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Special Report 18

AN EVALUATION OF THE AREA STRATIFICATION USED FOR SAMPLING TUNAS IN THE EASTERN PACIFIC OCEAN AND IMPLICATIONS FOR ESTIMATING TOTAL ANNUAL CATCHES

by

Jenny M. Suter

La Jolla, California, USA
2010

The Antigua Convention, which was negotiated to strengthen and replace the 1949 Convention establishing the Inter-American Tropical Tuna Commission (IATTC), entered into force on 27 August 2010. The IATTC is responsible for the conservation and management of the "stocks of tunas and tuna-like species and other species of fish taken by vessels fishing for tunas and tuna-like species" in the eastern Pacific Ocean, and also for the conservation of "species belonging to the same ecosystem and that are affected by fishing for, or dependent on or associated with, the fish stocks covered by [the] Convention."

The members of the Commission and the Commissioners are listed in the inside back cover of this report.

The IATTC staff's research responsibilities are met with four programs, the Data Collection and Data Base Program, the Biology and Ecosystem Program, the Stock Assessment Program, and the Bycatch Program and International Dolphin Conservation Program.

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INTER-AMERICAN TROPICAL TUNA COMMISSION

SPECIAL REPORT 18

AN EVALUATION OF THE AREA STRATIFICATION USED FOR SAMPLING TUNAS IN THE EASTERN PACIFIC OCEAN AND IMPLICATIONS FOR ESTIMATING TOTAL ANNUAL CATCHES

This is a copy of a copyrighted thesis accepted by the faculty of San Diego State University in partial fulfillment of the requirements of the degree of Master of Science. This Special Report is identical to the thesis, except for some corrections made in Table 1.1.

by

Jenny M. Suter

La Jolla, California, USA
2010

AN EVALUATION OF THE AREA STRATIFICATION USED FOR SAMPLING TUNAS IN THE EASTERN PACIFIC OCEAN AND IMPLICATIONS FOR ESTIMATING TOTAL ANNUAL CATCHES

A Thesis

Presented to the

Faculty of

San Diego State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Statistics

---

by

Jenny Marie Suter

Spring 2008

SAN DIEGO STATE UNIVERSITY

The Undersigned Faculty Committee Approves the

Thesis of Jenny Marie Suter:

An Evaluation of the Area Stratification Used for Sampling Tunas in the Eastern Pacific Ocean and Implications for Estimating Total Annual Catches

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Approval Date

DEDICATION

I am dedicating this thesis to Pat Tomlinson. He is a sampling guru! And the backbone of the sampling program at the IATTC. More importantly, he is a good friend. He kept me motivated to finish this project and provided me with the years of support I needed to do so. Pat has been there to answer all of my questions, no matter how intelligent, insightful, or annoying. He is a resource of information and I could not have completed this without him! Thanks, Pat!

One fish, two fish, red fish, blue fish. Black fish, blue fish, old fish, new fish. This one has a little star. This one drives a little car. Say, what a lot of fish there are!

-Dr. Seuss

ABSTRACT OF THE THESIS

An Evaluation of the Area Stratification Used for Sampling Tunas in the Eastern Pacific Ocean and Implications for Estimating Total Annual Catches
by
Jenny Marie Suter
Masters of Science in Statistics
San Diego State University, 2008

The Inter-American Tropical Tuna Commission (IATTC) staff has been sampling the size distributions of tunas in the eastern Pacific Ocean (EPO) since 1954, and the species composition of the catches since 2000. The IATTC staff use the data from the species composition samples, in conjunction with observer and/or logbook data, and unloading data from the canneries to estimate the total annual catches of yellowfin (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*), and bigeye (*Thunnus obesus*) tunas. These sample data are collected based on a stratified sampling design. I propose an update of the stratification of the EPO into more homogenous areas in order to reduce the variance in the estimates of the total annual catches and incorporate the geographical shifts resulting from the expansion of the floating-object fishery during the 1990s.

The sampling model used by the IATTC is a stratified two-stage (cluster) random sampling design with first stage units varying (unequal) in size. The strata are month, area, and set type. Wells, the first cluster stage, are selected to be sampled only if all of the fish were caught in the same month, same area, and same set type. Fish, the second cluster stage, are sampled for lengths, and independently, for species composition of the catch. The EPO is divided into 13 sampling areas, which were defined in 1968, based on the catch distributions of yellowfin and skipjack tunas. This area stratification does not reflect the multi-species, multi-set-type fishery of today.

In order to define more homogenous areas, I used agglomerative cluster analysis to look for groupings of the size data and the catch and effort data for 2000–2006. I plotted the results from both datasets against the IATTC Sampling Areas, and then created new areas. I also used the results of the cluster analysis to update the substitution scheme for strata with catch, but no sample. I then calculated the total annual catch (and variance) by species by stratifying the data into new Proposed Sampling Areas and compared the results to those reported by the IATTC.

Results showed that re-stratifying the areas produced smaller variances of the catch estimates for some species in some years, but the results were not significant.

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LIST OF ABBREVIATIONS AND DEFINITIONS

Abbreviations

IATTC – Inter-American Tropical Tuna Commission

EPO – Eastern Pacific Ocean, from the coastline of the Americas to 150°W

LFSC – Length frequency and species composition sampling program

CYRA – Commission's (IATTCs) yellowfin regulatory area

CAE – Data on the catches and effort (number of sets made) for a fishery.

TAC – Total annual catch, reported in metric tons

Species

YFT – Yellowfin tuna (*Thunnus albacares*)

SKJ – Skipjack tuna (*Katsuwonus pelamis*)

BET – Bigeye tuna (*Thunnus obesus*)

Set types

DOL – dolphin associated

UNA – unassociated school

FOB – floating-object

FAD – fish aggregating device, type of floating object set

Vessel types

PS – purse-seine vessel

LP – pole-and-line (baitboat) vessel

LL – longline vessel

Units of measurement

mm – millimeter

cm – centimeter

kg – kilogram

mt – metric ton

Definitions

5° x 5° area – A 5° x 5° block of ocean (latitude x longitude), defined by its southeast corner

Samplers – IATTC field office staff that take LFSC samples in various ports

Observers – Scientists placed aboard larger purse-seine vessels to monitor the catches, bycatches, and discards of fish and other sea animals

Surface fleet – Purse-seine and pole-and-line vessels that fish for tunas in the EPO

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CHAPTER 1

INTRODUCTION

The Inter-American Tropical Tuna Commission (IATTC) is an international fisheries organization, founded in 1949, to manage the tuna fisheries of the eastern Pacific Ocean (EPO). Based on recommendations from its scientific staff and other factors, two of the duties of the IATTC staff are to estimate the total annual catch (TAC) of each species of tuna and the size composition of the catch by purse-seine and pole-and-line vessels in the EPO. To achieve these objectives the staff obtains data from captain's logbooks, records of scientific observers monitoring fishery impacts on dolphins, unloading records from canneries, as well as from its own length-frequency and species composition sampling program (also known as 'the sampling program').

The three main species caught by the surface fleet are yellowfin (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*), and bigeye (*Thunnus obesus*) tunas. Pacific bluefin (*T. orientalis*) and black skipjack (*Euthynnus lineatus*) tunas are also taken by this fishery, but in much smaller numbers. Tunas are caught by several different types of fishing vessels and gear types that target fish in different depths of the ocean. In the EPO, purse-seine, pole-and-line, and longline vessels take the majority of the tuna catch, although recreational and artisanal fisheries also exist in the coastal areas. Purse-seiners use large nets to encircle schools of fish and catch tunas in three types of sets: (1) sets in which tunas are associated with dolphins, (2) sets in which tunas are associated with floating objects, and (3) sets on unassociated schools of fish. Pole-and-line vessels use bait to attract schools of fish, and use poles (up to four at a time) with lines and artificial lures or baited hooks to catch tunas. Longline vessels lay miles of lines with hooks at various intervals and depths, targeting fish in deeper waters than the purse-seine and pole-and-liners. More comprehensive explanations of these and other types of fishing gear and methods may be found in Bayliff (2001).

The IATTC staff samples fish caught by the purse-seine and pole-and-line fleets (also known as 'the surface fleet') and uses this information, in conjunction with data received from canneries, observers and logbooks, to estimate total annual catches, by species, for these fisheries. Data from longline vessels are collected in a different manner and are not discussed further in this paper. The TAC of all species combined is calculated by summing all of the catch information received for each vessel trip from the canneries and the establishments that process fish destined for the fresh fish market. For a small portion of the trips this information is not available and the catch information is calculated based upon data from the observers or the vessel logbooks. Previously, these data were also summed by species and used as the TAC by species. In 2000, the sampling program was expanded to include independent estimates of the species composition of the catches, and these data are now used in conjunction with the cannery and observer and/or logbook data to estimate the TAC by species.

Since the inception of the species composition sampling, studies have shown that the amounts of bigeye tuna have often been underestimated in the catches reported by the canneries, observers, and vessel logbooks (IATTC, unpublished data). This is most likely due to the fact that bigeye and yellowfin tuna can be difficult to distinguish from one another, especially at certain sizes (Schaefer, 1999). Due to these findings, the IATTC began adjusting the data on the catches of yellowfin, skipjack, and bigeye tunas based on the species composition estimates obtained from sampling the catches. These estimates are shown in Table 1.1 (p. 4; modified from Tomlinson, 2004).

While the species composition estimates from sampling are believed to be more accurate than those from the unloading data, the design of the sampling program to collect these data may still be improved. The fishery for tunas in the EPO has changed and expanded over the years, from a coastal fishery off of the Americas dominated by pole-and-line vessels, to one fished mostly by purse-seine vessels that usually fish further offshore. For sampling purposes, the EPO is divided into smaller areas, which have been changed with the expansion of the fishery. However, the existing area stratification does not fit the current state of the fishery because the areas have not been updated since the late 1960's. If the areas can be redrawn to encompass more homogenous fisheries, the accuracy of the TAC estimates may be increased.

This study has several objectives related to sampling program and the estimation of the TAC by species:

1. Review the history of the fishery and the sampling program, emphasizing the importance of the area stratification and how it has been derived.
2. Examine the geographical distributions of the average sizes and standard deviations of the three main species of tunas caught by purse-seine and pole-and-line vessels and compare those to the IATTC Sampling Area stratification and to the results of objective 3.
3. Examine the geographical distributions of the catches of the different species of tunas made by purse-seine and pole-and-line vessels and the different types of sets made by purse seiners and compare those to the IATTC Sampling Area stratification and to the results of objective 2.
4. Propose new sampling areas and estimate the TAC and variance by species
5. Evaluate the Proposed Sampling Areas and compare the TAC and variance estimates to those calculated for the IATTC Sampling Areas.
6. Derive a method to calculate the variance of the estimates of TAC by species.

