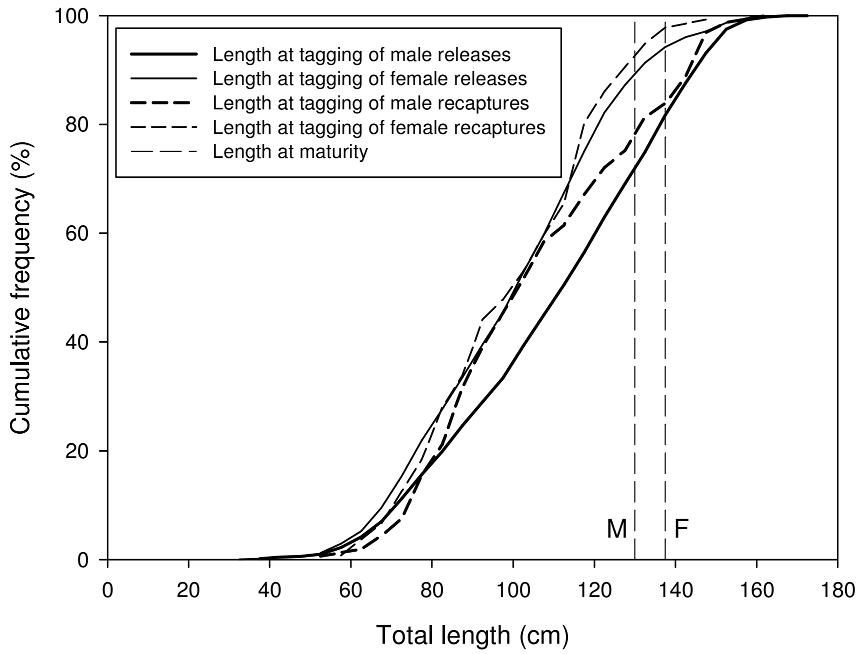

Figure 11: Cumulative length frequency distributions of released and recaptured school shark (both at time of release) by sex (School shark (NIWA)).

Table 5: Release QMAs for tagged school shark (School shark (NIWA)).

QMA	Number released	Percentage of releases
SCH 1E	4	0.1
SCH 1W	113	2.5
SCH 2	239	5.3
SCH 3	742	16.5
SCH 4	306	6.8
SCH 5	1188	26.4
SCH 7	1586	35.2
SCH 8	318	7.1
Unknown	10	0.2
Total	4506	100.0

Just over half (55%) of recaptured school shark were caught in the release QMA. This pattern was consistent for QMAs having sample sizes of more than 30 released sharks (SCH 2, 3, 5, and 7) (Table 6). Movements away from the release QMA were often to adjacent QMAs, but there were also frequent long distance movements, including 24 migrations to Australia (8.4% of all recaptures). Division of the recaptures into subsets based on period at liberty indicated that the proportion moving outside the release QMA increased with time (Table 6): after 2–5 years at liberty, only 40% of recaptured school shark were caught in the release QMA, and after 5–17 years at liberty this had dropped to 31%.

Movement patterns were further analysed by sex, period at liberty, and QMA of recapture. In the first 2 years after release, males and females showed similar movement patterns: about 70% of both sexes were caught within the release QMA (Figure 12). However, after 2–5 years at liberty only about 40% of school sharks (both sexes) were caught in the release QMA. Differences between the sexes became apparent after more than 5 years at liberty. Females were half as likely as males to be recaptured in the release QMA and twice as likely to have travelled long distances: 19% of females and 38% of males were recaptured in the release QMA, and 19% of females and 8% of males were recaptured in Australia.

Table 6: Classification of recaptured school shark by release QMA and recapture QMA (School shark (NIWA)). The number of recaptures is expressed as a percentage of all recaptured school shark released in the release QMA. The first panel shows all recaptures, and the next four panels show recaptures classified by period at liberty. Shading is used to emphasise high percentages (see legend).

