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FACTORS AFFECTING THE USE OF SPECIES COMPOSITION DATA COLLECTED BY OBSERVERS AND PORT SAMPLERS FROM PURSE SEINERS IN THE WESTERN AND CENTRAL PACIFIC OCEAN

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1. Introduction

It has long been known that the estimates of catches of tuna taken by purse seiners that are reported on logsheets and during unloading are biased in regard to their species composition (Fonteneau 1975). In this regard, species composition data are collected from purse seiners in the Atlantic Ocean, the Indian Ocean and the Eastern Pacific Ocean through port sampling programmes. In these programmes, the wells in which the fish are stored onboard the vessel are selected for sampling in port according to a stratified sampling design, with strata of time period, geographic area, school association and other factors (Pianet et al. 2000, Tomlinson 2002).

In contrast, species composition data covering fleets fishing in the Western and Central Pacific Ocean, other than the United States fleet, have been collected on a purely opportunistic basis through observer programmes and port sampling programmes managed by several of the Pacific island countries (i.e., Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Papua New Guinea and Solomon Islands). Data covering the United States fleet have been collected through a port sampling programme managed by the National Marine Fisheries Service (NMFS) and through an observer programme managed by the Pacific Islands Forum Fisheries Agency (FFA). In recent years, FFA has also managed an observer programme covering vessels of FFA-member countries that operate under the FSM Arrangement.

The port sampling and observer programmes of the Pacific island countries were established beginning in the early 1990s; however, data collected during the early- to mid-1990s were generally of poor quality (Lawson 2002), due in large part to problems related to the discontinuous operation of the programmes over the years. While data quality has improved since then, most sampling programmes continue to operate irregularly, although with the notable exceptions in recent years of the observer programme in Papua New Guinea and the port sampling programme in the Marshall Islands (DCC 2004). This paper reviews factors affecting the use of purse-seine species composition data collected since the mid-1990s. The structure of the paper is as follows:

- Section 2 summarises the quantity of observer data and port sampling data currently held by the SPC Oceanic Fisheries Programme (OFP).
- Section 3 compares the lengths of fish covered by port sampling and observer data, and shows that port sampling data do not cover the very small fish discarded at sea.
- Section 4 discusses the effect of raising species composition samples by the set weight, and shows that the unraised and raised species compositions are considerably different due to the current sampling protocol.

- Section 5 discusses the relationship between set weight and the species composition, and shows that port sampling data are not representative in regard to the distribution of set weights, such that species compositions determined from port sampling data tend to over-estimate the proportion of skipjack.

- Section 6 discusses the time-area representativeness of observer data and shows that the data have been more or less representative, except for much higher coverage rates in the waters of Papua New Guinea since 2002.

- Section 7 discusses the representativeness of port sampling data and shows that because of poor coverage, port sampling data have not been representative, except for data covering the United States fleet in most years.

- Section 8 considers the species composition by geographic area and shows that there is a smaller proportion of skipjack and bigeye, and a greater proportion of yellowfin, in catches in the western part of the region than in the eastern part.

- Section 9 discusses the distribution of unloadings by port and month, and notes that for most ports, purse-seine visits have been sporadic, except for five ports for which visits have been regular. The areas fished by vessels visiting the five ports are shown to be representative.

- Section 10 discusses the problem of well mixing for port sampling programmes.

- Section 11 introduces the concept of grab sample bias, wherein species compositions determined from grab samples tend to over-estimate the proportion of species of small fish relative to species of large fish. The concept of spill samples is also introduced.

- Section 12 presents the results of simulations conducted to examine the relationship between grab sample bias and set weight. Spill samples are shown to be essentially unbiased.

- Section 13 considers a potential correction for grab sample bias.

- Section 14 describes an experiment conducted in Papua New Guinea in March 2008 to test the feasibility of spill samples and compares data collected from spill samples and grab samples of the same sets.

- Section 15 considers the layering of fish in the set or well, by species and size, by examining observer data and port sampling data.

- Section 16 discusses the possible size selection bias of observers, wherein the probability of selecting large yellowfin and bigeye is greater than the random probability, such that species compositions determined from observer data tend to under-estimate the proportion of skipjack and over-estimate the proportion of yellowfin.

- Section 17 considers the effects of grab sample bias and size selection bias on estimates of the proportion of bigeye in ‘yellowfin plus bigeye’, which are currently used by the OFP to correct aggregated bigeye and yellowfin catch data.

- Section 18 introduces size-separate analyses of species composition data, wherein the species composition for small (< 80 cm) and large (≥ 80 cm) fish are analysed separately.

- Section 19 applies size-separate analyses of both observer data and port sampling data to estimate annual catches in the WCPFC Statistical Area.

- Sections 20 and 21 conclude the paper with a discussion and considerations of the use of historical data and future data collection.

2. Coverage of Observer Data and Port Sampling Data

The FFA-managed observer programmes have a target coverage rate of 20% of days fished and the target has consistently been achieved over the years. In contrast, the placement of observers in the national programmes, other than that of Papua New Guinea, has been opportunistic and coverage rates have usually been not more than one or two percent. The Papua New Guinea programme is the largest national programme and has achieved coverage rates of about 20% in recent years (DCC 2004).

The sampling protocol for observers is to grab five fish per brail as the fish are transferred from the set to the vessel, for every set during the trip. Each fish is identified by species and its length is measured. Data for all fish sampled from a set are used in the estimation of both species compositions and length frequencies.

The number of sets sampled by observers onboard purse-seiners in the WCPFC Statistical Area (Figure 34) for which the data are of an acceptable quality are summarised by vessel flag and school association in Tables 1 and 2 respectively. Data covering a total of 17,839 sets were available.

Table 1. Number of sets sampled by observers, by vessel flag

Year	CN	FM	JP	KI	KR	MH	NZ	PG	PH	SB	TW	US	VU	Total	%
1995	0	21	13	0	9	0	0	8	0	0	30	0	0	81	0.5
1996	0	8	13	0	91	0	0	8	19	0	230	0	12	381	2.1
1997	0	0	23	0	70	0	0	32	43	0	134	3	30	335	1.9
1998	0	5	38	0	174	0	0	86	0	26	401	203	20	953	5.3
1999	0	0	14	7	87	0	0	49	14	72	81	286	9	619	3.5
2000	0	42	43	7	100	0	0	83	0	15	103	373	0	766	4.3
2001	0	53	59	0	59	22	0	74	41	12	128	589	0	1,037	5.8
2002	0	81	47	27	30	2	0	762	374	184	120	401	0	2,028	11.4
2003	0	54	86	32	62	107	0	1,005	342	119	69	333	3	2,212	12.4
2004	0	113	69	11	276	173	0	1,503	511	140	247	361	116	3,520	19.7
2005	64	51	44	0	146	225	29	1,428	443	85	278	264	127	3,184	17.8
2006	27	0	69	57	213	261	2	1,127	404	0	163	20	41	2,384	13.4
2007	16	9	20	0	48	66	0	87	20	20	53	0	0	339	1.9
Total	107	437	538	141	1,365	856	31	6,252	2,211	673	2,037	2,833	358	17,839	100.0
%	0.6	2.4	3.0	0.8	7.7	4.8	0.2	35.0	12.4	3.8	11.4	15.9	2.0	100.0	

Table 2. Number of sets sampled by observers, by school association

Year	Log	Drifting FAD	Anchored FAD	Other Associated	Unassociated	Total	%
1995	41	7	1	12	20	81	0.5
1996	179	22	11	11	158	381	2.1
1997	132	68	33	16	86	335	1.9
1998	288	129	83	42	411	953	5.3
1999	28	324	110	10	147	619	3.5
2000	32	472	46	15	201	766	4.3
2001	96	485	88	18	350	1,037	5.8
2002	332	301	910	26	459	2,028	11.4
2003	466	284	827	35	600	2,212	12.4
2004	1,085	660	1,101	62	612	3,520	19.7
2005	820	541	781	88	954	3,184	17.8
2006	771	367	653	69	524	2,384	13.4
2007	77	68	55	26	113	339	1.9
Total	4,347	3,728	4,699	430	4,635	17,839	100.0
%	24.4	20.9	26.3	2.4	26.0	100.0	

Port sampling by the non-NMFS programmes is usually done during transshipment. The sampling protocol for the non-NMFS programmes is similar to the sampling protocol for observers; five fish per net are grabbed as fish are transferred from the wells to the reefer vessels. The sampling protocol for the NMFS programme is different from the non-NMFS programmes: 50 fish are grabbed for a length frequency sample from strata of species category and size category, after the fish have been sorted; if more than one species occurs in the first 50 fish, an additional 50 fish are selected to make up a species composition sample of 100 fish. The NMFS port sampling programme is described in detail in Appendix A.

The number of purse-seine wells sampled by port samplers in the WCPFC Statistical Area are summarised by vessel flag and school association in Tables 3 and 4 respectively. Data covering a total of 4,942 wells were available. The United States fleet accounted for a large proportion, 75.3%, of the wells sampled. NMFS does not record the school association for associated schools broken down by log, drifting FAD or anchored FAD, so a separate column is presented in Table 4 for “NMFS associated” schools.

Table 3. Number of wells sampled in port, by vessel flag

Year	CN	FM	KR	MH	NZ	PG	PH	SB	SU	TW	US	VU	Total	%
1993	0	5	5	0	0	0	0	0	0	7	0	0	17	0.3
1994	0	6	85	0	0	0	1	1	1	14	3	0	111	2.2
1995	0	1	5	0	0	0	0	0	0	1	4	1	12	0.2
1996	0	1	36	0	0	1	0	0	0	1	50	1	90	1.8
1997	0	0	22	0	0	1	0	0	0	6	416	0	445	9.0
1998	0	0	19	0	0	0	4	0	0	21	443	1	488	9.9
1999	0	0	0	0	0	0	0	1	0	0	424	0	425	8.6
2000	0	0	1	0	0	10	0	1	0	0	426	0	438	8.9
2001	0	3	29	0	2	23	16	0	0	27	419	0	519	10.5
2002	0	9	40	0	0	5	24	0	0	39	407	0	524	10.6
2003	0	0	14	37	12	19	0	0	0	56	278	51	467	9.4
2004	2	6	17	30	0	32	0	0	0	79	228	51	445	9.0
2005	0	1	0	21	11	6	0	0	0	10	303	18	370	7.5
2006	12	2	106	31	0	26	0	0	0	57	220	34	488	9.9
2007	0	0	0	4	0	0	0	0	0	0	99	0	103	2.1
Total	14	34	379	123	25	123	45	3	1	318	3,720	157	4,942	100.0
%	0.3	0.7	7.7	2.5	0.5	2.5	0.9	0.1	0.0	6.4	75.3	3.2	100.0	

Table 4. Number of wells sampled in port, by school association

Year	Log	Drifting FAD	Anchored FAD	Other Associated	NMFS Associated	Unassociated	Total	%
1993	0	0	0	0	0	17	17	0.3
1994	2	2	1	0	0	106	111	2.2
1995	0	0	0	0	0	12	12	0.2
1996	3	0	0	1	41	45	90	1.8
1997	2	1	1	20	259	162	445	9.0
1998	7	2	4	18	249	208	488	9.9
1999	0	11	1	2	401	10	425	8.6
2000	7	4	2	11	295	119	438	8.9
2001	30	10	9	2	224	244	519	10.5
2002	46	20	10	7	184	257	524	10.6
2003	43	72	16	0	137	199	467	9.4
2004	95	47	15	0	167	121	445	9.0
2005	23	23	0	1	207	116	370	7.5
2006	132	89	0	0	164	103	488	9.9
2007	4	0	0	0	86	13	103	2.1
Total	394	281	59	62	2,414	1,732	4,942	100.0
%	8.0	5.7	1.2	1.3	48.8	35.0	100.0	

Table 5 presents the coverage of purse-seine sets by observer data and port sampling data held by the OFP. The total number of sets excludes the domestic fisheries of Indonesia and the Philippines, and the Japanese fleet north of 20°N. The number of sets sampled in port was determined as the product of the number of wells sampled and the average number of sets per sampled well, which was 1.41. Data for 2007 are incomplete. With observer coverage of 4.04% and coverage by port sampling of 1.58%, observer coverage has been 2.6 times greater than coverage by port sampling during 1993–2007, based on data held by the OFP. Coverage by the NMFS and non-NMFS port sampling has been 1.16% and 0.42% of the total number of sets respectively. Coverage by NMFS port sampling of the United States fleet has been 7.6%.

Table 5. Coverage of total sets by observers and port sampling

Year	Total Sets	Sets Observed	%	Sets Sampled in Port	%
1993	28,953	0	0.00%	24	0.08%
1994	27,452	0	0.00%	156	0.57%
1995	26,279	81	0.31%	17	0.06%
1996	28,308	381	1.35%	127	0.45%
1997	28,316	335	1.18%	627	2.21%
1998	28,846	953	3.30%	687	2.38%
1999	24,719	619	2.50%	599	2.42%
2000	27,571	766	2.78%	617	2.24%
2001	27,743	1,037	3.74%	731	2.63%
2002	30,957	2,028	6.55%	738	2.38%
2003	30,521	2,212	7.25%	658	2.16%
2004	32,033	3,520	10.99%	627	1.96%
2005	36,964	3,184	8.61%	521	1.41%
2006	32,977	2,384	7.23%	687	2.08%
2007	29,641	339	1.14%	145	0.49%
Total	441,280	17,839	4.04%	6,961	1.58%

3. Lengths of Fish Covered by Port Sampling and Observer Data

Figure 1 presents length frequencies in terms of numbers of fish determined from port sampling data and observer data, for unassociated and associated sets. Click *View* and *Zoom To...* to view the figures at a resolution of 150% in Adobe Reader. The samples were raised by the set weight, except for the NMFS port sampling data, which were raised by the amount unloaded from the well.

By the term ‘raised’, it is meant that a weighted average of the species compositions determined from the samples was taken, where the weighting was done on the basis of the weight of the set from which each sample was taken. The term ‘raised’ is used to avoid having to refer to “weighted averages of weight frequencies determined from average weights and set weights”. In an unraised sample, the proportion of species *i* at length *j* in the sample, P_{ij}, is given by:

$$P_{ij} = \frac{n_{ij} w_{ij}}{\sum_i \sum_j n_{ij} w_{ij}} \quad (1)$$

$$w_{ij} = a_i \cdot L_{ij}^{b_i} \quad (2)$$

where n_{ij} is the number of fish of species *i* and length j in the sample, w_{ij} is the weight of a fish of species *i* at length *j*, which is determined from the length, L_{ij}, and length-weight conversion factors a_i and b_i. Lengths (cm) were converted to weights (kg) using the length-weight parameters below:

Species	**a**	**b**
Skipjack	0.8639E-05	3.2174
Yellowfin	2.5120E-05	2.9396
Bigeye	1.9729E-05	3.0247

The weight of fish of species *i* and length *j* in a raised sample, W_{ij}, is given by:

$$W_{ij} = W \cdot P_{ij} \tag{3}$$

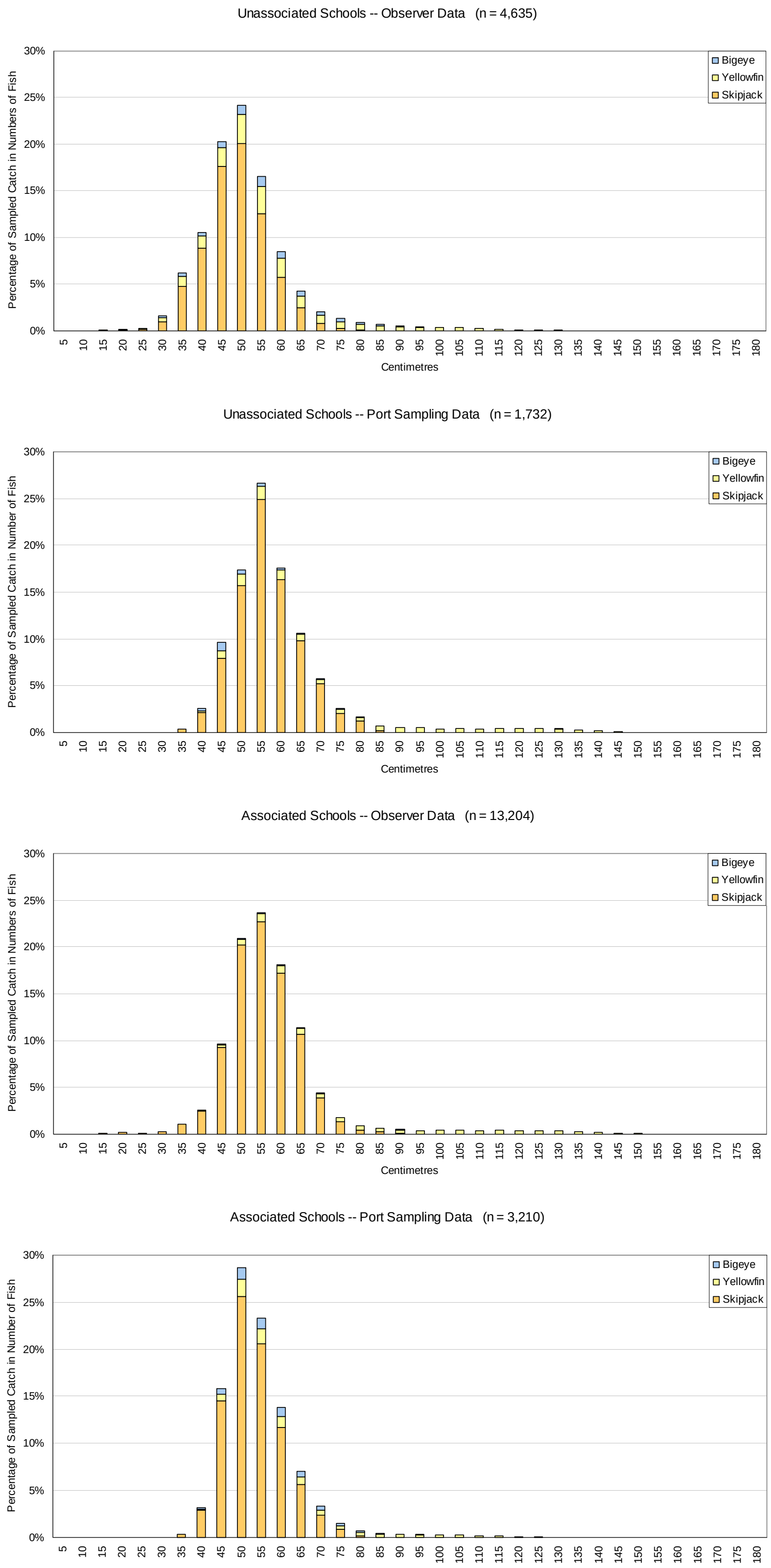
where W is the set weight.

Length frequencies will always be presented in terms of weight, except for Figure 1, which is in terms of numbers of fish. The numbers of fish of species *i* and length *j* in a raised sample, N_{ij}, is given by:

$$N_{ij} = \frac{W_{ij}}{w_{ij}}. \tag{4}$$

The data presented in Figure 1 were not screened such that the time-area strata represented by the port sampling data and the observer data were the same, and so the data are not directly comparable. Nevertheless, that the port sampling data cover fewer very small (≤ 40 cm) fish than the observer data, due to the discarding of small fish at sea, is clear. The percentage of very small fish in unassociated schools determined from observer data and port sampling data is 18.9% and 2.9% respectively, while for associated schools, the percentages are 4.4% and 3.5% respectively. These percentages are in terms of numbers of fish; in terms of weight, the percentages for unassociated schools are 0.8% and 0.6% respectively, and the percentages for associated schools are 5.3% and 1.1% respectively.

Figure 1. Length frequency distributions in numbers of fish determined from port sampling and observer data



4. Effect of Raising Species Composition Samples by the Set Weight

Table 6 and Figure 2 present the species compositions (in weight, rather than numbers of fish) by school association (unassociated and associated) determined from observer data and port sampling data. The data for all samples were aggregated over all geographic areas, time periods and flags, and so represent the general tendency. Data are also presented separately in Table 6 for United States and non-United States observer data, and NMFS and non-NMFS port sampling data. The species compositions were determined either without or with raising of the individual samples by the weight (tonnes) of the set from which the sample was taken or, for NMFS port sampling data, the amount unloaded from the well since the set weight was not available. Without raising, the species composition refers to all sampled fish, whereas with raising, the species composition more accurately reflects that of the catch. In each case, the sampling data used in the unraised and raised species composition data are the same.

Before examining the differences between unraised and raised samples, and between the species compositions determined from observer data and port sampling data, some comments on the NMFS port sampling data are in order. Appendix A describes the NMFS port sampling programme and how the data are used to estimate annual catches for the United States fleet. In summary, the NMFS data are sorted by species and size prior to sampling, and separate samples are taken of species-size categories in the well; the samples are then raised by the amounts of the species-size category unloaded from the well. The raised samples are stratified by year, school association (unassociated and associated), size category and species category, and estimates of annual catches of yellowfin and bigeye are adjusted by applying the species composition for each strata to annual catch estimates for those strata; the unadjusted annual catches are determined from cannery receipts. Instead of the opportunistic sampling done by the non-NMFS port sampling programmes, there are targets for the number of wells to be sampled for each stratum of US Treaty area (Figure A1) and month.

The NMFS port sampling programme is therefore quite different from the non-NMFS programmes, which select vessels and wells on a more or less random basis (subject to certain criteria regarding the homogeneity of time, area and school associations of the sets in each well) and which sample unsorted fish, usually from the entire well.

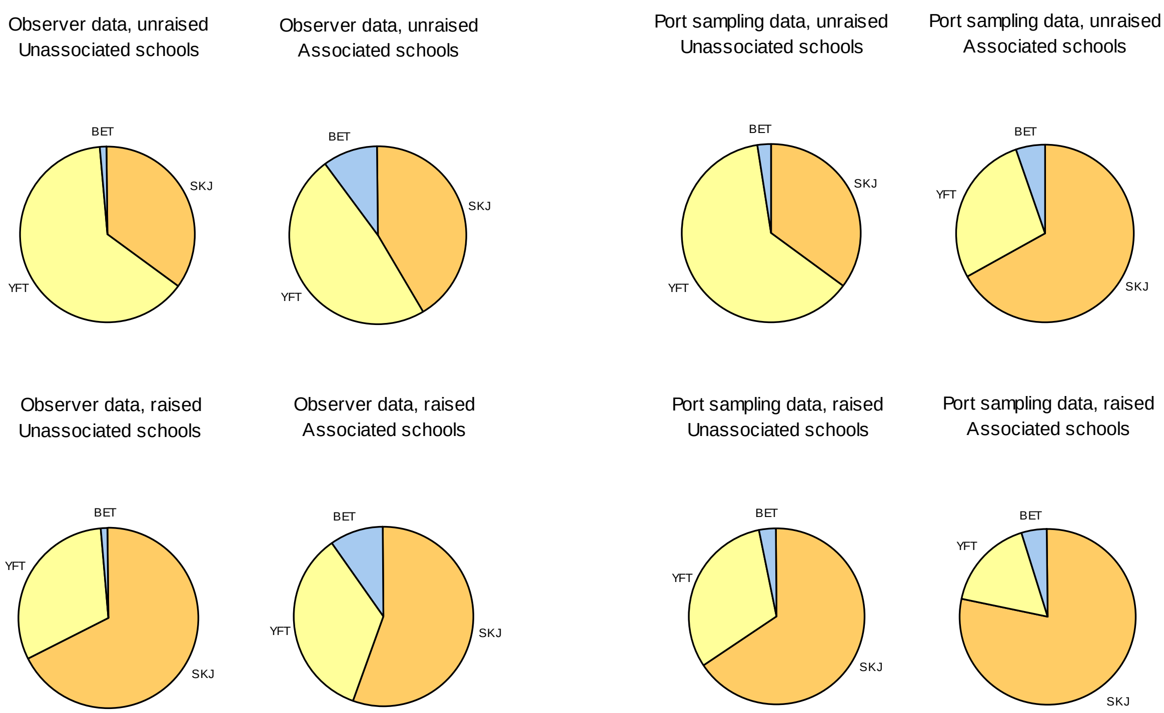
The species compositions for associated schools determined from unraised samples presented in Table 6 for the NMFS and non-NMFS data are quite different, with much less skipjack and much more yellowfin and bigeye in the NMFS data than in the non-NMFS data. One of the reasons for this is the difference in the sampling protocols. Under the NMFS sampling protocol, 50 fish are selected for each stratum of species and size category, and if all 50 fish are of the same species, there is no further sampling; otherwise, an additional 50 fish are selected to make up a species composition sample of 100 fish. Under the non-NMFS sampling protocol, five fish are selected from nets during the entire unloading process. The result is that the average numbers of skipjack in the NMFS and non-NMFS samples of wells containing skipjack are 58.9 and 116.8 respectively; that is, the non-NMFS samples contain about twice as much skipjack as the NMFS samples. The opposite effect is observed for yellowfin and bigeye. The average numbers of yellowfin and bigeye in NMFS samples of wells containing yellowfin and wells containing bigeye are 67.1 and 50.5 respectively, whereas for the non-NMFS samples, the average numbers of fish are 38.7 and 12.4 respectively.

There are several reasons why the proportion of skipjack in the species composition for associated schools determined from unraised samples of non-NMFS port sampling data is so large, 68.9%. First, port samples tend to be of large schools, and large associated schools contain a greater proportion of skipjack than smaller schools (see section 5). The same is probably true of the NMFS port samples, but because of the NMFS sampling protocol, the amount of skipjack in the unraised samples is less than for the non-NMFS samples. Second, the time series of non-NMFS port sampling data is dominated by data for 2006, which accounts for 25.6% of the catch sampled during 1993–2007. Catch rates for skipjack in associated schools were high in 2006, 28.0 tonnes per day, compared to the 1997–2005 average of 20.7 tonnes per day. Third, the geographic coverage of the non-NMFS port sampling data is greater in the eastern part of the region, where the proportion of skipjack is greater (see section 8). Fourth, it may be that the procedure for selecting the wells to sample in certain ports results in a tendency to select wells containing pure skipjack (see section 5).

Table 6. Estimates of purse-seine species composition (%) determined from observer data and port sampling data, with and without raising of the samples by the weight of the set or the amount unloaded from the well

Type of Data	Raised or Unraised	Unassociated Schools			Associated Schools		
		SKJ	YFT	BET	SKJ	YFT	BET
US Observer Data	Unraised	38.6	60.6	0.8	43.0	45.6	11.4
	Raised	73.7	25.8	0.5	53.1	35.5	11.4
Non-US Observer Data	Unraised	34.1	64.3	1.6	41.1	49.3	9.7
	Raised	66.0	32.7	1.3	55.8	35.0	9.1
All Observer Data	Unraised	35.0	63.6	1.4	41.5	48.4	10.1
	Raised	67.4	31.5	1.2	55.3	35.1	9.6
NMFS Port Sampling Data	Unraised	23.1	76.3	0.6	19.6	60.2	20.1
	Raised	65.7	33.9	0.4	68.9	21.4	9.7
Non-NMFS Port Sampling Data	Unraised	35.4	62.1	2.6	67.1	27.6	5.3
	Raised	65.2	31.8	3.0	78.0	17.3	4.8
All Port Sampling Data	Unraised	27.4	71.4	1.3	26.3	55.7	18.1
	Raised	65.5	32.8	1.7	72.4	19.8	7.8

Figure 2. Estimates of purse-seine species composition determined from all observer data and non-NMFS port sampling data, with and without raising of the samples by the weight of the set



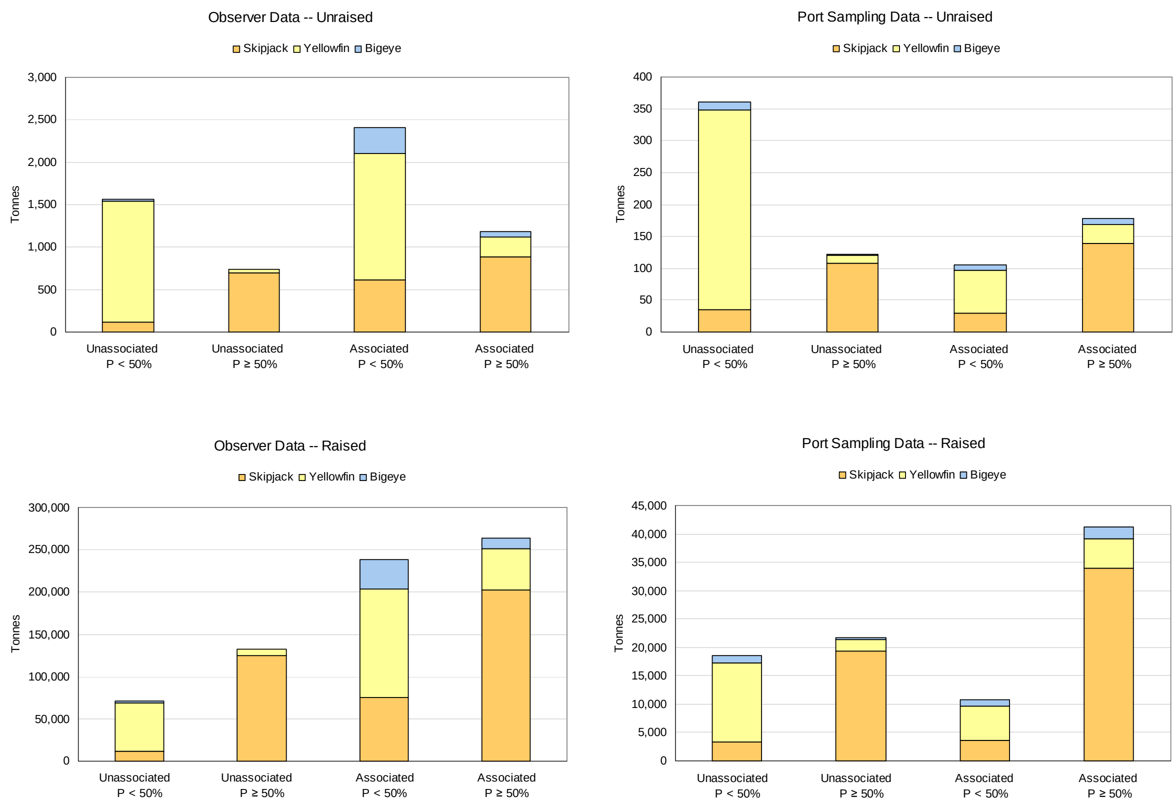
Regarding the differences between unraised and raised samples in Table 6 and Figure 2, we see that the species compositions determined from samples that were raised by the weight of the set (the bottom row of Figure 2) have much much more skipjack and less yellowfin than those determined from unraised samples (the top row). The reason has to do with the differences in size of fish among the three species and the fact that the sampling protocol is to select a certain number of fish from the set sampled by observers or the well sampled in port.

To further illustrate this, Figure 3 presents the total unraised and raised weights of fish sampled from sets in which the proportion of skipjack was either less than or greater than 50%. The two histograms on the left were determined from observer data and the two on the right from non-NMFS port sampling data; the NMFS data were excluded since the data are raised by the amount unloaded from the well, rather than the set weight, and so are not strictly comparable.

It can be seen that for unraised samples from unassociated sets (top histograms, two left-hand bars), the amount of yellowfin in the $p < 50\%$ and $p \geq 50\%$ samples combined is about twice that of skipjack. However, when the samples are raised (bottom histograms, two left-hand bars), there is more skipjack than yellowfin. The reason is that even though there are more yellowfin than skipjack in the samples, the schools from which most of the yellowfin were drawn represent a smaller amount of the catch than the schools from which most of the skipjack were drawn. For observer data, the weight of the fish sampled from unassociated sets for which the proportion of skipjack is *greater* than 50% amounts to only 738 tonnes, even though the total weight of those sets was 132,810 tonnes. With the same sampling protocol, the weight of fish sampled from unassociated sets for which the proportion of skipjack is *less* than 50% amount to 1,567 tonnes, but the total weight of those sets was only 70,794 tonnes.

The same is true for associated sets (two right-hand bars of all four histograms), although the difference between the species compositions determined from unraised and raised samples is somewhat less than for unassociated schools because the sizes of skipjack and yellowfin in associated schools are more uniform.

Figure 3. Sampled weights and raised weights for sets with the proportion of skipjack less than or greater than 50%



Figures 2 and 3 illustrate the considerable differences between the species compositions of unraised and raised samples, which are due to the differences in sizes of fish among species. If the sampling protocol for observer and port sampling programmes was based on the weight of fish selected for sampling, and not on the number of fish selected, then presumably the differences in Figures 2 and 3 between the unraised and raised samples would not exist. This concept is considered further in section 11 on bias in grab samples and section 14 on spill samples.

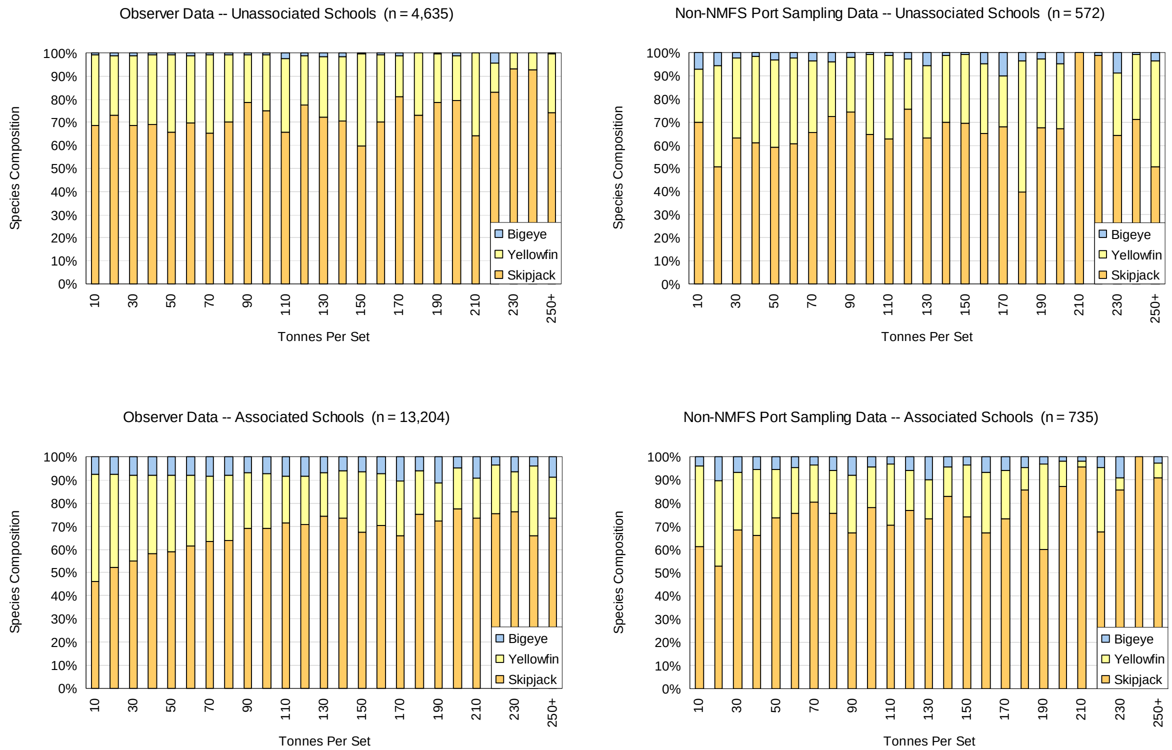
Finally, we note the difference between the species compositions determined from observer data and port sampling data in Table 6 and Figure 2. Comparing all observer data to all port sampling data, we see that for unassociated schools, the species compositions determined from the raised samples are similar. For associated schools, however, the situation is quite different, with much less skipjack and much more yellowfin and bigeye in the observer data compared to the port sampling data. The large differences for associated schools is due to the lack of representativeness of the port sampling data in regard to the distribution of set weights (section 5), the geographic coverage of the data (section 8), probably well mixing (section 10) and possibly size selection bias on the part of observers (section 16).

5. Relationship of Species Composition to Set Weight

The proportions of skipjack in associated schools determined from unraised and raised observer samples (the two right-hand bars of the two histograms on the left of Figure 3 above) are 41.3% and 55.3%, whereas the proportions of skipjack in associated schools determined from unraised and raised port samples (the two right-hand bars of the two histograms on the right) are 59.4% and 72.1%. One of the reasons why the port samples contain more skipjack than the observer samples has to do with the relationship between the species composition and the size of the school.

Figure 4 presents the relationship between the species composition and set weight for unassociated and associated schools, determined from observer data and non-NMFS port sampling data. For observer data, the species composition is clearly related to set weight for associated schools (bottom left histogram in Figure 4), with the proportions of skipjack and yellowfin increasing and decreasing respectively, with increasing set weight. For unassociated schools (top left), the effect is not clear. For port sampling data, the number of samples is much smaller and so the effect is less clear, but the same relationship appears to apply for associated schools (bottom right).