Table 1.1: Estimates of Total Annual Catch used by the IATTC, 2000–2006

Year	Species	Standard Catch	Species Composition		
			Catch	Low	High
2000	Yellowfin	272,105	257,748	251,375	264,248
	Skipjack	210,252	204,486	193,731	216,007
	Bigeye	74,578	94,701	83,826	104,683
2001	Yellowfin	397,417	384,626	378,548	392,184
	Skipjack	144,949	143,270	135,556	151,983
	Bigeye	47,399	60,870	53,743	67,518
2002	Yellowfin	423,136	413,406	406,976	418,323
	Skipjack	160,829	153,917	147,566	161,830
	Bigeye	40,814	57,457	51,634	62,230
2003	Yellowfin	399,821	380,832	372,777	387,588
	Skipjack	264,818	275,559	266,958	286,674
	Bigeye	45,965	54,212	46,912	60,298
2004	Yellowfin	282,516	269,667	260,442	277,843
	Skipjack	200,244	197,834	187,428	207,932
	Bigeye	51,837	67,096	59,501	76,049
2005	Yellowfin	277,734	269,376	262,146	278,621
	Skipjack	276,178	263,153	253,096	272,113
	Bigeye	48,429	69,813	63,932	74,775
2006	Yellowfin	185,870	166,748	161,845	171,298
	Skipjack	301,890	297,284	291,226	304,659
	Bigeye	60,099	83,827	77,848	88,842

Note: ‘Standard’ refers to using the cannery data for the estimates of catches by species and ‘species composition’ refers to the method used in this paper.

CHAPTER 2

HISTORY OF THE FISHERY AND THE SAMPLING PROGRAM

In this chapter, I give a brief history of the tuna fishery in the EPO since the 1950s, with emphasis on the expansion of the fishery, followed by a section on the history of the length-frequency and species composition sampling (LFSC) program developed and used by the IATTC staff. I describe the sampling design and methods used to take samples, and briefly outline the history of the estimation process and some of its caveats. In the last section, I outline other studies that were conducted to test different assumptions inherent to the sampling program, and give a summary of studies that have used the data from the sampling program and how their results pertain to the my research. Finally, I review additional published literature regarding methods for sampling fisheries populations.

2.1 History of the Fishery

The tuna fisheries of the EPO have gradually expanded further offshore as a result of the increasing size of vessels and gear modifications. In addition, the fleet has changed dramatically from being dominated by small, US-flag vessels to an international fleet consisting of many large vessels with capacities of more than 1,000 metric tons (mt) of fish. The international fleet began increasing in numbers during 1968-1970 (Calkins & Chatwin, 1971), and has dominated the fishery since the mid 1990s (IATTC, 2006). Yellowfin and skipjack tuna were the primary species fished in the EPO until the 1990s, when fishermen realized they could attract skipjack and bigeye tunas to the surface by placing fish-aggregating devices (FADs) in the water and encircling them with a purse-seine net. About 80% of the sets on floating objects since the mid-1990s have been made on FADs (IATTC, 2006: Table A-9). This change in fishing strategy has greatly affected not only the bigeye, but has increased the catches of smaller yellowfin and of skipjack tunas, and bycatches of other marine species (IATTC, 2006). The floating-object fishery extends west, far beyond the traditional areas used to manage the yellowfin fishery in the past. The IATTC staff has been studying different aspects of the current state of the fisheries in the EPO, yet many of the studies rely partially on the data from the sampling program based on sampling areas that were defined well before these changes occurred.

Prior to and during the 1950s, the fishery targeted yellowfin and skipjack tunas, mostly off the coast of North America (Shimada, 1958). The fishery expanded to the south into warmer waters, where fishing could be carried out throughout the year (Shimada, 1958). Pole-and-line or "baitboat" vessels dominated the fishery until about 1960, when many of the larger ones were converted to purse-seiners. These vessels were much more efficient at catching tunas, and the fishing intensity increased remarkably (Alverson, 1963). By the end of 1963, the purse seiners were fishing further offshore than before (Calkins & Chatwin, 1967). The increased fishing intensity led the IATTC to implement the first quota on fishing for yellowfin tunas within the Commission's Yellowfin Regulatory Area (CYRA) (Figure 2.1) in 1966 (Calkins & Chatwin, 1967). In 1969, the fishery expanded outside of the CYRA into areas that were not previously exploited (Calkins & Chatwin, 1971). These offshore areas produced large catches of yellowfin tunas that were taken in association with spotted and spinner dolphins (*Stenella attenuata* and *S. longirostris*), mostly between 5^{o}N and 15^{o}N (Calkins, 1975; IATTC, 2005: Figure 9). During 1971–1974, the fishery moved westward to 150^{o} W (Calkins, 1975; IATTC, 1975). The fishery continued to expand into other areas, but at a lesser rate, during 1975–1978 (Orange & Calkins, 1981). Catches of yellowfin and skipjack reached record highs in 1976 and 1978, respectively (Orange & Calkins, 1981), but then began to decline. Regulations on yellowfin catches continued through 1979 in the CYRA (IATTC, 1986). Skipjack and other tunas were not regulated during this time.

In 1982, the fleet capacity began to decline after more than a decade of growth, due to vessels leaving the fishery for the western Pacific or other areas (IATTC, 2006). This decline continued until 1985, when some of those vessels returned to the eastern Pacific to fish (IATTC, 2002). In 1982–1984, a major El Niño developed in the EPO, which may have affected the vulnerability of the fish to capture (IATTC, 2006). Catches of yellowfin were low during 1982 and 1983 (IATTC, 2006), but increased substantially in 1984–1985, when effort was directed toward larger, higher-priced yellowfin tunas that were caught in association with dolphins (IATTC, 2002).

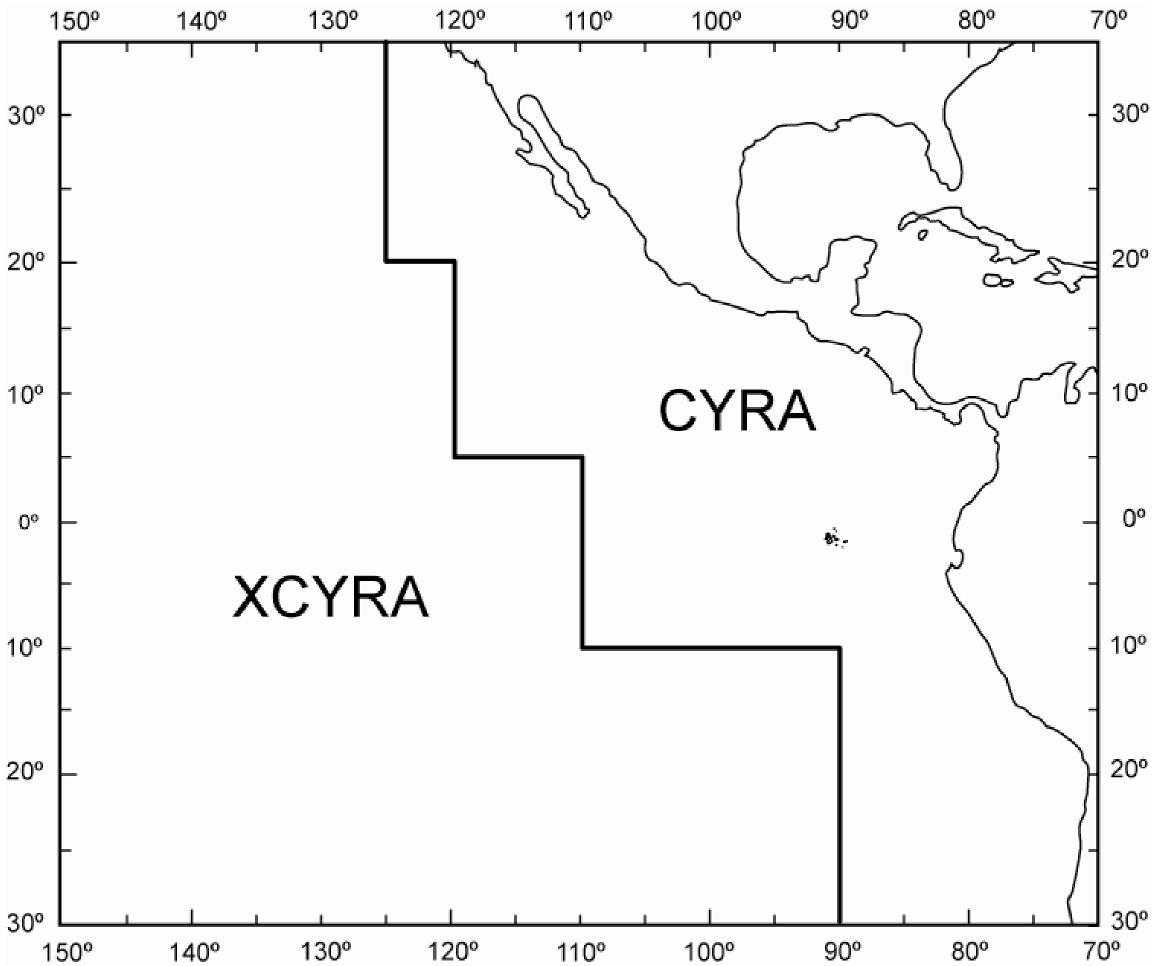

Figure 2.1. Map of the Commission's Yellowfin Regulatory Area (CYRA).

In 1990, the U.S. tuna-canning industry adopted a policy of not purchasing tunas caught in association with dolphins, and many of the U.S.-flag vessels left the EPO for the western Pacific or changed their registrations to other nations (IATTC, 2006). The number of vessels fishing in the EPO declined during this period, but began to increase again during the 1990s (IATTC, 2006). The storage capacities of the newer vessels that entered the fishery in the 1990's were much greater than before. Thus, even with a reduced number of vessels, the overall storage capacity was greater (IATTC, 2006).

Fishing for tunas by attracting schools of fish to FADs placed in the surface water, became common during the 1990s (IATTC, 2006). Previously, tunas were sometimes caught in association with flotsam, such as logs, whale carcasses, kelp patties, and other debris that floated in the surface waters. The new FAD fishery, which targeted mostly skipjack tuna, incidentally increased the catches of bigeye tuna (IATTC, 2006). Previous to the early 1990s, only small catches of bigeye were taken by purse-seiners and pole-and-line vessels. The FAD fishery quickly expanded south of the traditional floating-object fishery area (Watters, 1999). Due to the increasing catches of bigeye, the IATTC regulated bigeye tuna catches in the EPO for the first time in 1998 per a resolution adopted at the 61st meeting of the IATTC, in June 1998 (IATTC, 2000, p. 11-13). However the greatest catch of bigeye tuna (94,000 mt) was taken in 2000 and the catches have remained high ever since (IATTC, *in press*) (Table 2.1).

As the vessel capacity continued to increase through 2006 (IATTC, *in press*), catches of yellowfin (439,000 mt in 2002) and skipjack (278,000 mt in 2003) tunas reached record highs (Table 2.1). The IATTC has passed various regulations (area and/or seasonal closures) on fishing for yellowfin and bigeye tunas in recent years to try to protect the stocks from over-exploitation (IATTC, 2006).

More detailed records and maps of the expansion of the fisheries through 1978 can be found in Calkins and Chatwin (1967), Calkins and Chatwin (1971), Calkins (1975), and Orange and Calkins (1981). Maps of the geographical distributions of the catches of yellowfin, skipjack, and bigeye tunas, along with the numbers of purse-seine sets, by set type, in the EPO, 1965–1998, can be found in Watters (1999). Additional information on the fisheries in the EPO may be found in the Annual Reports (1950 to present) and Fishery Status Reports (2003 to present) of the IATTC. Similar information on the geographical distributions of catch and effort data in the EPO during the time series (2000–2006) covered in this report may be found in Section 4.1.