Legend		
11-25%	26-50%	> 50 %

	Recapture QMA (percentage of school shark released in release QMA)										Sample
Release QMA	AUST	SCH 1E	SCH 1W	SCH 2	SCH 3	SCH 4	SCH 5	SCH 7	SCH 8	Total	size
All recaptures											
SCH 1W			80.0				20.0			100	5
SCH 2	9.1	9.1	3.0	66.7	3.0			3.0	6.1	100	33
SCH 3	8.3		2.1	6.3	58.3		14.6	10.4		100	48
SCH 4						100.0				100	2
SCH 5	13.5		5.8		9.6		63.5	5.8	1.9	100	52
SCH 7	7.1	0.7	11.4	0.7	0.7		20.7	46.4	12.1	100	140
SCH 8			28.6					14.3	57.1	100	7
Total	8.4	1.4	9.4	9.1	12.2	0.7	24.4	26.1	8.4	100	287
0-0.99 years											
SCH 1W			100.0							100	3
SCH 2	8.3	8.3		83.3						100	12
SCH 3				5.3	78.9		10.5	5.3		100	19
SCH 4											0
SCH 5	5.9				17.6		64.7	5.9	5.9	100	17
SCH 7			4.8				7.1	71.4	16.7	100	42
SCH 8			33.3					16.7	50.0	100	6
Total	2.0	1.0	7.1	11.1	18.2		16.2	33.3	11.1	100	99
1-1.99 years											
SCH 1W			100.0							100	1
SCH 2				100.0						100	4
SCH 3			7.1	7.1	71.4			14.3		100	14
SCH 4						100.0				100	1
SCH 5	11.1						88.9			100	9
SCH 7	8.3		25.0				4.2	54.2	8.3	100	24
SCH 8											0
Total	5.7		15.1	9.4	18.9	1.9	17.0	28.3	3.8	100	53
2-4.99 years											
SCH 1W							100.0			100	1
SCH 2	7.1	14.3	7.1	50.0				7.1	14.3	100	14
SCH 3	25.0				37.5		25.0	12.5		100	8
SCH 4											0
SCH 5	16.7		16.7		8.3		58.3			100	12
SCH 7	17.0	2.1	14.9	2.1			23.4	31.9	8.5	100	47
SCH 8									100.0	100	1
Total	15.7	3.6	12.0	9.6	4.8		25.3	20.5	8.4	100	83
5-17 years											
SCH 1W											0
SCH 2	33.3			33.3	33.3					100	3
SCH 3	40.0			20.0			20.0	20.0		100	5
SCH 4						100.0				100	1
SCH 5	21.4		7.1		7.1		50.0	14.3		100	14
SCH 7			3.8		3.8		53.8	23.1	15.4	100	26
SCH 8											0
Total	12.2		4.1	4.1	6.1	2.0	44.9	18.4	8.2	100	49