Figure 4. Estimates of purse-seine species composition determined from observer data and port sampling data, by the weight of the set

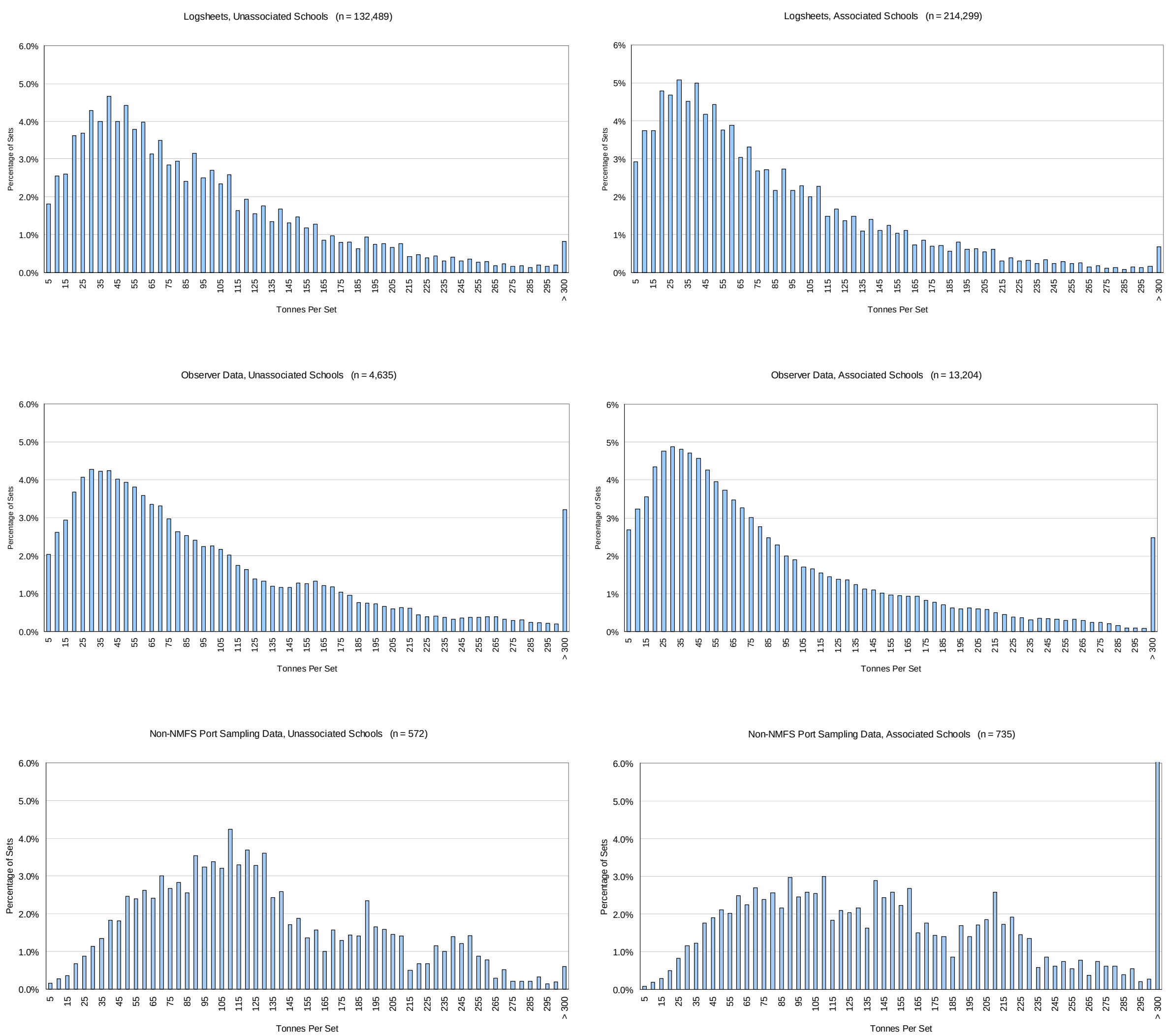


The relationship between species composition and set weight shown in Figure 4 implies that the species composition will be biased if the sizes of the sets chosen for sampling are not representative of the sizes of schools caught by the purse-seine fleet.

Figure 5 presents the distribution of sets by size of set determined from (i) operational (logsheet) catch and effort data, (ii) observer data and (iii) non-NMFS port sampling data. All histograms were smoothed. The coverage of the purse-seine logsheet data held by the OFP is high and, apart from rounding errors, representative of the distribution for the purse-seine fleet as a whole (although small sets may sometimes be recorded on logsheets in combination with a subsequent large set). For wells sampled by port samplers containing more than one set, the average set weight was used.

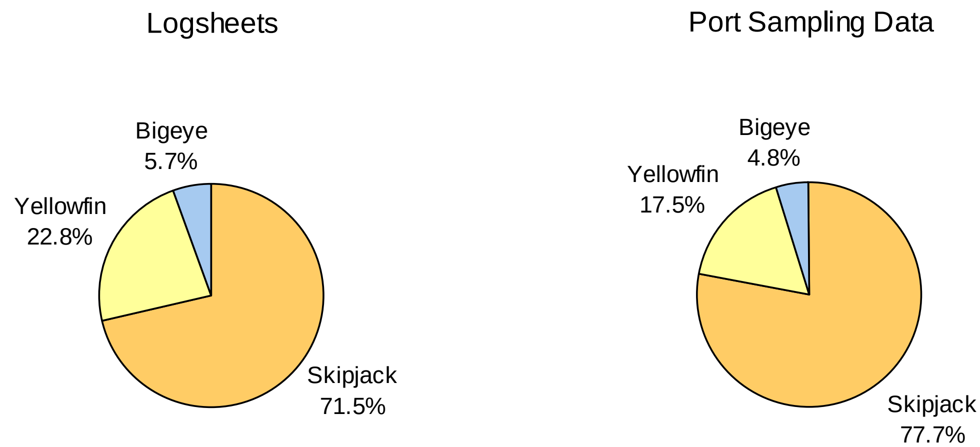
The observer data (middle row of Figure 5) are generally representative of the distribution of size of sets caught by the fleet (top row), whereas this is not true of the port sampling data (bottom row). The lack of representativeness of the port sampling data is related to the fact that port samplers are instructed to select wells for sampling that are homogeneous in regard to the date and location of the catch, and the type of school association; wells containing a small number of large sets meet these criteria more often than wells containing several small sets.

Figure 5. Distribution of sets by size of set determined from logsheets, observer data and port sampling data



Since large sets tend to contain more skipjack than smaller sets, particularly for associated schools (Figure 3), species compositions determined from port sampling data will tend to over-estimate the proportion of skipjack. An indication of the extent of this bias is presented in Figure 6, which shows the species compositions determined from the relationship between the species composition and set weight for associated schools based on non-NMFS port sampling data (lower right-hand histogram of Figure 4) and the distributions of set weights based on logsheet data (top right-hand histogram of Figure 5) and non-NMFS port sampling data (bottom right-hand histogram in Figure 5). The percentage differences in the proportions per species is an indication of the magnitude of the bias that is introduced in catch estimates. The bias in catches estimated from the species composition determined from port sampling data is considerable, with the percentage difference in the proportion of skipjack being (77.7 – 71.5) / 71.5 = +8.7% and the percentage differences in the proportions of yellowfin and bigeye being –23.2% and –15.8% respectively.

Figure 6. Average species composition based on the distribution of set weights determined from logsheets and port sampling data



While port sampling data will over-estimate the proportion of skipjack because of the non-representativeness in regard to set weights, there may be other factors involved that are also related to the selection of wells. Table 7 presents the percentage of skipjack in species compositions determined from raised port samples of associated sets, for strata of year and vessel flag for which there are at least 10 sampled wells. Fleets other than those of the Philippines and Solomon Islands have relatively high average proportions. The low values for the Philippines vessels, which fished in the waters of Papua New Guinea, and the Solomon Islands vessels may be the related to those vessels fishing in the western part of the region and setting primarily on schools associated with anchored FADs.

For the fleets of the Federated States of Micronesia, Korea, Papua New Guinea, Chinese Taipei and Vanuatu, some of the proportions of skipjack in Table 7 are alarmingly high. Values greater than about 80% suggest that there may be another source of bias occurring. This could be due to samplers possibly selecting wells that contain only skipjack. For Chinese Taipei vessels sampled in Pohnpei during 2001–2006, 187 out of 207 wells with catches from associated schools contained pure skipjack. Given that a large proportion of associated schools contain more than one species, selecting 90.3% of wells with pure skipjack is suspect, and this is almost certainly due to well mixing (see section 10).

Table 7. Percentage of skipjack in species compositions determined from port samples of wells containing catches from associated schools, by flag

Year	Federated States of Micronesia	Republic of Korea	Papua New Guinea	Philippines	Solomon Islands	Chinese Taipei	Vanuatu
1997						34.8	
1998		100.0		37.5		55.5	100.0
1999					34.0		
2000			50.4		10.8		
2001		95.6	57.8	28.5		90.4	
2002	68.7	75.7	100.0	38.7		93.3	
2003		88.8	63.1			62.1	79.5
2004	81.5	78.4	75.7			76.1	84.4
2005			72.1			86.5	67.3
2006		87.9	93.5			90.2	82.1
Average	75.1	87.8	73.2	34.9	22.4	73.6	82.7

Table 8 presents the percentage of skipjack in species compositions determined from raised port samples of associated sets, for strata of year and port for which there are at least 10 sampled wells. The low values for Honiara and Kavieng may again be the related to vessels landing in those ports fishing in the west and setting on schools associated with anchored FADs. The ports of Pohnpei and Tarawa have average values over 80%, while Majuro has an average value of 78.3%. This suggests that procedures for selecting wells in those three ports may be resulting in samples that are subject to well mixing or that are otherwise unrepresentative of the catch.

Table 8. Percentage of skipjack in species compositions determined from port samples of wells containing catches from associated schools, by port

Year	Honiara	Kavieng	Levuka	Majuro	Pohnpei	Tarawa
1997	9.1					
1998						100.0
1999			45.7			
2000			69.8			
2001		39.6	55.5		90.4	
2002		30.6	22.5		98.7	
2003				79.5	62.1	
2004			64.4	84.4	76.1	
2005			81.2	67.3	86.5	
2006				82.1	90.2	83.8
Average	9.1	35.1	56.5	78.3	84.0	91.9

Table 9 presents the number of wells sampled during 2001–2006, by flag, for certain ports. Most of the fleets for which the proportion of skipjack in associated schools in Table 7 is high have transshipped in both Majuro and Pohnpei, while in Tarawa, mostly Korean vessels have transhipped. Tables 7–9 suggest that the problem of well selection is widespread, rather than confined to a particular fleet in a particular port.

Table 9. Number of wells sampled, by flag, during 2001–2006, for certain ports

Flag	Honiara		Kavieng		Levuka		Majuro		Pohnpei		Tarawa		Total	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
China	66	2.4					323	2.1	37	1.4			426	1.6
Federated States of Micronesia	128	4.7			238	9.6	51	0.3	141	5.3			558	2.1
Korea	1,005	36.8			314	12.7	288	1.9	720	26.9	2,442	90.2	4,769	17.7
Marshall Islands							3,670	24.4	7	0.3			3,677	13.7
New Zealand	35	1.3			515	20.8	294	2.0	17	0.6			861	3.2
Papua New Guinea	432	15.8	99	7.7	250	10.1	1,450	9.6	415	15.5			2,646	9.8
Philippines			1,184	92.3									1,184	4.4
Chinese Taipei	894	32.8					3,678	24.4	1,316	49.1			5,888	21.9
United States	37	1.4			1,016	41.0	681	4.5	26	1.0	264	9.8	2,024	7.5
Vanuatu	132	4.8			147	5.9	4,624	30.7					4,903	18.2
Total	2,729	100.0	1,283	100.0	2,480	100.0	15,059	100.0	2,679	100.0	2,706	100.0	26,936	100.0

Port sampling data contain more skipjack than observer data because the species composition depends on the size of the school (Figure 4) and port samples tend to be of larger sets (Figure 5), which contain more skipjack. Another reason may be that the selection of wells in certain ports is biased towards those containing pure skipjack (Tables 7–9). A third reason may be because the observer data are subject to size selection bias, and this is discussed in section 16.

6. Time-Area Representativeness of Observer Data

For unbiased estimates of the species composition, the time-area distribution of the samples collected by observers should be representative of the time-area distribution of the catch and fishing effort, either for the region as a whole or, if data are collected from and catches estimated for strata of area, within strata. Figure 7 compares the annual geographic distributions of days fished by all purse seiners and days monitored by observers. Throughout this time series, observers have been placed onboard vessels purely on an opportunistic basis, and this is evident in Figure 7. While the geographic distribution of observed effort is only somewhat different from that of the fleet as a whole for 1995–2001, they are considerably different for 2002–2006, particularly as a result of increased observer coverage in Papua New Guinea.

Figure 7. Distribution of purse-seine days fished and days observed

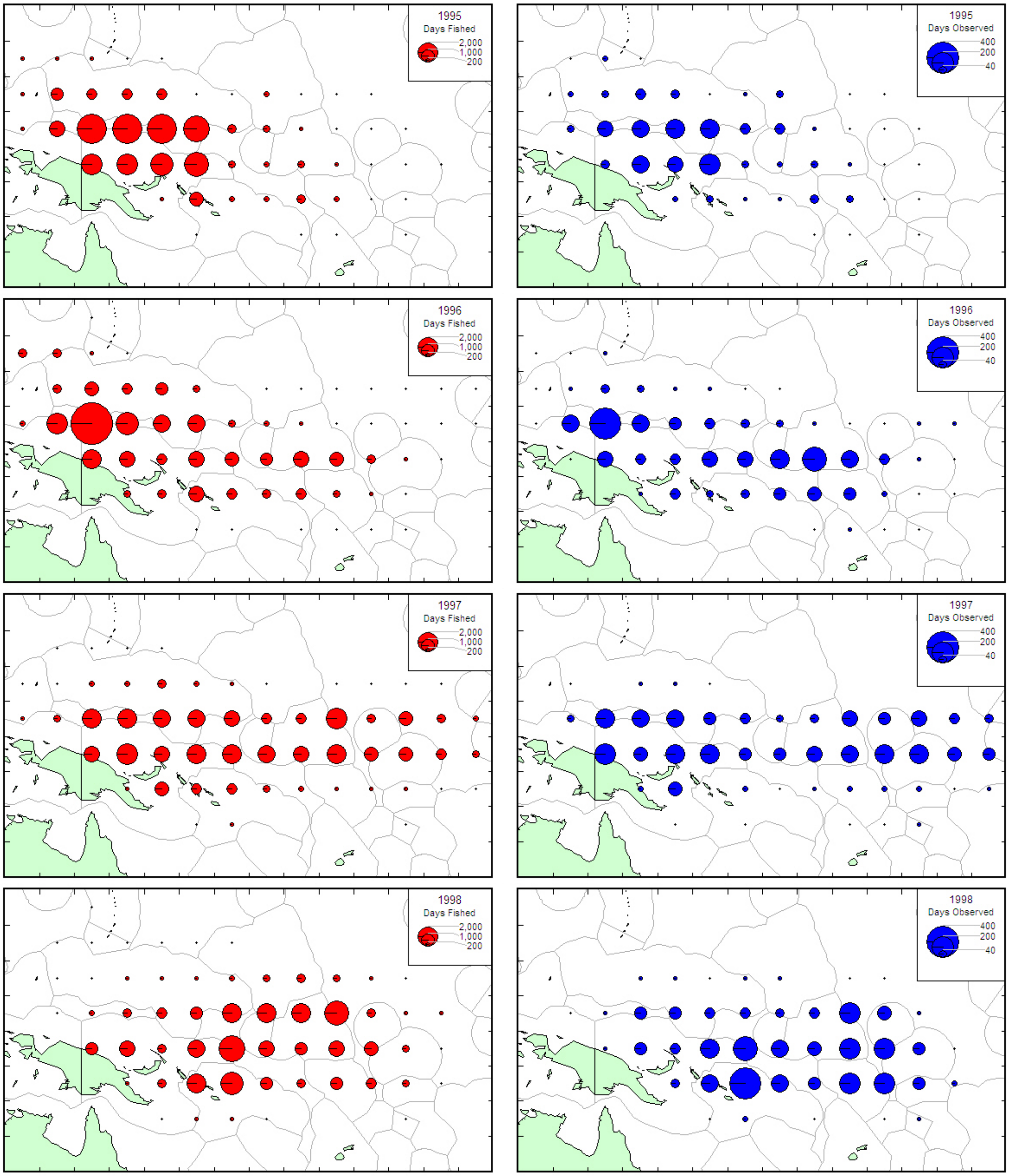
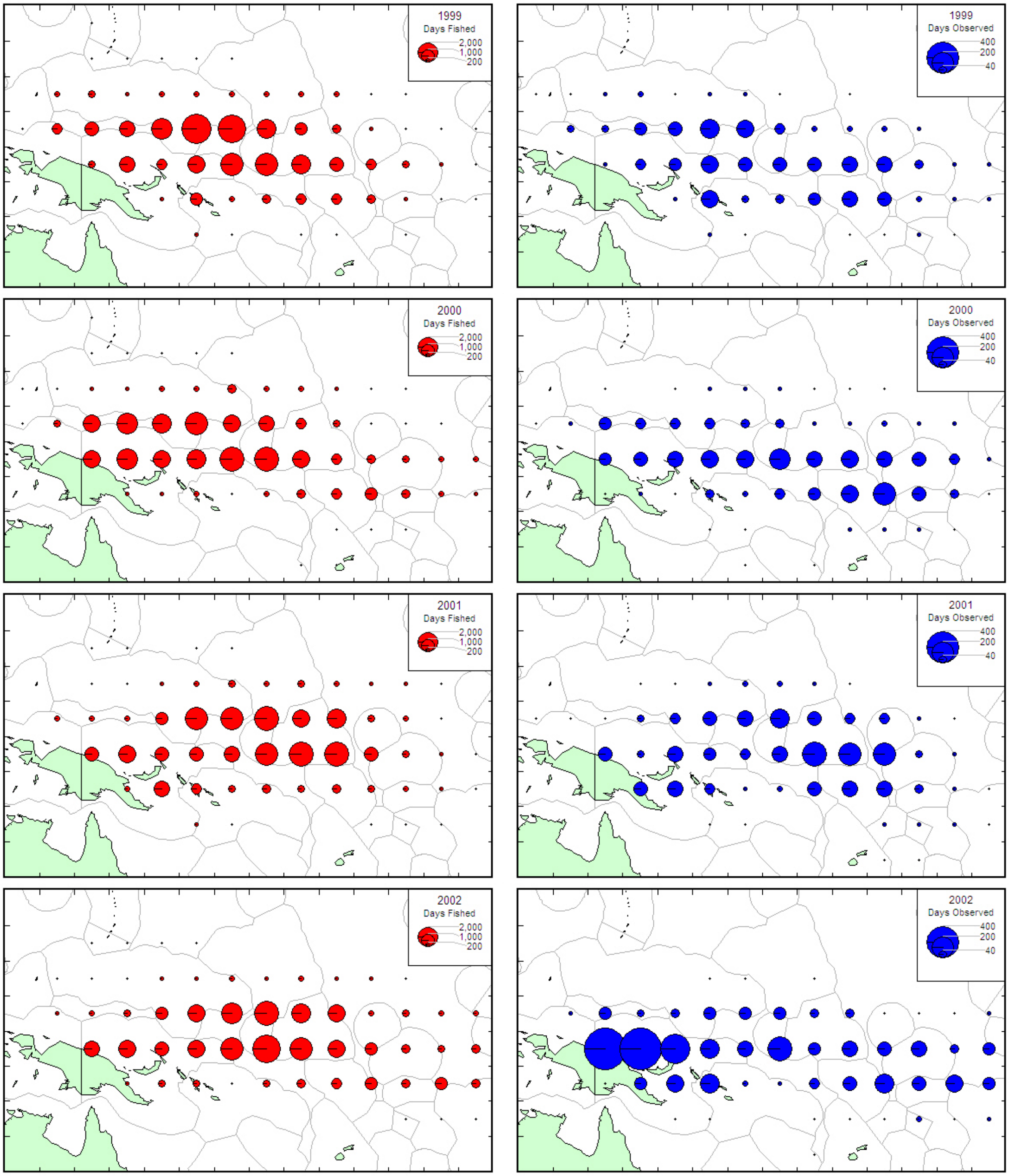


Figure 7 (continued)



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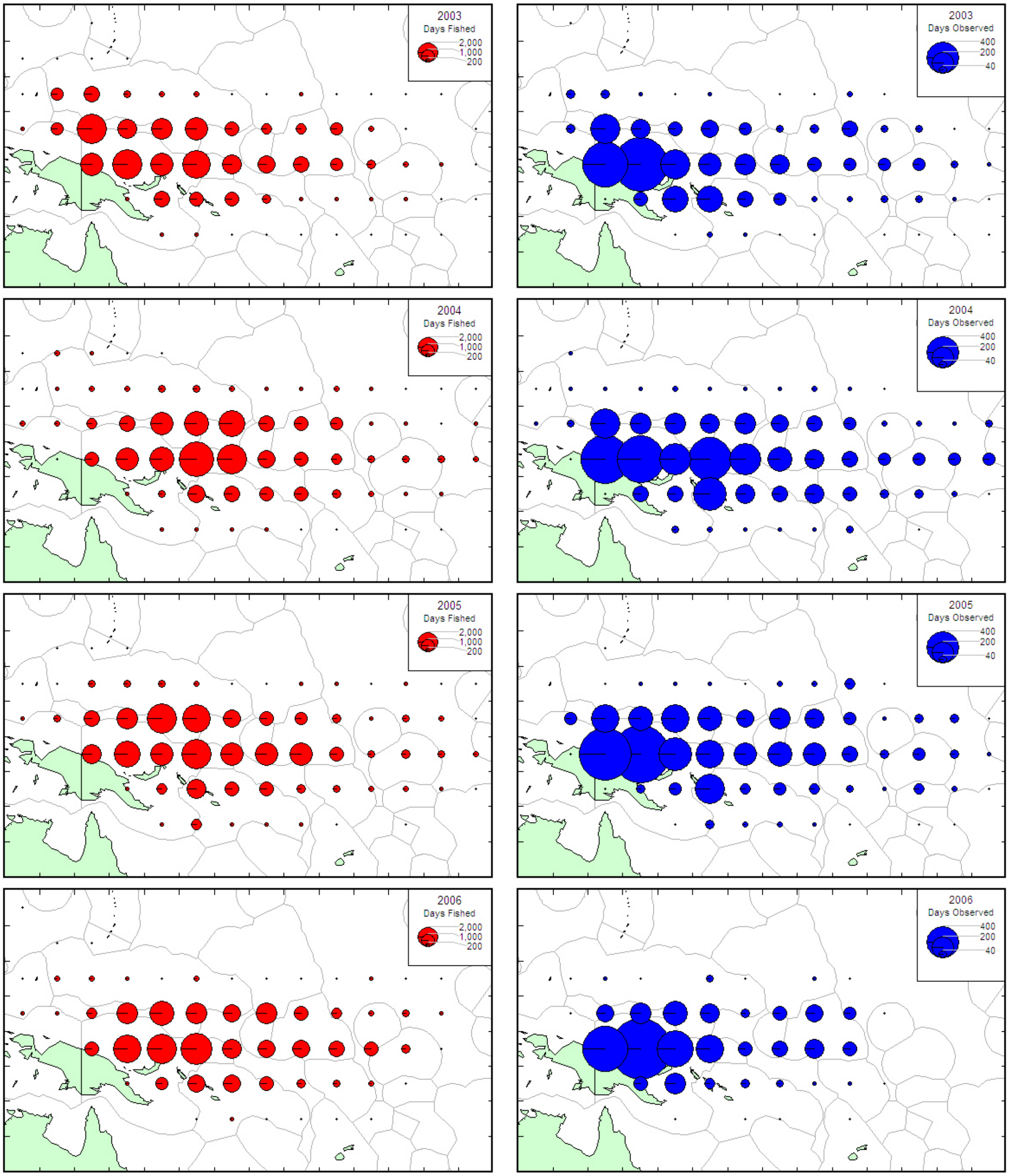
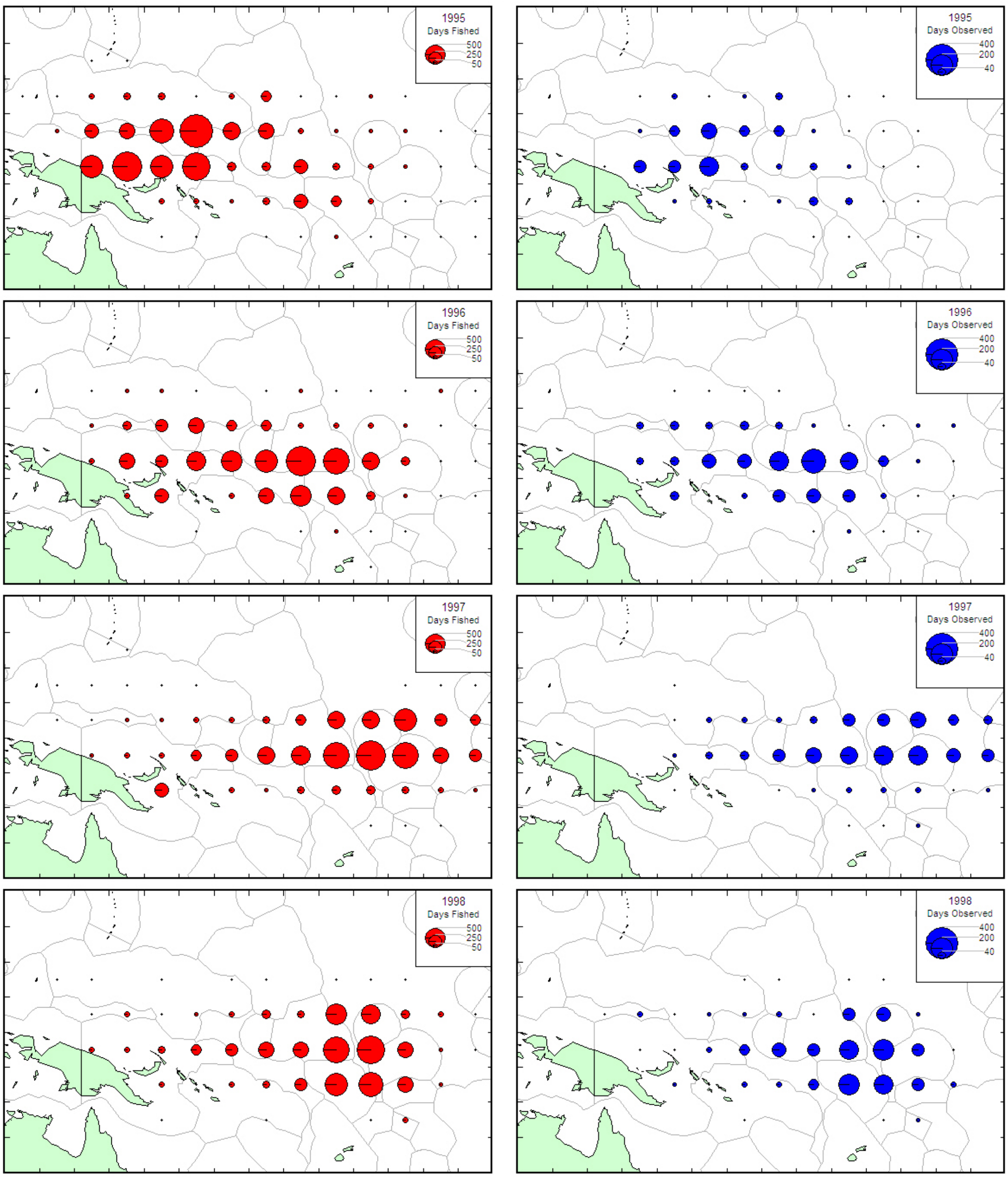


In Figure 7 above, the time-area distribution of days fished by purse seiners of all flags are compared to observer data which represent primarily United States vessels from 1995 to 2001, then decreasing importance of the United States fleet and increasing importance of vessels operating under the FSM Arrangement from 2002 to 2006, particularly vessels operating in Papua New Guinea. In contrast, Figure 8 presents the same comparisons, but only for logsheet data and observer data covering the United States fleet. As might be expected for a fleet for which coverage has consistently been relatively high, about 20% throughout the time series, the observer data are more representative of the time-area distribution of fishing effort for the United States fleet than the observer data for all fleets combined are representative of the time-area distribution of fishing effort of all fleets combined (Figure 7).

Figure 8. Distribution of days fished and days observed covering the United States purse-seine fleet



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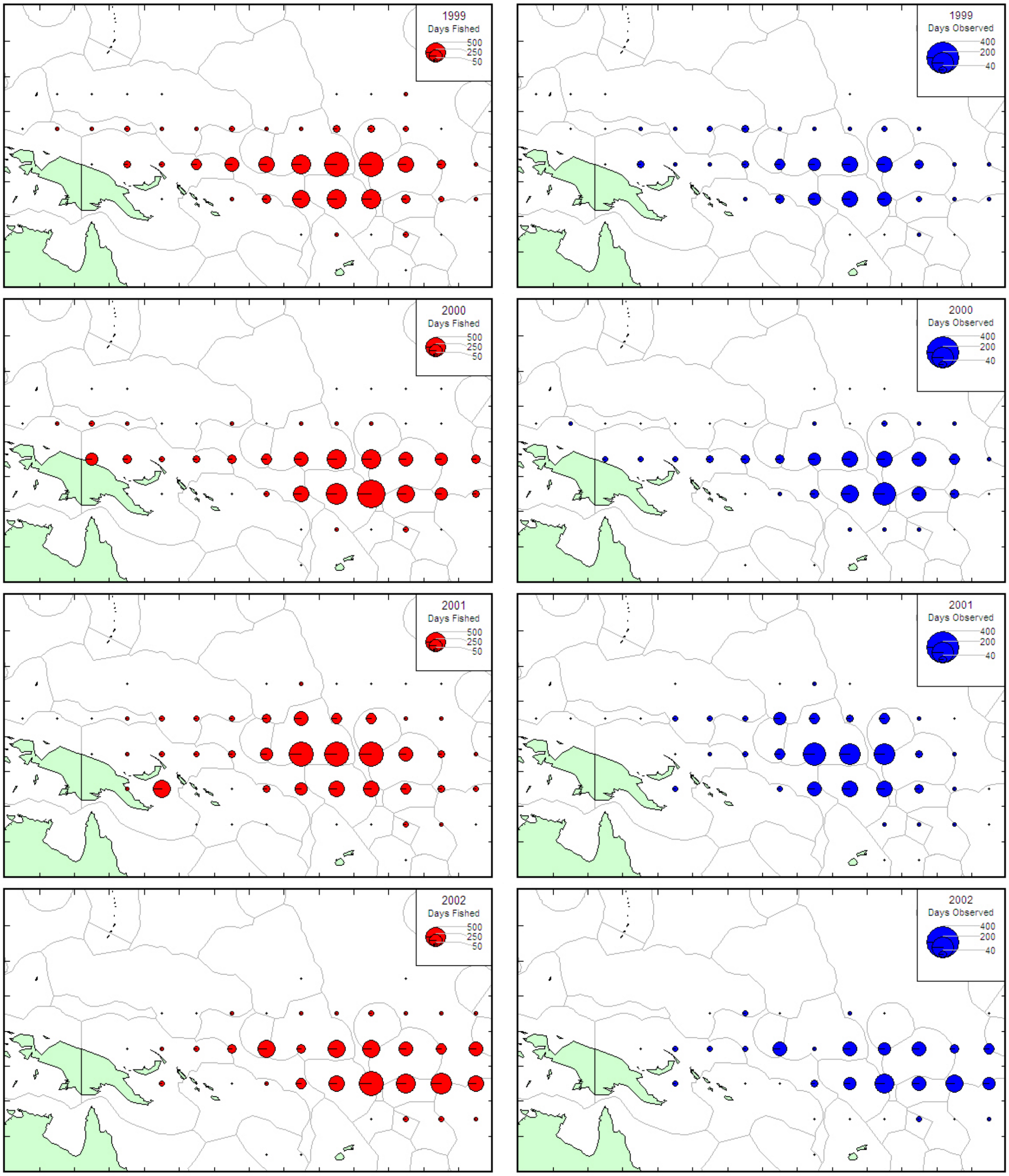
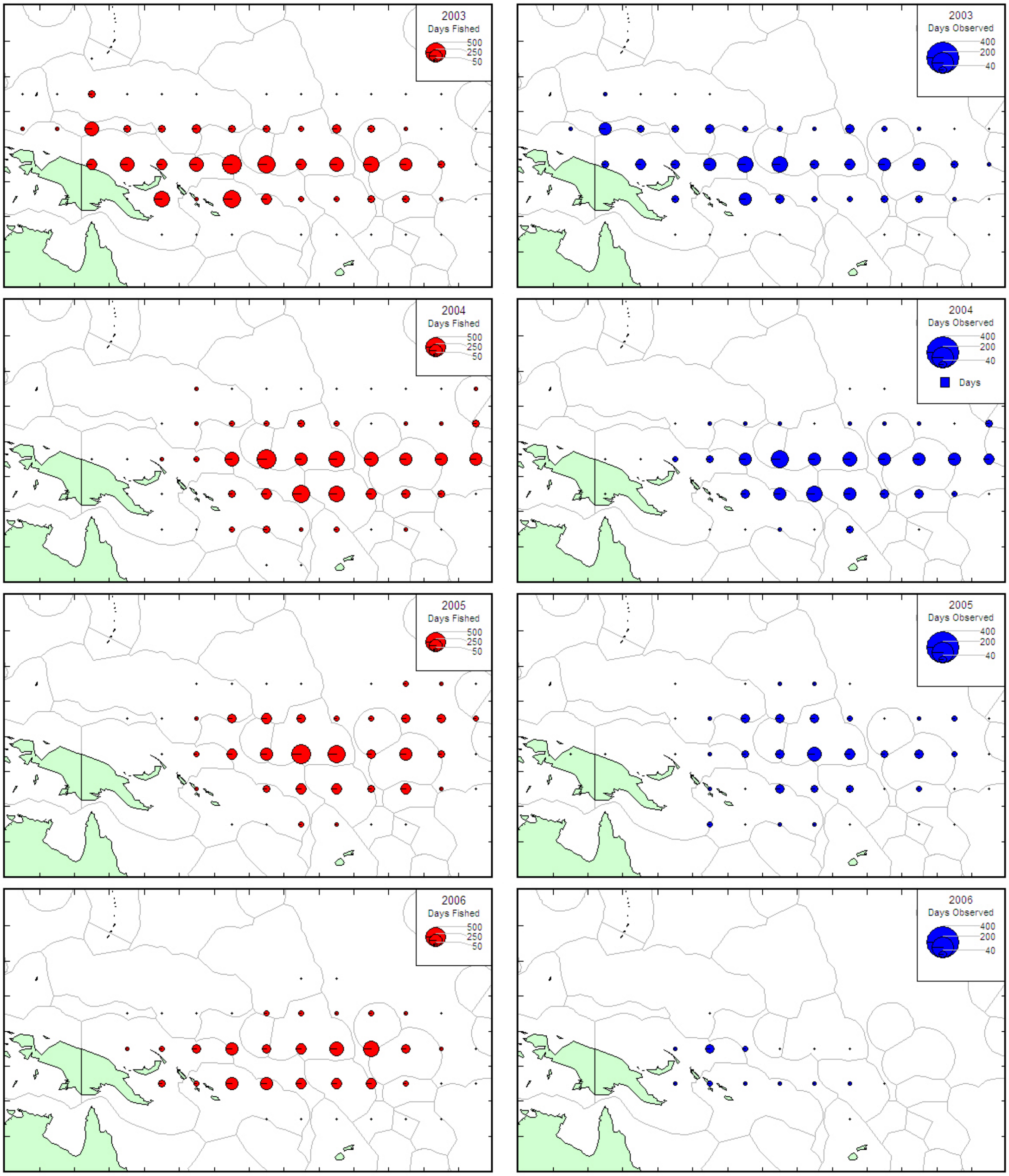


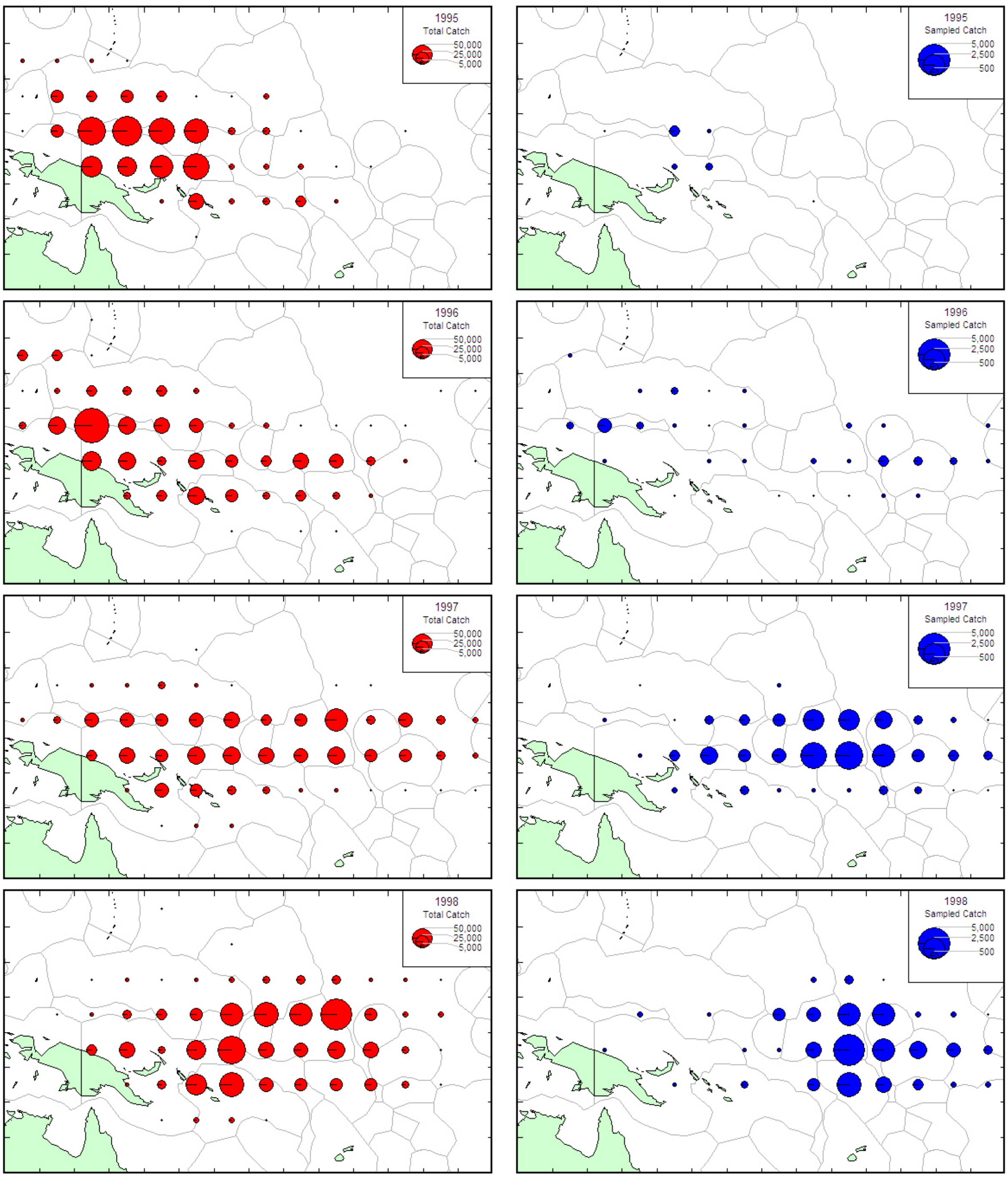
Figure 8 (continued)



7. Time-Area Representativeness of Port Sampling Data

Figure 9 compares the annual geographic distributions of the catch taken by all purse seiners and the catch sampled in port. The catch sampled in port was estimated from the average set weight for each well sampled for non-NMFS port samples and the amount unloaded from each well sampled for the NMFS port samples, since set weight was unavailable for the NMFS samples. For all years, the distributions of the total and sampled catches are noticeably different. This is perhaps to be expected, since the only port sampling programme in the region that has been maintained throughout the time series has been in Pago Pago, American Samoa, where vessels regularly unload to the two canneries; for most other ports, the sampling of vessels visiting port has been sporadic, due to the difficulty of maintaining the sampling programmes in the face of the unpredictable timing of the port visits.