2.2 History of the Sampling Design and Methods

The IATTC staff has been sampling the size distributions of yellowfin and skipjack tunas caught in the EPO since 1954, Pacific bluefin tuna since 1973, and bigeye tuna since 1975. The goal of the initial sampling program was to sample fish from each month in each sampling area, so the modal progression of the sizes of fish could be studied (since fish grow over time), along with movement patterns among areas (Hennemuth, 1957). The size data have also been used to estimate growth, mortality, yield per recruit, and year-class abundance (IATTC, 1996), and are some of the basic data used in age-structured stock assessment

Table 2.1. Estimated Retained Catches (mt) of Tunas in the EPO by Gear Type, 1977–2006

Year	Yellowfin					Skipjack					Bigeye					ALL SPECIES	
	PS	LP	LL	Other	Total	PS	LP	LL	Other	Total	PS	LP	LL	Other	Total	PS + LP	ALL GEARS
1977	184,922	1,841	12,355	262	199,380	84,603	7,522	112	1,871	94,108	11,161	2	74,086	-	85,249	290,051	378,737
1978	158,801	3,888	10,188	1,119	173,996	172,294	6,047	61	1,274	179,676	18,539	-	70,659	-	89,198	359,569	442,870
1979	170,650	4,789	11,473	225	187,137	133,695	6,346	33	1,430	141,504	12,097	-	55,435	1	67,533	327,577	396,174
1980	143,042	1,481	13,477	850	158,850	130,912	5,225	26	1,945	138,108	21,938	-	64,335	130	86,403	302,598	383,361
1981	168,234	1,477	7,999	804	178,514	119,165	5,906	20	910	126,001	14,921	-	53,416	2	68,339	309,703	372,854
1982	114,755	1,538	10,961	283	127,537	100,499	3,760	28	383	104,670	6,939	42	53,365	-	60,346	227,533	292,553
1983	83,929	4,007	10,895	1,182	100,013	56,851	4,387	28	884	62,150	4,575	39	60,043	98	64,755	153,788	226,918
1984	135,785	2,991	10,345	357	149,478	59,859	2,884	32	838	63,613	8,861	2	46,394	16	55,273	210,382	268,364
1985	211,459	1,070	13,198	309	226,036	50,829	946	44	181	52,000	6,056	2	66,325	21	72,404	270,362	350,440
1986	260,512	2,537	22,808	292	286,149	65,634	1,921	58	135	67,748	2,686	-	102,425	9	105,120	333,290	459,017
1987	262,008	5,107	18,911	333	286,359	64,019	2,233	37	175	66,464	1,177	-	100,121	16	101,314	334,544	454,137
1988	277,293	3,723	14,660	959	296,635	87,113	4,325	26	661	92,125	1,535	5	72,758	6	74,304	373,994	463,064
1989	277,996	4,145	17,032	566	299,739	94,934	2,940	28	1,028	98,930	2,030	-	70,963	-	72,993	382,045	471,662
1990	263,253	2,676	34,633	1,722	302,284	74,369	823	41	1,884	77,117	5,921	-	98,871	15	104,807	347,042	484,208
1991	231,257	2,856	30,730	1,248	266,091	62,228	1,717	33	1,917	65,895	4,870	31	104,194	21	109,116	302,959	441,102
1992	228,121	3,789	18,527	3,277	253,714	84,283	1,957	24	1,090	87,354	7,179	-	84,799	21	91,999	325,329	433,067
1993	219,492	4,951	23,809	3,701	251,953	83,830	3,772	61	2,270	89,933	9,657	-	72,473	59	82,189	321,702	424,075
1994	208,408	3,625	29,545	1,979	243,557	70,126	3,240	73	730	74,169	34,899	-	71,359	807	107,065	320,298	424,791
1995	215,434	1,268	20,054	2,570	239,326	127,047	5,253	77	1,915	134,292	45,321	-	58,256	1,381	104,958	394,323	478,576
1996	238,607	3,762	16,425	1,355	260,149	103,973	2,555	52	1,512	108,092	61,311	-	46,957	746	109,014	410,208	477,255
1997	244,878	4,418	21,448	2,004	272,748	153,456	3,260	135	121	156,972	64,272	-	52,571	23	116,866	470,284	546,586
1998	253,959	5,085	14,212	2,166	275,422	140,631	1,684	294	208	142,817	44,129	-	46,347	617	91,093	445,488	509,332
1999	281,920	1,783	10,651	3,947	298,301	261,565	2,044	201	1,409	265,219	51,158	-	36,425	541	88,124	598,470	651,644
2000	255,025	2,431	22,772	2,034	282,262	205,459	231	68	67	205,825	93,753	-	47,579	269	141,601	556,899	629,688
2001	382,229	3,916	28,475	1,339	415,959	143,784	448	1,215	479	145,926	61,408	-	68,726	47	130,181	591,785	692,066
2002	412,407	950	24,002	1,799	439,158	153,398	616	261	388	154,663	57,437	-	74,405	31	131,873	624,808	725,694
2003	381,147	470	23,763	2,894	408,274	274,490	638	635	2,817	278,580	54,509	-	59,666	39	114,214	711,254	801,068
2004	269,463	1,884	16,970	3,153	291,470	198,678	528	712	1,116	201,034	67,337	-	43,354	210	110,901	537,890	603,405
2005	268,585	1,844	10,442	3,968	284,839	261,599	1,278	241	1,786	264,904	68,699	-	43,433	47	112,179	602,004	661,921
2006	166,739	693	3,976	1,878	173,287	308,148	429	184	89	308,850	71,195	-	30,271	8	101,474	547,204	583,610

Note: The purse-seine (PS) and pole-and-line (LP) data have been adjusted to the species composition estimates and are preliminary. (LL=Longline) models (IATTC, 2006). In 2000, the length-frequency sampling program was broadened to include an independent sample of the species composition of the catches. The species composition data are used in conjunction with the size data, observer and/or logbook data, and cannery data, to estimate the TAC of the three main species of tuna.

Sampling began in San Diego, California, and was expanded to San Pedro, California, by the end of 1954, covering 10 different canneries. As the fishery expanded south, landings in Peru were first sampled in 1956, and those in Ecuador beginning in 1958 (Hennemuth, 1961a). By the early 1960's, samples were also taken in ports in Costa Rica, Mexico, Panama, and Puerto Rico (Alverson, 1963). Currently, the IATTC is headquartered in La Jolla, California, and operates field offices in Manta and Las Playas, Ecuador, Manzanillo and Mazatlan, Mexico, Panama City, Panama, and Cumaná, Venezuela. The IATTC has plans to open another office in Puntarenas, Costa Rica (E. Everett, IATTC; pers. comm.). At other times in the history of the sampling program, the IATTC had field offices in Ensenada, Mexico, Terminal Island, California, and Mayagüez, Puerto Rico. Infrequently, samplers have also been sent to other, smaller ports.

The current sampling frame (Cochran, 1977) employed by the IATTC staff is a stratified two-stage (cluster) random sampling design with first stage units varying (unequal) in size (Tomlinson, Tsuji, & Calkins, 1992). Sampling within both stages is assumed to be simple random sampling (Tomlinson *et al.*, 1992), but these are sampled opportunistically to approximate random sampling (Wild, 1994). This is common in most fishery sampling programs and is difficult to circumvent (Crone, 1995; Tomlinson, 1971). This scheme is similar to that of the initial design, with some modifications and additions made as the fishery and unloading processes changed over time. The initial goal of sampling fish in each *month* in each *area* defined the stratification of the sampling model. These strata were continually used as the basis for taking a sample until 2000, when a third level of stratification was added, *set type* (purse-seine vessels only). Wild (1994) confirmed that by stratifying the length-frequency samples by set type, the variance of the monthly catches of the individual cohorts of fish decreased overall.

The current strata are 12 months, 13 areas, and 7 gear types, giving 1092 possible strata. The reason for this design is due primarily to the manner in which the fish are caught, stored on the vessels, and unloaded at the canneries; however, other parts of the design are included to control some of the variances. Since after capture, fish are stored in multiple wells on each vessel, the sampling model also required choosing wells to sample and choosing fish within wells to measure, yielding a two-stage cluster model. Each of the following sections includes a description of a particular feature of the sampling design, with reasons for the stratification or clustering, a brief history of the changes, and how the strata are used for reporting purposes. This is followed by a section on dealing with strata with missing data and a section on how the procedure for estimating the total catch by species has changed over time. The sampling instructions employed by the IATTC are included in the Appendix. The last section in this chapter contains a review of the other literature that addresses sampling fishes or is related to my research.

2.2.1 Area Stratification

The sampling areas used for data collection changed as the fishery expanded and fishing methodologies improved. The IATTC staff adopted the first area stratification in 1957 (IATTC, 1979). The areas expanded with the growing fishery, and by the late 1960s the IATTC categorized the EPO into 10 main fishing areas, 4 of which had "experimental" subareas (P. Tomlinson, IATTC; pers. comm.). The IATTC staff used this area stratification for sampling the lengths of fish until the late 1990s, when it redefined the EPO by 13 sampling areas. For reporting purposes, however, these area strata were often grouped into larger areas. The IATTC staff continues to use these 13 areas as the basis for sampling the catches. This current area stratification is based on the boundary of the CYRA (Figure 2.1), which does not reflect the multiple-species and multiple-gear-types fisheries of today.

In the 1950s, there were 12 original sampling areas (Figure 2.2) determined by the distribution of the total catch of yellowfin and skipjack tunas (Hennemuth, 1957). The catches were consistently concentrated in certain areas, and lines were drawn through zones of lesser concentration of total catch (areas with less than about 50 short tons of a species (yellowfin or skipjack) per 1^{o} x 1^{o} area per year) (Hennemuth, 1957; Shimada 1958). It was believed that 1^{o} x 1^{o} areas with less than the 50 short tons of catch were less likely encountered during sampling (Hennemuth, 1957).