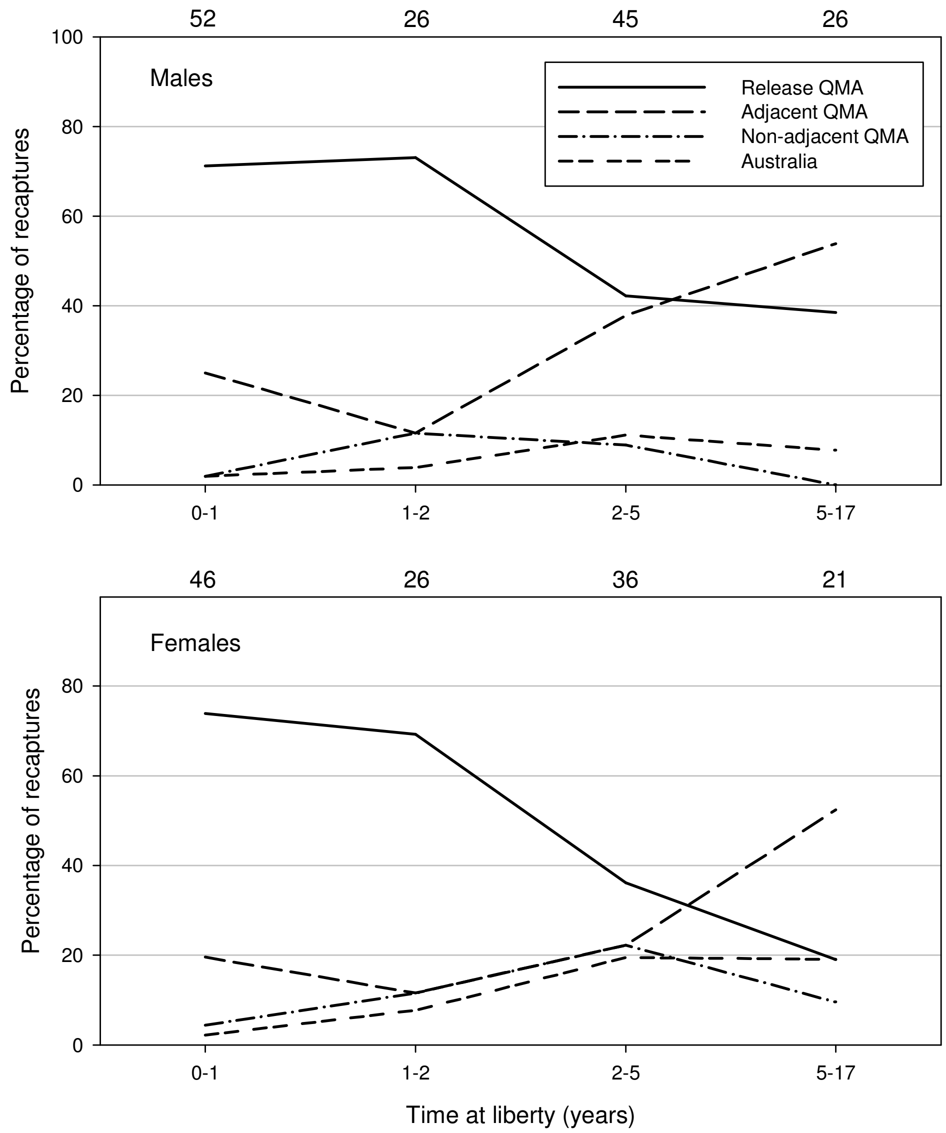

Figure 12: Percentage of male and female school shark recaptures classified by recapture QMA and period at liberty (School shark (NIWA)). Sample sizes for each time period are shown at the top of each panel.

3.2.2 School shark – GAME

Only a few tagged school sharks were released by game fishers (137) and recaptured (33) (see Table 4). Releases occurred in two main pulses, one in 1986–94 and the other in 1999–2009 (Figure 13). Most recaptures occurred following the first release pulse (Figure 13). Most recaptures (77%) occurred within 5 years of tagging. Tagged sharks were not sexed by game fishers, and lengths were estimated (not measured) for about one-third of them. Most sharks were about 100–170 cm TL (Figure 14), and therefore fell in the upper half of the length range of NIWA tag releases (see Figure 10). Nearly all school shark (94%) were released around the northern North Island in SCH 1E and 1W (Table 7).

The number of recaptures was very low, so only a broad summary of the results is warranted. Just over half (52%) of recaptured school shark were caught in the release QMA. There was considerable movement between SCH 1E and 1W, and sharks released in SCH 1E were recaptured in most other QMAs (Table 8).