Figure 9. Distribution of total catch (tonnes) and catch sampled in port (tonnes)



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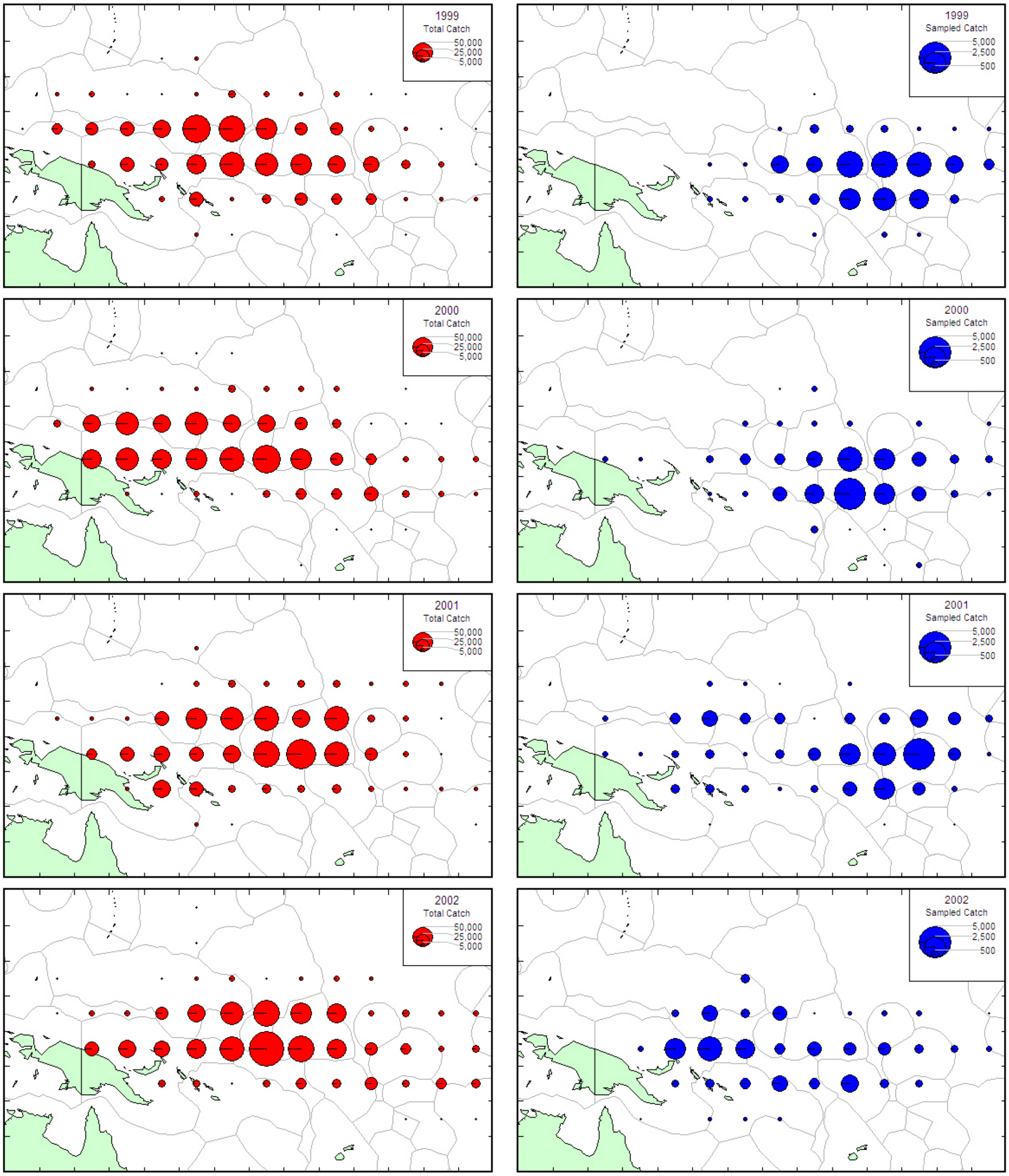
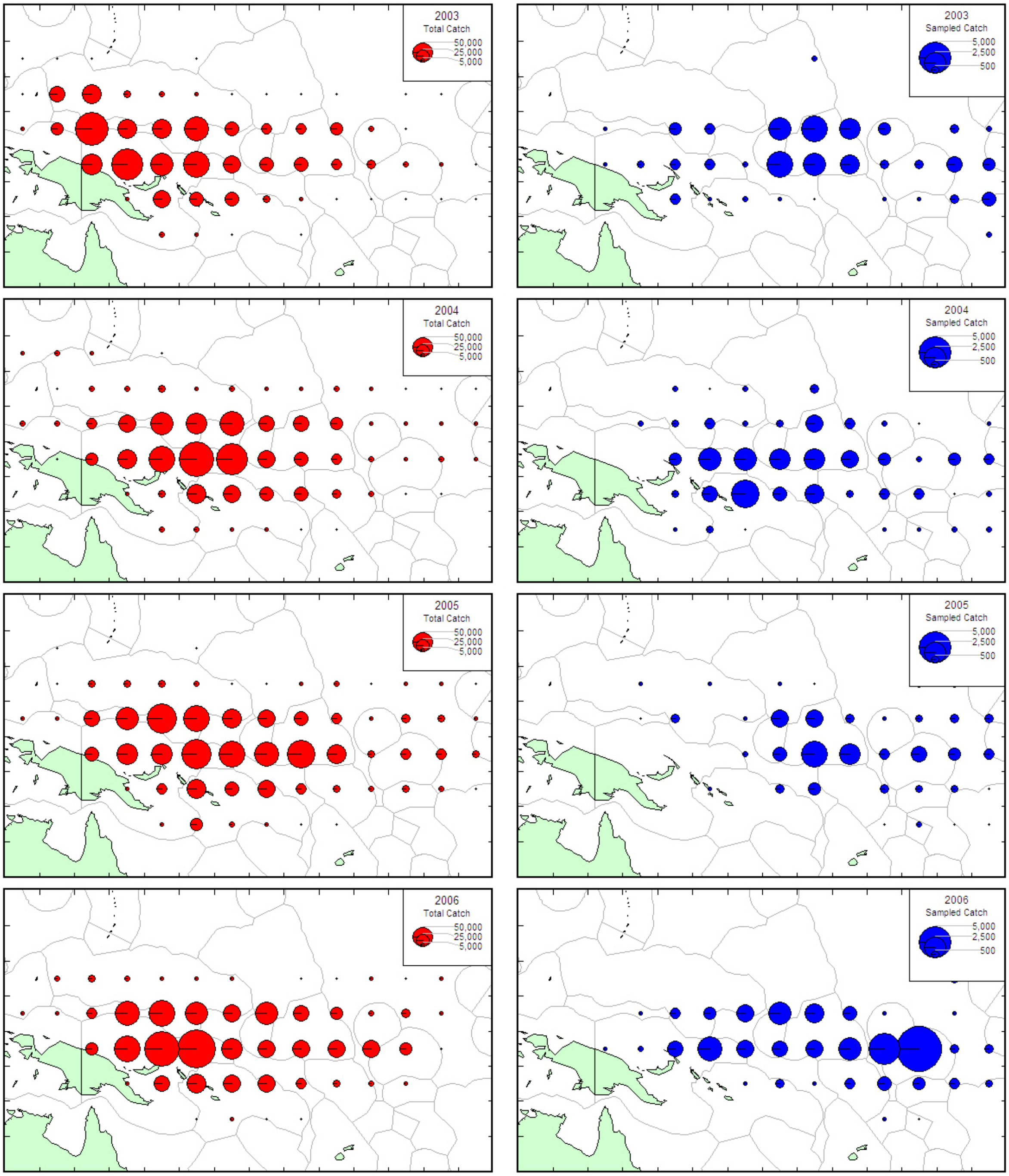


Figure 9 (continued)



Interpretation of Figure 9 is complicated because the NMFS samples are raised on the basis of the amount unloaded per well, rather than by the set weight, and thus are under-weighted relative to the non-NMFS samples. Figure 10 therefore compares the annual geographic distributions of the catch taken and the catch sampled by port samplers for United States purse seiners only. For most years shown, particularly 1997–2000 and 2004–2005, the NMFS port sampling data are representative, and for other years have a relatively high degree of overlap with the total catch. Under the NMFS programme, wells are chosen for sampling such that there are a target number of samples from each stratum of US Treaty area and month (Appendix A), where the area strata consist of several large areas (Figure A1); while this protocol ensures that there will usually be a high degree of overlap with the total catch, it was not designed so that the samples would be as representative as would be expected from random selection of vessels and wells with a moderate level of coverage. Figure 10 also suggests that when fishing takes place further to the west (e.g., 2003) vessels may unload in ports other than Pago Pago and hence may not be sampled in port under the NMFS programme.

Figure 10. Distribution of total catch (tonnes) and catch sampled in port (tonnes) for United States purse seiners

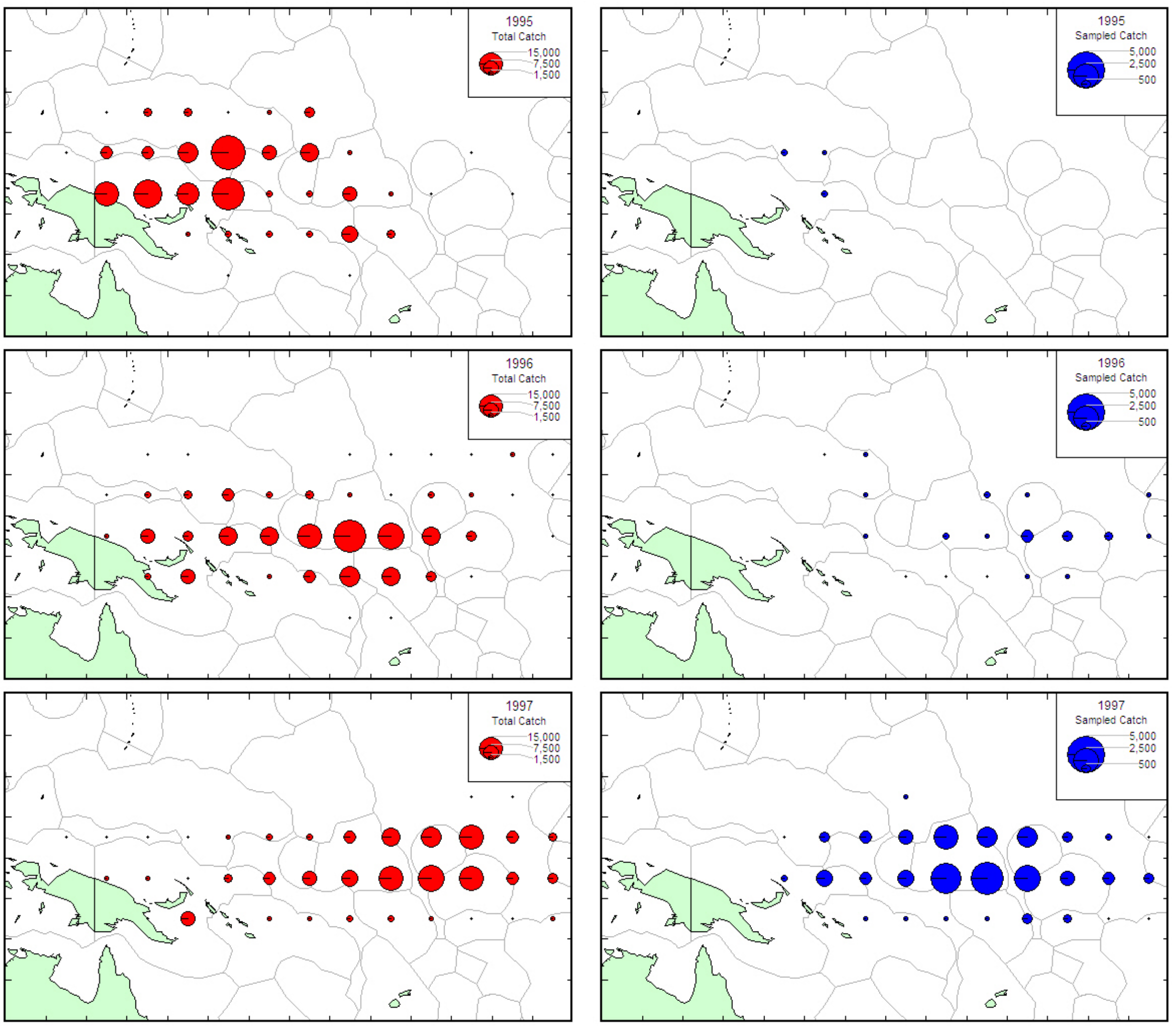
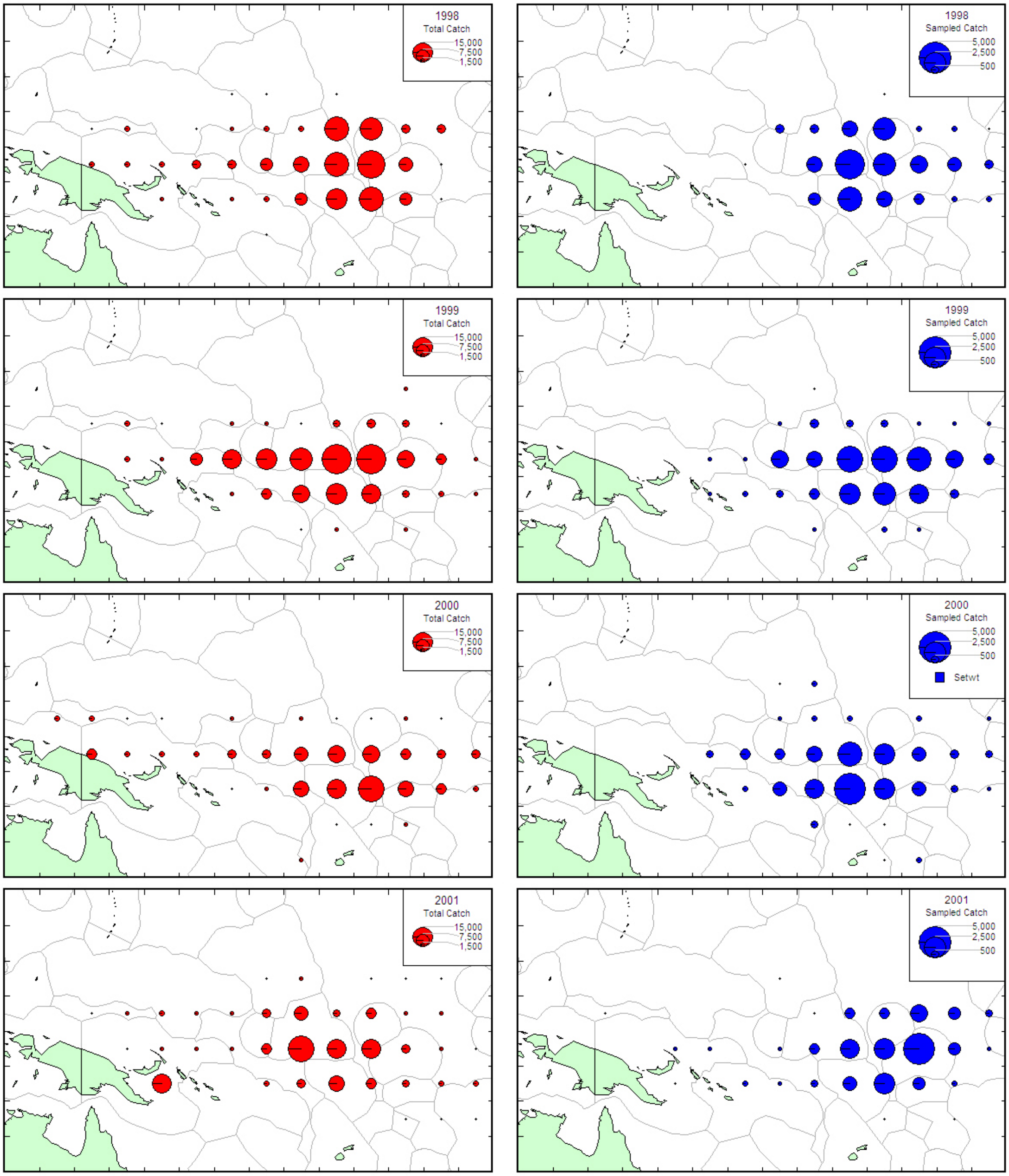


Figure 10 (continued)



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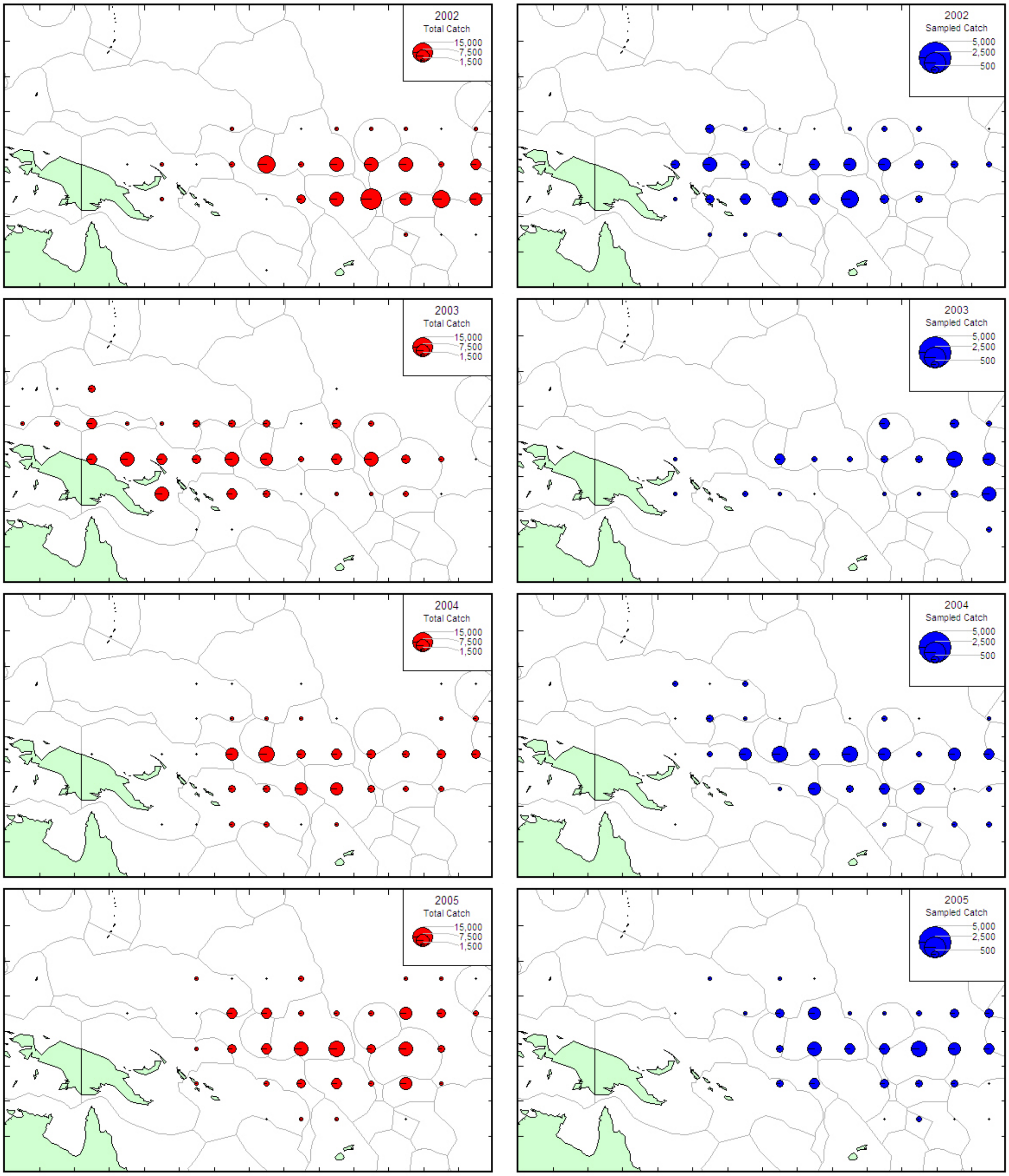
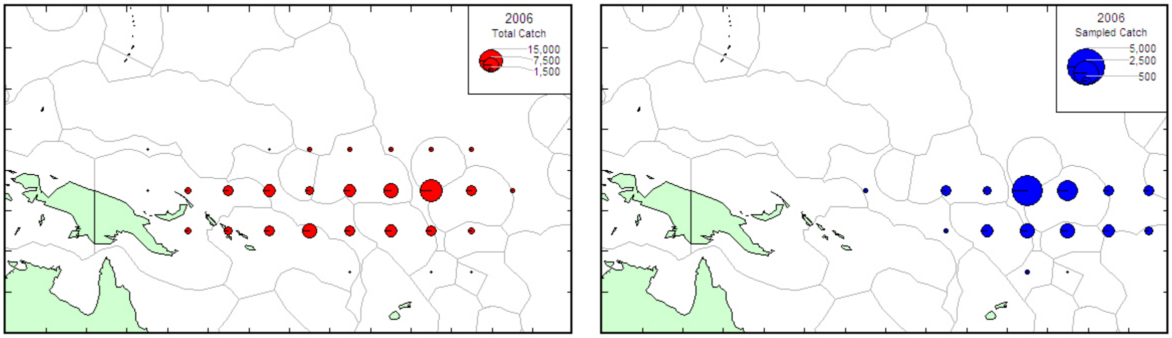


Figure 10 (continued)



8. Species Composition By Geographic Area

Observer coverage has increased in the western part of the region during 2002–2006 (Figure 7), while the coverage by port sampling tends to be higher in the eastern part of the region (Figure 9). If the species composition differs across the region, then this might explain part of the differences between the species compositions determined from observer data and port sampling data (Table 6, Figure 2). Figure 11 shows the species compositions for unassociated and associated schools determined from observer data and port sampling data, for areas of 5° latitude and 5° longitude for which there are at least 30 sets or wells sampled. The observer data for both unassociated and associated schools suggest that the proportion of yellowfin is greater in the west, on average, particularly in the vicinity of Papua New Guinea and the Solomon Islands, than elsewhere. While there are fewer areas covered in the west by port sampling data in Figure 11, the data for unassociated schools also suggest a greater proportion of yellowfin in the vicinity of Papua New Guinea and Solomon Islands, while the data for associated schools do not suggest differences among areas.

According to logsheet catch and effort data held by the OFP, unassociated schools and schools associated with anchored FADs accounted for 36.3% and 17.6% respectively of the catch in the EEZs of Papua New Guinea and Solomon Islands during 1997–2006; the unassociated schools and schools associated with anchored FADs contained 28.2% and 29.1% ‘yellowfin plus bigeye’ respectively. Schools associated with logs and drifting FADs accounted for 43.6% of the catch and contained 14.1% yellowfin and bigeye.

In comparison, in the remainder of the region, unassociated schools and schools associated with anchored FADs accounted for 28.9% and 3.2% respectively of the catch during 1997–2006; the unassociated schools and schools associated with anchored FADs contained 22.9% and 14.0% ‘yellowfin plus bigeye’ respectively. Schools associated with logs and drifting FADs accounted for 33.5% of the catch and contained 14.3% yellowfin and bigeye. The greater proportion of yellowfin in the vicinity of Papua New Guinea and Solomon Islands is therefore related to fishing on schools associated with anchored FADs.

Figure 11. Average species compositions determined from observer data and port sampling data, by school association

Skipjack = orange Yellowfin = yellow Bigeye = blue

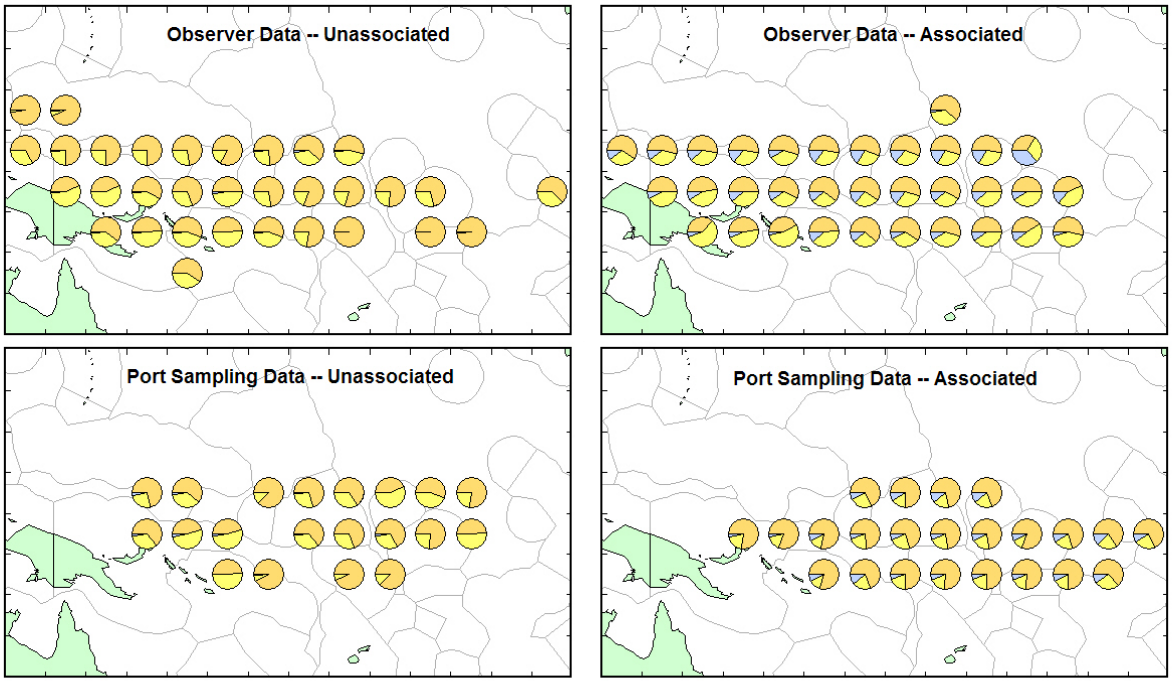


Table 10 presents the species compositions determined from observer data and port sampling data for the areas to the west and east of 170°E (i.e., the six tic of longitude from the left in Figure 11). It can be seen that the proportions of skipjack are lower, and the proportions of yellowfin higher, in the west than in the east, which confirms our observations of Figure 11. However, for associated schools, there are still considerable differences in the species compositions determined from observer data and port sampling data, with less skipjack and more yellowfin in the observer data than in the port sampling data, and this holds for the areas both to the west and east of 170°E. Whereas the differences for unassociated schools were minor for the region as a whole (Table 6), in Table 10 the differences are somewhat larger, and opposite those for associated schools, but still relatively small compared.

Table 10. Estimates of purse-seine species composition (%) for the areas west and east of 170°E

Area	Type of Data	Raised or Unraised	Unassociated Schools			Associated Schools		
			SKJ	YFT	BET	SKJ	YFT	BET
West of 170°E	All Observer Data	Unraised	34.1	64.4	1.5	41.6	48.6	9.9
		Raised	65.3	33.5	1.2	54.9	36.0	9.2
	All Port Sampling Data	Unraised	29.4	68.5	2.1	35.7	47.9	16.4
		Raised	62.4	34.8	2.8	73.5	19.6	6.8
East of 170°E	All Observer Data	Unraised	37.0	61.7	1.3	45.5	42.1	12.4
		Raised	73.7	25.4	0.9	56.9	31.4	11.7
	All Port Sampling Data	Unraised	26.2	73.0	0.8	24.4	56.9	18.7
		Raised	68.3	31.0	0.7	72.2	19.6	8.2

9. Distribution of Unloadings by Port and Month

The implementation of port sampling programmes in the region has been hampered by the large number of ports that have been used for transhipments and the irregularity of their use. Table 11 presents the number of purse-seine trips by the port of return recorded on catch and effort logsheets held by the OFP. Note that the coverage of the logsheet data is incomplete, although high, and the "port of return" recorded on the logsheet may not necessarily be the port of unloading.

Port sampling programmes have been implemented in several ports in the region, with varying degrees of success. Table 12 presents the number of purse-seine wells sampled determined from data held by the OFP for which the quality of data is adequate, by port of unloading and year. In recent years, successful port sampling programmes have been operating only in Majuro and Pago Pago, while a small but relatively consistent amount of sampling has been done in Pohnpei. The reasons for the lack of success of the other programmes have been specific to the port or country, and include the irregular use of the port by purse seiners, lack of trained samplers, lack of supervision of samplers, more emphasis being placed on observer programmes than port sampling programmes, or having port sampling within a country being concentrated in one port and not in others.

Table 11. Number of purse-seine trips by port of return and year

ENTITY	PORT	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	TOTAL	%
AUSTRALIA	VARIOUS	6	5	1	3	3	0	2	4	2	0	0	0	26	0.1%
CHINESE TAIPEI	KAOHSIUNG	12	18	7	23	29	21	10	59	48	71	50	68	416	1.3%
FED STATES OF MICRONESIA	CHUUK	236	63	148	137	422	588	129	35	24	6	113	10	1,911	5.9%
	KOSRAE	0	0	4	7	30	18	19	8	0	11	0	0	97	0.3%
	POHNPEI	3	5	11	3	73	56	534	667	779	1,445	1,145	1,199	5,920	18.4%
	YAP	0	31	31	5	34	4	0	3	182	13	4	0	307	1.0%
FIJI ISLANDS	LEVUKA	0	3	2	6	4	3	3	9	0	2	20	0	52	0.2%
	SUVA	0	1	1	1	1	3	2	0	0	0	3	2	14	0.0%
INDONESIA	VARIOUS	2	0	1	0	1	0	2	0	0	1	4	0	11	0.0%
JAPAN	MAKURAZAKI	47	53	49	78	80	91	78	57	47	73	88	120	861	2.7%
	SHIMIZU	10	17	12	16	16	23	19	0	11	5	0	0	129	0.4%
	YAIZU	182	188	298	301	386	376	296	371	291	237	268	324	3,518	10.9%
	YAMAGAWA	29	33	34	44	36	62	63	53	56	50	76	62	598	1.9%
	OTHER	1	10	5	12	2	0	1	14	1	4	1	3	54	0.2%
KIRIBATI	CANTON ISLAND	0	0	0	0	0	0	0	0	0	0	13	0	13	0.0%
	KIRITIMATI	0	0	95	0	4	0	0	407	0	0	43	0	549	1.7%
	TARAWA	0	13	131	318	11	11	178	284	1	18	307	603	1,875	5.8%
KOREA, REPUBLIC OF	BUSAN	0	0	2	1	2	2	0	0	4	2	7	3	23	0.1%
	MASAN	0	3	0	0	0	6	9	9	1	6	12	8	54	0.2%
	OTHER	0	0	0	0	0	14	8	0	2	0	0	10	34	0.1%
MARSHALL ISLANDS	MAJURO	0	0	0	238	303	396	1,013	1,352	407	717	659	433	5,518	17.1%
NAURU	NAURU	0	0	0	0	25	23	11	2	0	0	1	5	67	0.2%
NEW CALEDONIA	NOUMEA	0	1	0	0	0	0	0	0	0	0	0	0	1	0.0%
NEW ZEALAND	VARIOUS	0	0	0	1	0	10	3	0	0	8	0	0	22	0.1%

Table 11 (continued)

ENTITY	PORT	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	TOTAL	%
PALAU	KOROR	1	4	0	0	0	1	0	0	8	0	0	1	15	0.0%
PAPUA NEW GUINEA	KAVIENG	62	30	18	0	0	46	23	19	27	13	29	69	336	1.0%
	MADANG	3	0	6	9	20	0	1	1	4	2	31	32	109	0.3%
	MANUS	27	80	0	0	0	0	0	0	0	2	6	6	121	0.4%
	RABAUL	27	37	102	151	77	103	182	157	234	289	253	956	2,568	8.0%
	WEWAK	35	233	79	22	7	104	1	6	423	90	184	154	1,338	4.1%
	OTHER	0	0	0	2	1	0	3	8	6	4	19	9	52	0.2%
PHILIPPINES	GENERAL SANTOS	13	11	6	3	20	6	17	44	57	24	35	67	303	0.9%
	MANILA	7	15	14	8	24	20	7	18	17	23	22	39	214	0.7%
	ZAMBOANGA	4	14	14	8	15	18	2	5	29	34	11	0	154	0.5%
	OTHER	2	2	1	2	8	0	4	0	15	12	10	26	82	0.3%
SAMOA	APIA	0	0	0	0	4	0	0	0	0	0	2	0	6	0.0%
SOLOMON ISLANDS	HONIARA	47	72	162	355	35	6	0	2	63	274	317	346	1,679	5.2%
	NORO	2	1	0	0	0	0	1	13	16	66	57	71	227	0.7%
	TULAGI	4	34	46	47	52	2	1	3	0	15	36	2	242	0.8%
THAILAND	BANGKOK	0	0	0	0	1	1	0	0	9	0	0	7	18	0.1%
TUVALU	FUNAFUTI	2	0	0	0	0	0	0	0	0	0	0	0	2	0.0%
UNITED STATES	GUAM	150	93	86	61	75	60	133	88	102	63	70	56	1,037	3.2%
	PAGO PAGO	117	144	134	166	133	126	127	167	184	136	94	116	1,644	5.1%
	OTHER	4	2	1	0	1	1	6	5	3	0	0	0	23	0.1%
VANUATU	SANTO	0	0	1	0	1	1	4	4	6	0	0	0	17	0.1%
	TOTAL	1,035	1,216	1,502	2,028	1,936	2,202	2,892	3,874	3,059	3,716	3,990	4,807	32,257	100.0%

Table 12. Number of purse-seine wells sampled by port and year

ENTITY	PORT	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	TOTAL	%
FED STATES OF MICRONESIA	CHUUK	7	17	10	1	0	0	0	0	0	0	0	0	35	0.7%
	KOSRAE	0	0	0	0	0	0	4	0	0	0	0	0	4	0.1%
	POHNPEI	0	0	1	0	0	0	58	48	22	27	4	48	208	4.4%
FIJI ISLANDS	LEVUKA	0	0	0	0	10	5	13	22	0	11	17	0	78	1.7%
KIRIBATI	KIRITIMATI	0	0	0	0	0	0	0	6	0	0	0	0	6	0.1%
	TARAWA	0	0	13	33	0	0	0	0	0	0	0	106	152	3.2%
MARSHALL ISLANDS	MAJURO	0	0	0	0	0	0	0	0	167	141	48	139	495	10.6%
NAURU	NAURU	0	0	0	0	0	1	0	0	0	0	0	0	1	0.0%
PAPUA NEW GUINEA	KAVIENG	4	0	0	0	0	0	11	15	0	0	0	0	30	0.6%
	LAE	0	0	0	0	0	0	0	9	0	0	0	0	9	0.2%
	MANUS	0	20	0	0	0	0	0	0	0	0	0	0	20	0.4%
	RABAUL	0	0	0	0	0	0	4	24	0	0	0	0	28	0.6%
	WEWAK	0	5	3	6	0	0	4	0	0	0	0	0	18	0.4%
SOLOMON ISLANDS	HONIARA	1	0	3	5	1	0	0	0	7	49	0	0	66	1.4%
	TULAGI	0	0	0	0	1	1	0	0	0	0	0	0	2	0.0%
UNITED STATES	PAGO PAGO	0	48	415	443	413	422	411	400	271	217	301	195	3,536	75.4%
	TOTAL	12	90	445	488	425	429	505	524	467	445	370	488	4,688	100.0%

The irregular use of a port by purse seiners is problematic because once vessels cease visiting a port and port samplers are assigned other duties within the fisheries agency or find employment elsewhere, it is difficult to recommence the sampling programme if and when the vessels return. Port sampling programmes therefore have a greater chance of success in ports that are visited regularly. Six ports for which the number of trips has been consistently high during recent years (2002–2006) are highlighted in yellow in Table 11, i.e., Pohnpei, Yaizu, Majuro, Rabaul, Pago Pago and Honiara.