Hennemuth (1957) stated that areas of high catch were likely associated with oceanographic and topographic phenomena, so they could vary from year to year, or season

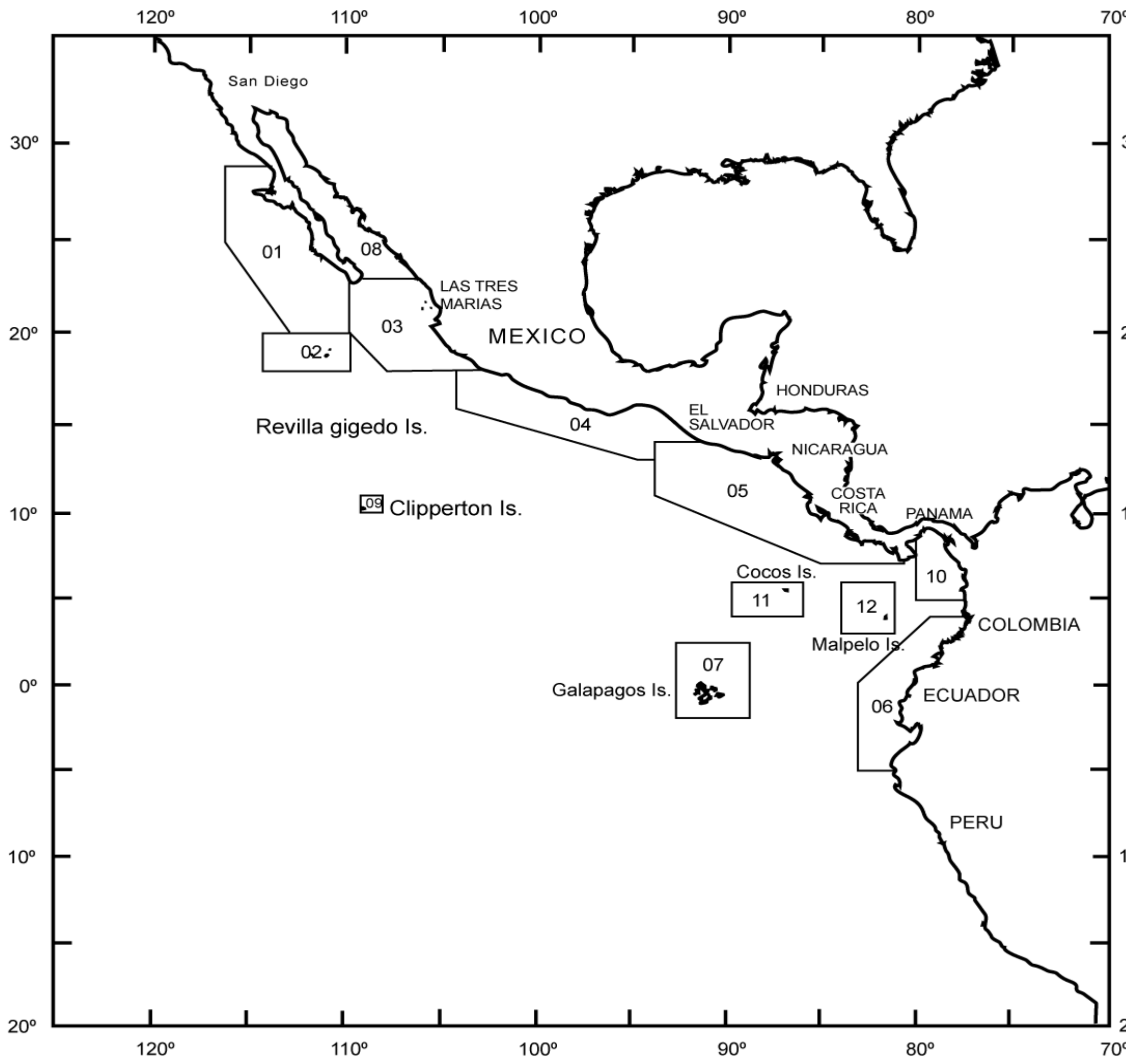

Figure 2.2. The 12 original sampling areas used to sample tunas along the coast of the EPO in the mid-1950s.

to season, but, he did not investigate this. Further, he noted that the lines of demarcation could vary from year to year due to changes in the distribution of total catches. No such design feature was incorporated into the sampling designs; however, the areas were redrawn in order to encompass the growing fishery.

Hennemuth (1961a) described 14 areas (Figure 2.3); the initial 12 were the same as in Figure 2.3, with two areas added off the coasts of Peru and Chile since in 1956, fish were unloaded in Peru for the first time and length-frequency samples were taken there. These areas were based on the distribution of total catch for 1951–1953.

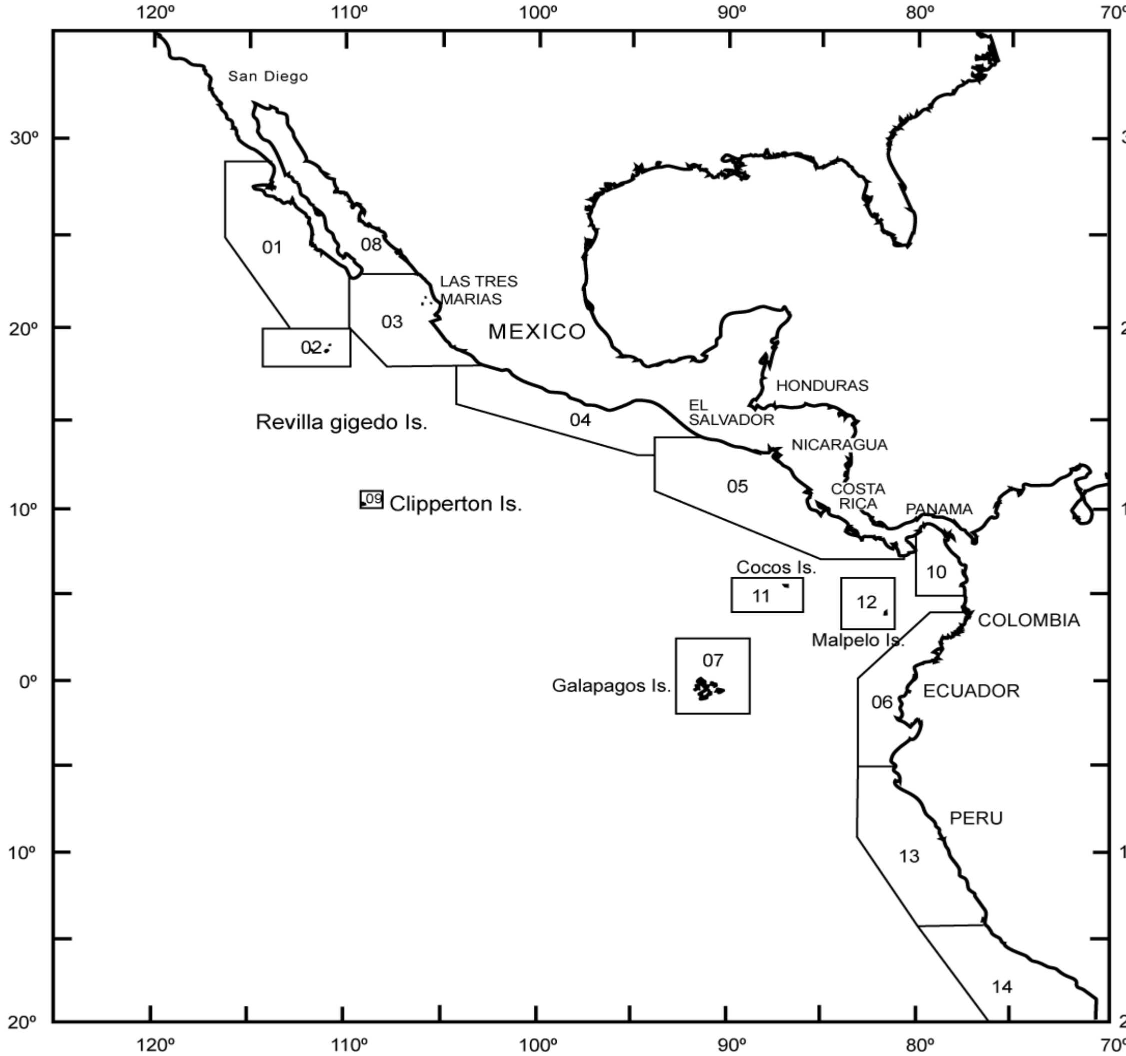

Figure 2.3. The second area stratification used for sampling tunas along the coast of the EPO in the late 1950s to the early 1960s.

Davidoff (1963) described 14 areas (Figure 2.4, p. 14) based on the areas in described by Hennemuth (1961a: Figure 2.3); with some areas expanded due to the incorporation of data from the California State Fisheries Laboratory. Similar areas were also described in Calkins (1965) and Davidoff (1965).

Although not published until 1985 (IATTC, 1985), in 1968 the EPO was divided into 10 areas (Figure 2.5, p. 15), four of which were each split into a coastal area and an "experimental" area between the coast and the western boundary of the CYRA (Figure 2.1). The IATTC staff used these areas for sampling the lengths of fish, until it regrouped the experimental areas, resulting in the 13 sampling areas (referred to as 'IATTC Sampling

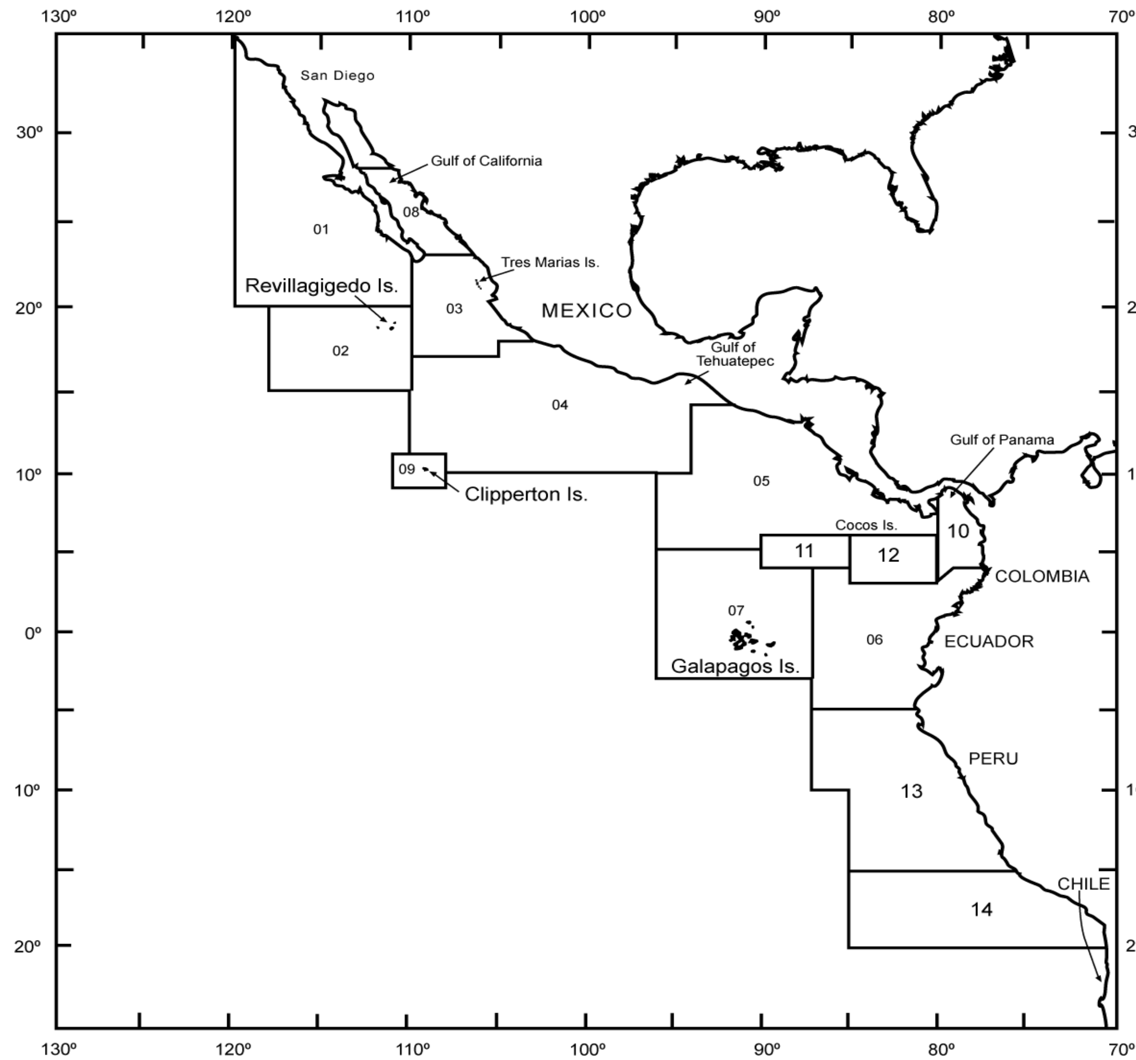

Figure 2.4. The third area stratification used for sampling tunas along the coast of the EPO in the early to mid 1960s.