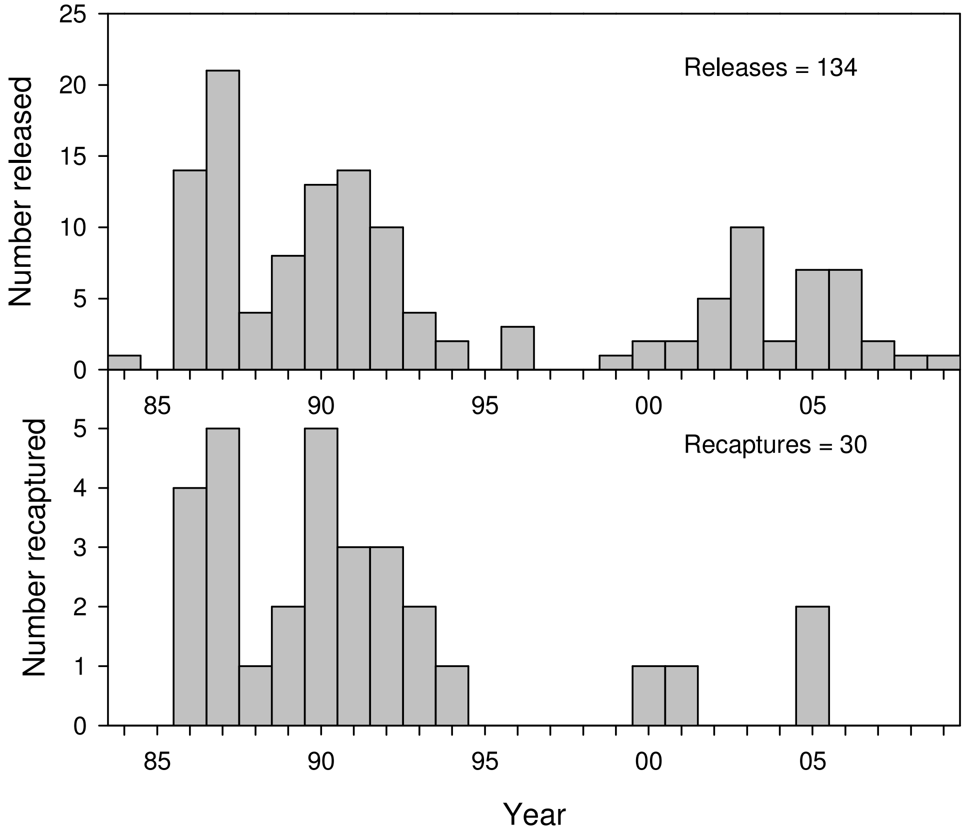

Figure 13: Number of school shark tag releases and recaptures by year (School shark (GAME)).

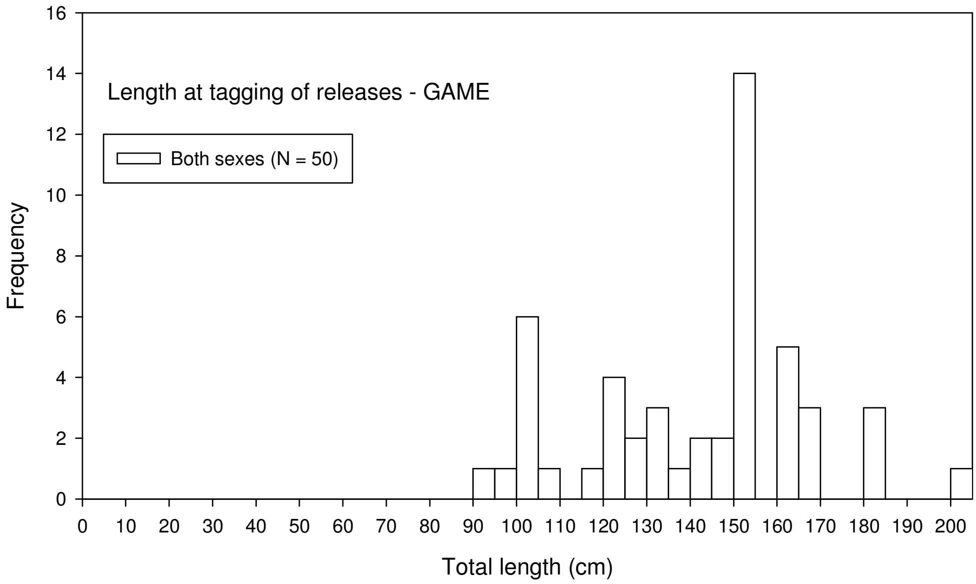

Figure 14: Length frequency distribution of released school shark (School shark (GAME)).

Table 7: Release QMAs for tagged school shark (School shark (GAME)).