Table 13 shows the number of trips per month during 2002–2006 for each of the six ports and indicates that, with the exception of Honiara, each port is regularly used throughout the year, although the number of trips per month can sometimes be low in Majuro, Rabaul and Pago Pago. For Honiara, there would appear to be very few port visits from May to September, which suggests that a port sampling programme in Honiara may be problematic.

Table 13. Number of purse-seine trips by year and month for five major ports

PORT	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
POHNPEI	2002	58	78	82	102	81	62	9	26	5	5	42	117	667
	2003	164	146	60	34	30	3	22	56	86	57	74	47	779
	2004	96	92	114	104	123	107	170	153	107	153	135	91	1,445
	2005	33	78	85	36	85	114	68	199	127	158	84	78	1,145
	2006	111	116	169	129	121	147	117	41	62	64	82	40	1,199
YAIZU	2002	48	19	24	30	48	26	37	23	41	25	34	16	371
	2003	30	23	22	19	27	16	13	12	15	36	45	33	291
	2004	23	18	15	21	30	15	20	17	13	17	21	27	237
	2005	20	20	17	26	21	24	23	22	12	29	30	24	268
	2006	21	38	26	24	15	17	31	14	33	43	27	35	324
MAJURO	2002	57	57	80	62	111	108	175	136	164	129	93	180	1,352
	2003	63	25	11	12	6	10	26	52	51	49	49	53	407
	2004	26	38	55	74	69	66	44	36	79	90	71	69	717
	2005	23	48	18	28	56	101	62	71	36	96	53	67	659
	2006	32	2	3	1	23	28	86	82	97	31	18	31	434
RABAUL	2002	83	9	11	12	18	0	0	0	0	0	13	11	157
	2003	2	35	65	17	9	4	6	10	13	48	25	0	234
	2004	12	21	60	33	7	28	7	12	59	2	3	45	289
	2005	22	19	25	54	18	2	4	3	21	62	23	0	253
	2006	82	103	131	201	173	78	2	4	15	50	57	61	957
PAGO PAGO	2002	23	14	12	23	11	13	10	17	8	11	13	12	167
	2003	22	7	17	19	16	18	18	13	14	13	12	15	184
	2004	9	4	5	12	20	4	19	4	29	11	13	6	136
	2005	3	5	6	8	11	9	8	9	5	11	10	9	94
	2006	6	3	16	10	17	5	11	9	18	2	16	3	116
HONIARA	2002	0	0	0	0	0	2	0	0	0	0	0	0	2
	2003	0	0	0	0	0	0	0	0	0	0	27	36	63
	2004	74	48	31	37	6	0	0	0	7	27	15	29	274
	2005	28	28	14	11	0	1	0	4	0	18	68	145	317
	2006	98	90	67	5	0	0	0	0	0	0	0	87	347

Figure 12 shows the annual geographic distribution of purse-seine effort by vessels that have returned to the major ports, excluding Honiara, and suggests that the data are more or less representative of effort of all purse seiners.

Figure 12. Distribution of purse-seine days fished for all purse seiners (left) and purse seiners unloading at five major ports (right)

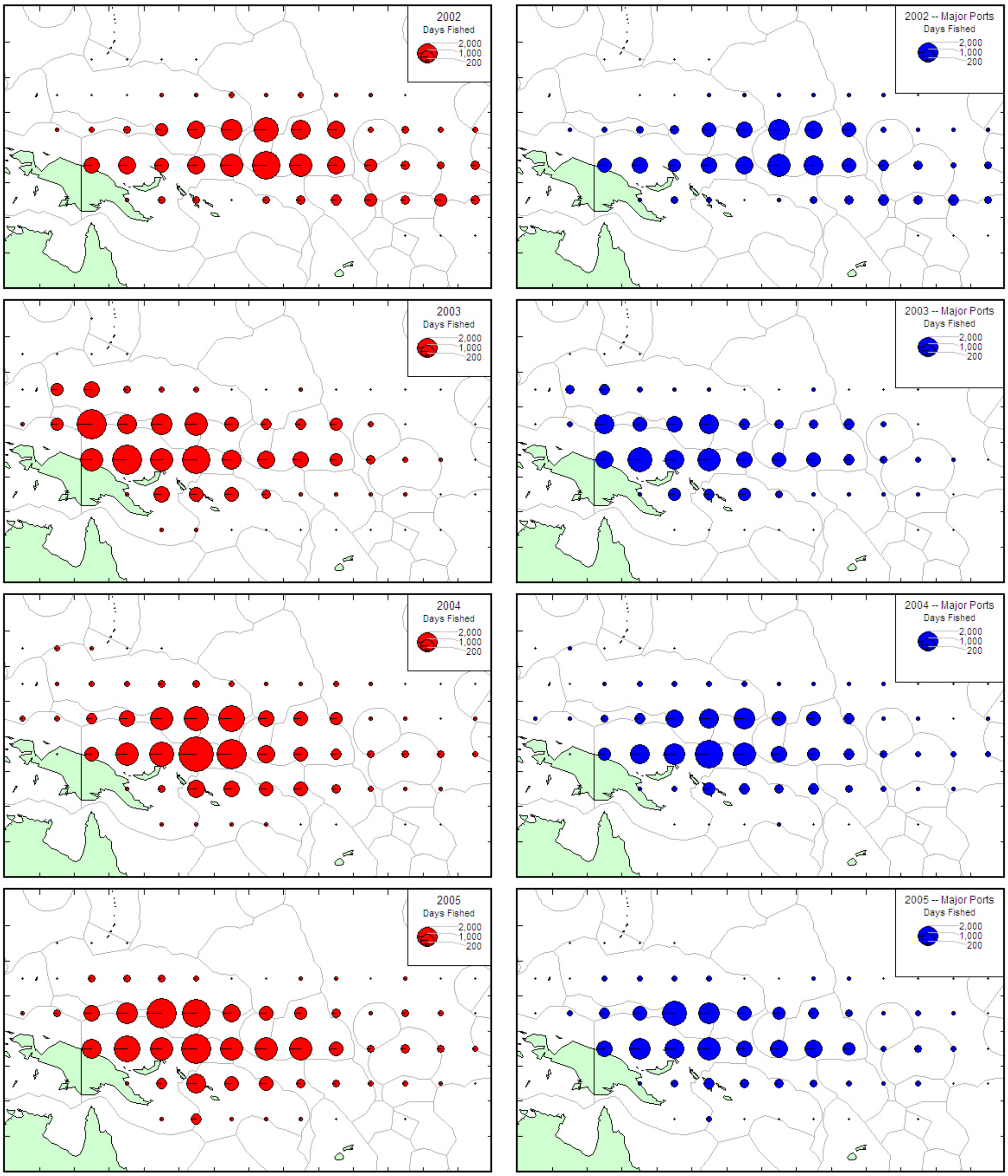


Figure 12 (continued)

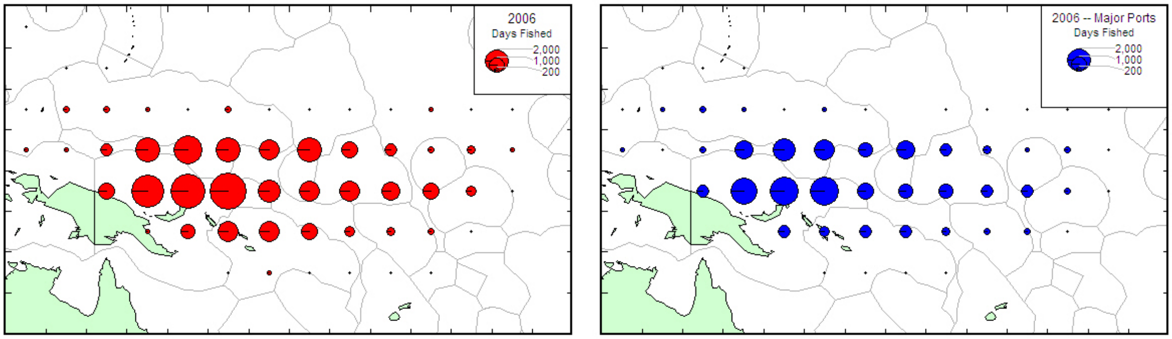


Table 13 above suggests that the port sampling programmes in Majuro, Pago Pago and Pohnpei will continue to be successful and that the establishment of a port sampling programme in Rabaul has a good chance of being successful. The current level of port sampling in Yaizu is unknown, but port sampling should be successful there. Figure 12 suggests port sampling programmes in these five major ports would be more or less representative of the geographic distribution of purse-seine effort in the region. However, account has not been taken in this section of the fact that well mixing may present serious problems for the selection of wells for certain fleets and ports (section 5), particularly Majuro and Pohnpei. It should also be noted that the use of a port for transshipment depends strongly on the competitiveness of the port charges and transshipment fees, and on other environmental and social conditions, which have been known to change; while certain transshipment ports have been used regularly in the recent past, circumstances may change in the future.

10. Well Mixing

Port samplers select wells to sample based on information recorded on logsheets regarding the sets that have been stored in each well. Wells that contain a small number of sets, each of which are of the same school association, are usually selected. However, fish stored in a well can be transferred to another well while the vessel is at sea, which renders the information recorded on logsheets less accurate regarding the contents of each well. Well mixing usually occurs to sort fish by species and size category, but can also occur for reasons unrelated to sorting. If well mixing is common and not accounted for, then information regarding the date, location and school association of port samples will be inaccurate.

Our knowledge of well mixing in the Western and Central Pacific is primarily anecdotal. It is known to be extensive on vessels that have dry lockers; the tuna are first frozen in brine wells and then moved to the dry lockers to free up space. Chinese Taipei vessels typically have dry lockers and so well mixing is common in that fleet.

Well mixing appears to have become more common in recent years. In Pohnpei, for example, vessels attempt to reduce their time spent in port by sorting fish among wells while en route from the fishing ground. This is particularly the case when arrangements have been made for the purse seiner to transship its catch to different reefer vessels according to the species category and size category of the catch, which is apparently quite common. Another problem occurs during transshipment when conveyor belts are used to load fish from multiple wells into the net at the same time.

Section 5 considered the relationship between the species composition and set weights, and found that port samples tend to over-estimate the proportion of skipjack because of their lack of representativeness of the set weights. Tables 7–9 in that section then went on to suggest that for certain fleets and ports, the proportion of skipjack was even greater than what would be accounted for by the set weight bias. Well mixing is probably responsible for this anomaly, and we can therefore suppose that well mixing is probably widespread among those fleets and ports.

Quantitative information on the extent of well mixing is generally lacking; however, observers from the Pacific island countries have the option of completing the *Vessel Logsheet and Well Loading Reconciliation (PS–5) Form*. Data on the PS–5 form covering a relatively small number of trips during 2004–2007 are summarised in Table 14. Well mixing was recorded for 26.5% of the 83 trips covered; on average, there were 3.2 well transfers recorded per trip with well mixing. The quality of these data, however, is suspect; in particular, the PS–5 forms, being optional, were probably not completed consistently over the entire trip in most cases, so the extent of well mixing is probably under-estimated.

Table 14. Incidence of well mixing determined from observer data

Flag	Number of Trips			Well Transfers Per Trip		
	Total	With Transfers	%	Average	Minimum	Maximum
China	1	1	100.0%	3.0	3.0	3.0
Japan	4	1	25.0%	1.0	1.0	1.0
Marshall Islands	4	3	75.0%	3.0	2.0	4.0
Papua New Guinea	46	12	26.1%	3.7	1.0	13.0
Philippines	20	4	20.0%	5.5	4.0	8.0
Chinese Taipei	8	1	12.5%	3.0	3.0	3.0
Total	83	22	26.5%	3.2	1.0	13.0

11. Bias of Species Compositions Determined From Grab Samples

Under the current sampling protocol, observers grab five fish per brail; however, given that the objective of sampling is to estimate the species composition in terms of weight, rather than number of fish, it is possible that the species compositions determined from data collected under the current sampling protocol are biased. This was examined by simulating the sampling of three sets, each containing skipjack and yellowfin.

The first set contained 9.5 tonnes of 2 kg skipjack (4750 fish) and 0.5 tonnes of 10 kg yellowfin (50 fish), such that the proportions of skipjack and yellowfin were 95% and 5% respectively.

The second set contained 5 tonnes of 2 kg skipjack (2500 fish) and 5 tonnes of 10 kg yellowfin (500 fish), such that the proportions of skipjack and yellowfin were each 50%.

The third set contained 0.5 tonnes of 2 kg skipjack (250 fish) and 9.5 tonnes of 10 kg yellowfin (950 fish), such that the proportions of skipjack and yellowfin were 5% and 95% respectively.

Two types of sample selection were simulated for a given coverage rate: under ‘grab’ samples, the coverage rate was applied to the number of fish in the set and that number of fish was randomly selected with a uniform random number generator. Under ‘spill’ samples, the coverage rate was applied to the weight of the set and fish were randomly selected until the weight of fish in the sample was equal to that weight. Spill samples are described in detail in section 14.

Ten coverage rates from 0.2% to 2.0% were examined and 1000 replicates of sampling were conducted for each combination of set, sampling protocol and coverage rate. Under the current sampling protocol, actual coverage rates of individual sets greater than 20 tonnes average 0.88% in terms of weight.

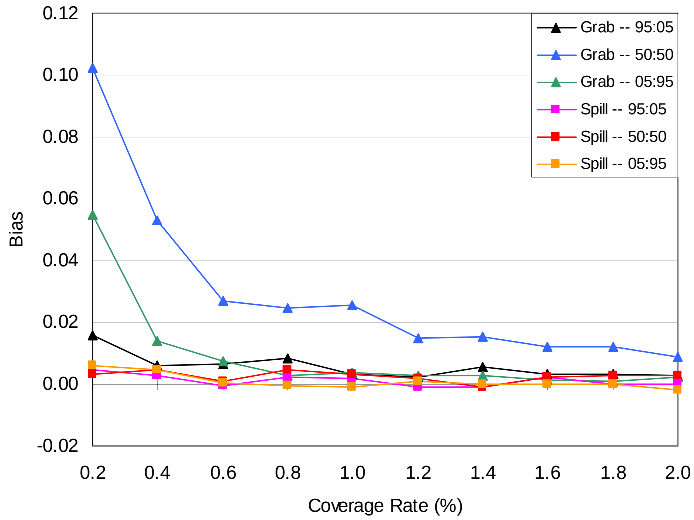
Figure 13 presents the bias of estimates of the proportion of skipjack for the two sampling protocols (“grab” and “spill”) and the three sets (“95:05”, “50:50” and “05:95”). It can be seen that the grab samples result in significant bias, with the proportion of skipjack being consistently over-estimated and the proportion of yellowfin being under-estimated. The highest degree of bias in the proportion of skipjack is for the set with equal amounts of skipjack and yellowfin in terms of weight; for a coverage rate of 0.2%, the average estimate of the proportion of skipjack is 60.2%, compared to the true value of 50.0%, giving a bias of +10.2%. The bias declines with an increase in the sample size, e.g., with an increase in the coverage rate for a given size of set or (not shown here) with an increase in the size of the set for a given coverage rate.

While the bias in the estimate of the proportion of skipjack is least for the set with 95% skipjack and 5% yellowfin, the bias still has a major effect on the estimate of the amount of yellowfin in that set. For example, if the bias in the estimate of the proportion of skipjack is +1%, then the estimate of the proportion of yellowfin is 4% instead of 5%, and the amount of yellowfin in the set will be under-estimated by 20%.

The spill samples exhibit a minor positive bias at low coverage rates due to manner in which the spill samples were modelled. Fish were randomly selected until the total weight of fish selected reached or exceeded a maximum. For small sample sizes, which for spill samples are in terms of weight, on average there will be slightly more skipjack in the sample than yellowfin, since more skipjack can be selected towards the end of the sample than yellowfin, before the sample size is exceeded. This effect is an artefact of modelling and will not occur during actual spill sampling.

The variances of estimates of the proportion of skipjack in the set are similar for grab and spill samples.

Figure 13. Bias of estimates of the proportion of skipjack in simulated sampling under "grab" and "spill" protocols



The bias resulting from grab samples may be counter-intuitive, but is explained as follows. Suppose we have a set containing N fish of which N_s are skipjack (and $N - N_s$ are yellowfin), and that n fish are selected in a sample of which n_s are skipjack (and $n - n_s$ are yellowfin). If the fish are selected by grabbing, then n_s is a binomial random variable with probability $p = \frac{N_S}{N}$ of selecting a skipjack.

The estimate of the proportion of skipjack in the set in terms of weight P_s is given by:

$$P_S = \frac{w_s n_s}{w_s n_s + w_y (n - n_S)} \tag{5}$$

where, for simplicity, w_s and w_y are the weights of each and every skipjack and yellowfin respectively.

The expected value of the proportion of skipjack in the set is given by:

$$E[P_S] = \sum_{n_S=0}^{n} \frac{w_s n_s}{w_s n_s + wy_Y (n - n_s)} \cdot f(n_s) \tag{6}$$

where $f(n_S)$ is the binomial probability of obtaining n_s skipjack in a sample of n fish with probability p of selecting an individual skipjack, and is given by:

$$f(n_S) = \frac{n!}{n_s!(n - n_s)!} \cdot p^{n_s} (1 - p)^{n - n_s} \tag{7}$$

When the skipjack and yellowfin are all of the same size, then $w_s = w_y$ and equation (6) reduces to:

$$E[P_S] = \frac{1}{n} \sum_{n_S=0}^{n} n_S \cdot f(n_S) \tag{8}$$

$$= \frac{1}{n} \cdot np \tag{9}$$

$$= p \tag{10}$$

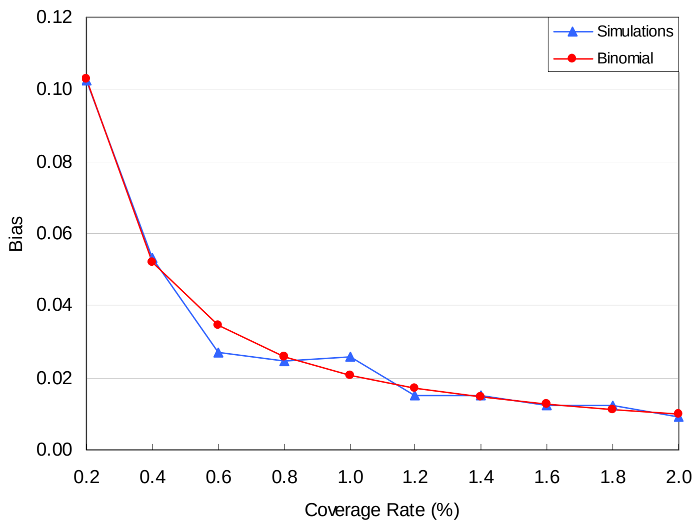
When $w_S \neq w_y$, then equation (10) does not hold and the expected value of the estimate of the proportion of skipjack in the set is other than p. In contrast to equation (6), we derive our intuitive expectation of this proportion by substituting the expected value of n_s, i.e., $E[n_S] = np$, into equation (5):

$$P_S^{True} = \frac{w_S\, p}{w_S\, p + w_Y (1 - p)} \tag{11}$$

However (and this is the counter-intuitive part), while equation (11) represents the true value, it does *not* represent the expected value of the proportion of skipjack estimated from grab samples. This is an example of the general rule that for any function of a random variable — e.g., equation (5) — the expected value of the function — i.e., equation (6) — may not be equal to the function of the expected value of the random variable — i.e., equation (11).

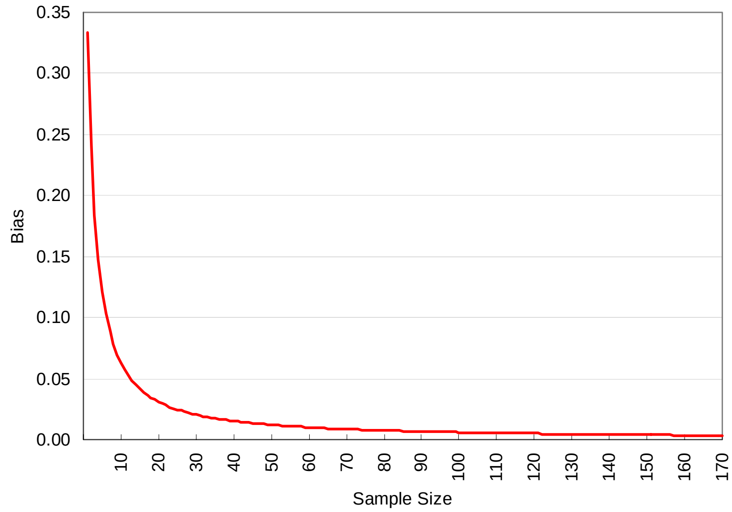
That the expected value is indeed given by equation (6), rather than equation (11), is shown in Figure 14, which compares the bias predicted by equation (6) to the bias resulting from the simulations, in the proportion of skipjack determined from grab samples of a set containing 5 tonnes of 2 kg skipjack and 5 tonnes of 10 kg yellowfin (i.e., “Grab -- 50:50” in Figure 13). The bias predicted by equation (6) matches almost perfectly the bias resulting from the simulations.

Figure 14. Bias of estimates of the proportion of skipjack determined from simulated grab samples and as predicted by the binomial distribution



It is evident from Figures 13 and 14 that the bias strongly depends on the sample size. Figure 15 presents the relation between sample size and the bias predicted by equation (6) for grab samples from the set described in the previous paragraph (i.e., “Grab -- 50:50”). For a sample size of one fish, the bias in the estimate of the proportion of skipjack is 33.3%. The bias declines steeply to 10% at 6 fish, 5% at 12 fish, 2% at 26 fish, then declines less steeply to 1% at 41 fish and 0.5% at 110 fish. In general, this relationship will vary depending on the species composition of the set and the difference in the size distributions among species.

Figure 15. Relationship between sample size and bias of estimates of the proportion of skipjack determined from grab samples



Note that the effect of grab sample bias does not depend on how the estimation of the species composition is formulated. If the species composition of a sample is estimated from counts of the number of fish of each species and their average weights, where F_i is the proportion of species *i* in terms of number of fish and $\overline{w}_i$ is the average weight of species *i*, then the proportion of species i in the sample in terms of weight, P_i, is given by:

$$P_i = \frac{F_i \cdot \overline{w}_i}{\sum_i F_i \cdot \overline{w}_i} \tag{12}$$

It can be shown that equation (12) is equivalent to the following formulation in terms of the weight frequency of the sample:

$$P_i = \frac{\sum_j n_{ij} w_{ij}}{\sum_i \sum_j n_{ij} w_{ij}} \tag{13}$$

where n_{ij} and w_{ij} are the number of fish and the weight of individual fish of species *i* and length *j*. Equation (13) is just a generalised form of equation (5).

Grab sample bias affects the sample and does not depend on how the data from the sample are formulated to estimate the species composition. On the other hand, a sampling programme with separate protocols for (a) the species composition in terms of numbers of fish and (b) the average weights, such as the programme in the Eastern Pacific (Tomlinson 2002), may be affected to a lesser extent by grab sample bias than a sampling protocol based only on the total number of fish selected from the set or well, if the sample size in numbers of fish for each type of sub-sample is appropriate.

Grab sample bias also depends strongly on the distribution of sizes of fish within the set or well. If the sizes are unimodal, then there will be less grab sample bias than if the sizes are multi-modal. Table 15 shows that 48.4% of all observed sets contained both small (< 80 cm) and large (≥ 80 cm) fish, which suggests that grab sample bias will potentially be an important factor in a large percentage of samples.

Table 15. Number of observed sets with small fish (< 80 cm) or large fish (≥ 80 cm) or both small and large fish

Year	Small Fish		Large Fish		Both		Total
	N	%	N	%	N	%	N
1995	14	17.3%	7	8.6%	60	74.1%	81
1996	262	68.8%	12	3.1%	107	28.1%	381
1997	140	41.8%	13	3.9%	182	54.3%	335
1998	386	40.5%	152	15.9%	415	43.5%	953
1999	208	33.6%	25	4.0%	386	62.4%	619
2000	240	31.3%	39	5.1%	487	63.6%	766
2001	391	37.7%	70	6.8%	576	55.5%	1,037
2002	922	45.5%	42	2.1%	1,064	52.5%	2,028
2003	929	42.0%	89	4.0%	1,194	54.0%	2,212
2004	2,000	56.8%	72	2.0%	1,448	41.1%	3,520
2005	1,313	41.2%	151	4.7%	1,720	54.0%	3,184
2006	1,442	60.5%	56	2.3%	886	37.2%	2,384
2007	207	61.1%	23	6.8%	109	32.2%	339
Total	8,454	47.4%	751	4.2%	8,634	48.4%	17,839

12. Effect of Size of Set on Grab Sample Bias

Grab sample bias was further examined by simulating grab and spill sampling of unassociated and associated sets of 25, 75, 125 and 200 tonnes. The species and size compositions of the four sets were the average species and size compositions, raised on the basis of set weight, determined from sampled sets of 0–50, 50–100, 100–150 and >150 tonnes respectively. The species and size compositions determined from both observer data and port sampling data were examined.

The parameters used in the simulations are presented in Table 16. The set weights were slightly less than 25, 75, 125 and 200 tonnes due to rounding to zero of the number of fish for very large lengths, which were more often less than 0.5 fish than greater than 0.5 fish. The coverage rates for the grab samples were determined from observer data and so represent the actual average levels of coverage for sets within the ranges of set weights mentioned in the previous paragraph. Experiments with spill samples (Table 18) indicate that the coverage by spill samples is about three times that of grab samples; the coverage rates for spill samples in the simulations was therefore taken as triple the coverage of grab samples. The coverage rates determined from the observer data were also used for sets for which the species and size compositions were determined from port sampling data, so that the results would be comparable. The true species compositions are similar to those shown in the bottom row of Figure 2, with the proportions of skipjack generally increasing with set weight, particularly for associated schools. The size distributions for each set are presented in Appendix B.

Table 16. Simulation parameters for the effect of size of set on grab sample bias

Species and Size Composition	Set Weight (Tonnes)	School Association	True Species Composition			Sample Type	Coverage Rate	Sample Size	
			Skipjack	Yellowfin	Bigeye			Number of Fish	Kilograms
Observer Data	24.828	Unassociated	66.73%	32.74%	0.53%	Grab	0.0075	47	
						Spill	0.0224		555
	24.649	Associated	49.45%	41.93%	8.62%	Grab	0.0075	67	
						Spill	0.0224		551
	74.556	Unassociated	67.61%	31.71%	0.68%	Grab	0.0047	80	
						Spill	0.0142		1,060
	74.571	Associated	56.12%	34.28%	9.60%	Grab	0.0047	123	
						Spill	0.0142		1,060
	124.977	Unassociated	66.09%	32.15%	1.76%	Grab	0.0037	101	
						Spill	0.0110		1,370
	124.841	Associated	61.63%	28.28%	10.08%	Grab	0.0037	164	
						Spill	0.0110		1,369
	199.823	Unassociated	70.19%	29.14%	0.67%	Grab	0.0027	123	
						Spill	0.0082		1,645
	199.770	Associated	65.20%	25.20%	9.60%	Grab	0.0027	185	
						Spill	0.0082		1,645
Port Sampling Data	24.868	Unassociated	60.17%	37.46%	2.37%	Grab	0.0075	44	
						Spill	0.0224		556
	24.830	Associated	69.11%	24.99%	5.90%	Grab	0.0075	63	
						Spill	0.0224		555
	74.836	Unassociated	67.41%	30.39%	2.20%	Grab	0.0047	96	
						Spill	0.0142		1,064
	74.948	Associated	76.02%	18.82%	5.16%	Grab	0.0047	115	
						Spill	0.0142		1,066
	125.241	Unassociated	67.86%	29.41%	2.73%	Grab	0.0037	119	
						Spill	0.0110		1,373
	125.152	Associated	75.50%	19.40%	5.10%	Grab	0.0037	146	
						Spill	0.0110		1,372
	200.425	Unassociated	62.18%	33.56%	4.27%	Grab	0.0027	152	
						Spill	0.0082		1,650
	199.971	Associated	83.06%	12.95%	3.99%	Grab	0.0027	175	
						Spill	0.0082		1,647

Figures 16 and 17 present the results of the simulations of 2000 replicates for each combination of set weight and school association. The bias is shown as a percentage of the true value of the species composition, rather than the absolute value of the bias (as shown in Figures 13 and 14) as our main interest is not the absolute value of the bias, but the effect of the bias on the estimate of the catch. For example, in the top left plot in Figure 16, the grab sample bias in the proportion of skipjack in the 25 tonne unassociated set is +5.2% of the true proportion of skipjack, which is 66.73% (Table 15).

It can be seen in Figures 16 and 17 that for skipjack and yellowfin, the grab sample bias behaves as suggested by the analysis in the previous section, with the proportion of the species that is smaller and more numerous, i.e., skipjack, being over-estimated and the proportion of the species that is larger and less numerous, i.e., yellowfin, being under-estimated, with the bias generally decreasing with increasing size of set.

The proportion of bigeye in all of the sets is small, particularly for unassociated schools (Table 16), so even a small bias in the absolute value of the proportion of bigeye in the set has a large effect on the bias as expressed as a percentage of the true value. Even with 2000 replicates, the biases estimated for bigeye are unstable for both grab and spill samples; presumably the estimated bias will be more accurate with a greater number of replicates. There is a tendency for the bigeye bias to shift from positive to negative with increasing size of set; this is because the average weight of bigeye tends to increase with size of set, while the relative proportion of bigeye in numbers of fish tends to decrease.

Apart from the unstable results for bigeye, the results for the sets determined from observer data and port sampling data are similar.

The biases in the estimates of skipjack and yellowfin for spill samples are minor and would be expected to decrease further with an increase in the number of replicates used in the simulations.

Figure 16. Effect of size of set on grab sample bias on sets for which the species and size composition was determined from observer data

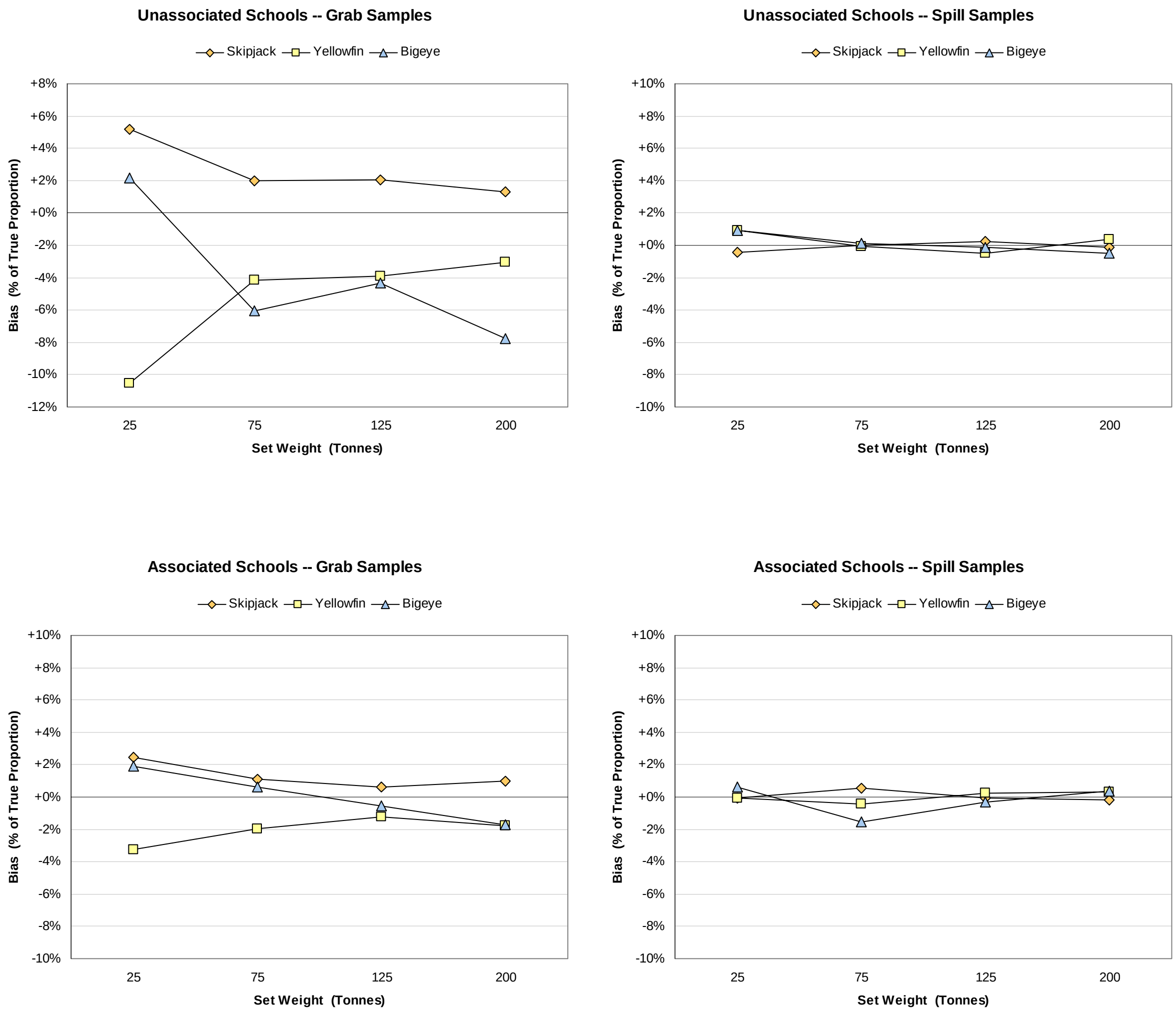
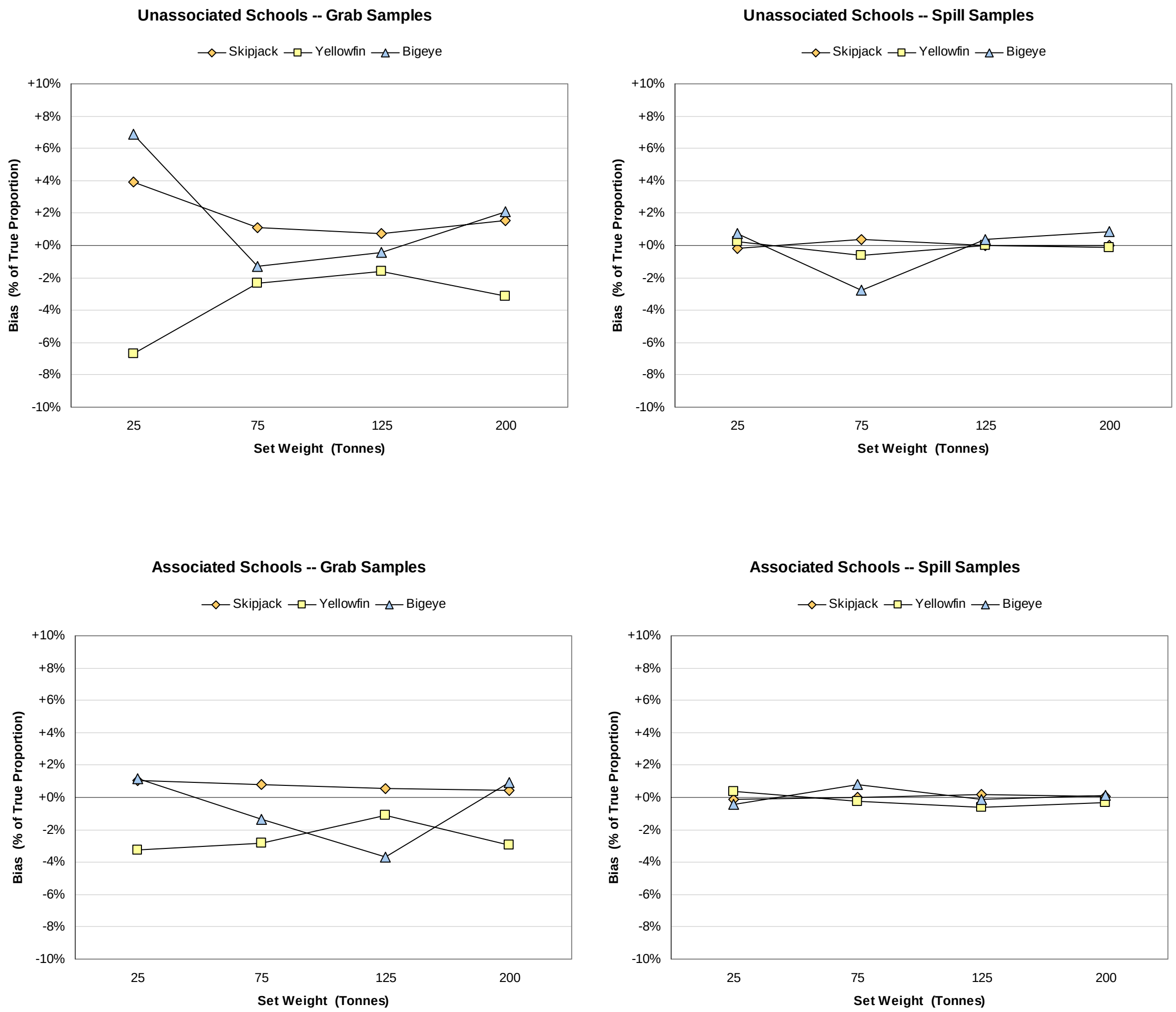


Figure 17. Effect of size of set on grab sample bias on sets for which the species and size composition was determined from port sampling data



13. Correcting for Grab Sample Bias

Species compositions determined from samples collected by observers and non-NMFS port samplers are typically raised by the set weight and aggregated to estimate the species composition for the trip or for a time-area stratum. The grab sample biases shown in the previous section will thus affect the estimated species composition for the trip or time-area stratum unless corrected.