Areas', see Figure 2.6, p. 16). To create the IATTC Sampling Areas (Figure 2.6), the experimental areas were split into their own distinct areas; however Areas 4E and 5E were combined to form Area 3. These figures can be found in Tomlinson *et al.* (1992). The IATTC Sampling Areas first appeared in an IATTC Annual Report for 1998 (IATTC, 1999), however, IATTC scientists doing age-structured population modeling used these areas as early as 1968 (P. Tomlinson, IATTC; pers. comm.), and mentioned in the IATTC Annual Report of 1989 (IATTC, 1990).

In the IATTC Annual Report for 1996 (IATTC, 1997), 12 sampling areas were reported, 11 within the CYRA and one outside area between the CYRA boundary and 150^{o}W

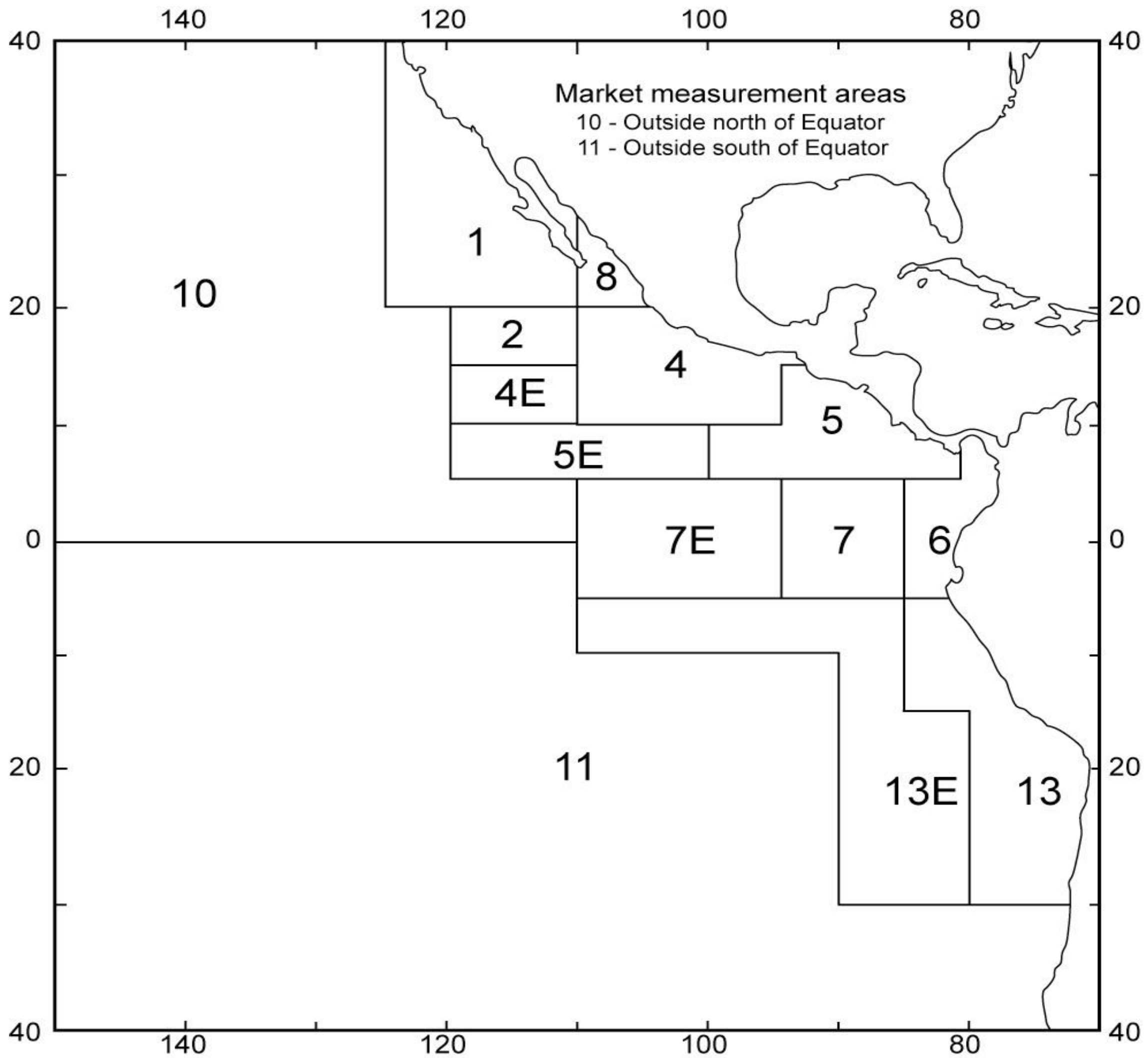

Figure 2.5. The fourth area stratification used for sampling tunas in the EPO from 1968–1997 with 'experimental' areas denoted by E.

(areas 10 and 11 collapsed into one area for reporting purposes). The current IATTC sampling program is based on the 13 areas first used in 1968 (IATTC Sampling Areas).

The IATTC regularly publishes Quarterly and Annual Reports, along with Bulletins and Special Reports at irregular intervals. Various area groupings have been used for these different reports. Since 1968, the EPO was divided into 10 areas, 8 within the CYRA and 2 between the CYRA and 150^{o} W for the IATTC Annual Report series, as shown in the top panel of Figure 2.7 (p. 17). The area grouping for the Annual Reports was simply aggregations of the IATTC Sampling Areas (Figure 2.6). For the IATTC Quarterly Report

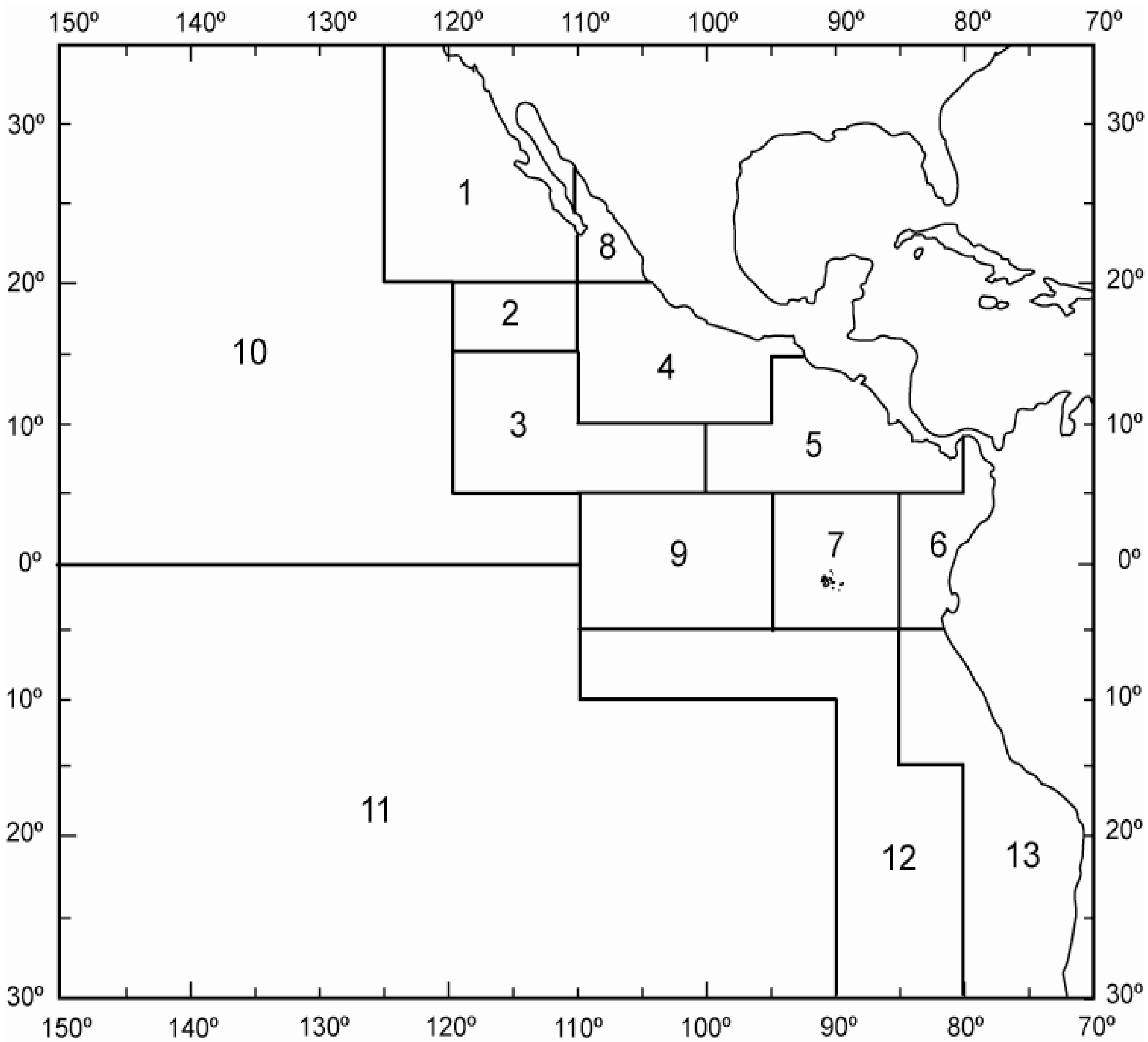

Figure 2.6. The current IATTC area stratification used for sampling tunas in the EPO.

series data were divided into 8 areas, 7 within the CYRA and one between the CYRA and 150° W (Figure 2.7, lower panel).