QMA	Number released	Percentage of releases
SCH 1E	98	71.5
SCH 1W	31	22.6
SCH 2	3	2.2
SCH 7	1	0.7
Unknown	4	2.9
Total	137	100.0

Table 8: Classification of recaptured school shark by release QMA and recapture QMA (School shark (GAME)). The number of recaptures is expressed as a percentage of all recaptured school shark released in the release QMA. Shading is used to emphasise high percentages (see legend).

Legend		
11-25%	26-50%	> 50 %

Release QMA	Recapture QMA (percentage of school shark released in release QMA)									
	SCH 1E	SCH 1W	SCH 2	SCH 3	SCH 4	SCH 5	SCH 7	SCH 8	Total	Sample size
All recaptures										
SCH 1E	42	21		11	5	5	11	5	100	19
SCH 1W	29	57				14			100	7
SCH 2			100						100	2
SCH 3										0
SCH 4										0
SCH 5										0
SCH 7								100	100	1
SCH 8										0
Total	34	28	7	7	3	7	7	7	100	29

4. DISCUSSION

Use of tagging data to estimate movement rates is fraught with problems. A quantitative movement analysis assumes that tagged sharks are equally likely to be caught in any QMA to which they migrate, which in turn assumes that fishing effort and shark population density are equal in all QMAs. This assumption is necessary because the tag to tonne ratio in the recapture QMA depends on the dilution rate (i.e., whether tagged sharks are entering a large population or a small one) as well as the movement rate. These assumptions can be avoided by using a modified Petersen tagging model (Carbines 2004, J. McKenzie, NIWA, pers. comm.) to estimate mixing rates among QMAs. This method explicitly takes into account the possibility of varying population densities in different QMAs. In practice, the population density is not known so CPUE scaled by the habitat area of each QMA can be used as a proxy for it.

Unfortunately, application of a modified Petersen model to the rig and school shark data in the present study proved impossible. Standardised CPUE analyses are not available for some school shark stocks, none of the CPUE indices for rig or school shark extend back to before 1989–90, and most of the indices are for target set net fisheries which index only part of the population because of the size-selectivity of set nets. Furthermore, several methodological aspects of the tagging programmes affect the probability of recapture, including double-tagging of a significant proportion of sharks which increases the number of sharks recaptured, use of different tag types (dart, lock-on, internal) which have different retention and detection probabilities, use of different capture methods (set net, trawl) which affect initial mortality rates and the size composition of released and recaptured sharks, and the existence of different sex ratios and size compositions among QMAs.

Different capture methods have different length selectivities. For set nets, mesh size drives the selection process, with small sharks passing through the meshes and large sharks tending to 'bounce off' because they don't penetrate far enough to become trapped. This favours the capture of intermediate-sized sharks (depending on mesh size), leading to domed selection curves. This is the probable cause of the domed variation in recapture rates by length shown in Figures 5 and 10. For trawl nets, large sharks are able to out-swim the net, thus biasing captures towards smaller sharks. Length selectivity causes problems with the analysis of movements because the probability of recapture varies with shark length, which also varies with the period at liberty.

All of the above problems also affect the analyses presented here, notably the between-QMA movements shown in Tables 3, 6, and 8. The problems are less important for the analyses of relative recapture rates in release, adjacent, and non-adjacent QMAs (Figures 7 and 12) because they combine data across all release QMAs and across release and recapture methods, and present results for periods at liberty that integrate across the entire tagging period. It should be remembered that for both rig and school shark the data are strongly dominated by releases into South Island QMAs, but there is no reason to expect North Island and South Island rig and school shark to behave differently.

A further consideration is that conventional tagging only provides information on a shark's location at release and recapture, and not on the track travelled by the shark. Consequently, the apparent distance travelled may be an underestimate if the shark migrated some distance away from the release point and then returned to nearer the release point. This may be an important issue if rig and school shark are philopatric (i.e, they return annually to the same site for breeding) and most recaptures are made during a short season. However, Francis (1988b) found no evidence of philopatric 'homing' in rig in an analysis of a large subset of the data used in the present study. School shark pupping grounds are not well defined, but may be more widespread than currently known. Consequently, it is not possible to interpret tagging results in relation to reproduction.