An obvious approach for correcting the bias is to predict an approximate value of the bias with a generalised version of equation (6):

$$E[Px] = \sum_{n_x=0}^{n} \frac{w_x n_x}{w_x n_x + w_{x'}(n-n_x)} \cdot f(n_x) \qquad (14)$$

where w_x and $w_{x'}$ are the average weights of fish of species x and fish not of species x respectively, and where $f(n_x)$ is the probability of obtaining n_x fish of species x in a sample of n fish, and is given by:

$$f(n_x) = \frac{n!}{n_x!(n-n_x)!} \cdot \hat{p}^{n_{sx}} (1-\hat{p})^{n-n_{sx}} \tag{15}$$

where $\hat{p}$ is the estimate $\frac{n_x}{n}$ of the probability of selecting a fish of species x.

Equation (14) only approximates the bias since the probability of selecting a fish of species x is unknown and therefore estimated from the sample, and the size distributions are approximated by the average weights, also estimated from the sample.

The bias predicted by equation (14) was compared to the simulation results presented in the previous section, under the optimum, although unrealistic, conditions in which the true probability of selecting a fish of species x and the true average weights for fish of species x and not of species x are known. The results in Table 17 are not encouraging. While equation (14) predicts a positive bias for skipjack and a negative bias for yellowfin, the same as the simulations, the absolute values of the biases are considerably smaller than those determined from the simulations, particularly for the unassociated schools.

Table 17. Comparison of bias of grab sample bias (bias as a proportion of the true value) determined from simulations and as predicted by the binomial distribution

Species and Size Composition	Set Weight (Tonnes)	School Association	Binomial			Simulations			Difference		
			Skipjack	Yellowfin	Bigeye	Skipjack	Yellowfin	Bigeye	Skipjack	Yellowfin	Bigeye
Observer Data	24.828	Unassociated	1.84%	-3.92%	0.09%	5.15%	-10.54%	2.15%	-3.31%	6.62%	-2.06%
	24.649	Associated	0.70%	-0.82%	-0.54%	2.44%	-3.27%	1.91%	-1.73%	2.45%	-2.45%
	74.556	Unassociated	1.04%	-2.29%	-0.32%	2.00%	-4.13%	-6.05%	-0.96%	1.84%	5.73%
	74.571	Associated	0.39%	-0.58%	-0.48%	1.10%	-1.98%	0.63%	-0.72%	1.41%	-1.11%
	124.977	Unassociated	0.89%	-1.86%	-1.03%	2.03%	-3.93%	-4.32%	-1.13%	2.07%	3.29%
	124.841	Associated	0.26%	-0.48%	-0.45%	0.64%	-1.20%	-0.54%	-0.38%	0.73%	0.10%
	199.823	Unassociated	0.58%	-1.43%	-0.32%	1.33%	-3.03%	-7.77%	-0.75%	1.60%	7.46%
	199.770	Associated	0.23%	-0.49%	-0.45%	0.95%	-1.81%	-1.73%	-0.72%	1.32%	1.28%
Port Sampling Data	24.868	Unassociated	1.16%	-2.40%	1.01%	3.90%	-6.71%	6.88%	-2.74%	4.31%	-5.87%
	24.830	Associated	0.51%	-1.33%	-0.75%	1.07%	-3.22%	1.15%	-0.56%	1.90%	-1.90%
	74.836	Unassociated	0.47%	-1.17%	0.04%	1.10%	-2.35%	-1.27%	-0.63%	1.18%	1.30%
	74.948	Associated	0.29%	-1.12%	-0.59%	0.79%	-2.83%	-1.38%	-0.50%	1.71%	0.79%
	125.241	Unassociated	0.26%	-0.75%	0.23%	0.71%	-1.60%	-0.41%	-0.45%	0.84%	0.65%
	125.152	Associated	0.25%	-0.95%	-0.49%	0.54%	-1.13%	-3.69%	-0.29%	0.18%	3.20%
	200.425	Unassociated	0.30%	-0.72%	0.15%	1.54%	-3.11%	2.08%	-1.24%	2.39%	-1.93%
	199.971	Associated	0.16%	-1.03%	-0.44%	0.41%	-2.93%	0.92%	-0.25%	1.90%	-1.36%
Average		Unassociated	0.82%	-1.82%	-0.02%	2.22%	-4.42%	-1.09%	-1.40%	2.61%	1.07%
		Associated	0.35%	-0.85%	-0.52%	0.99%	-2.30%	-0.34%	-0.64%	1.45%	-0.18%

Approximating the size distributions with average weights renders equation (14) less than useful for correcting for grab sample bias. An alternative may be to conduct a series of simulations similar to those in the previous section such that a much broader range of set weights, and species and size compositions, are covered by estimates of bias. But this would be computationally intensive, to say the least, with results only approximating the actual bias. Even if separate sampling protocols are used for the species composition in terms of number of fish and average weights, both will still be grab samples and subject to grab sample bias, and possibly bias due to sorting or size selection (section 16). A much better solution may be to do away with grab samples altogether.

14. Spill Samples

A potentially useful protocol for obtaining a sample of fish, without the problem of grab sample bias (or size selection bias — see section 16), is to spill all of the fish to be sampled directly from a brail, without any intervention by the observer, into a bin. In this regard, experiments were conducted by the OFP onboard a purse seiner fishing anchored FADs in the waters of Papua New Guinea in

March 2008. For each of the sets during the trip, a portion of every tenth brail was spilt into a bin (Figure 18). The first brail in each set to be sampled was varied among sets in order to reduce potential effects of layering in the set; the extent of layering of fish by species or size in purse-seine sets and wells is examined in section 15.

Figure 18. Sampling tuna onboard a purse seiner after spilling fish from the brail into a bin

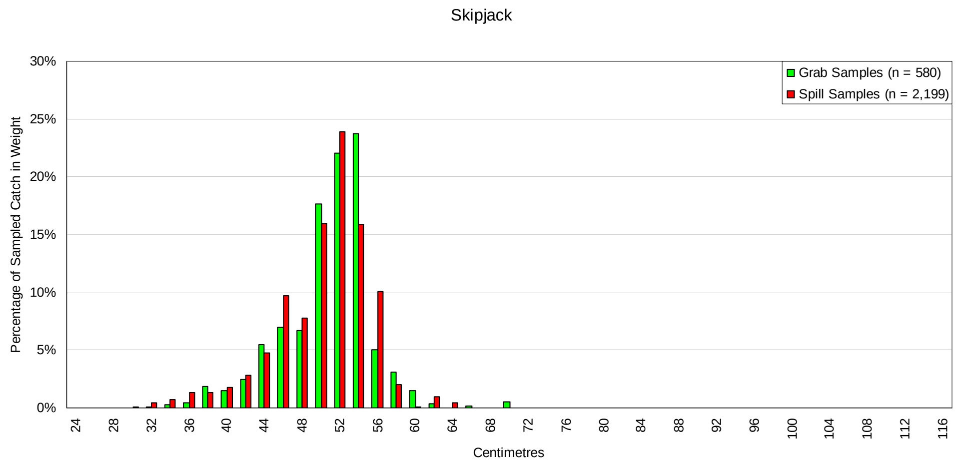
Table 18 presents the number and weight of fish sampled in each spill and grab sample during the experiment. On average, the coverage rates in terms of weight for spill samples were 3.23 times the coverage rates for grab samples. Excluding the set sampled on March 22, for which grab samples were taken from every second brail, rather than every brail, the coverage rate for spill samples was 2.94 times that for grab samples.

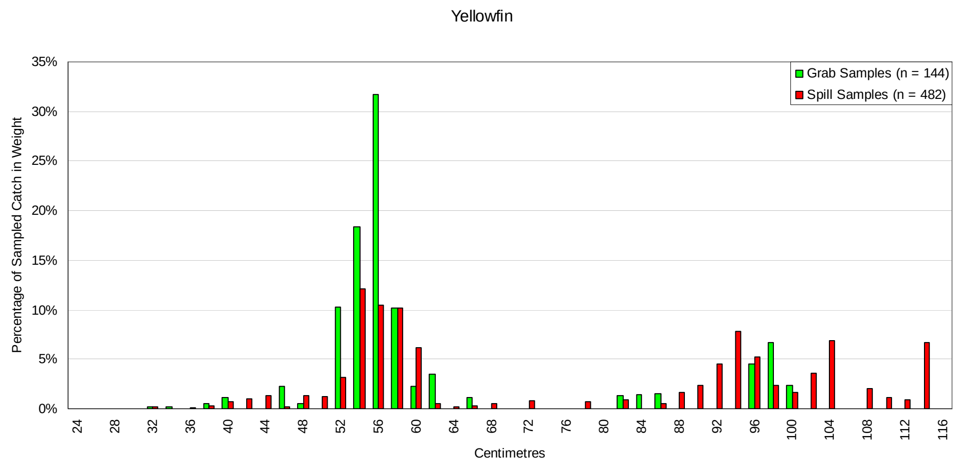
Table 18. Set weight (tonnes) and number and weight (tonnes) of fish sampled during spill sample experiments

Set Date	Set Weight	Spill Samples			Grab Samples			Spill : Grab
		N	Weight	%	N	Weight	%	
15-Mar-08	124.0	814	2.228	1.80%	225	0.616	0.50%	3.61
17-Mar-08	44.6	419	1.038	2.33%	95	0.252	0.57%	4.12
18-Mar-08	157.0	414	1.042	0.66%	240	0.570	0.36%	1.83
22-Mar-08	26.0	321	0.637	2.45%	20	0.035	0.13%	18.33
23-Mar-08	32.0	369	0.556	1.74%	55	0.097	0.30%	5.74
25-Mar-08	36.3	354	0.650	1.79%	62	0.141	0.39%	4.60
26-Mar-08	57.5	170	0.470	0.82%				
27-Mar-08	32.0	84	0.654	2.04%	60	0.257	0.80%	2.54
Average	63.7	368	0.910	1.43%	108	0.281	0.44%	3.23

Figure 19 compares the size distributions for the seven sets for which both grab and spill samples are available. Each sample was raised by the set weight; the set weights ranged from 26 tonnes to 157 tonnes. The size distributions for skipjack determined from the two types of samples are similar, while those for yellowfin and bigeye are somewhat different, but the numbers of yellowfin and bigeye in the samples are relatively small and the differences may largely be due to chance.

Figure 19. Size distributions for a trip by the *Dolores 828* fishing anchored FADs in Papua New Guinea during March 2008, determined from grab and spill samples





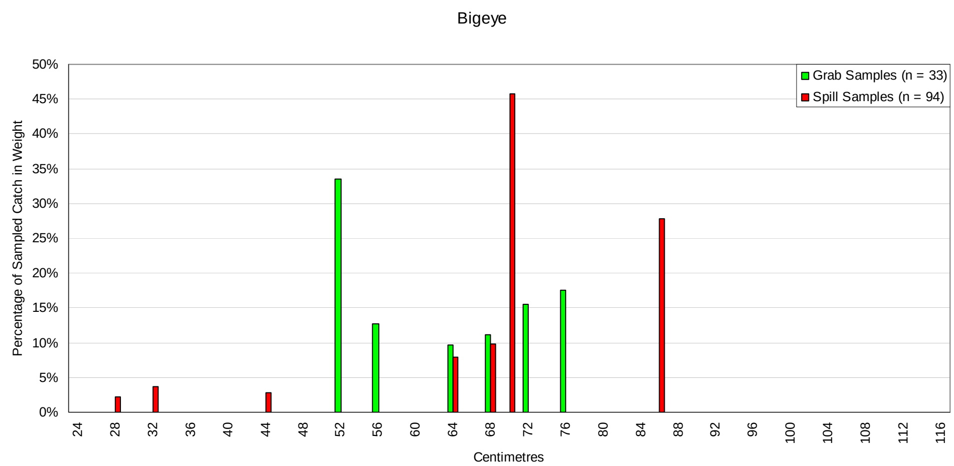
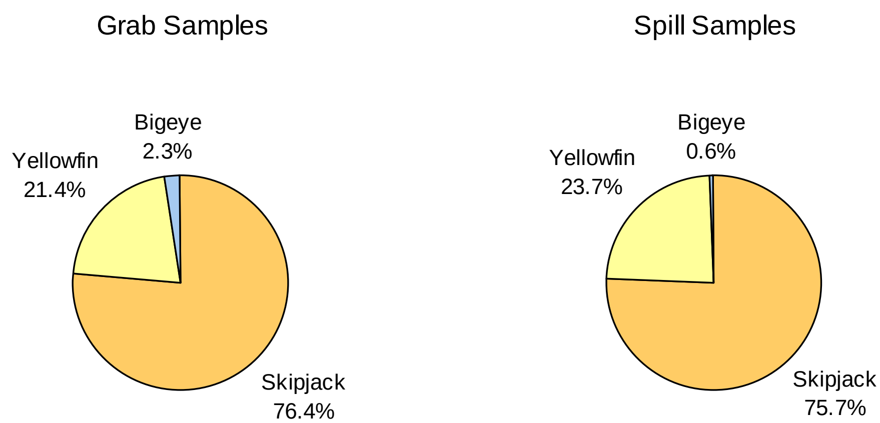


Figure 20 presents the species composition for the seven sets for which both grab and spill samples are available. The species compositions are similar, although there is more skipjack and bigeye, and less yellowfin, in the grab samples than in the spill samples, which is consistent with grab sample bias (but not size selection bias). However, the number of sets sampled is small and these results may be due to chance.

Figure 20. Species composition for a trip by the *Dolores 828* fishing anchored FADs in Papua New Guinea during March 2008 determined from grab and spill samples



With only seven sets to compare, it is not possible to draw any general conclusions regarding consistent differences between species compositions determined from grab samples and spill samples, which, if they exist, would be indications of bias. Nevertheless, the spill sample experiment is encouraging since it showed that spill samples were feasible.

15. Layering of Fish in the Set or Well by Species and Size

The non-random distribution of fish in a set among brails, possibly caused by layering of fish in the set by species and/or by size, was examined by considering the sequential order of fish sampled by observers. Under the current sampling protocol, observers select five fish from each brail, so the sequential order of the species and sizes of fish in the sample should be indicative of layering in the set, if it occurs.

Observers are instructed to record the five fish in sequential order on the PS–4 data collection form (DCC 2004). However, the form has six columns in which the species and length of 25 fish can be recorded, and rather than recording the fish in sequential order, observers sometimes record the data in columns according to species, e.g., all skipjack in column #1, all yellowfin in column #2, etc. Also, sometimes the observer may not have time to measure the fish between brails and so will put the selected fish to one side; when the observer finally measures the fish, they may be sorted by species first and so the data recorded on the form will not represent the sequential order of the fish as they were selected.

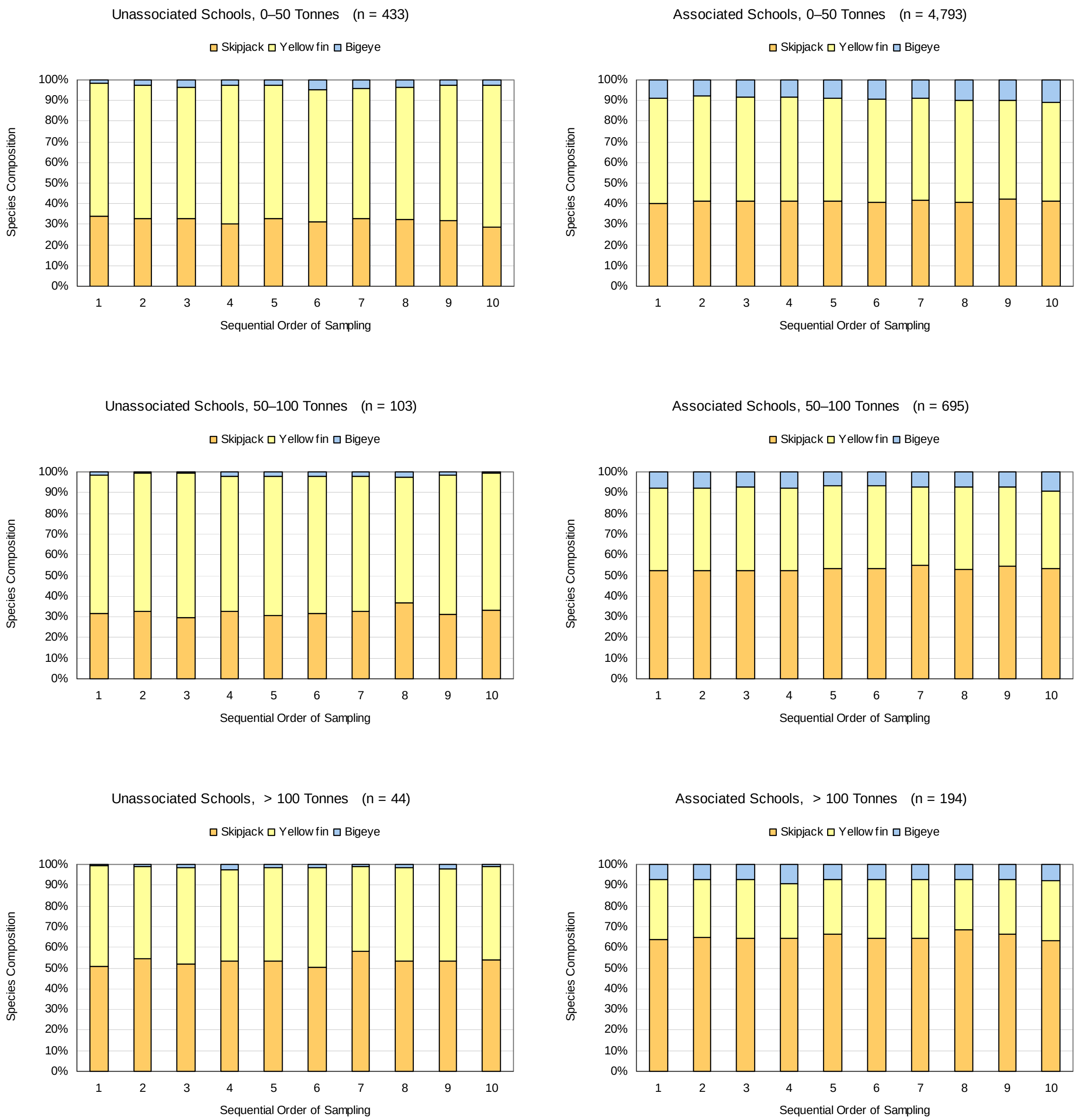
To identify sets for which the data were not recorded in sequential order, runs tests were conducted. A run is defined to be a maximal subsequence of like events; for example, the sequence SKJ, SKJ,

SKJ, YFT, YFT, SKJ contains three runs, including maximal subsequences of three skipjack, two yellowfin and one skipjack. If observers record data by listing them in columns by species or after sorting them by species, then there will be a much smaller number of runs in the data than expected.

The runs tests were conducted on sampled sets containing skipjack and yellowfin and/or bigeye that were screened to eliminate sets that, based on the size of the set and the number of fish sampled, were probably not sampled throughout the entire brailing process. The runs tests were conducted by (a) generating a probability distribution of the number of runs for the sample by simulating 1000 replicates of sampling, given the numbers of skipjack, yellowfin and bigeye in the sample, and (b) determining the cumulative probability of the number of runs in the actual data recorded by the observer from the generated probability distribution. Samples with a cumulative probability of less than 5%, i.e., a much smaller number of runs than expected, were excluded from the analysis. Out of 11,005 samples with skipjack and yellowfin and/or bigeye, 4,743 or 43.1% failed the runs test, leaving 6,262 samples for analysis. Species other than skipjack, yellowfin and bigeye were not considered in the runs tests since data for non-target species are usually recorded after the sampling of tuna.

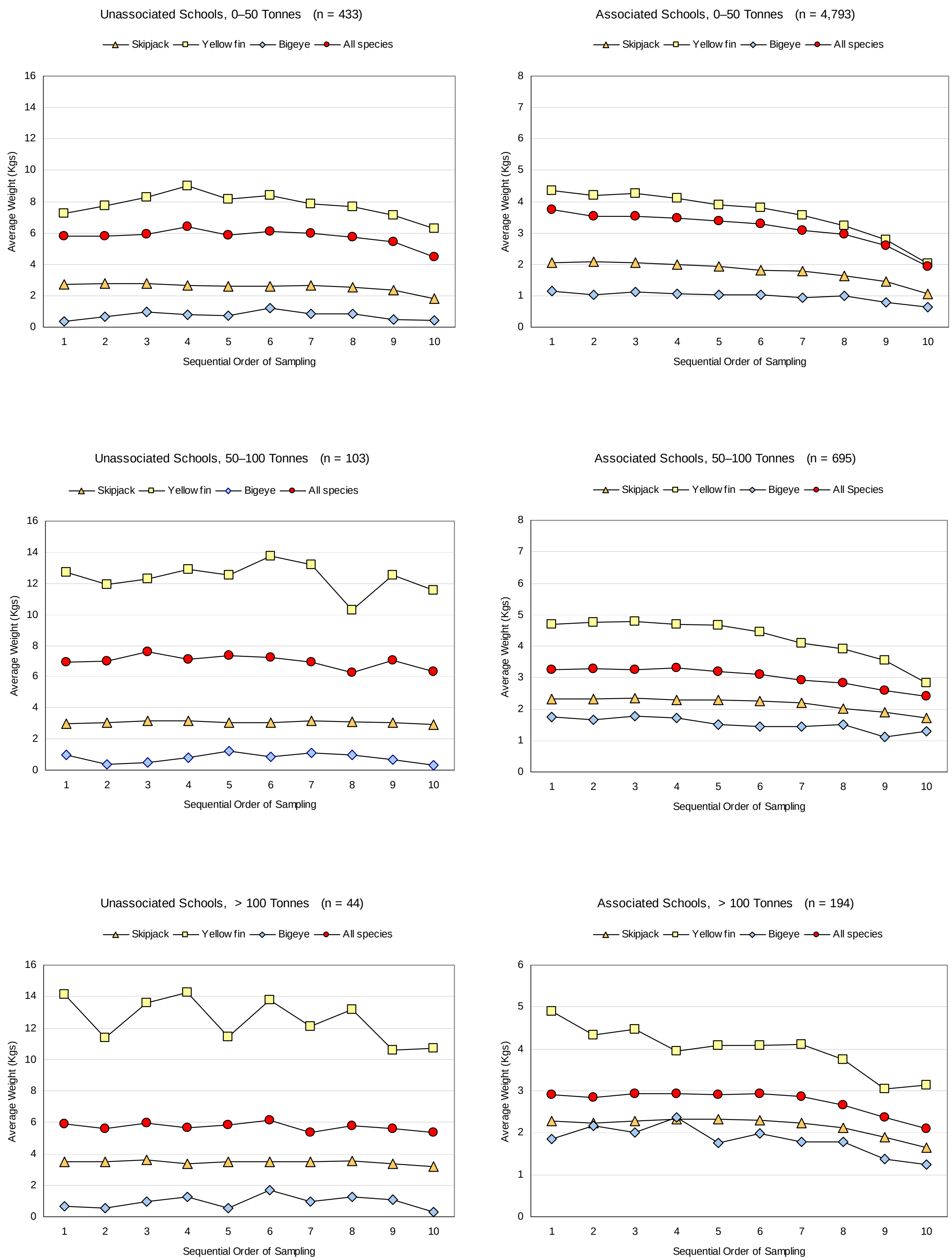
Figure 21 presents average species compositions (in weight) for sets with skipjack and yellowfin and/or bigeye (so they are not representative of the entire fishery) by ten 10% increments of the sequential order of sampling, for unassociated and associated schools, and set weights of 0–10 tonnes, 50–100 tonnes and greater than 100 tonnes. In each case, the species compositions are relatively constant across the ten increments and suggest that, *on average*, layering, if it occurs, does not affect the species composition.

Figure 21. Average species composition (%) by sequential order of sampling by observers



While Figure 21 suggests that the species composition is constant throughout the sampling of a set, on average, the size composition may still vary. Figure 22 presents average weights (kilograms) of skipjack, yellowfin, bigeye and all three species combined by ten 10% increments of the sequential order of sampling, for unassociated and associated schools, and set weights of 0–10 tonnes, 50–100 tonnes and greater than 100 tonnes. The plots indicate that the average size of fish decreases towards the end of sampling, particularly for associated schools and small unassociated schools. While layering by size of fish does not appear to affect estimates of the species composition, it will definitely affect estimates of the size composition, unless sampling is conducted, on average, throughout the brailing process.

Figure 22. Average weight of fish (kilograms) by sequential order of sampling by observers



A similar analysis was conducted with non-NMFS port sampling data. Out of 601 samples with skipjack and yellowfin and/or bigeye, 320 or 53.2% failed the runs test, leaving 281 samples for analysis. Figure 23 presents average species compositions (in weight) for wells with skipjack and yellowfin and/or bigeye by ten 10% increments of the sequential order of sampling, for unassociated and associated schools, and set weights of 0–10 tonnes, 50–100 tonnes and greater than 100 tonnes. The numbers of samples are much smaller than for the observer data, and the results cannot be considered definitive; however, there does not appear to be a consistent pattern of layering in regard to the species composition.

Figure 23. Average species composition (%) by sequential order of sampling by port samplers

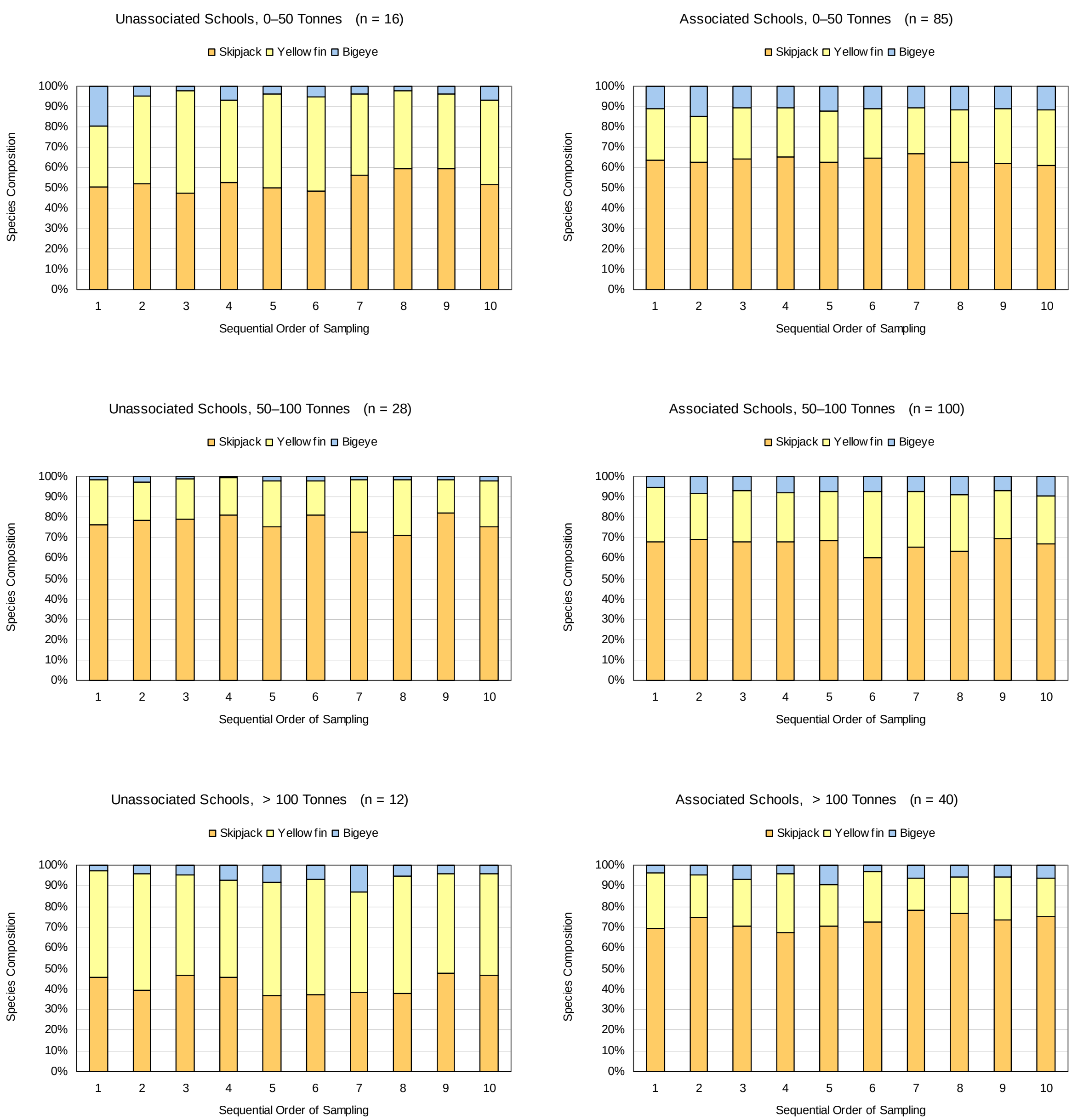
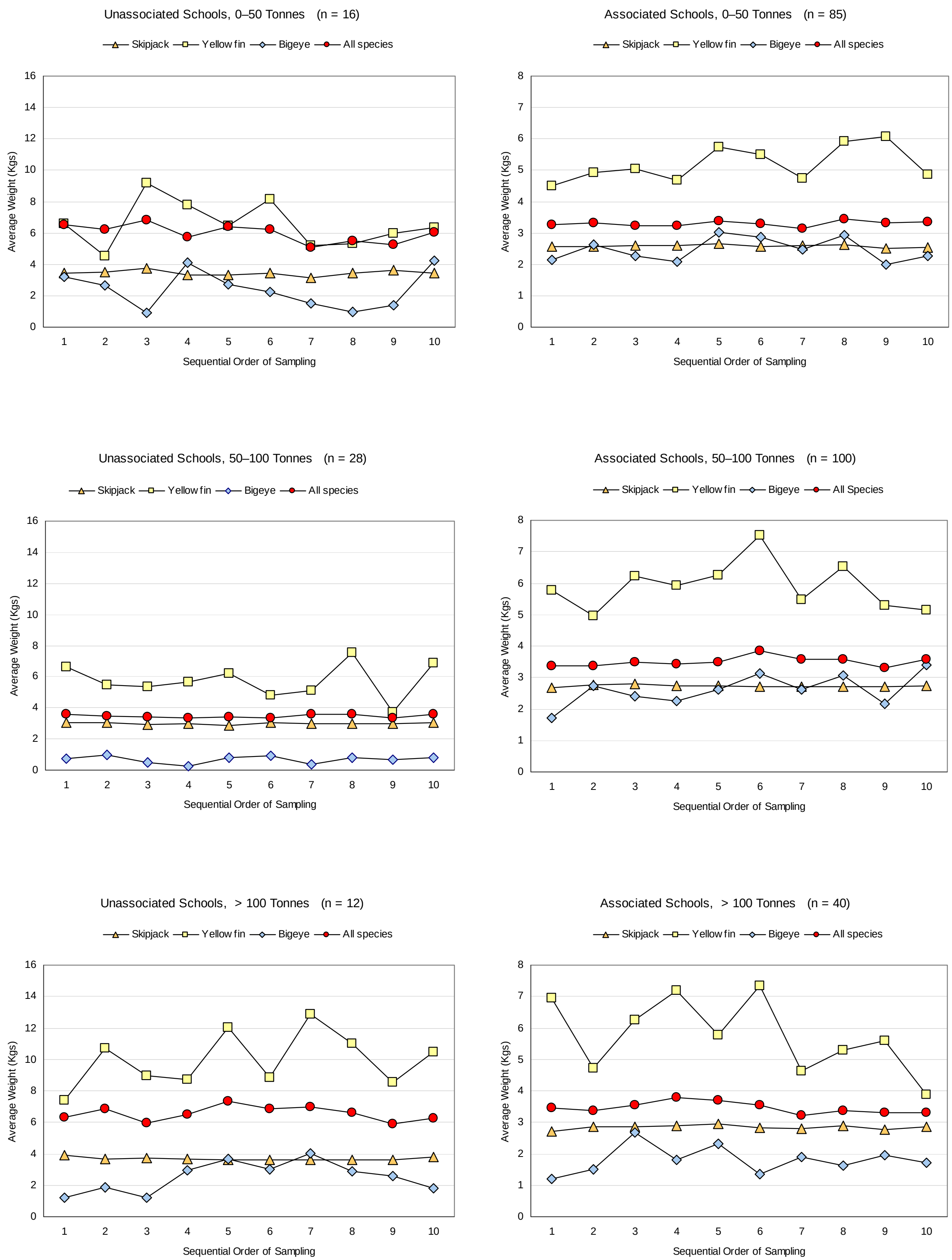


Figure 24 presents average weights (kilograms) of skipjack, yellowfin, bigeye and all three species combined by ten 10% increments of the sequential order of sampling, for unassociated and associated schools, and set weights of 0–10 tonnes, 50–100 tonnes and greater than 100 tonnes. The lines for yellowfin and bigeye are jagged as a result of the small numbers of port samples, but the lines for skipjack and all species combined are relatively smooth and suggest that, in contrast to the observer data, there is no consistent layering of sizes of fish, on average, during the unloading of wells.

Figure 24. Average weight of fish (kilograms) by sequential order of sampling by port samplers



Wild (1994) found trends of sizes of fish during the unloading of six test wells, with cyclic changes in the mean sizes and standard deviations. The cycles occurred when unloaders were observed to select fish by size, but also when size selection was not observed. Pianet et al. (2000) observed changes in the species composition and mean sizes of fish during unloading when examining data from "super-sampling" purse-seine wells. They considered that the sorting of the fish during unloading may have been the cause of the changes in the species composition and that the changes in sizes may be due to smaller fish slipping down the well during unloading. The results from these two studies indicate that trends in the species composition and sizes of fish during unloading do indeed occur, whether due to layering in the well or to selection during the unloading process. Nevertheless, they are based on only a small number of sampled wells and reflect what occurs in individual samples. In contrast, the results presented in Figures 23 and 24, which are based on samples from 281 wells, suggest that, *on average*, there is no consistent pattern of layering. This implies that port sampling data will not be biased because sampling did not occur throughout the entire unloading process. While there may have been layering in individual wells, the effects of the layering appear to cancel out when data from individual samples are combined to estimate the species composition or size frequency of a particular stratum.

It is possible that the lack of consistent patterns of layering in Figures 23 and 24 is due to well mixing; however, the extent of well mixing to which the sampled wells were subject is unknown and so this cannot be examined.

The analyses of layering were also conducted with a cumulative probability for failing the runs tests of 2.5% or less, with only minor quantitative changes and no qualitative changes in the results.

16. Size Selection Bias

In addition to the problem of grab sample bias discussed in sections 11 and 12, another problem with grab samples may be size selection bias. In this regard, Lawson & Williams (2005) compared the species composition determined from observer data to those determined from other types of data, including (i) logsheet catch and effort data, (ii) unloadings data, (iii) port sampling data and (iv) for the United States fleet, cannery receipts known as Final Out-Turn (FOT) reports. While the species compositions determined from the other types of data were all similar, the species composition determined from observer data indicated greater amounts of yellowfin and bigeye, particularly for associated schools (see the bottom row of Figure 2). They found that the difference was due primarily to greater amounts of large (> 80 cm) yellowfin and, to a lesser extent, large bigeye, in the observer data, compared to the port sampling data.

The current sampling protocol for observers is to randomly select five fish from each brail during the transfer of fish from the set to the vessel. A possible explanation for the difference is that observers have a size selection bias, such that large fish are selected in a non-random manner. To determine the level of bias in observer sampling that would be required to explain the discrepancy, Lawson & Williams (2005) simulated observer sampling of a set on an unassociated school and a set on an associated school. For random sampling, the probability of selecting a fish is $\frac{1}{N}$, where N is the number of fish in the set. In the simulations, the probability of selecting a large (> 80 cm) yellowfin or bigeye was varied from $\frac{1}{N}$ to $\frac{4}{N}$, while the probability of sampling all other fish was normalised, such that the sum of the probabilities for all fish in the set was equal to 1.0. The maximum probability of sampling large yellowfin and bigeye, i.e. $\frac{4}{N}$, is thus four times the random probability. For each level of probability, sampling of 1000 sets was simulated and the average percentage of the weight of skipjack in each sample was calculated.

For the unassociated set, the estimate of the proportion of skipjack in the catch declined from 85% for random sampling to 62% for the maximum size selection bias. The proportion of skipjack that was determined from actual observer data for unassociated sets, i.e. 71%, corresponded to a bias of 2.6 times the random probability. For the associated set, the estimate of the proportion of skipjack in the catch declined from 65% for random sampling to 41% for the maximum bias. The proportion of skipjack that was determined from actual observer data for associated sets, i.e. 48%, corresponded to a bias of 3.0 times the random probability.

While the level of size-selection bias required to explain the discrepancy was quite high, 3.0 and 2.6 times the random probability for associated and unassociated sets respectively, the difference in the absolute number of fish selected under random and biased sampling from an average-sized set was moderate for associated sets and small for unassociated sets. For the associated set, the average number of large yellowfin and bigeye in the 1000 simulated samples was 2.0 fish for random sampling and 5.7 fish for bias of 3.0 times the random probability. For the unassociated set, the average numbers of large yellowfin and bigeye was 1.0 fish for random sampling and 2.4 fish for bias of 2.6 times the random probability.