Currently, the Fishery Status Reports, which have taken place of the Annual Reports for summarizing the majority of the fishery data since 2003, contain length-frequency data stratified into the 13 areas in Figure 2.6, then further grouped into larger areas that are the same as those used for the stock assessments (Figure 2.8, p. 18). The large areas used for the stock assessments differ for each combination of species and gear type, yielding 10 yellowfin fisheries (one pole-and-line fishery and nine purse-seine fisheries), eight skipjack fisheries (one pole-and-line fishery and seven purse-seine fisheries), and seven bigeye fisheries (one

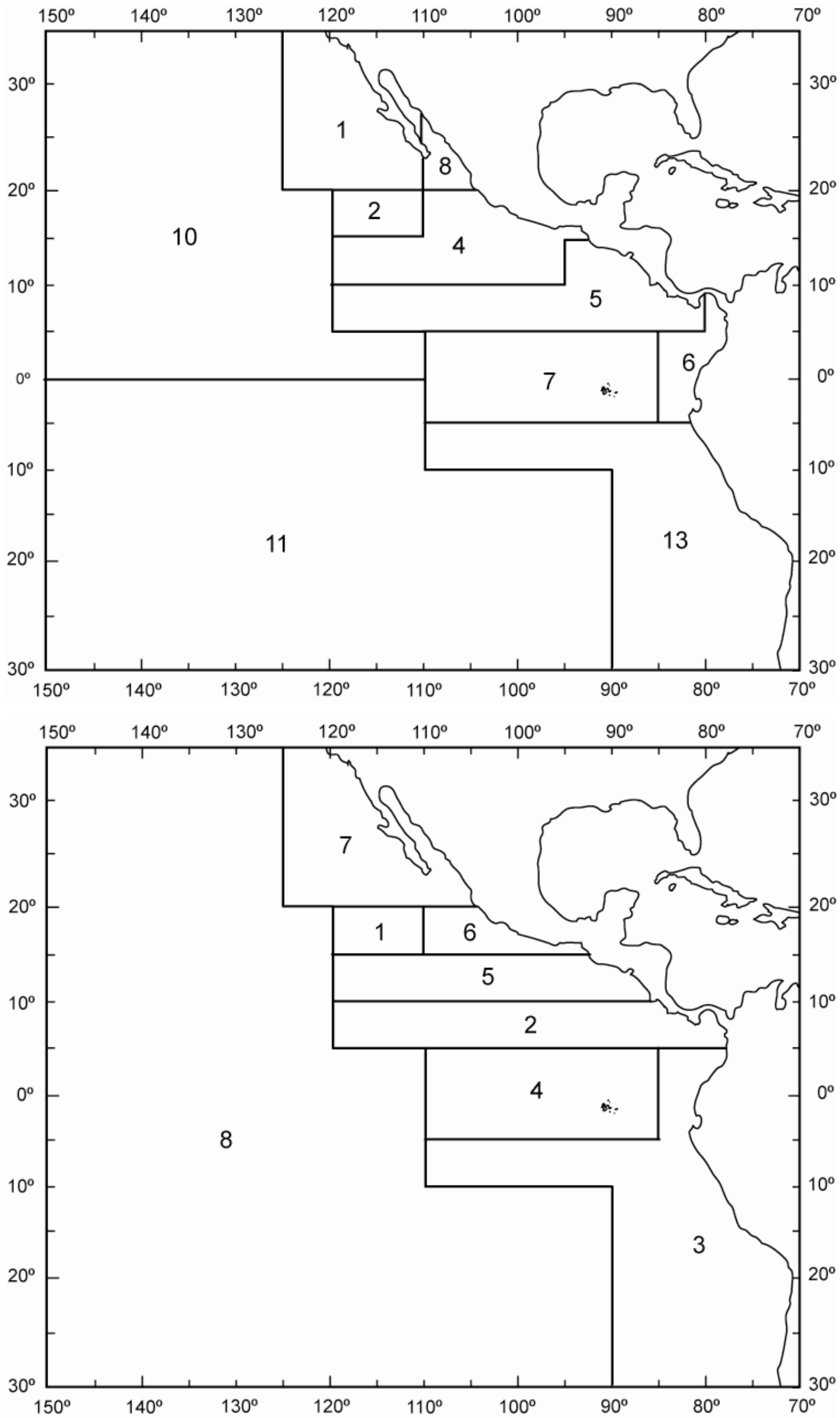

Figure 2.7. Map of the stratification of the EPO into 10 and.8 areas, respectively used for reporting fisheries data for the IATTC Annual (top panel) and Quarterly Reports (bottom panel), 1968–1999.

pole-and-line and six purse-seine fisheries). The stock assessment areas have been used since 2000. Since the fishery has changed dramatically since the inception of the FAD fishery during the early 1990s, it is due time to review this stratification and, if necessary, define more homogenous areas. This would yield better estimates of the TAC by species, resulting from improved estimates of the sizes of the captured tunas.

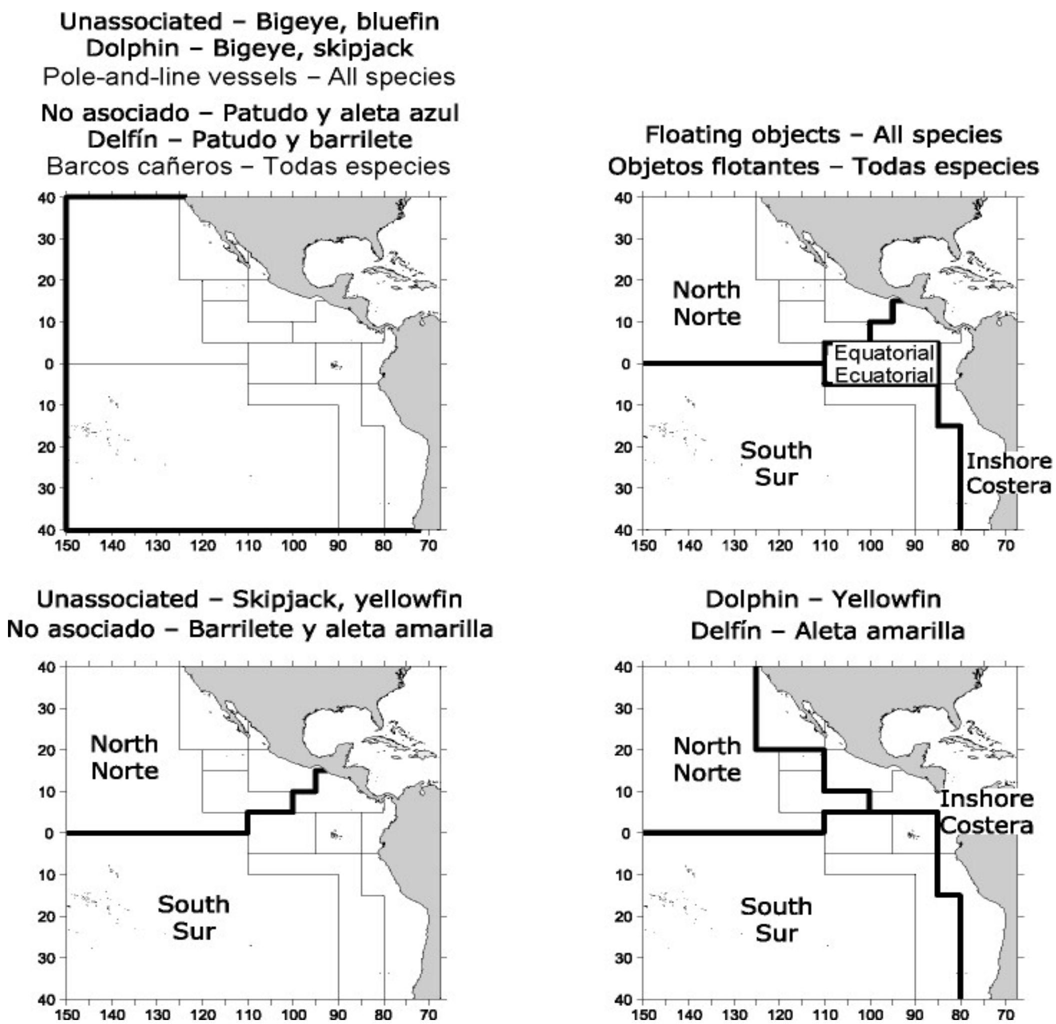

Figure 2.8 Map of the stratification of the EPO into for stock assessments and reporting purposes, 2000 to present.

2.2.2 Month Stratification

'Month' has been used as a stratum since the inception of the sampling program to compensate for growth of the fish over time. Hennemuth (1957) stated that sampling each month is desirable for the estimation of growth by modal progression and to provide information about the time and rate at which age groups enter into or depart from the catchable population. Months are often grouped into quarters for assessing the stocks of the different tunas and are reported that way in the Quarterly and Stock Assessment Reports of the IATTC.

2.2.3 Gear and/or Set Type Stratification

Besides month and area, the third level of stratification is gear type. Historically, gear type referred to the type of fishing vessel, such as pole-and-line or purse-seine. Pole-and-line vessels or "baitboats," dominated the fishery until about 1960 (IATTC, 2006). Many of the larger pole-and-line vessels were then converted to purse-seine vessels, which have dominated the fishery since (IATTC, 2006).

For sampling purposes, gear type is a combination of vessel type, vessel size class, and/or set type. For purse seiners, there are six vessel size classes, although for research purposes, they have often been classified as large (> 425 m^3 capacity) or small (≤425 m^3 capacity) by the amount of storage space, or well volume, available onboard. Combining two purse-seine vessel size classes with the three types of sets (dolphin, floating object, and unassociated), plus a category for pole-and-liners, results in seven gear types (Tomlinson, 2002 and 2004), as shown in Table 2.2.

Table 2.2. Gear Types Defined for the Sampling Program

Gear	Vessel Type	Vessel Size	Set type
1	Pole and line	—	—
2	Purse seine	Small	Floating object
3	Purse seine	Small	Unassoicated
4	Purse seine	Small	Dolphin
5	Purse seine	Large	Floating object
6	Purse seine	Large	Unassoicated
7	Purse seine	Large	Dolphin

It is possible to ignore vessel size and reduce the number of gear types to four, which has often been the case in past research (Tomlinson *et al*., 1992). In the past, when set type was ignored, data from pole-and-line and purse-seine vessels was also combined (Davidoff, 1963). For the current stock assessments, the purse-seine size classes are pooled and the data are identified by set type only, as described in Section 2.2.1 and are shown in Figure 2.8.

2.2.4 First Stage Units: Wells on Vessels

Within the described stratification, there are two cluster stages. The sampling unit (the first stage) is a well of a vessel. Wells are selected for sampling opportunistically since there are many logistical issues for choosing and/or sampling appropriate wells. For example, it is not known until the time of the vessel unloading, how many wells contain fish caught in the same month-area-set type strata. Since the total amount of catch taken in a single set is often less than the capacity of a well, multiple sets are often stored together, which can cause a well to contain fish from mixed strata. However, most of the time there are multiple wells on a vessel that do meet the stratification criteria, but, due to logistical issues; they may not always be available for sampling. A vessel may unload fish at night, when samplers are not available, or only wells with mixed strata are unloaded when samplers are available, or the unloading process of one well may be interrupted before a full sample is taken. Vessels sometimes unload in ports too far away for samplers to reach. Fortunately, most vessels that arrive in a port near an IATTC field office do have a good chance of being sampled.

Infrequently in the early years of the sampling program, wells that contained fish from more than one month and area were sampled, but only when at least 90% of the tonnage was from a single stratum (Hennemuth, 1961a). This idea was revisited during the 1970s when the rapid expansion of the fleet and vessel sizes increased the number of wells with mixed areas or months. From 1975–1979, two samples of 25 fish were taken from mixed wells in order to prevent under sampling various strata (Muhlio-Mela, 1986). The practice was discontinued, and it is not known whether the sampling data were saved or discarded.

In the 1950s the initial 10 California canneries varied in how they unloaded fish from the wells, and four different sampling methods were used to account for these differences. Hennemuth (1957) compared the different methods in order to standardize the process. He concluded that although sampling fish systematically (three slightly different methods were tested) worked in some cases, taking a “grab” sample (a fourth method) was applicable in nearly all types of unloading situations. The grab method consisted of selecting, as arbitrarily as possible, a varying number of fish from several of the buckets by which they were unloaded (Hennemuth, 1957). If the fish were unloaded via a flume that carried them into the weighing station, they were often grabbed from the chute and measured, or measured at the cutting table (P. Tomlinson, IATTC, pers. comm.). Wild (1994) confirmed that fish were sampled using the "grab" technique; however, samplers were generally working near the well opening on the vessel. This has been the most common method of sampling fish. The samplers are not instructed as to where they must be to measure fish, only that they verify that the fish that they are sampling are coming from the well they chose to sample (E. Everett, IATTC, pers. comm.).