It is not clear whether the distances moved by rig and school shark increase at maturity, as might be expected if breeding migrations occur. Francis (1988b) found no significant difference in the distances moved by immature and mature male rig (maturity status was determined at release but not at recapture). For female rig, he found inconsistent results with mature females travelling significantly further than immature females in SPO 3 but not in SPO 7. Hurst et al. (1999) estimated the maturity status at both release and recapture of school sharks that travelled to Australia. They found that on recapture in Australia, 60% of males and 30% of females were probably mature. Thus many of the Australian migrants were probably immature, indicating that the trans-Tasman movements were unlikely to have been breeding migrations.

Despite the caveats above, it is possible to draw several robust conclusions from the tagging results.

- Male rig rarely moved outside the release QMA, even after more than 5 years at liberty.
- Female rig were more mobile than male rig, with about 30% moving beyond the release QMA boundaries within 2–5 years of release. The proportion moving beyond the release QMA increased steadily with time. However, few females moved more than one QMA away from the release point.
- Female school shark were slightly more mobile than males, with higher proportions of the former moving to non-adjacent QMAs and to Australia.
- About 30% of recaptured school sharks moved outside the release QMA within a year of release, and this was maintained in the second year after release. After 2–5 years at liberty about 60% of school sharks (both sexes) had moved outside the release QMA. After more than 5 years at liberty, 8% of males and 19% of females had moved to Australia.

5. IMPLICATIONS FOR MANAGEMENT BOUNDARIES

An important basic principle when establishing fisheries management boundaries is that the management areas need to be small enough to encompass individual biological stocks, rather than multiple stocks. If management areas encompass more than one stock, it is difficult or impossible to optimise management measures (such as TACs) for all stocks simultaneously. Thus a conservative approach requires that management areas are comparable in size and location to biological stocks.

Male rig move shorter distances than female rig, so a conservative management approach would be to set rig QMAs at a size appropriate for males. Tagging data indicate that male rig do not often move outside current QMA boundaries, so the existing QMAs appear to be suitable for their management.

A large proportion of tagged school sharks moved outside the QMA of release within 5 years, and a significant proportion eventually moved to Australia. These trends in apparent movement are consistent across two decades of tagging. From the tagging evidence, there is probably a single biological stock in the New Zealand EEZ.

In companion studies, Smith (2009) and Blackwell & Francis (2010) reviewed genetic information, and biological and fishery information, respectively, for evidence of separate stocks of rig and school shark in New Zealand. Little genetic variation was found that might indicate different stocks of either species. Some differences were found in CPUE trends for rig at a small spatial scale: Manukau Harbour differed from other SPO 1 subareas and from the adjacent SPO 8; west coast South Island and Tasman–Golden bays subareas of SPO 7 differed; and SCH 1E differed from SCH 1W and SCH 2. However, stock separation at these small scales seems unlikely, and the CPUE differences may have resulted from processes acting below the stock level, such as localised exploitation of different sexes or different size classes of sharks (Blackwell & Francis 2010). The only persuasive evidence for a mismatch between existing QMA boundaries and biological stocks in these studies was the apparent lack of juvenile school shark nursery areas in SCH 4 and SCH 5, suggesting that these Fishstocks are not distinct, but are instead maintained by recruitment from other QMAs (Blackwell & Francis 2010). Thus these companion studies provided minimal additional information on the size and location of rig and school shark stocks.

The existing QMAs are probably appropriate for rig stocks, although the boundaries between biological stocks are not clearly defined, especially in the Cook Strait region. Insufficient rig tagging occurred in SPO 1 to determine whether division of that stock into separate 1E and 1W stocks is warranted. School shark QMAs are much smaller than the ranges inhabited by the sharks. However, management of school shark in the current small QMAs is probably not having a detrimental effect on the stock. The relative importance of various breeding grounds around New Zealand (e.g., aggregations of breeding females in Kaipara Harbour) and whether females return to the area in which they were born are unknown. Therefore, the current stock management units may be a wise precautionary measure to spread fishing effort; amalgamation of all QMAs into one QMA for the whole country could create unacceptable risks to stock sustainability.

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