It cannot be definitively concluded that the discrepancy in the species compositions determined from observer data and other types of data is the result of observer size selection bias; however, the simulation study suggests that the levels of bias required to explain the discrepancy are not unreasonable. The extent of the bias is probably over-estimated since factors resulting in a high proportion of skipjack in the port sampling data — such as the lack of representativeness of set weights, the fact that port sampling data tend to cover the eastern part of the region, and that there may be serious problems with the selection of wells — were not taken into account. In any case, it would be preferable if observers could obtain samples of fish without selecting the individual fish themselves, and this is further justification for the use of spill samples rather than grab samples.

17. Effects of Grab Sample Bias and Size Selection Bias on Estimates of the Proportion of Bigeye in 'Yellowfin Plus Bigeye'

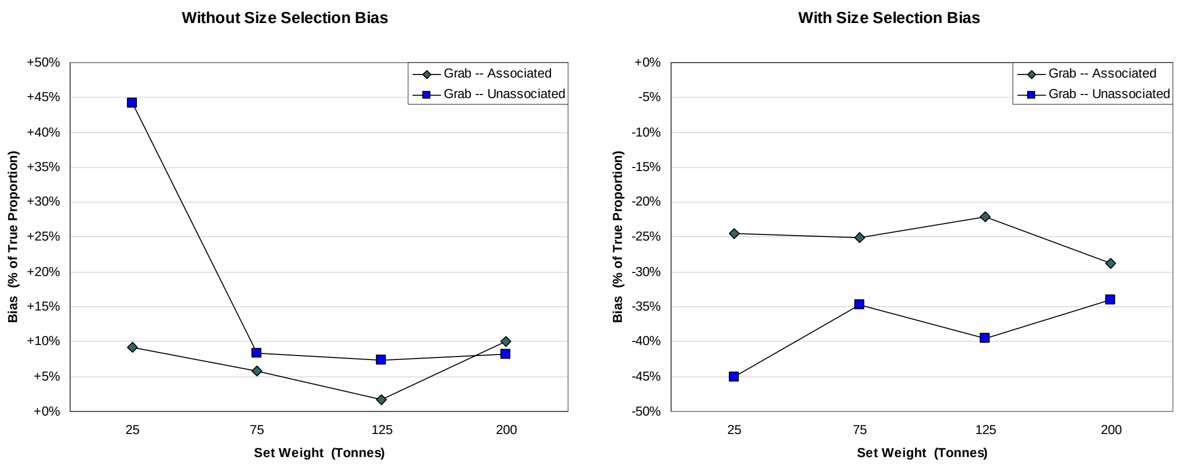
Due to possible size selection bias, observer data have not been used to estimate the complete species composition of skipjack, yellowfin and bigeye. However, due in part to the relatively small number of non-NMFS port samples available — 1,222 for 1993–2007, or 81 wells sampled per annum on average, for all school associations combined — observer data have been used to estimate the proportion of bigeye in the combined catch of yellowfin plus bigeye. Bigeye are often combined with yellowfin in catches reported on logsheets and unloadings data, and so the proportions of yellowfin and bigeye in 'yellowfin plus bigeye' must be estimated. Small bigeye can also be combined with skipjack, and this is considered in the section 18.

Bias in the estimates of the proportion of bigeye in 'yellowfin plus bigeye' were also examined in the simulations of grab sampling conducted with the parameters given in Table 15. The results for the sets for which the species and size compositions were determined from port sampling data are shown in Figure 25, for both grab sampling without and with size selection bias. The results for the sets for which the species and size compositions were determined from observer data are similar.

In the absence of size selection bias, the proportion of bigeye in ‘yellowfin plus bigeye’ is over-estimated. For associated sets, the bias is less than about 10%, while for unassociated sets, there is a large positive bias for the 25 tonne set, which then declines from 14% to 3% for larger sets.

Size selection bias was modelled by increasing the probability of selecting a large (> 80 cm) yellowfin or bigeye by 2.6 and 3.0 times the random probability for unassociated and associated sets respectively, which are the values of size selection bias that might explain the difference between the species and size distributions determined from observer data and port sampling data (Lawson & Williams 2005). In the presence of size selection bias, the proportion of bigeye in ‘yellowfin plus bigeye’ is under-estimated.

Figure 25. Bias of estimates of the proportion of bigeye in ‘yellowfin plus bigeye’ determined from simulated grab samples



The results presented in Figure 25 can be explained with reference to the size distributions of the sets. Figure B2 (Appendix B) presents the size distributions determined from port sampling data for unassociated and associated sets of 0–50, 50–100, 100–150 and greater than 150 tonnes. There are more small, and fewer large, bigeye than yellowfin in small unassociated sets, so the grab sample bias, which over-estimates the proportion of the small bigeye and under-estimates the proportion of the large yellowfin, results in a large positive bias of the proportion of bigeye in ‘yellowfin plus bigeye’ in the absence of size selection bias. The size distributions of bigeye and yellowfin in small associated sets and larger unassociated and associated sets are more similar and so the bias is less pronounced.

In the presence of size selection bias, fish over 80 cm have a higher than random probability of being selected. Since there are more yellowfin greater than 80 cm than bigeye in each of the sets, the bias in the proportion of bigeye in ‘yellowfin plus bigeye’ is negative and more than offsets the grab sample bias.

These results suggests that the current OFP practise of correcting catch data for the proportion of bigeye in ‘yellowfin plus bigeye’ is less than satisfactory.

18. Size-Separate Analyses of Species Composition Data

While estimates of the proportion of bigeye in ‘yellowfin plus bigeye’ determined from observer data have been used by the OFP to correct aggregated catch data, no correction is made for the mis-identification of small bigeye as skipjack in catches reported on logsheets. Figures B1 and B2 (Appendix B) show that there is considerable overlap in the distribution of bigeye and skipjack for fish less than 80 cm, and so the mis-identification of small bigeye as skipjack is certain to occur.

However, it would not be appropriate to extend the current methodology and estimate both (a) the proportion of small bigeye in ‘skipjack plus small bigeye’ and (b) the proportion of bigeye in ‘yellowfin plus bigeye’ using the same observer data, since the proportion of bigeye would then be double-counted when correcting both ‘skipjack plus small bigeye’ and ‘yellowfin plus bigeye’.

Recognising that both the effects of grab sample bias and size selection bias are directly related to the size distributions in a given set suggests that an alternative approach would be to determine the species composition for small and large fish separately. If species composition data covering fish less than 80 cm are analysed separately from fish larger than 80 cm, then the grab sample bias, which over-estimates the proportion of small fish at the expense of large fish, should have less of an effect. Equally, size selection bias for fish greater than 80 cm, if it occurs, should have less of an effect when data for small and large fish are analysed separately. A size-separate approach to the analysis of species composition data has also been taken by NMFS (Appendix A) and to a certain extent in the Atlantic and Indian Oceans (Pianet et al. 2000).

In this regard, the data generated in the simulated sampling of the sets described by the parameters determined from port sampling data in Table 16 were analysed separately for small and large fish. Table 19 presents the species composition of the simulated sets broken down by categories of small and large fish. Figure 26 presents the results of the simulations.

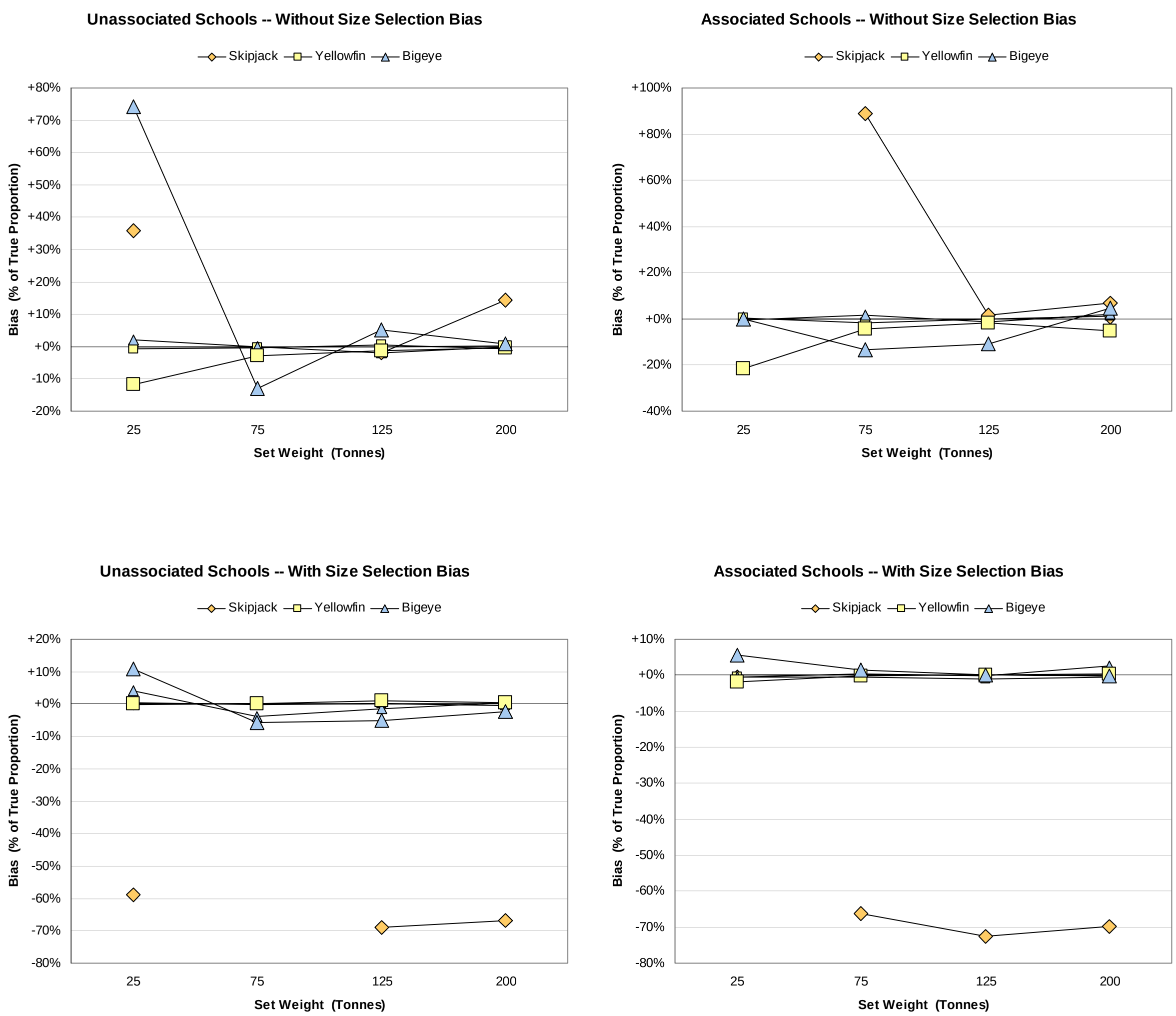
Table 19. Species composition of simulated sets by categories of small and large fish

Set Weight (Tonnes)	School Association	Fish < 80 cm			Fish >= 80 cm		
		Skipjack	Yellowfin	Bigeye	Skipjack	Yellowfin	Bigeye
24.868	Unassociated	59.80%	8.69%	2.31%	0.05%	29.11%	0.05%
24.830	Associated	67.97%	11.57%	4.71%	0.00%	14.53%	1.22%
74.836	Unassociated	67.27%	9.27%	1.69%	0.00%	21.26%	0.51%
74.948	Associated	74.99%	6.11%	3.59%	0.04%	13.63%	1.65%
125.241	Unassociated	68.10%	10.03%	2.38%	0.29%	18.84%	0.36%
125.152	Associated	74.92%	6.48%	3.30%	0.03%	13.42%	1.85%
200.425	Unassociated	63.20%	8.81%	3.26%	0.08%	23.64%	1.01%
199.971	Associated	82.07%	3.34%	2.79%	0.05%	10.47%	1.27%

In the absence of size selection bias (top row of Figure 26), the grab sample bias for small fish (small markers) is considerably reduced compared to the bias for small and large skipjack and yellowfin combined (Figure 17). However, for large fish (large markers), the grab sample bias is much greater than for small and large yellowfin combined. This suggests that even though large skipjack represent only 0.00% to 0.29% and large bigeye represent only 0.05% to 1.85% of sets (Table 17), the differences in their sizes compared to large yellowfin (see Appendix B) is such that even their relatively small numbers result in considerable grab sample bias.

In the presence of size selection bias (bottom row of Figure 26), the large negative biases in the proportion of large yellowfin are absent, since the selection bias for large yellowfin offsets the grab sample bias. Instead, we see large negative biases for large skipjack.

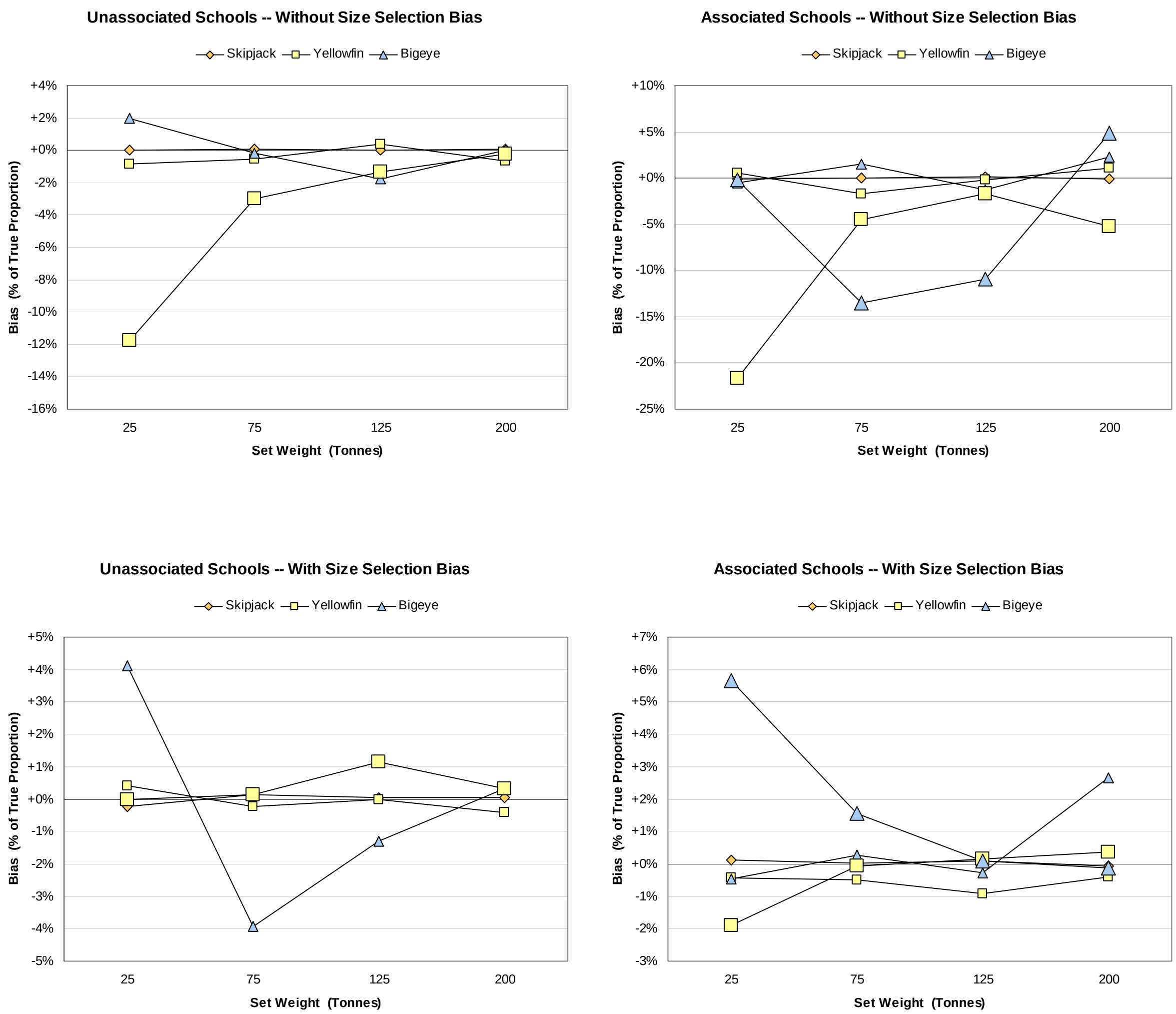
Figure 26. Bias of estimates of the species composition of small (< 80 cm, small markers) and large (≥ 80 cm, large markers) fish determined from simulated grab samples, in the absence and presence of size selection bias



The results shown in Figure 26 are somewhat misleading because of the very small proportion of large skipjack in all sets and the very small proportion of large bigeye in unassociated sets; even negligible biases in the absolute values of the proportions of large skipjack and large bigeye will have a large impact in the bias when it is expressed as a percentage of the absolute value. Figure 27 presents the same results as Figure 26, except that large skipjack in all sets and large bigeye in unassociated sets, which represent 1% or less of the set weight in each case (Table 19), have been ignored.

Without size selection bias, there are large negative biases for large yellowfin in unassociated schools, and for large yellowfin and large bigeye in associated schools, due to grab sample bias. With size selection bias, the biases for skipjack and yellowfin are relatively small, since the size selection bias offsets the grab sample bias. The biases for bigeye are somewhat unstable, but appear to depend on the set weight.

Figure 27. Bias of estimates of the species composition of small (< 80 cm, small markers) and large (≥ 80 cm, large markers) fish determined from simulated grab samples, in the absence and presence of size selection bias, ignoring large skipjack in all sets and large bigeye in unassociated sets



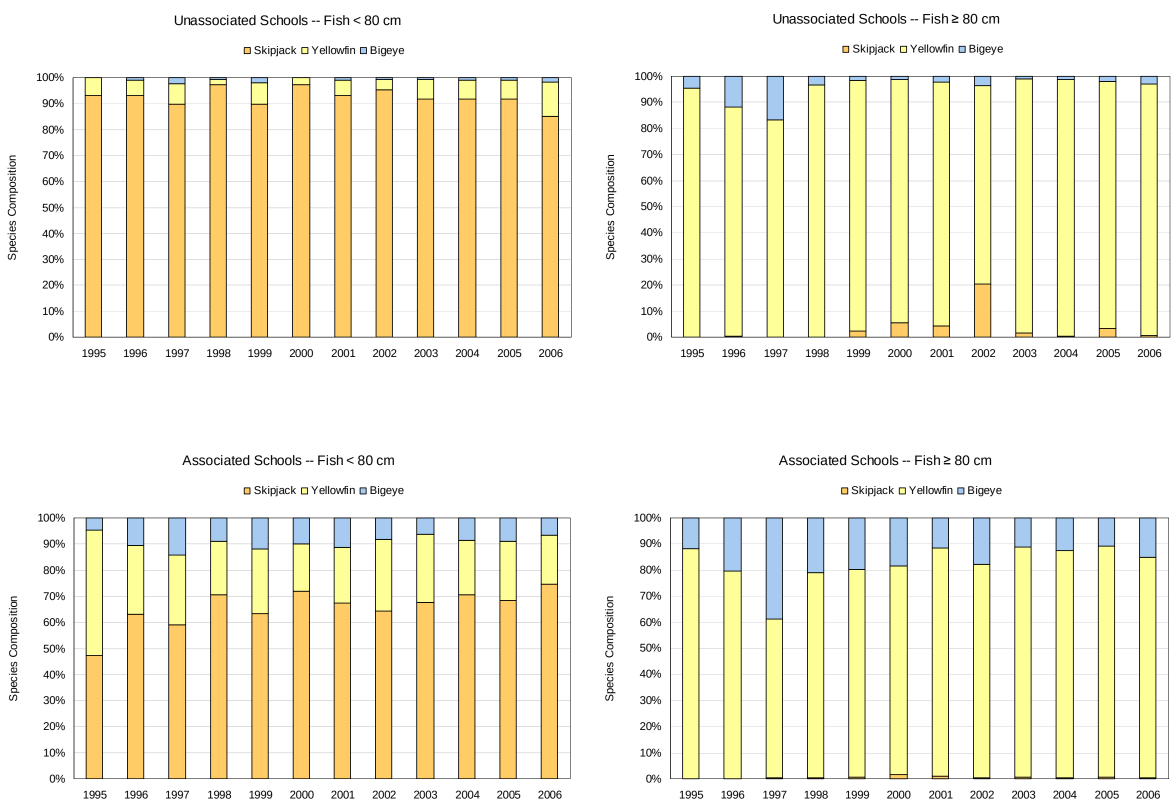
In general, in the presence of size selection bias, determining the species compositions for small and large fish separately (bottom row of Figure 27) would appear to be much more accurate than the species composition determined for small and large fish combined (Figure 17). This result is not dependent on the source of data used to determine the true species and size distribution; the results obtained from simulations conducted on sets for which the parameters were based on observer data (Table 16) exhibited even smaller bias for the size-separate analyses.

19. Application of Size-Separate Analyses of Species Composition Data

Size-separate analyses of species composition data were conducted to estimate annual catches of purse seiners in the WCPFC Statistical Area (excluding the domestic fleets of Indonesia and the Philippines, and the Japanese fleet north of 20°N). Stratifying the data by area would certainly be justified based on the results of section 8, but this was not done for the sake of simplicity; the results are presented only as an example of the methodology and application of the method to higher resolutions of time-area will be the subject of future work.

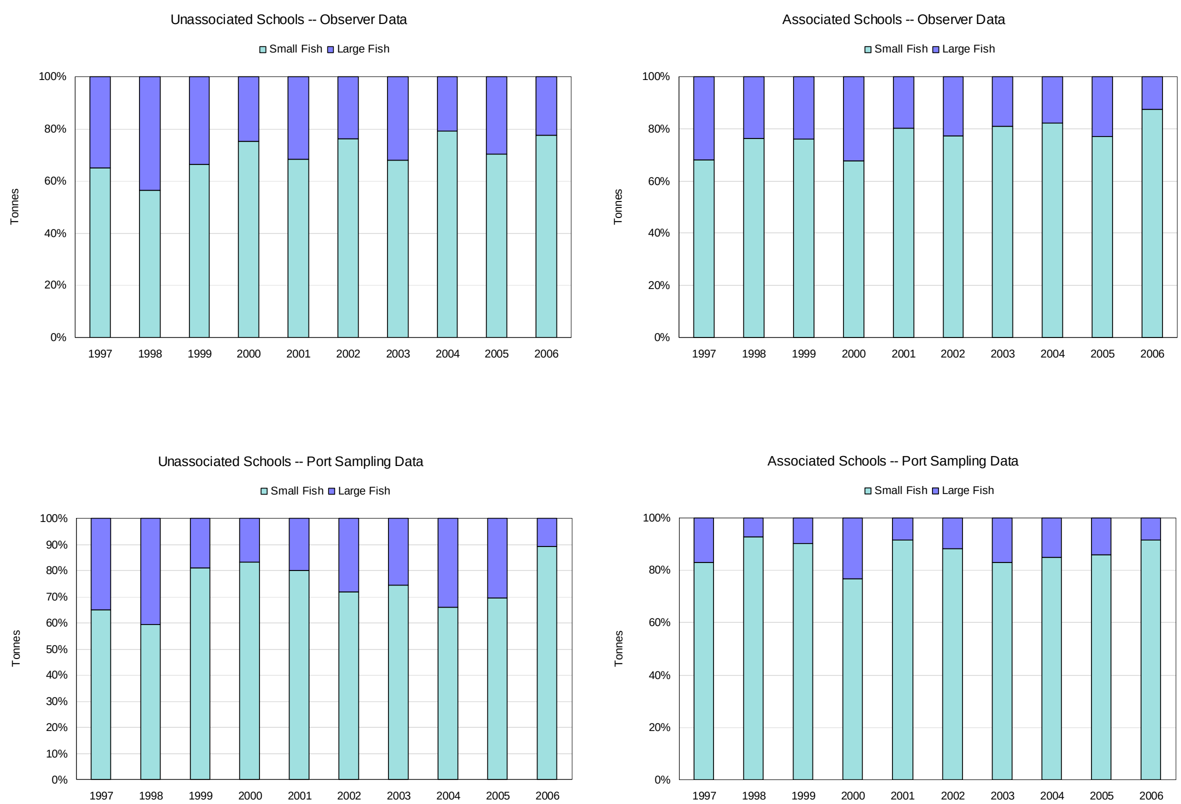
The estimation of annual catches using the size-separate analyses consists of two procedures: the estimation of the annual species composition for small and large fish, which is straightforward, and the estimation of the proportions of the total annual catches that are small and large fish, which is less so. Figure 28 presents the species composition for small and large fish determined from observer data for 1995–2006. The figure illustrates the points noted in the previous section, i.e., the small proportion of large skipjack in unassociated and associated sets, and the small proportion of bigeye in unassociated sets.

Figure 28. Annual purse-seine species composition for small and large fish, determined from observer data



If purse-seine catches in the Western and Central Pacific were reported on logsheets for small and large fish separately, as done in the Eastern Pacific, then determining the proportions of small and large fish in annual catches would be relatively straightforward. In the absence of such data, however, either observer data or port sampling data must be used. But there are two problems. For observer data, if size selection bias has indeed occurred, then the proportion of small fish will be under-estimated and the proportion of large fish over-estimated. For port sampling data, the port samples are not representative of the distribution of set weight (Figure 5), covering fewer small sets and more large sets relative to the proportions of small and large sets in the catch. Large sets, particularly on associated schools, contain more skipjack (Figure 4), and so the proportion of small fish estimated from port sampling data should be over-estimated and proportion of large fish under-estimated. As expected, Figure 29 shows that the proportion of small fish estimated from observer data, 77.0% for all years and school types combined, is smaller than the proportion estimated from port sampling data (including both NMFS and non-NMFS data), 82.4%. Only the years 1997–2006 have been shown in Figure 29 because of the small number of port samples for 1995 and 1996.

Figure 29. Proportion of small and large fish in the purse-seine catch, determined from observer data and port sampling data



Nevertheless, the proportions of small and large fish determined from port sampling data were used in the size-separate analyses of the species composition data. Figure 30 presents the results of the size-separate analyses using species composition data collected by observers (middle histogram) and port samplers (bottom histogram). The size-separate analysis of the port sampling data included both the NMFS and non-NMFS samples.

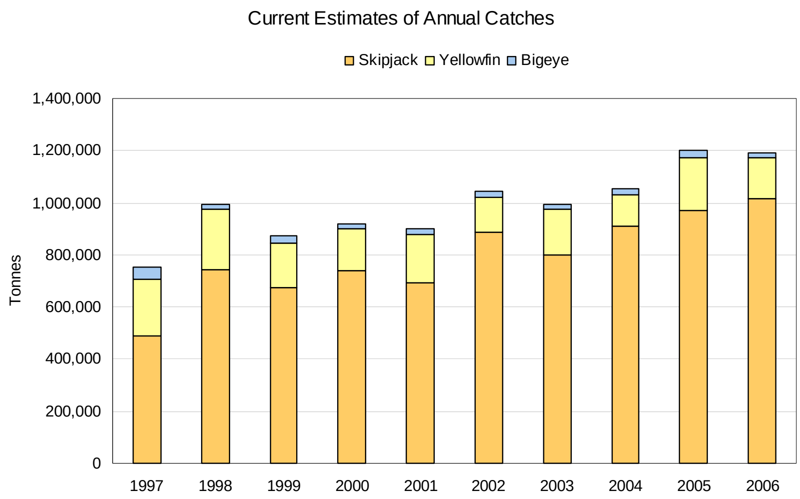
The current estimates of annual catches (top of Figure 30) were determined from catch data aggregated by 1° latitude, 1° longitude and month (the OFP's 's_best' database). The 's_best' data are compiled from two sources: aggregated data covering the Japanese fleet are provided by Japan, while aggregated data covering the fleets of China, Korea, Chinese Taipei, the United States and the Pacific Island countries have been determined from operational (logsheet) data provided to the OFP that have been raised to represent the total catch. The Japanese data covering 1996 onwards are assumed to have been corrected for the mis-identification of bigeye; the remaining data were adjusted for the mis-identification of bigeye as yellowfin using the method of Lawson (2007).

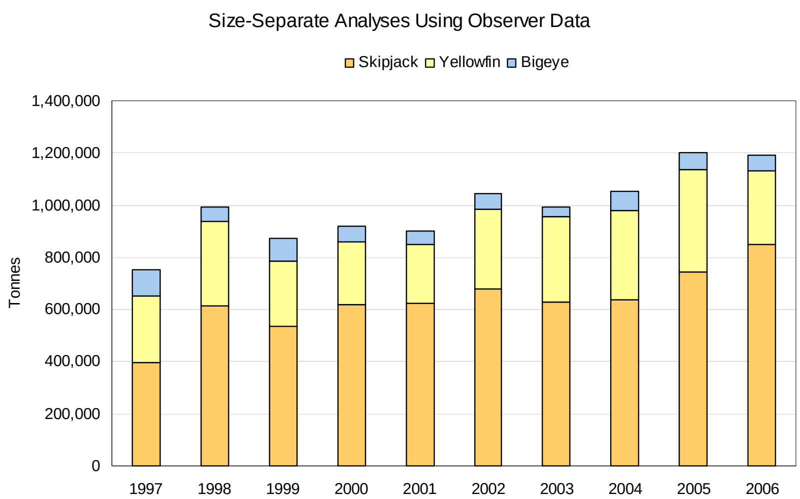
The species compositions for all years combined for the estimates determined from the size-separate analyses and the current estimates are shown in Figure 31. Even with the proportions of small and large fish determined from port sampling data, which over-estimate the proportion of small fish, the annual catch estimates determined from the size-separate analyses of species composition data exhibit much smaller proportions of skipjack, 63.8% for the analyses using observer data and 72.2% for the analyses using port sampling data, than the proportion of skipjack in the 's_best' data, 79.8%.

When the proportions of small and large fish are determined from observer data, which under-estimate the proportion of small fish if size selection bias occurs, the proportion of skipjack is 58.9% for the size-separate analyses using observer data (not shown in Figure 30).

Note further that if size selection bias by observers is *not* occurring, then, according to the simulation studies, the proportion of large yellowfin would be under-estimated due to grab sample bias (Figure 27) and if corrected, the proportion of skipjack in the annual catch estimates would be even smaller than 63.8%. Likewise, if size selection bias *is* occurring, then, assuming only yellowfin and bigeye are subject to the bias, the proportion of large skipjack would be under-estimated; but the proportion of large skipjack is so small (Table 5) that the effect of correcting for the bias on the estimates of the annual catches would be negligible.

Figure 30. Estimates of annual purse-seine catches determined from size-separate analyses of species composition data compared to current estimates





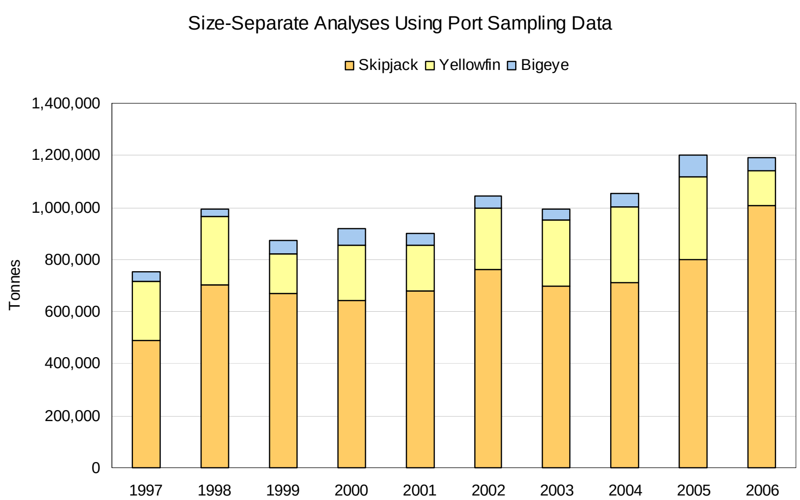
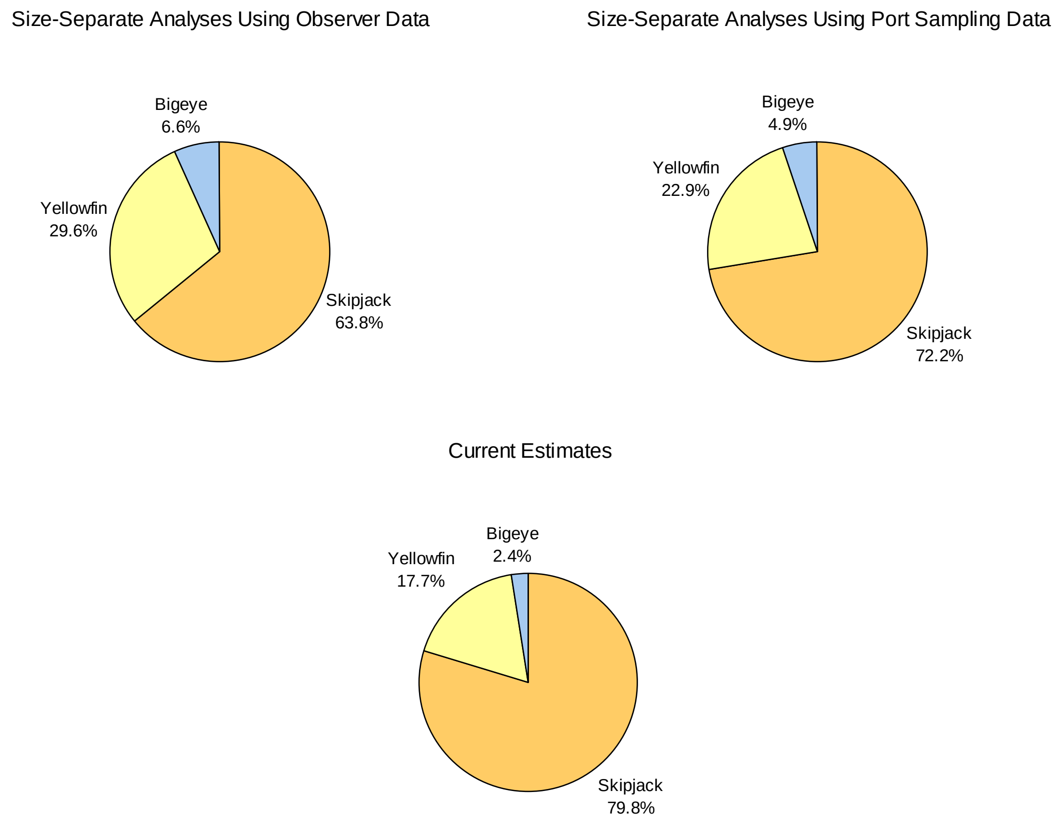


Figure 31. Species composition of the purse-seine catch, 1995–2006, determined from size-separate analyses compared to current estimates



So, which of the series of annual catches and species compositions is the most accurate?

Much of the observer data cover primarily the western part of the region, where the proportion of skipjack is lower, and may be subject to size selection bias, which would also lower the proportion of skipjack. Hence, the proportion of skipjack determined from size-separate analyses using observer data (Figure 31, top left) could be considered a lower boundary.

On the other hand, since the proportion of skipjack is over-estimated by the port sampling data because (a) they are not representative of the set weights, (b) they may be subject to bias due to well selection, (c) there is grab sample bias and (d) they cover primarily the eastern part of the region, the species composition determined from size-separate analyses using port sampling data (top right) could be considered an upper boundary.

This implies that the true proportion of skipjack probably lies between 63.8% and 72.2%. Similar reasoning can be applied to yellowfin, which suggests that the true proportions of yellowfin probably lies between 22.9% and 29.6%. This suggests that the current estimates (bottom) of the proportion of skipjack are too high by about 11.8% and that the proportion of yellowfin is too low by about 8.5%. It follows that the proportion of bigeye is too low by about 3.3%.

Table 20 compares estimates of annual catches based on species compositions that are intermediate between those determined from size-separate analyses of observer data and port sampling data to the current estimates from the ‘s_best’ database. Compared to the current estimates, the average annual catch of skipjack during 1997–2006 determined from the intermediate species compositions declines from 791,916 tonnes to 674,688 tonnes, while the average annual catches of yellowfin and bigeye increase from 176,019 tonnes to 260,227 tonnes and from 24,025 tonnes to 57,045 tonnes respectively.

The average catches of skipjack, yellowfin and bigeye determined from the size separate analyses of the port sampling data were 716,100 tonnes, 227,038 tonnes and 48,823 tonnes respectively. The average catches of skipjack, yellowfin and bigeye determined from the size separate analyses of the observer data were 633,276 tonnes, 293,416 tonnes and 65,268 tonnes respectively.

Table 20. Comparison of estimates of annual catches by purse seiners in the WCPFC Statistical Area (excluding Indonesia and the Philippines), based on species compositions intermediate between those determined by size-separate analyses of observer data and port sampling data, and current estimates

Year	"Intermediate" Species Composition						Current Estimates From "s_best"						Total
	Skipjack		Yellowfin		Bigeye		Skipjack		Yellowfin		Bigeye		
	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes
1997	445,153	59.1%	237,145	31.5%	71,480	9.5%	490,349	65.1%	215,923	28.6%	47,506	6.3%	753,778
1998	658,853	66.4%	292,941	29.5%	41,087	4.1%	743,068	74.8%	230,038	23.2%	19,776	2.0%	992,881
1999	602,756	69.2%	201,833	23.2%	66,732	7.7%	672,413	77.2%	173,065	19.9%	25,843	3.0%	871,321
2000	630,662	68.6%	226,253	24.6%	63,020	6.9%	740,619	80.5%	159,904	17.4%	19,411	2.1%	919,934
2001	651,411	72.4%	201,287	22.4%	46,979	5.2%	691,762	76.9%	187,677	20.9%	20,237	2.2%	899,676
2002	721,113	69.2%	270,417	25.9%	51,067	4.9%	884,955	84.9%	137,682	13.2%	19,960	1.9%	1,042,597
2003	661,047	66.6%	292,145	29.4%	39,501	4.0%	798,582	80.4%	175,652	17.7%	18,458	1.9%	992,693
2004	675,177	64.1%	315,863	30.0%	61,733	5.9%	911,398	86.6%	120,798	11.5%	20,577	2.0%	1,052,773
2005	773,280	64.4%	354,429	29.5%	73,550	6.1%	969,500	80.7%	204,625	17.0%	27,133	2.3%	1,201,258
2006	927,430	77.8%	209,958	17.6%	55,306	4.6%	1,016,511	85.2%	154,830	13.0%	21,352	1.8%	1,192,694
Average	674,688	68.0%	260,227	26.2%	57,045	5.8%	791,916	79.8%	176,019	17.7%	24,025	2.4%	991,961

Tables 21 and 22 compare estimates of annual catches based on intermediate species compositions and the current estimates from the ‘s_best’ database for unassociated and associated schools respectively. As might be expected, the difference in the species compositions are much greater for associated schools than unassociated schools.