To study the possibility of size-depth stratification of fish within the wells, three wells containing both yellowfin and skipjack were sampled throughout the entire unloading process (Hennemuth, 1957). He divided these results into upper, middle, or lower one-third proportions of each well and compared their length-frequency distributions. He concluded that there was some size-depth separation for skipjack, but not yellowfin. He further concluded that it is important to have a random selection for which portion of a well is sampled. Currently, the well is divided into quarters instead of thirds, but the section sampled is chosen opportunistically, since the unloading process is lengthy and it is not feasible for the samplers to know what portion of the well may be available to sample until they are standing next to it.

In some ports, fish are unloaded from wells based on their size and/or species. This type of unloading began in 1985, when some canneries offered higher prices for larger yellowfin tuna (Wild, 1994). Prior to 2000, if a well was unloaded this way, each "sort" was treated as an independent well sample and recorded in the database that way (P. Tomlinson, IATTC; pers. comm.). When the sampling program was revised in 2000, a well unloaded by size and/or species groupings was recorded as a "sorted" well. These data were treated slightly differently during the estimation process. The first method used to handle sorted wells was to try to produce a well sample that looked like a sample from a non-sorted well by calculating a species composition estimate, then using a resampling technique that sampled the measurement data with probability proportional to the species composition estimate (Tomlinson, 2002 and 2004). The species composition estimate was produced by first estimating the average weight of the fish in a sort, then dividing that into the total catch of that sort provided by the vessel, to estimate the total number of fish in that sort. The numbers of fish per sort were summed by species, and the proportion in number was calculated by species (Tomlinson, 2002 and 2004). These data are handled in a slightly different manner in this report, as described in Section 3.4.1.

2.2.5 Second Stage Units: Fish within Wells

The secondary sampling unit, fish within a well, are also sampled opportunistically, since it is impossible to know how many fish are contained in each well prior to its unloading. Originally, it was thought that large numbers of fish (150-200) needed to be measured to account for the variability in size if multiple modes of fish were caught together. Hennemuth (1957) analyzed the sampling data from 1954–1955 and concluded that the optimum number of fish per sample was 50 per species, even if multiple modes (in the distribution of sizes) were present. There tended to be more variability in mean size among wells than within wells (Hennemuth, 1957; Tomlinson *et al*., 1992; Wild, 1994). With the exception of wells sorted by size and/or species, sampling 50 fish per species per well is still standard practice.

Fish are measured with specially-designed 2-meter calipers. During the first six months of sampling in 1954, samplers tested the use of scales to weigh fish instead of measuring lengths; however they were too cumbersome in the field. They also tried using measuring boards, but since fish are not thawed before measurements are taken, it was impossible to lay the fish flat enough to take an accurate measurement (Hennemuth, 1957).

Since 2000, a species composition sample has been taken by counting and identifying 100-400 fish per species per well. These fish are never the same fish that were measured. For wells sorted by species and size, this step is skipped. In rare cases, wells may be sorted by size groups that contain multiple species, so a species composition sample is required for each size sort.

For each well, there is an estimate of the catches of each species made by the observer or vessel personnel. These estimates are compared to those resulting from the species composition sampling. Results show that bigeye tuna tend to be underestimated by observers and logbooks (IATTC unpublished data). Thus, the total number of fish in a well is estimated by taking the total catch of all species combined in the well and dividing it by a weighted average weight of all species (and/or size sorts) in the well.

2.2.6 Strata with Missing Data

Since the sampling design is highly stratified (12 months, 13 areas, and 7 gear types, giving 1092 possible strata), length and species composition data do not exist for every strata for which there are catch data (especially in strata with catches of less than 1,000 mt per month (Tomlinson, 2004)). A substitution method for moving sampling data into strata for which they do not exist was determined in a somewhat arbitrary, but consistent, manner (Tomlinson *et al.*, 1992). In general, data are moved from the nearest neighboring area, with the same or similar gear type that has sampling data. If sampling data do not exist in a neighboring area, then data from the proceeding or following month may be used (Tomlinson *et al.*, 1992), and adjusted for growth (P. Tomlinson, IATTC; pers. comm.).

One of the assumptions of this substitution scheme is that length data are similar in neighboring areas. This may be true in some areas for some species; however, it has not been assessed since the inception of the floating-object fishery and the increased importance of bigeye tuna catches.

2.2.7 Estimation of the Average Weight and Total Annual Catch by Species

The methods used for estimating the TAC and average weight of each species were revised in major ways at two different times. The first was a revision to the average weight estimator, which dramatically changed the shape of the length frequency distributions for each species (P. Tomlinson, IATTC; pers. comm.). The second revision included using the information from the species composition samples coupled with the revised estimates of the average weights per species and the TAC of all species combined, to estimate the TAC by species. Graphs of the length-frequency distributions of yellowfin and skipjack tunas have been published in IATTC reports since 1954, yet until the mid 1990s, these distributions were raised only to the total catches obtained by summing the logbook records, not the cannery records.

Tomlinson *et al.* (1992) documented all of the methods that used the collected length data for yellowfin tuna to estimate their average weight and frequency distribution by length or weight for each stratum. He also conducted a simulation study to compare two methods and recommended the use of his “new” method. This new method used a ratio-type estimator for the average weight of yellowfin, instead of the unbiased estimator of the population mean for a two-stage cluster scheme (Scheaffer, Mendenhall III, & Ott, 1996). The old method tended to underestimate the number of small fish and overestimate the number of large fish in the catch (Tomlinson *et al.*, 1992). The new method is still used by the IATTC staff and in this research (see Section 3.4.1).

The IATTC collects records from canneries with information on the true weight of the catches landed by vessel and usually by species (Tomlinson *et al*., 1992). The sum of these records yields a TAC by species. When the cannery data are not available for a particular vessel trip, the estimates recorded by the observer or in the vessel’s logbook are used instead. Prior to the initiation of the species composition sampling in 2000, these TAC estimates were used in all of reports of the IATTC. The estimates of averages sizes, total number of fish per species and stratum, and the total number of fish per size bin per species and stratum followed the methods described by Tomlinson *et al*. 1992.

Beginning in 2000, the TAC by species was estimated using the information resulting from the species composition sampling. This model is described in detail in Section 3.4.1. The major difference in using the species composition data is that all three species are considered together in the estimation procedure and the TAC is determined through estimation, not simply by summing up the catch data provided by the canneries.

2.3 Other Studies Evaluating the IATTC Sampling Program

In any sampling program, there are potential sources of error, only some of which may be controlled. To attempt to determine controllable sources of error, many aspects of the IATTC’s sampling program have been studied over the years. Hennemuth (1957) was the first to parse out some of these potential errors, some of which are discussed in various sections of Chapter 2. Wild (1994) revisited some of the problems posed by Hennemuth and studied other issues pertaining to the sampling methods and estimation processes. Tomlinson *et al*. (1992) revised the techniques for estimating the length-frequency distribution of yellowfin tuna under the sampling model, as discussed in Section 2.2.7. Other IATTC staff scientists have used the data collected by the sampling program in conjunction with data from IATTC's other databases to make inferences regarding the tuna fisheries in the EPO. Results from these studies provide information on schooling behavior, growth, and distribution in time of space of yellowfin and/or skipjack tunas. These data provide further insight into the variability of the length measurements.

2.3.1 Studies Regarding Sampling Assumptions and Errors

Hennemuth's (1957) main objective was to determine the most efficient sampling program, given the circumstances inherent to the unloading processes of tuna vessels. He reviewed the different methods of selecting fish from a well, the different techniques for measuring fish, the accuracy of measurements taken between samplers, and the potential size-depth separation of fish within a well (see Section 2.2.5). He concluded that, based on two years of data, there is a large sample-to-sample variation, which overshadows other variations, such as between sampling methods, areas, and months. This was confirmed by Tomlinson *et al.* (1992) and Wild (1994).

Wild (1994) reviewed several aspects of the sampling program, some of which were continuations of work conducted by Hennemuth (1957). He looked at size variation and vertical mixing of yellowfin tuna within wells, the effect of different parts of the sampling scheme on the statistics derived from the samples, re-estimated the number of primary units (wells) to be sampled per month and area, determined the effect of adding set type as a third stratification for sampling, and evaluated the estimates and calculated the variances of the number of yellowfin recruited to the fishery.

To study the size variation of yellowfin in a well, six wells were systematically sampled in their entirety. Results suggested size separation of fish to some degree regardless of the number of sets that were loaded into a well. To test the effect of vertical mixing, 128 fish from seven separate sets were tagged, and all were loaded into one well. The order of the fish that were placed in the well was compared to the order the fish were unloaded. Wild (1994) concluded that the wells appeared to be unloaded in a non-random manner, and suggested that the minimum sampling requirements be increased.

In order to study three different methods (random, protracted (sampling every n^{th} fish), and consecutive sampling) of removing fish from a well, the data from the six test wells were used to simulate the contents of 25 wells. The results of the random method were used to evaluate the other two methods. Results showed that even if a well could truly be sampled randomly, the variance of size estimates among wells is still much greater than the variance within and, therefore, increasing the number of wells sampled is important to reduce the overall variance of these estimates. Wild (1994) concluded that sampling one well in six from each month-area stratum would be a reasonable goal. Stratifying the samples by set type further decreased the variability among wells (Wild, 1994).

2.3.2 Other Research that Used the Sampling Data

Muhlia-Melo (1986) studied the lengths of yellowfin tuna occurring in different areas of the EPO in 1976-1978, and explored three different methods for comparing the size distributions of yellowfin tuna by months and areas. The first method consisted of identifying length groups by area, and deciding by simple inspection, which ones were most similar. His second method involved dividing the size distributions into seven length groups and computing the means, standard deviations, and proportions by length, which could then be compared statistically. However, not enough computing power was available at the time to carry out this analysis. Therefore, he used cluster analysis (third method) to analyze these data, but found too much overlap in the results to draw any conclusions.

Punsly and Deriso (1991) used the length-frequency data, in conjunction with data on purse-seine catch rates and results of cohort analysis to estimate the number of yellowfin tuna of different ages in various regions of the EPO. They estimated the number of individuals caught of each defined age group in each logged purse-seine set. For sets for which no length samples were taken, they used the length distribution from the “nearest” sample available. The nearest sample was defined as that which was taken in the closest purse-seine set in time, distance, and set type, recorded in the logbook database. Catch rates of yellowfin tuna were used to divide the EPO into six large regions. The length-frequency data (available for less than 5% of the sets) could then be extrapolated to the logbook data, which contains information for over 90% of the purse-seine sets made in the EPO each year (Punsly & Deriso, 1991). These techniques used by Punsly and Deriso (1991) to divide the EPO into areas and to substitute “nearest” samples for sets with no sample data is similar to the concept I apply to my research.

Broadhead and Orange (1960) studied the composition of the catch of individual schools of fish, by species and size. They found that yellowfin and skipjack tend to school by size and species, although the geographical distributions of the two species overlap. Yellowfin caught in association with skipjack tended to be smaller on average than those caught in pure yellowfin sets, but the sizes were more variable in the pure yellowfin schools. Calkins (1965) further examined yellowfin schooling behavior and looked for factors that may affect the extent and consistency of an aggregation of fish. He found that the tendency to aggregate by size was stronger than the tendency to aggregate by species. Yellowfin caught in sets associated with dolphins tended to be more variable in size than those caught in other set types (Calkins, 1965). These results help explain some of the variability seen in the average weight and species composition estimates within and among well samples.