Table 21. Comparison of estimates of annual catches from unassociated schools, based on species compositions intermediate between those determined by size-separate analyses of observer data and port sampling data, and current estimates

Year	"Intermediate" Species Composition						Current Estimates From "s_best"						Total
	Skipjack		Yellowfin		Bigeye		Skipjack		Yellowfin		Bigeye		
	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes
1997	186,157	60.6%	109,526	35.6%	11,602	3.8%	196,015	63.8%	103,671	33.7%	7,598	2.5%	307,285
1998	282,224	58.2%	198,490	40.9%	4,580	0.9%	308,799	63.6%	170,869	35.2%	5,625	1.2%	485,293
1999	183,220	77.2%	51,666	21.8%	2,327	1.0%	179,082	75.5%	57,082	24.1%	1,049	0.4%	237,213
2000	337,715	82.2%	71,709	17.5%	1,390	0.3%	318,315	77.5%	91,205	22.2%	1,294	0.3%	410,814
2001	377,290	77.3%	107,127	21.9%	3,799	0.8%	359,493	73.6%	125,068	25.6%	3,656	0.7%	488,217
2002	354,754	74.3%	118,242	24.8%	4,507	0.9%	399,506	83.7%	75,442	15.8%	2,555	0.5%	477,503
2003	367,511	69.8%	152,228	28.9%	6,780	1.3%	417,052	79.2%	107,675	20.5%	1,792	0.3%	526,519
2004	152,429	59.4%	101,973	39.7%	2,334	0.9%	203,351	79.2%	51,791	20.2%	1,594	0.6%	256,736
2005	370,518	67.0%	176,283	31.9%	6,133	1.1%	439,479	79.5%	110,819	20.0%	2,635	0.5%	552,934
2006	343,734	82.2%	69,983	16.7%	4,580	1.1%	324,907	77.7%	90,164	21.6%	3,226	0.8%	418,297
Average	295,555	71.0%	115,723	27.8%	4,803	1.2%	314,600	75.6%	98,379	23.6%	3,102	0.7%	416,081

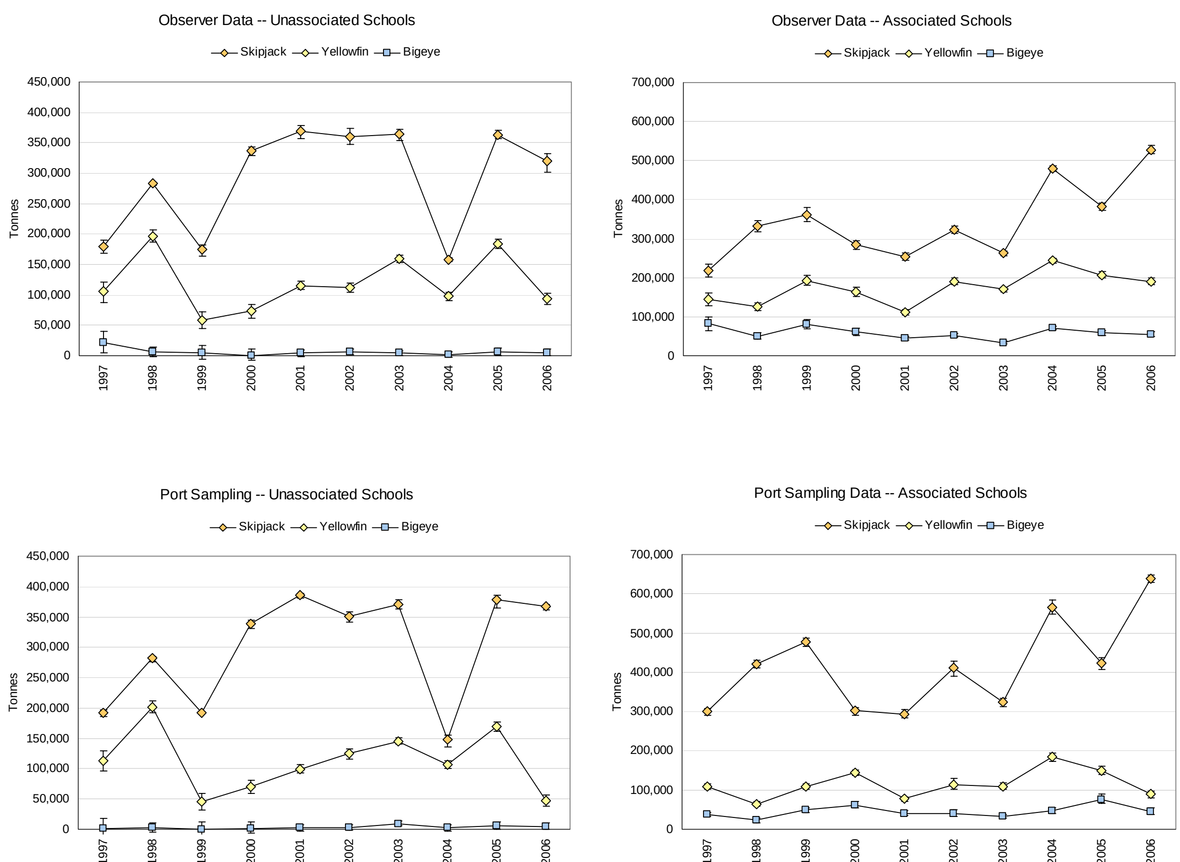
Table 22. Comparison of estimates of annual catches from associated schools, based on species compositions intermediate between those determined by size-separate analyses of observer data and port sampling data, and current estimates

Year	"Intermediate" Species Composition						Current Estimates From "s_best"						Total
	Skipjack		Yellowfin		Bigeye		Skipjack		Yellowfin		Bigeye		
	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes
1997	258,996	58.0%	127,619	28.6%	59,878	13.4%	294,334	65.9%	112,251	25.1%	39,908	8.9%	446,494
1998	376,629	74.2%	94,452	18.6%	36,508	7.2%	434,268	85.6%	59,169	11.7%	14,151	2.8%	507,588
1999	419,536	66.2%	150,167	23.7%	64,405	10.2%	493,332	77.8%	115,983	18.3%	24,794	3.9%	634,108
2000	292,946	57.5%	154,544	30.4%	61,630	12.1%	422,304	82.9%	68,699	13.5%	18,117	3.6%	509,120
2001	274,120	66.6%	94,160	22.9%	43,180	10.5%	332,269	80.8%	62,610	15.2%	16,581	4.0%	411,460
2002	366,359	64.8%	152,175	26.9%	46,561	8.2%	485,449	85.9%	62,240	11.0%	17,405	3.1%	565,094
2003	293,536	63.0%	139,917	30.0%	32,721	7.0%	381,530	81.8%	67,977	14.6%	16,666	3.6%	466,174
2004	522,748	65.7%	213,890	26.9%	59,399	7.5%	708,047	88.9%	69,007	8.7%	18,983	2.4%	796,037
2005	402,762	62.1%	178,145	27.5%	67,417	10.4%	530,022	81.8%	93,805	14.5%	24,497	3.8%	648,324
2006	583,695	75.4%	139,975	18.1%	50,726	6.6%	691,604	89.3%	64,666	8.4%	18,126	2.3%	774,397
Average	379,133	65.8%	144,504	25.1%	52,242	9.1%	477,316	82.9%	77,641	13.5%	20,923	3.6%	575,880

Hoyle & Cameron (2003) examined several bootstrap methods to derive confidence intervals for estimates of recreational catches and found that the bootstrap-t method was the most accurate for their study. However, the bootstrap-t method requires standard errors of the catch estimates, which were not available in the current study. Instead, the BCa (bias-corrected and accelerated) bootstrap method (Efron & Tibshirani 1993) was used to estimate 95% confidence intervals of the annual catch estimates for unassociated and associated schools determined from observer data and port sampling data. Confidence intervals determined from the BCa method are asymmetric, transformation respecting and second-order accurate.

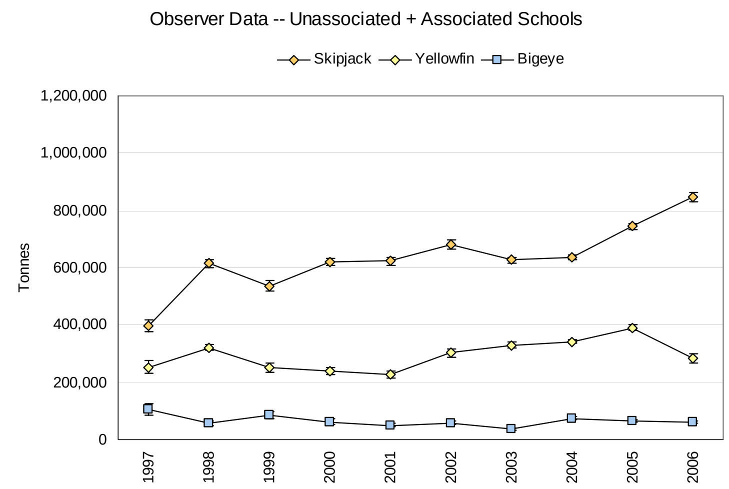
Figure 32 presents the annual catch estimates from the size-separate analyses with 95% confidence intervals determined from resampling with 1000 replicates and BCa corrections. The upper and lower intervals average less than 10,000 tonnes for all three species. Expressed as half the full interval as a percentage of the point estimate — the intervals are asymmetric, but, roughly speaking, these are the 'plus or minus' percentages about the point estimates — the intervals averaged 2–4% for skipjack, 5–9% for yellowfin, 12–17% for bigeye in associated schools and 60–89% for bigeye in unassociated schools. The large percentages for bigeye in unassociated schools are due to the low catch estimates (Table 19).

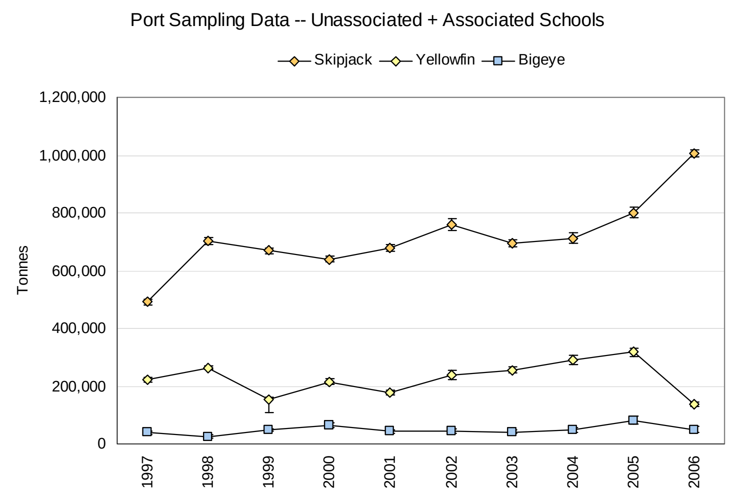
Figure 32. Catch estimates determined from size-separate analyses of observer data and port sampling data, by school association, with 95% confidence intervals based on the BCa bootstrap method

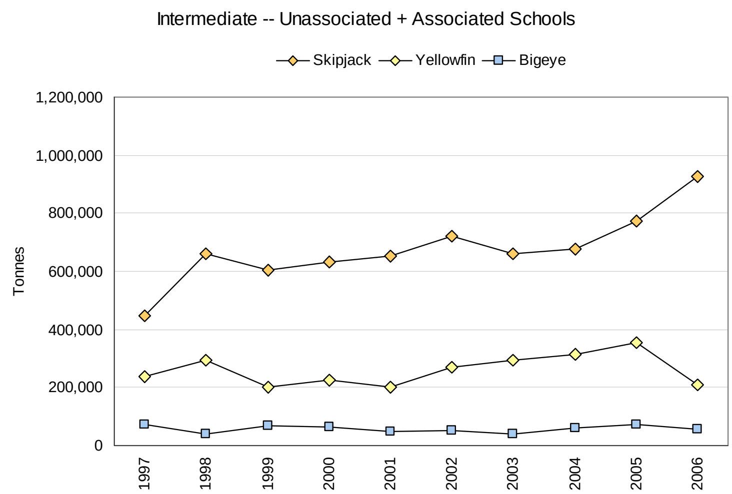


The BCa method is not applicable to estimates of the total annual catch by species, i.e., the sum of the estimates of the catches from unassociated and associated schools, so intervals without the BCa corrections were examined by resampling with 1000 replicates. Figure 33 presents the estimates of total catches determined from observer data and port sampling data, with uncorrected 2.5% and 97.5% intervals, and the estimates of total catches from the intermediate analysis (without confidence intervals). Expressed as half the full interval as a percentage of the point estimate, the intervals averaged 1–3% for skipjack, 4–6% for yellowfin and 12–18% for bigeye.

Figure 33. Catch estimates determined from size-separate analyses of observer data and port sampling data, with 95% bootstrap intervals, and from the intermediate analysis







The confidence intervals in Figures 32 and 33 are narrow; however, it should be emphasised that the main issue here is the accuracy (or bias) of the catch estimates, rather than their reliability (or variance). These confidence intervals represent the variability in the species composition samples among sets or wells, and do not capture the uncertainties that are due to the biases in the data. Furthermore, the estimates are at a low level of resolution; the confidence intervals for estimates of catches stratified at a higher resolution of time and area will be considerably wider than those for annual catch estimates for the WCPFC Statistical Area.

20. Discussion

Port sampling data and observer data both have their problems. Port samples do not cover very small fish (≤ 40 cm) discarded at sea; are taken from wells, which may contain only part of one large set or several smaller sets together; are subject to errors in the date, location and school association of the set or sets sampled due to well mixing; and are not representative of the sizes of schools fished.

The sampling protocol for port samples is to grab fish during unloading either from the well itself, or from the net used to transfer fish from the well to the reefer vessel or bins on the deck or the dock, or from the bins. Hence, port samples are also subject to grab sample bias. The median well capacity based on port sampling data for the United States fleet is about 55 tonnes; hence, the average bias for a sampled well will be intermediate between the bias for the 25 tonne set, i.e., a high level of bias, and the 75 tonne set, i.e., a moderate level of bias, which were examined in the simulations in section 12.

For fish that are sorted by species and size before port sampling, which is done by the United States vessels sampled by NMFS (Appendix A), the level of grab sample bias will be influenced by both the amounts of fish and the uniformity of sizes of the fish from which the samples are drawn. The bias will increase as the amounts of fish from which the samples are drawn decreases; that is, after the fish within a well are sorted by species and size, the amounts of fish from which each of the samples are drawn may be much smaller than the median well capacity of 55 tonnes. On the other hand, the bias will decrease as the sizes of fish from which the samples are drawn become more uniform. Simulations could be conducted to examine the trade-off between the amount of fish in the stratum and the uniformity of sizes of fish.

Lawson & Williams (2005) found in their comparative study that the proportion of skipjack determined from catches reported on logsheets, unloadings data and Final Out-Turn reports were 78%, 77% and 74% respectively. The proportion of skipjack determined from the size-separate analyses of port sampling data presented in section 18 is 72.2% and this value is probably too high because of set weight bias, grab sample bias and the geographic area covered by the data. This suggests that the species compositions determined from logsheets and unloadings data over-estimate the proportion of skipjack by at least 5–6% and probably more. In any case, the species composition determined from port samples appears to be more consistent with logsheets, unloadings and FOT reports than is the species composition determined from observer data.

Lawson & Williams (2005) found that the proportion of skipjack determined from observer data was 55% and suggested that the difference with the proportion determined from port sampling data may be due to observers being positively biased towards selecting large yellowfin and bigeye. Simulations were conducted to determine the level of bias that would explain the difference, but no mechanism was proposed that would explain why only observers, and not both observers and port samplers, might exhibit size selection bias. Under current sampling protocols, both observer samples and port samples are grab samples, and while both are certainly subject to grab sample bias, it is not clear why both should not also be subject to size selection bias, if it exists, when sampling fish that have not been sorted by species and size. Also, it is not clear why size selection bias should occur for associated sets and not unassociated sets, which is apparent when the species compositions are estimated separately for the western and eastern parts of the region (section 8, Table 9).

The current sampling protocols, which, for both observers and port samplers, are to grab a certain number of fish, result in large differences in the species compositions determined from unraised samples and from samples raised by the set weight. The accuracy of the set weight used to raise the sample is therefore an important consideration. For sets sampled by observers, the set weight is easily obtained from the logsheet or the observer's own estimate based on the number of brails used to transfer the fish from the net to the vessel. However, for port sampling, the wells that are selected may contain fish from more than one set, in which case the set weight will be an average, and if well mixing has occurred, the set weight will be even less accurate.

In this regard, it should be noted that the NMFS port sampling programme (Appendix A) uses a different method to raise port samples. United States purse seiners sort their catch by species and size of fish prior to or during unloading; hence, samples are taken of categories of species and size of fish found within wells, and not necessarily of entire wells. Given the sampling protocol, the NMFS samples of species and size categories cannot be combined for each well sampled and raised by the set weight. Rather, the samples for each species and size category are raised by the amount of that species and size category that were unloaded from the well; those amounts are recorded on the FOT reports. However, there is no certainty that the size categories that were sampled for the stratum are representative, nor that the samples raised by the amount of the species and size category unloaded from the well have any relation to samples that would be raised by the amount in the set, if the amount in the set were known. Hence, in addition to the problem of lack of representativeness of set weights, there is reason to suspect other inaccuracies in the species compositions determined from NMFS port sampling data.

To summarise, port sampling data have problems with very small fish, well mixing, the representativeness of set weights, the procedure for selecting wells to sample in certain ports, the accuracy of the set weights that are used to raise samples, grab samples bias, but apparently not size selection bias, and species compositions determined from port sampling data are more consistent with those determined from logsheets, unloadings and FOT reports than are those determined from observer data. Observer data, on the other hand, have no problems with very small fish, well mixing or representativeness and accuracy of set weights, and so would clearly be preferred to port sampling data, if not for the problem of grab sample bias and possibly size selection bias, which may be the reason why species compositions determined from observer data are not consistent with those determined from the other types of data.

Spill samples may be the solution to the problems of both grab sample bias and size selection bias, and, if the samples are representative of the set weights, should not require that samples be raised by an estimate of the set weight. Section 12 showed that spill samples, as modelled in the simulations, were essentially unbiased, while section 14 showed that spill samples by observers are indeed feasible. The number of spill and grab samples that were compared in section 14 is insufficient for drawing definitive conclusions regarding actual differences in species compositions determined from the two types of samples. But on a theoretical basis, there is no reason to believe that spill samples would not be a major improvement in sampling of the purse-seine catch by both observers and port samplers.

Sections 18 and 19 examined size-separate analyses of species composition data, wherein analyses are conducted separately for small (< 80 cm) and large (≥ 80 cm) fish. The results are still affected by the biases inherent in port sampling data and observer data, but less so than for analyses of small and large fish combined. At this point, however, we can only conclude that, given those biases and the difficulties in correcting for them, *species compositions determined from grab samples taken by observers or port samplers are inaccurate*, whether they are the result of size-separate analyses or not.

The size-separate analyses presented in section 19 were used to estimate annual catches. They should also be applied to catch data stratified by time-area and the adjusted data made available for stock assessments. This should be done by conducting size-separate analyses for relatively large time-area strata to reduce the need for substitutions for those strata for which species composition data are missing. The area strata could be MULTIFAN areas or other relatively large areas specifically chosen to minimise the variance of species compositions within strata.

Lawson (2007) parameterised a general linear model (GLM) with observer data to predict the proportion of bigeye in 'yellowfin plus bigeye' from year, school association, latitude and longitude, and thereby adjust catch data stratified by time-area. The use of GLMs to predict the size-separate species compositions discussed in sections 18 and 19 would be considerably more complex, since the models would have to predict the proportions of small and large fish, as well as the proportions of skipjack, yellowfin and bigeye for each category of size of fish, i.e., two dependent variables of size category and six of species compositions (or one variable of size and four of species composition given the constraint that the proportions must sum to unity). If catches were recorded on logsheets for small and large fish separately, then it would not be necessary to estimate the proportions of small and large fish from observer or port sampling data; however, the GLMs would still be required to predict six variables of species composition. While complex, GLMs would have certain advantages. Substitutions would be unnecessary. Instead of being locked into a fixed definition of areas, more complex relationships between the species composition and latitude and longitude could be modelled with cubic splines. In addition to independent variables such as year, quarter, latitude, longitude, school association and set weight, other independent variables could also be examined.

Regardless of how stratified catch data are adjusted for species compositions determined from grab samples taken by port samplers or observers, the results will be uncertain because of the various biases. It remains to be seen how species compositions determined from spill samples compare to those determined from grab samples, but the expectation is that those determined from spill samples will be more accurate. If spill samples taken by observers prove to be practical on a large scale, then such data would be much preferred to grab samples taken by either port samplers or observers.

It should also be noted that during the course of the analyses, the set of length-weight parameters for skipjack, yellowfin and bigeye was changed from a set that has been used by the OFP Statistics and Monitoring Section for various statistical purposes to a set used by the OFP Stock Assessment and Modelling Section in the MULTIFAN-CL analyses (and which are presented in section 3). While the results of the analyses did not change qualitatively, they did change quantitatively. For example, the differences in the species compositions resulting from the size-separate analyses of observer data and port sampling data presented in section 19 were smaller than with the previous set of length-weight parameters. The estimation of species composition is clearly sensitive to the length-weight parameters that are used and this suggests that they should be examined closely. If the length-weight parameters are found to vary in regard to time, area or other variables, then this information should be taken into account when converting the lengths of fish measured by observers and port samplers to weights. In this regard, the OFP is considering equipping certain observers in the national programmes of SPC member countries with motion-compensated scales (see link below) to collect accurate weights of individual fish, which could then be used to parameterise length-weight functions.

http://www.marel.com/products/fishindustry/weighing/ProductID/11/

21. Use of Historical Data and Future Data Collection

To conclude, two questions are considered. First, how should historical species composition data be used? Second, how should species composition data be collected in the future?

Regarding the historical data, it may be possible to correct observer data and port sampling data for grab sample bias, using simulations of grab samples taken from a range of schools that are characterised by their set weight, the presence or absence of each species, and the sizes of fish of each species in the sample. It may also be possible to use simulations to correct port sampling data for bias due to the lack of representativeness in regard to set weights. However, this would be extremely computationally intensive and may not be feasible.

Correcting the observer data for size selection bias might be possible if (a) it were known to actually exist and (b) an estimate of the magnitude of the bias was available. Lawson & Williams (2005) attempted to estimate that magnitude by comparing the species compositions determined from observer data under various levels of bias to those determined from port sampling data, but their analysis did not take into consideration grab sample bias or the effect of the geographic areas covered in the port sampling data or observer data, or set weight bias in the port sampling data. There is also the problem of explaining why observer data should be subject to size selection bias, while port sampling data are not. At this point, the only reason why port sampling data are considered *not* to be subject to size selection bias is because species compositions determined from port sampling data are more consistent with those determined from logsheets, unloadings data and cannery receipts than those determined from observer data.

If the correction of historical data for biases is attempted, the corrections will be subject to errors, and this fact should be made explicit in stock assessments through sensitivity analyses comparing uncorrected and various sets of corrected data. Data could be corrected under various assumptions regarding the magnitude of size selection bias, for example, and the results of assessments using the different sets of data compared.

Logsheet data are biased, with catches of bigeye and yellowfin generally being under-reported. Unloadings data should be more accurate than logsheets since they are often the basis for payments to stevedores and reefer vessels. However, cannery receipts, such as the Final Out-Turn reports, which list the amounts delivered by species and size categories, should be the most accurate since they are the basis for payments at rates that depend on those species and size categories. At present, cannery receipts are only available for canneries in American Samoa. It would be useful to obtain the receipts from the canneries of other Pacific island countries, i.e., Papua New Guinea and Solomon Islands, and also canneries in Japan, Indonesia, the Philippines and Thailand.

Regarding the use of historical port sampling data from Majuro, Pohnpei and Tarawa, there is reason to suspect that the procedures for the selection of wells has introduced biases beyond those related to the lack of representativeness of the set weights (section 5). The quality of those data needs to be re-evaluated through the careful examination of those procedures.

Regarding future data collection, the use of spill samples by observers is promising. However, it will not be possible to draw conclusions regarding differences in species compositions determined from grab samples and spill samples until many more samples can be compared. The spill sample experiment that was discussed in section 14 should therefore be continued and arrangements are currently being made by the OFP to do so.

Port sampling programmes in five major ports — Majuro, Pohnpei, Pago Pago, Rabaul and Yaizu — would result in coverage that is representative of the geographic distribution of fishing. However, there are four aspects of port sampling programmes that need attention. First, more wells that contain multiple small sets need to be selected so that the samples are representative of the set weights. This means selecting wells containing small sets that are consistent in their set weight, school association, date and location, which may not be easily accomplished. Second, experiments with spill samples in port should be considered to deal with the problem of grab sample bias. Third, it is preferable to avoid sampling vessels that transfer fish among wells, particularly those that sort their catch by species and size at sea, so the extent of well mixing should always be established before a vessel is considered for port sampling. Fourth, based on experience with national port sampling programmes in the region, it is essential that a qualified programme supervisor be available on a full-time basis to train samplers, schedule samplers, monitor the sampling and to maintain data quality.

It has been suggested that large-scale port sampling programmes should be established in the Western and Central Pacific, based on the experience in other ocean areas (Fonteneau 2007). In this regard, it is of interest to note the port sampling protocols in the other areas. In the Atlantic and Indian Oceans, 50 to 100 fish are measured from wells containing unassociated schools of yellowfin and 300 to 500 fish are measured from wells containing unassociated schools of skipjack and associated schools, except that for skipjack, 50 fish are measured and the remainder counted (Pianet et al. 2000, Fonteneau 2007). In the Eastern Pacific, several hundred fish are counted and 50 fish of each species are measured from each well sampled (Tomlinson 2002). Both protocols involve grab sampling and so they will be subject to varying degrees of grab sample bias. The selection of wells under both protocols requires the homogeneity of date, location and school association of sets contained in the well; hence, the data may also be subject to bias related to the lack of representativeness of the set weights. As noted in the previous paragraph, large-scale port sampling programmes could be established in the Western and Central Pacific in addition to those in Majuro and Pago Pago, but, like all port sampling programmes, they will be subject to these biases. If correcting for the biases were straightforward, then they would not be so problematic, but this is not the case. The objective of sampling programmes should be to collect data that can be used to estimate species compositions that are unbiased. *The conclusion from this study is that the only sampling protocol with the potential for providing unbiased data is for observers to conduct spill samples at sea.*

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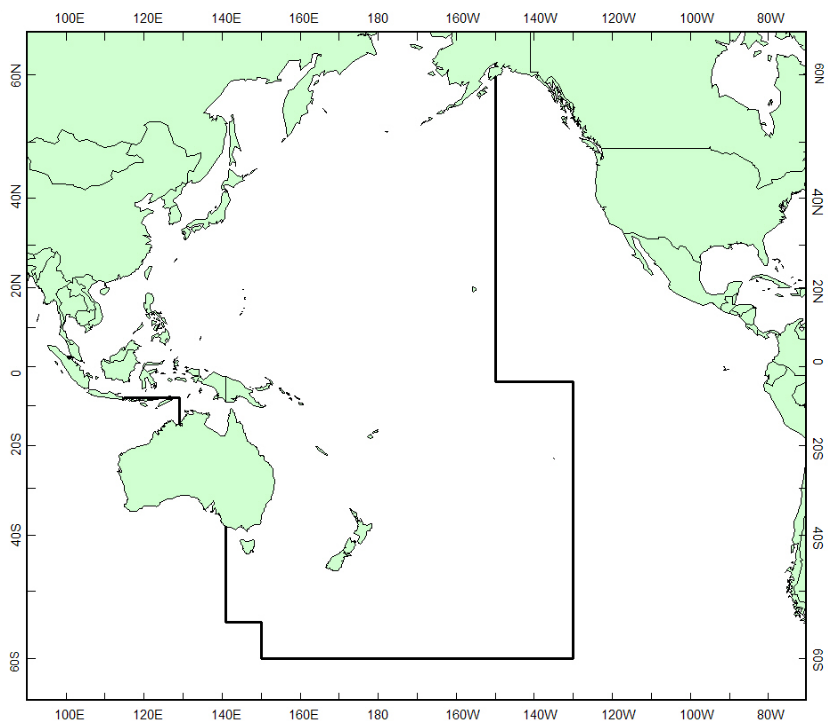
Figure 34. WCPFC Statistical Area



APPENDIX A. NMFS PORT SAMPLING PROGRAMME

The National Marine Fisheries Service (NMFS) conducts port sampling of United States purse seiners in Pago Pago, American Samoa and is currently expanding the programme to cover vessels landing in other ports in the region. The objective of the port sampling programme in Pago Pago is to estimate the species composition of the annual catch of yellowfin and bigeye by United States purse seiners and to obtain annual length frequencies for each of the three target species: skipjack, yellowfin and bigeye.

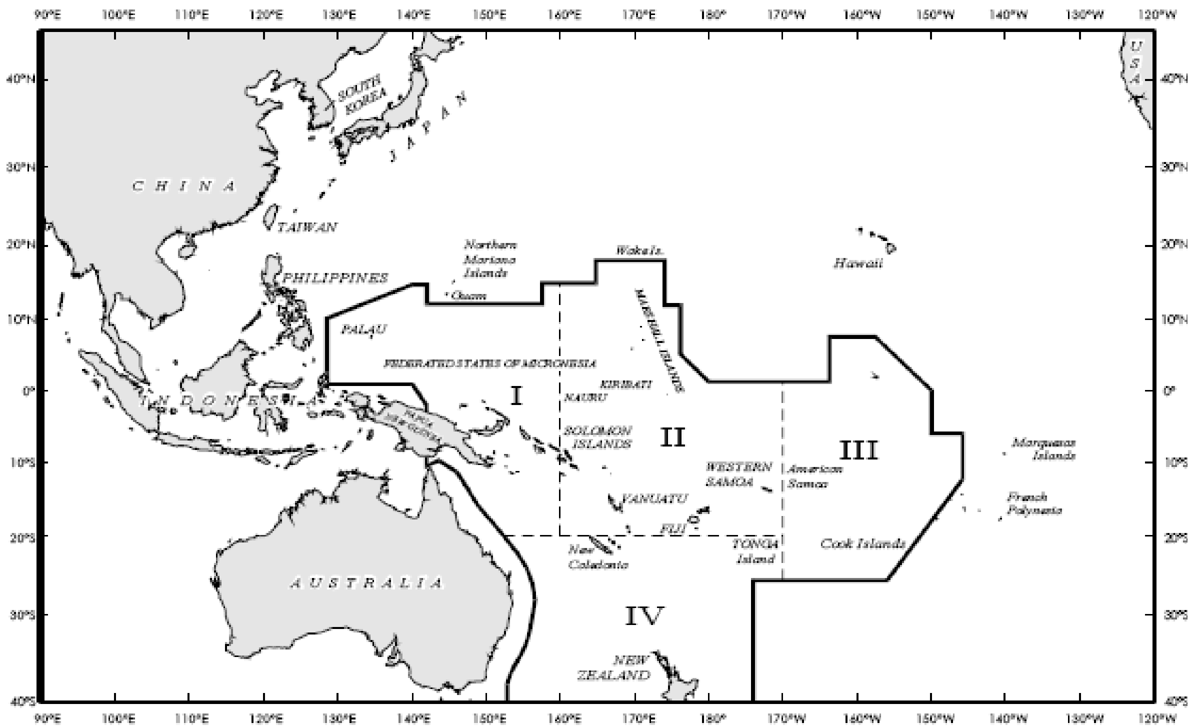
Sampling Protocol

The NMFS port sampling programme differs from the other purse-seine port sampling programmes in the region because the fish are usually sampled after they have been sorted by species and size category during unloading to canneries or transshipment to reefer vessels. The species composition and lengths are therefore sampled from landing categories of species and size of fish. The species categories are ‘skipjack’, ‘yellowfin’, ‘bigeye’ and ‘yellowfin plus bigeye’. Most of the bigeye catch is reported as ‘yellowfin plus bigeye’, rather than separately.

The Starkist cannery has an automated system for sorting the unloaded fish into four size categories for ‘skipjack’ — less than 3 lbs, 3–4 lbs, 4–7.5 lbs and greater than 7.5 lbs — and five size categories for ‘yellowfin’ — less than 3 lbs, 3–4 lbs, 4–7.5 lbs, 7.5–20 lbs and greater than 20 lbs. The COS cannery currently has a sorting line in place, but are still sorting fish into size categories onboard the vessel or on the dock. In both cases, port sampling takes place after the catch has been sorted. Note, however, that fish less than three pounds are not usually delivered to the cannery; these fish are usually sorted on the vessel before or during unloading. When fish sorted by size are sampled, the size categories are recorded by the sampler as ‘small’, ‘medium’ or ‘large’, or combinations thereof. Small, medium and large skipjack are 0–4 lbs, 4–7.5 lbs and 7.5–20 lbs respectively, while small, medium and large yellowfin and bigeye are 0–7.5 lbs, 7.5–20 lbs and greater than 20 lbs respectively.

The target number of samples is at least 13 wells containing skipjack, 13 wells containing yellowfin and 10 wells containing bigeye from each stratum of the US Treaty areas and month, for all school associations combined.

Figure A1. US Treaty areas



When sampling a species and size category, the sampling protocol is to grab 50 fish for a length sample from the bin into which the fish have been sorted and, if more than one species is randomly selected during sampling, to grab an additional 50 fish to make up a species composition sample of 100 fish, then to continue sampling the lengths of fish until 50 fish of each species have been sampled. If 50 fish are not available for a length frequency sample, then it assumed that all fish of that species were enumerated.

The amounts of fish of each species and size category that were unloaded and rejected from each well are reported by the canneries on Final Out-Turn (FOT) reports. The length samples of the species and size categories from each bin are raised by the amounts of each species and size category on the FOT reports for the well from which fish in the bin were taken, and then summed for the entire Treaty area by quarter and school association. The results are quarterly length frequencies for each stratum of school association and species.

Information on the month, area and school association for each sample are taken from the US Treaty logsheets for the trip (the Regional Purse Seine Logbook or RPL), which are verified with data recorded in the vessel's bridge logbook. The data are stratified by school association categories of 'unassociated' and 'associated'; the 'associated' category is not further disaggregated into categories for logs, drifting FADs and anchored FADs.

Estimation of the Annual Species Composition

Catches stratified by species category and school association are estimated from FOT reports, with information on school association obtained from the RPLs. The species categories are 'skipjack' and the combined catch of 'yellowfin', 'bigeye' and 'yellowfin plus bigeye' (referred to below as ‘yellowfin and bigeye’). The school associations are ‘unassociated’ and ‘associated’. The catch estimates are for all US Treaty areas combined.

The annual catch estimates of ‘yellowfin and bigeye’ are then further stratified by size category of small (< 9 lbs) and large (≥ 9 lbs) fish. This is done by combining the length frequencies for ‘yellowfin and bigeye’ in the size categories recorded by the sampler as ‘small’, ‘medium’ or ‘large’ (or combinations thereof) to give length frequencies for unassociated and associated schools. The length frequencies are then used to determine the proportions of small (< 9 lbs) and large (≥ 9 lbs) fish caught in unassociated and associated schools.

According to NMFS, species composition samples of ‘skipjack’ do not contain large quantities of bigeye and yellowfin; therefore, catches of skipjack on FOT reports are assumed to be accurate and the ‘skipjack’ species category is not adjusted.

The final step is to estimate the catches by species in the category of ‘yellowfin and bigeye’ in each stratum of school association (unassociated or associated) and size category (small or large). This is done by determining the proportions of yellowfin and bigeye (without quotes) in strata of school association and size class from the species composition data for ‘yellowfin and bigeye’ for each stratum. These proportions are then applied to the estimates of annual catches of ‘yellowfin and bigeye’ for each stratum of school association and size of fish to estimate the annual catches of yellowfin and bigeye in each stratum. The estimates of the annual catches of skipjack, yellowfin and bigeye for each stratum can then be summed to give the annual species composition by school association.

It should be noted that the targeting of at least 13 wells containing skipjack, 13 wells containing yellowfin and 10 wells containing bigeye from each stratum of the US Treaty areas and month is inconsistent with the method used to estimate the annual catches. It would be appropriate to have a target number of wells for strata of US Treaty areas to minimise the variance of estimates of catches for each area. But since the catches are estimated only for all US Treaty areas combined, the random selection of wells to sample (subject to criteria regarding the homogeneity of the date, location and school association of sets within the well), without regard to the US Treaty areas, may result in species composition data that are more representative of the geographic distribution of the catch (see section 6, Figure 8).

Annual catch estimates for 1995–2006 are presented in Table A1. The species compositions in Table A1 may not be directly comparable to species compositions presented elsewhere in this paper because species compositions depend strongly on the length-weight parameters that are used to convert sampled lengths to weights, and those used by NMFS are currently unavailable.

Table A1. Annual catch estimates for the United States purse-seine fleet

Year	Skipjack		Yellowfin		Bigeye		Total
	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes
1995	132,518	79.1%	31,845	19.0%	3,190	1.9%	167,553
1996	120,127	80.4%	19,417	13.0%	9,860	6.6%	149,404
1997	79,386	55.1%	54,638	37.9%	10,058	7.0%	144,082
1998	131,573	75.3%	37,678	21.6%	5,377	3.1%	174,628
1999	129,262	70.8%	34,529	18.9%	18,694	10.2%	182,485
2000	81,368	65.0%	29,961	23.9%	13,886	11.1%	125,215
2001	85,539	73.8%	24,143	20.8%	6,176	5.3%	115,858
2002	88,535	73.4%	27,191	22.5%	4,889	4.1%	120,615
2003	62,907	71.9%	20,079	23.0%	4,470	5.1%	87,456
2004	47,896	71.0%	14,492	21.5%	5,031	7.5%	67,419
2005	62,379	72.4%	17,685	20.5%	6,108	7.1%	86,172
2006	54,380	81.5%	8,193	12.3%	4,114	6.2%	66,687
Average	89,656	72.3%	26,654	21.5%	7,654	6.2%	123,965

Crone & Coan (2002) examined the variance of annual catch estimates for 1997–2001 determined from the NMFS port sampling data and found that the coefficients of variation were less than 6% for skipjack and yellowfin, and less than 13% for bigeye. Species compositions of individual samples within strata of year, species category, school association and size category that had not been raised by the amounts unloaded from the well were averaged to obtain means and standard errors of the species composition for each stratum. However, annual catches are actually estimated from species composition samples that have been raised (or weighted) by the amounts unloaded from the well, rather than from unraised (or unweighted) samples. It would therefore be more appropriate to examine variances by resampling the raised samples that are actually used to estimate annual catches.

Processing of the NMFS Port Sampling Data in the Current Study

The port sampling data provided by NMFS were processed into a format to allow comparison of the data with the non-NMFS port sampling data and the observer data held by the SPC Oceanic Fisheries Programme. This was accomplished by raising the species composition data stratified by vessel, sampling date, well, size category and species by the amounts unloaded from the wells for each stratum, and combining the raised species compositions for each sampled well. For a species within a stratum that was not covered by a species composition sample, it was assumed that the strata contained only one species and the length frequency sample, raised by the amount unloaded, was used. This procedure assumes that all species and size categories within each sampled well are sampled; this is known to not be the case, but the results still approximate raised species compositions for individual wells.

The NMFS data held by the OFP are contained in two main files. The length frequency samples are contained in the “LF.dat” files. Each record represents a stratum of vessel, sampling date, well, size category and species, and includes the lengths of individual fish in a length frequency sample and, for a subset of the strata, lengths of individual fish in a species composition sample.

Information on species composition samples is also contained in the “COMP.dat” files. Each record represents a stratum of vessel, sampling date, well and size category, and includes the number of fish sampled by species, but not the actual lengths of the fish sampled.

For strata of well and size category, the species composition data in the LF data and COMP data may not cover all species in the stratum. For example, if skipjack, yellowfin and bigeye occur in the stratum, there may be a species composition sample of yellowfin and bigeye, but not usually all three species, unless no sorting has occurred.

The data were screened for (a) duplicate records in the LF data, (b) strata in the LF data that were missing unloading weights, and (c) strata in the LF data for which there were neither a species composition sample nor a length frequency sample. The screening reduced the number of sampled wells for which data were available by 10.1%, from 4,044 to 3,635. (This number if different from the number of wells sampled listed in Table 3 for United States vessels because Table 3 also includes a small number of samples taken by non-NMFS programmes.)

There were 9,498 strata of well, size category and species; 1,978 strata had lengths of fish in a species composition sample in the LF data; 4,103 strata had the numbers fish in a species composition sample in the COMP data, and 1,758 strata had both.

The data for strata of well and size category were processed as follows:

- If there were lengths of individual fish in a species composition sample for the stratum of well and size category in the LF data, the species composition data for each species in the sample were combined and raised by the sum of the amounts unloaded for each species. If there was a species in the stratum that was not covered by a species composition sample, the lengths of individual fish in the length frequency sample were used and raised by the amount unloaded for that species.

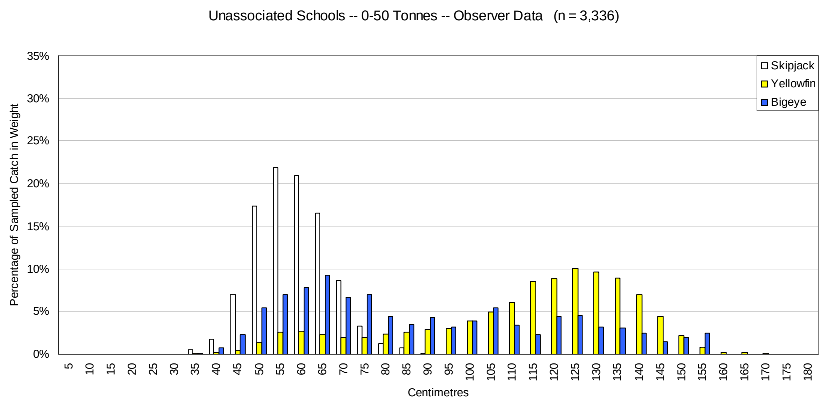
- If there were no species composition data in the LF data, the numbers of fish of each species in the species composition sample was obtained from the COMP data. If the number of fish of a species in the species composition sample was the same as the number of fish of that species in the length frequency sample in the LF data, then the length frequency sample was used and raised by the amount unloaded. If the number of fish of a species in the species composition sample was less than the number of fish of that species in the length frequency sample, then fish were randomly selected from the length frequency sample in the LF data until the number of fish selected was equal to the number of fish in the species composition sample in the COMP data. If there was a species for which the number of fish in a species composition sample was available in the COMP data, but there was no length frequency sample in the LF data, then that well was deleted from the set of data; this occurred for 177 sampled wells.

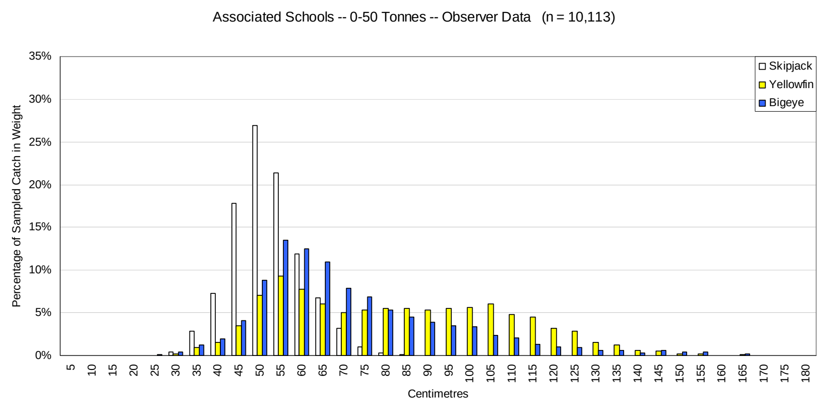
- If there was no species composition sample in either the LF or COMP data, then the length frequency data were used and the data raised by the amount unloaded for that species.

- The data for strata of size category were then aggregated for each well.

APPENDIX B. SIZE DISTRIBUTIONS OF SIMULATED SCHOOLS OF TUNA

Figure B1. Size distributions (percentage of the sampled catch in weight) determined from observer data





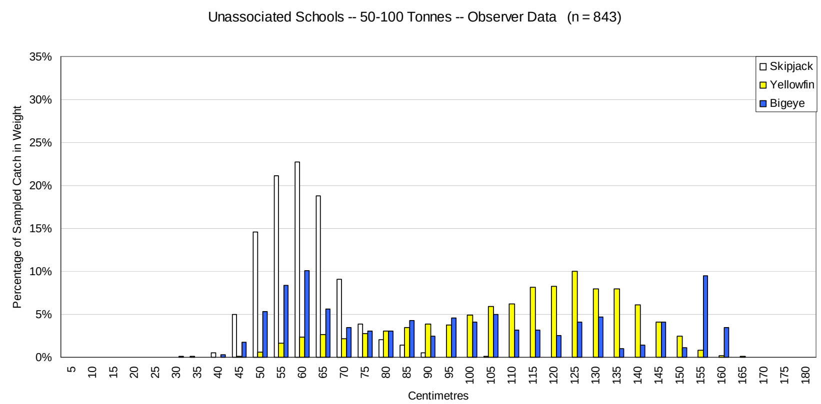
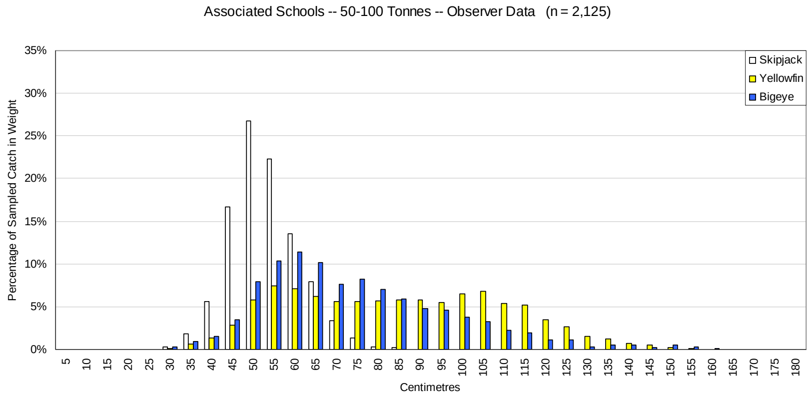
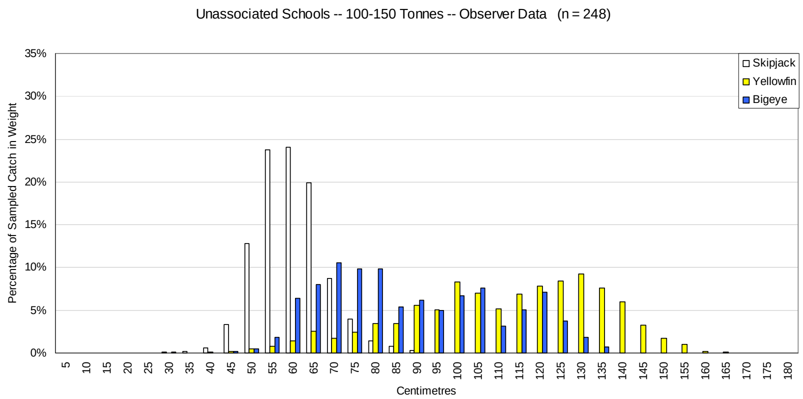


Figure B1 (continued)





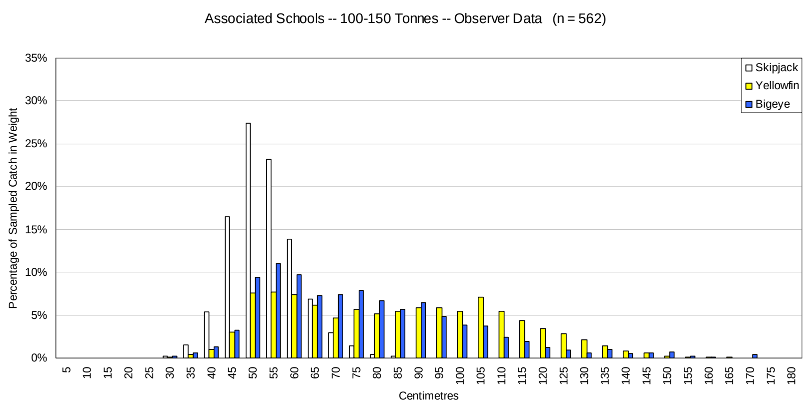
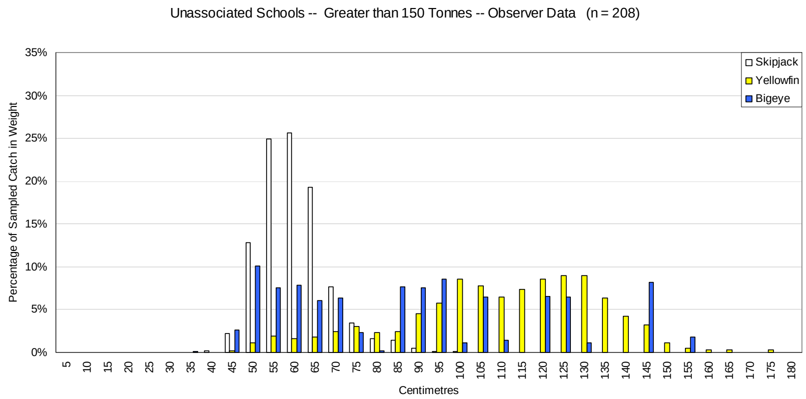


Figure B1 (continued)



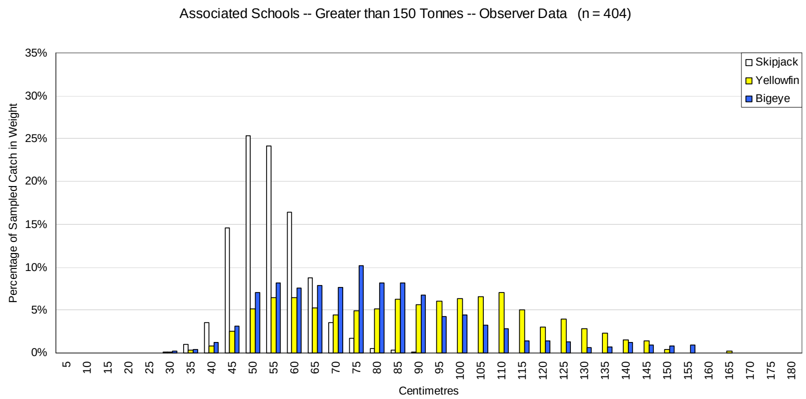
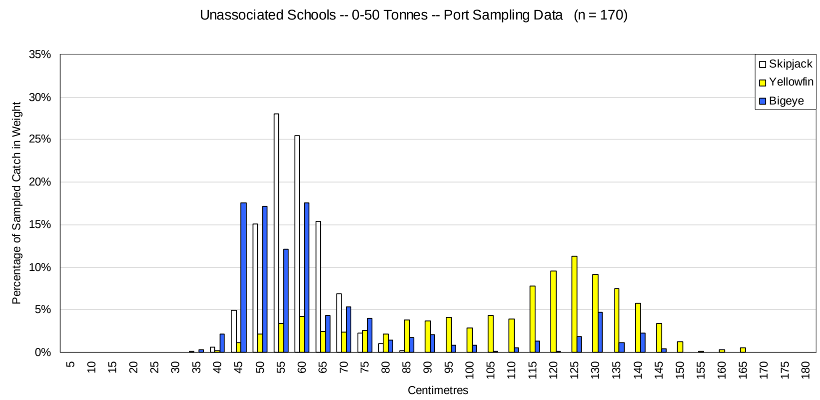
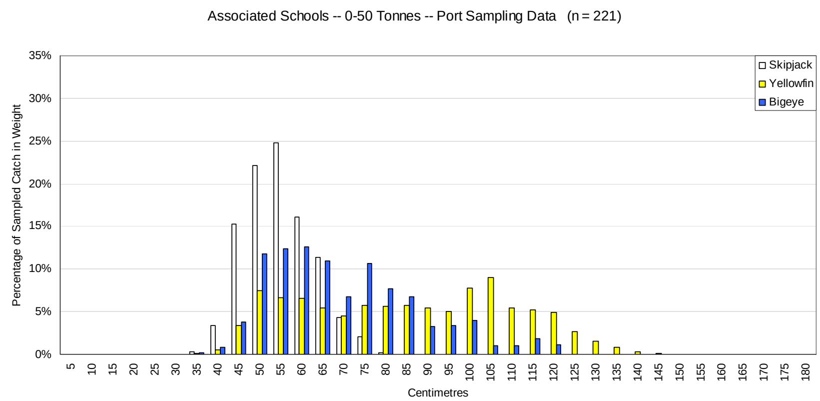


Figure B2. Size distributions (percentage of the sampled catch in weight) determined from port sampling data





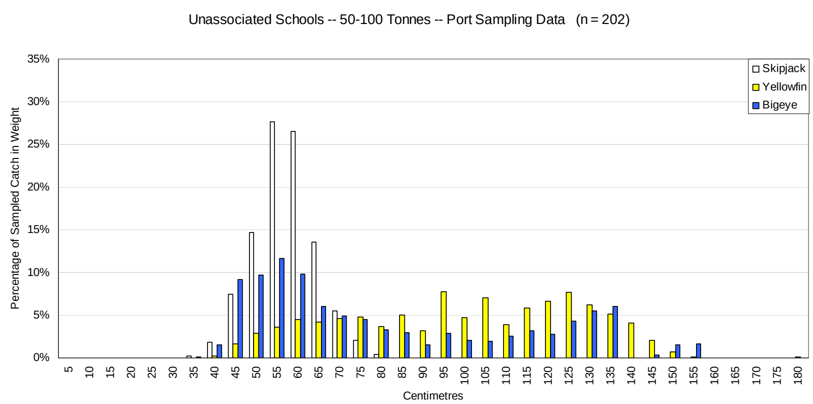
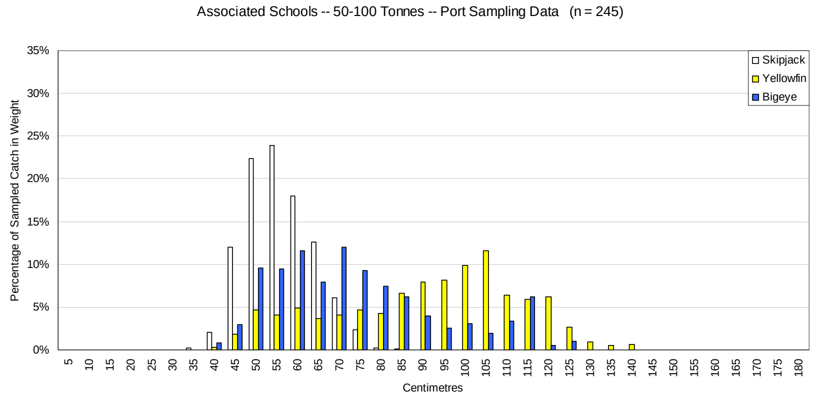
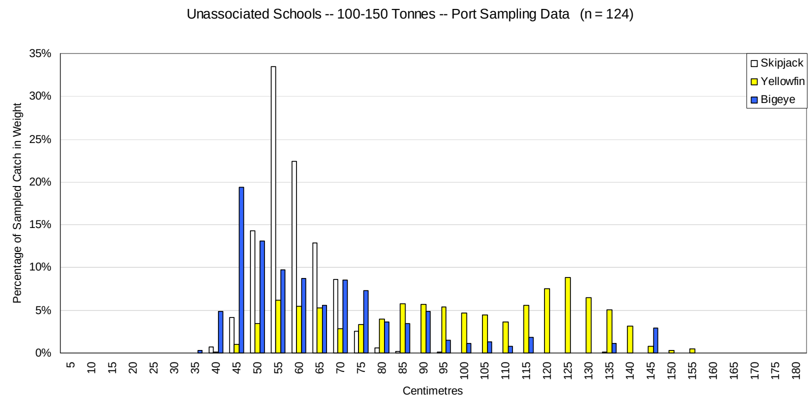


Figure B2 (continued)





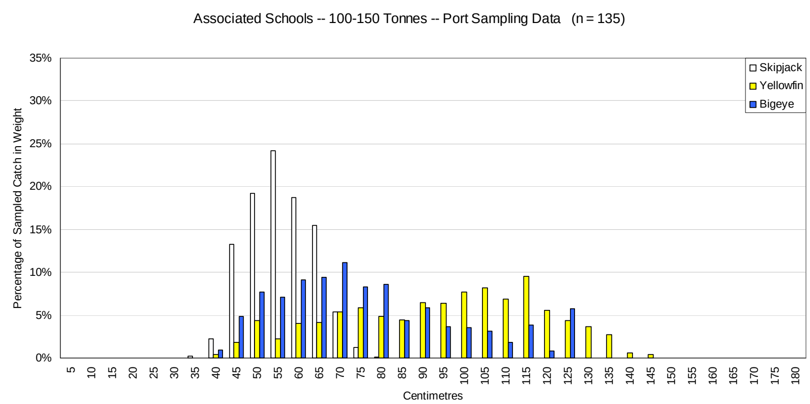
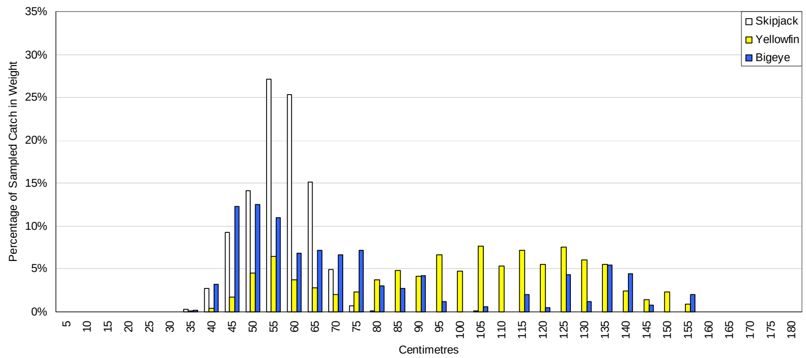


Figure B2 (continued)

Unassociated Schools -- Greater than 150 Tonnes -- Port Sampling Data (n = 76)



Associated Schools -- Greater than 150 Tonnes -- Port Sampling Data (n = 134)

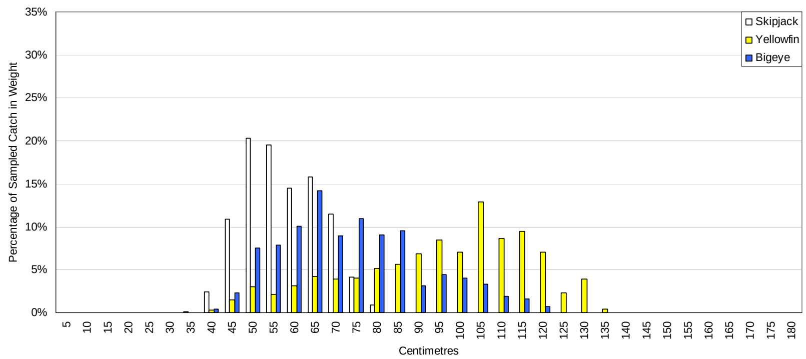
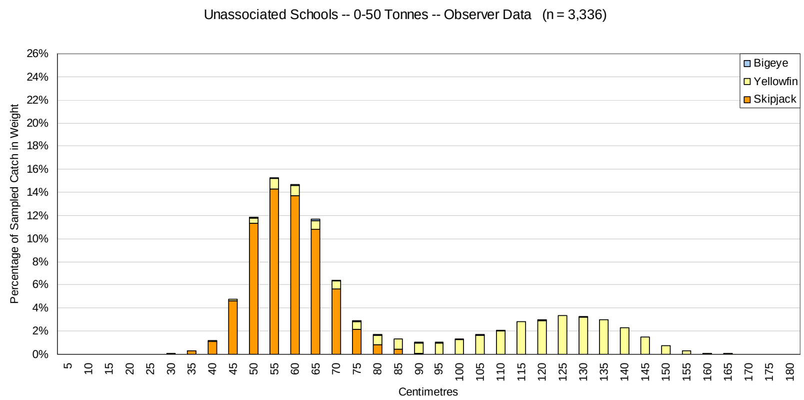
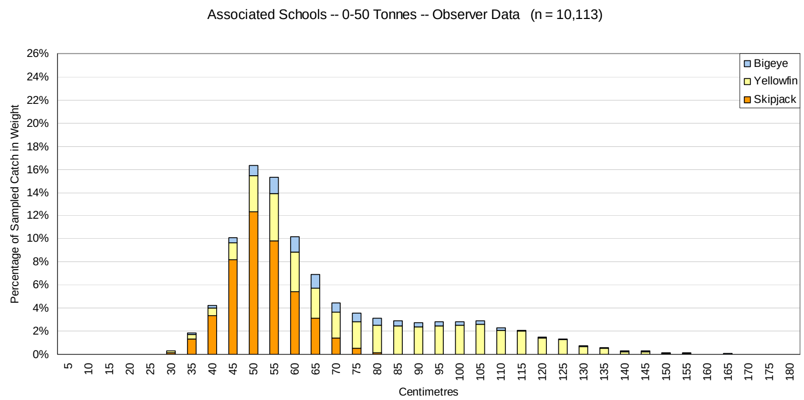


Figure B3. Stacked size distributions (percentage of the sampled catch in weight) determined from observer data





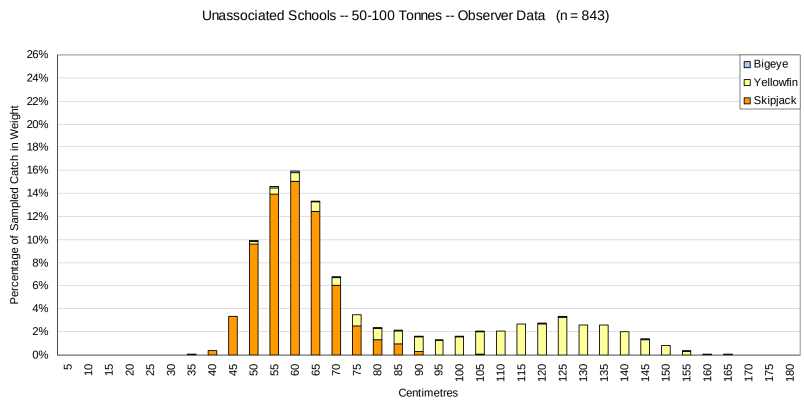
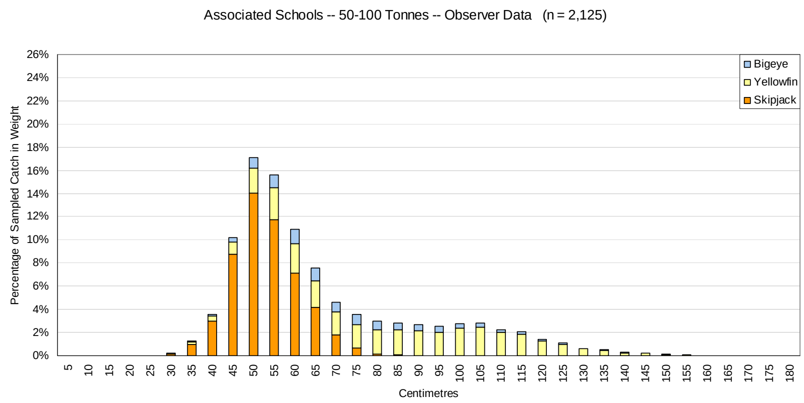
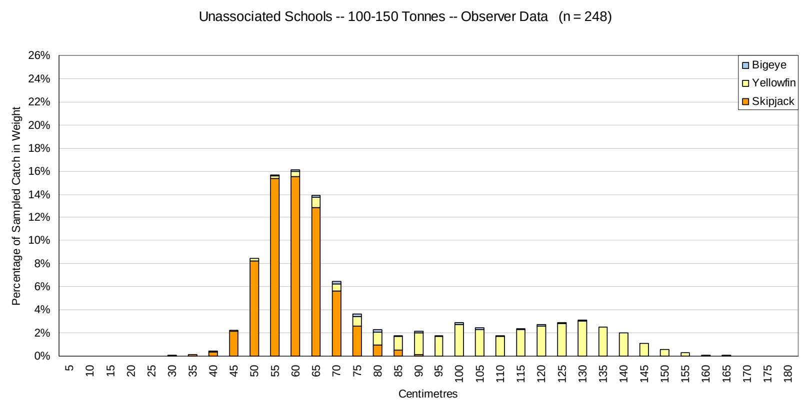


Figure B3 (continued)





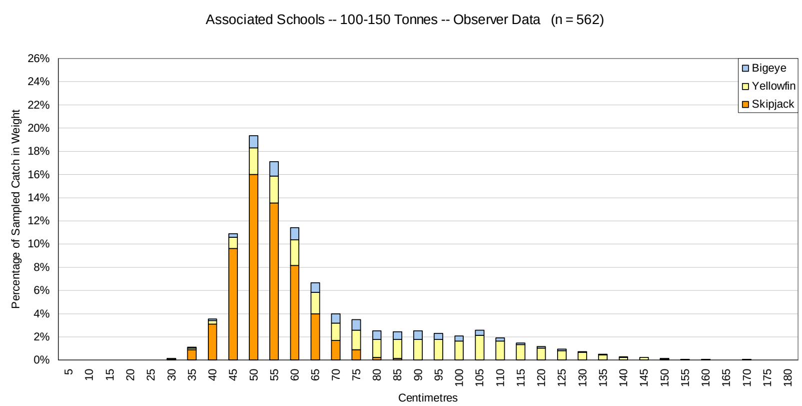
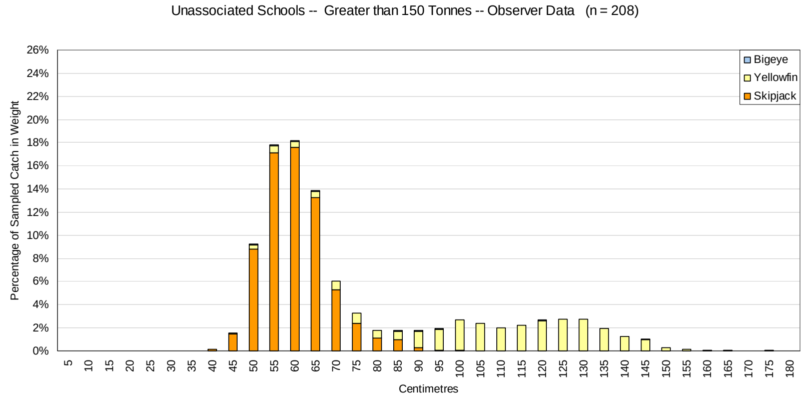


Figure B3 (continued)



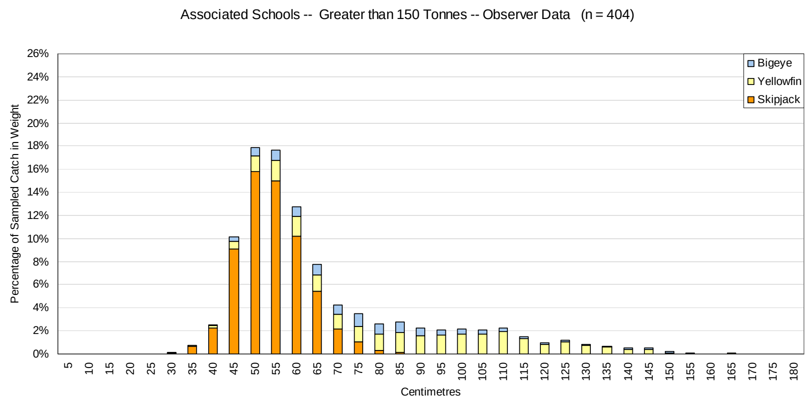
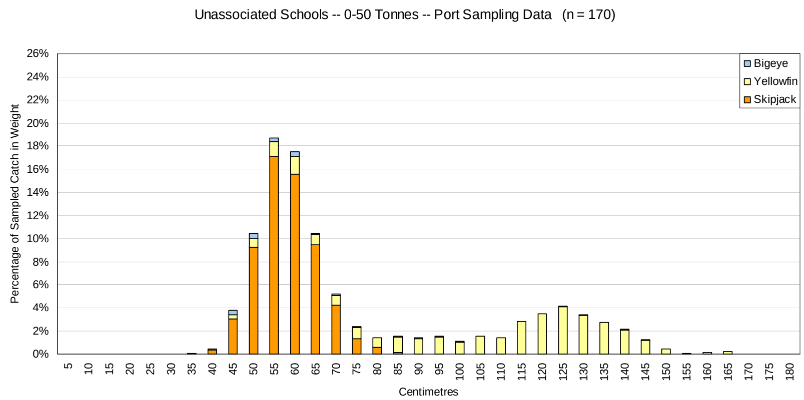
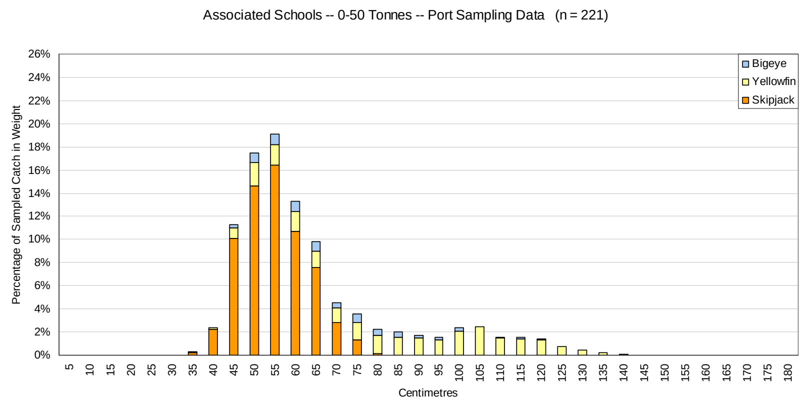


Figure B4. Stacked size distributions (percentage of the sampled catch in weight) determined from port sampling data





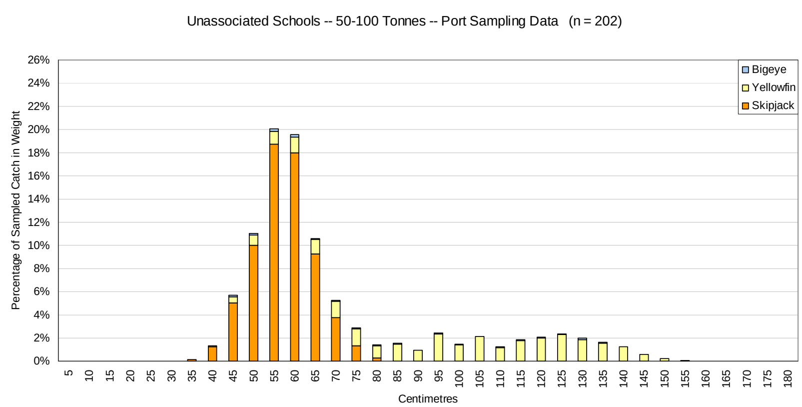
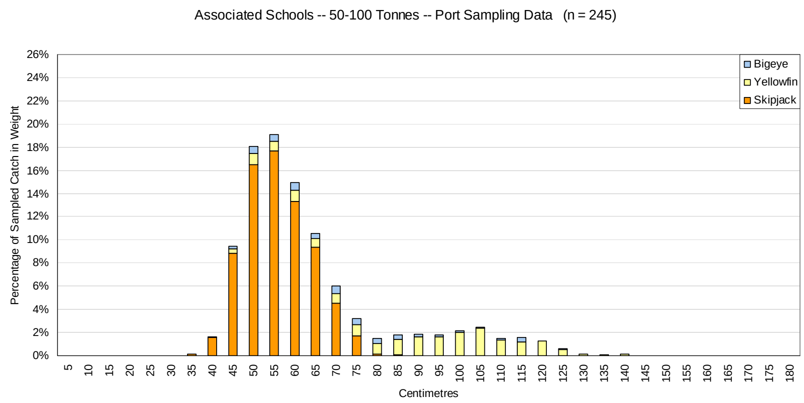
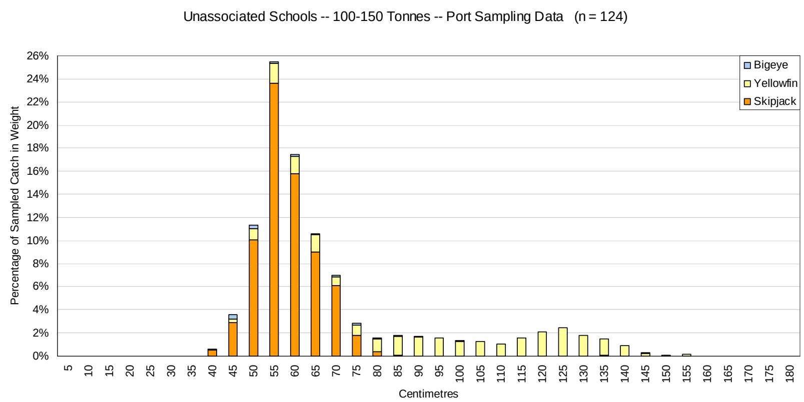


Figure B4 (continued)





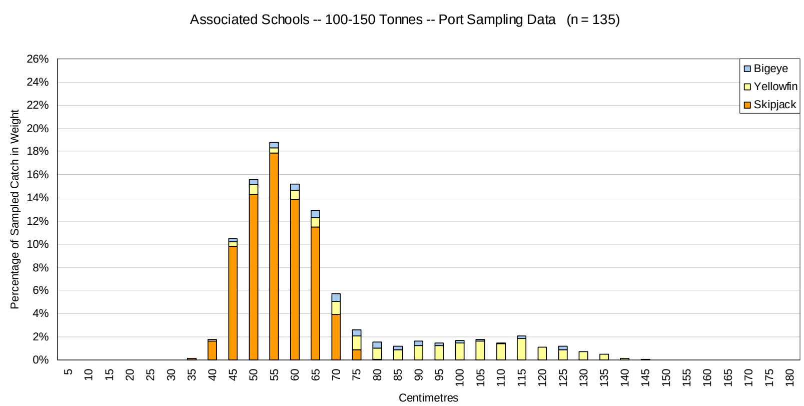


Figure B4 (continued)