Hennemuth (1961a) studied the growth of yellowfin tuna in four regions of the EPO formed by grouping sampling areas (Figure 2.3). He computed percentage length frequencies by month for 1954–1958, and looked for groups of sizes, which he interpreted as age groups of fish. In a given month, there were one or more distinct age groups of fish. He looked for modal progression of the sizes over time (months) and compared the results among sampling area within regions, and among regions. He estimated the overall growth rate for all regions to be 3.6 cm per month and that growth of the fish of an individual year class during a specific year is similar throughout all of the fishing areas. He found that stocks of fish from three of the regions to be closely related, but somewhat different than the stocks of fish from a northern region. Davidoff (1963) used Hennemuth's (1961a) methods for a larger series of years, 1951–1961. He drew conclusions similar to those of Hennemuth, except that he found that growth rates of different year classes of yellowfin within the same area were significantly different. Davidoff also looked at sea-surface temperatures in comparison to growth rates and found no relationship. He found that the growth rates of male and female yellowfin up to 130 cm to be similar.

Other studies that used data from the sampling program have been published. Estimations of year class abundance and mortality rates of yellowfin tuna were made by Hennemuth (1961b) and later by Davidoff (1965). Davidoff (1969) also studied variations in year class strength. Maunder and Watters (2003) used length data in their age-structured catch-at-length analysis for assessing tuna stocks in the EPO. Bayliff (1993) used length data to study the growth and age composition of northern bluefin tuna (bluefin tuna are not included in the present study, but are caught in the northern EPO and their lengths are sampled by IATTC samplers).

In summary, this collection of studies provides further evidence for the importance of having a solid sampling program, with sound, explainable assumptions, and a robust design.

2.4 OTHER PERTINENT RESEARCH ON SURVEY SAMPLING FOR FISHERIES DATA

Additional reviews evaluating sampling protocols include those published in thre scientific leterature, on websites, and in sampling manuals. Many guides for sampling fish and some of the problems mentioned in this Section may be found on the websites of many different fishing agencies. Recently, an overview of minimum requirements for improving the protocols for sampling commercial fisheries was provided by Cotter and Pilling (2007) as a revision of part of the sampling manual used by the International Commission for the conservation of Atlantic Tuna (ICCAT).

Tomlinson (1971) addressed some basic problems in fisheries work and discussed the use of a two-stage sampling model. He discussed the issue of obtaining a probability sample when it is impossible to inherently do so given that the total number of first and second stage units are normally not know. In fisheries, first stage units either refer to a vessel, a well, or some portion of fish taken from a well, such as a basket. Tomlinson (1971) also discussed sources of procedural bias that are common to the unloading processes of vessels.

Crone (1995) evaluated the statistical performance of a two-stage sampling design developed by Sen (1986) for sampling for sampling commercial fish landings. This is a common theme is most fisheries sampling. Crone (1995) documented the sampling variability assoiciated with the species and age composition of groundfish catches landing in Oregon ports. He described the relative magnitues (coefficients of variation) of variance among the two cluster stages, boat trips and baskets of fish. The catch from each vessel was post-stratified into market categories prior to sampling. The sampling objectives were to determine the species composition of the market categories and the age groups of certain species. Crone (1995) concluded that the sampling designs proposed by Sen (1986) were effective and generated relatively precise estimates. Most of the variation in the estimates was attributed to the first stage (agrees with Tomlinson *et al.* (1992) and Wild (1994)).

CHAPTER 3

METHODS

In this Chapter, I describe the design of my study, the process that the IATTC staff uses to collect basic fishery data along with the length frequency and species composition samples, how those data are processed, edited, and maintained, the data I used in my analyses, and a detailed explanation of the different analyses that I performed. For all of my analyses, I used data for 2000–2006.

3.1 Study Design

The objective of this study is to determine whether the area stratification used to collect size and species composition samples from tunas caught in the EPO may be improved so that the sampling areas are more homogenous and the variances of the estimates of TAC by species are minimized. Since I am interested in defining groups of related data, I used agglomerative cluster analysis to divide the data into groups, plotted the resulting groups on a map, and compared the new area groupings to the IATTC Sampling Areas, descriptively and statistically. To describe the new area groupings (Proposed Sampling Areas), I calculated summary statistics of the size and catch and effort data, and to compare them statistically to the IATTC Sampling Areas, I used the Wilcoxon signed-rank test to test if the differences of the variances of the catch statistics are symmetric around 0.

3.2 Data Collection and Maintenance

The majority of the purse-seine and pole-and-line vessels that fish for tunas in the EPO carry IATTC logbooks onboard, that are filled out by vessel captains. These logbooks are abstracted by IATTC Field Office staff (also referred to as 'samplers') when a vessel is in port. The logbooks contain data on date, location, set time, set type, catch by species, etc, as described in detail in Section 3.3. Similar, yet more detailed information is also available from Daily Activity Records (DARs) kept by biological observers (also referred to as 'observers') placed aboard the majority of the larger (>425 cubic meters of well volume) purse-seine vessels.

With the information recorded in the observer' and/or captain's logbooks, the samplers are able to determine whether a well may be selected for sampling. Length frequency and species composition samples are taken during the unloading process of a vessel. In order to be selected for sampling, a well must contain catches made within a calendar month and sampling area (Figure 2.6) and, for purse seiners, from a single type of set (dolphin, unassociated school, or floating object. Samplers measure the fork length (see Appendix) of the target species and take a species composition sample by counting and identifying to species, individual fish. Detailed sampling instructions are provided in the Appendix and further explanation of the two-stage sampling model is described in Sections 2.2.4 and 2.2.5.

After being reviewed by the samplers, the sampling data, vessel logbook data, and observer data are sent to the IATTC's main office in La Jolla, California. There the data processors edit and keypunch the data. The data are further scrutinized by various computerized error-checking programs.

3.3 Data Description

I used two databases maintained by IATTC staff, the length frequency and species composition (LFSC) database and the catch and effort (CAE) database. The LFSC database contains all of the information collected while sampling the sizes of tunas. The CAE database contains data compiled from the observer and/or logbook records in conjunction with the vessel unloading records, or total landed catch obtained from canneries

3.3.1 Length Frequency and Species Composition Database

The LFSC database contains information such as trip number, number of the well(s) sampled, date(s) fish caught and loaded in the well(s), number and location of well(s) sampled (such as Port 2 or Starboard 5), estimated catch (metric tons (mt)) per well, sample area (1-13), 5^o x 5^o area code (if all sets in well were not from the same 5^o x 5^o area, then the 5^o x 5^o area with the majority of the catch is recorded along with a code denoting multiple 5^o x 5^o areas), set type (dolphin, unassociated, or floating object), and for each species, number of fish counted (for species composition estimate), number of fish measured, and lengths in millimeters (mm) of the measured fish.

3.3.2 Catch and Effort Database

This CAE database includes, but is not limited to, trip number, vessel number and name, event date(s) and time(s), position of vessel (latitude and longitude in degrees and minutes), environmental conditions (sea-surface temperature, cloud cover, ocean conditions, wind speed, etc), set number (sequential list of each set made per vessel trip), type of set (dolphin, unassociated, or floating object), estimated catch by species per set from observer and/or logbook records, and total unloaded catch by species from the cannery records. For trips with no unloading record, the catch data recorded in the DARs or vessel logbooks are used in place, which yields one unloading record for every trip that each registered vessel of the surface fleet makes in each year.

3.4 ANALYSES

To investigate whether the IATTC Sampling Area stratification (Figure 2.6) may be improved, I describe the fishery in terms of catches, sizes of fish (average weight and standard deviation by species), numbers and types of sets made, and other summary statistics for each of the IATTC sampling areas, then re-stratify the data by 5^{o} x 5^{o} area into new sampling areas based on a series of cluster analyses, estimate the TAC (and variance) by species resulting from a bootstrapping procedure (Tomlinson, FORTRAN program, 2002; see Section 3.4.4.1), and compare those estimates to the ones obtained using the IATTC Sampling Area stratification (see Table 1.1). I also computed the TAC and variance per species for each area stratum using a multi-step variance equation derived from statistical principals (Section 3.4.4.2) and computed an overall estimate for all strata combined as described in Section 3.4.5. I describe the calculations necessary for estimating the TAC with a two-stage model in Section 3.4.1.

3.4.1 Sampling Model

As noted in Section 2.2, the current sampling frame (Cochran, 1977) employed by the IATTC staff is a stratified two-stage (cluster) random sampling design with first stage units varying (unequal) in size (Tomlinson *et al.*, 1992). Sampling within both stages is assumed to be simple random sampling (Tomlinson *et al.*, 1992), but wells and fish are sampled opportunistically to approximate random sampling (Wild, 1994).

Due to the two-stage structure of the sampling design, to estimate the TAC of each species in the EPO, I first estimated the catch of each species for each sampled well and then for each year-area stratum following the method explained by Tomlinson (2002 and 2004). The stratum estimates are summed together to produce estimates of total abundance of each species. I ignore the month and gear-type stratifications (see Section 2.2) in my research; however this model would work the same way if these data are further stratified.

For a given stratum, the estimate of total catch for one species is based on estimating the total number of fish, the proportion of each species, and the average weight of each species. I explain this process in a stepwise manner, beginning with the estimates for the first cluster stage, or well level.

Let the subscript ***i*** denote an individual fish, ***j*** denote the species, ***k*** denote the well, and ***l*** denote the stratum. The length t_{ijkl} of each measured fish in millimeters (mm) is first converted to weight (kg) by

$$w_{ijkl} = at_{ijkl}^{b} \tag{3.1}$$

The parameters of the length-weight relationship, ***a*** and ***b***, are shown in Table 3.1 (yellowfin tuna: Chatwin (1959); skipjack tuna: Hennemuth (1959); bigeye tuna: Nakamura & Uchiyama (1966)). Weight is used as a smoothing function so the data are more evenly distributed between small and large fish (Tomlinson *et al.*, 1992).

Table 3.1. Parameters of the Length-Weight Relationship of Three Species of Tuna

Species	***a***	***b***
Yellowfin	1.85E-05	3.02
Skipjack	5.53E-06	3.34
Bigeye	3.66E-05	2.90

Given a two-stage sampling model, for a sampled **well *k*** in **stratum *l***, the total number of fish counted for the species composition sample is

$$f_{\bullet\bullet kl} = \sum_{j=1}^{J} f_{\bullet jkl} \tag{3.2}$$

where $f_{\bullet jkl}$ denotes the number of fish counted of species *j* and ***J*** is the total number of species in well *k*.

For species j, the estimated proportion is

$$p_{\bullet jkl} = \frac{f_{\bullet jkl}}{f_{\bullet\bullet kl}} \tag{3.3}$$

and the estimated average weight (kg) is

$$\overline{w}_{\bullet jkl} = \frac{\sum_{i=1}^{m_{\bullet jkl}} w_{ijkl}}{m_{\bullet jkl}} \tag{3.4}$$

where $m_{\bullet jkl}$ is the number of fish sampled. The average weights are reported in kilograms (kg), which are standard for fisheries data; however, to calculate the catch estimates in metric tons (mt), the average weight must first be converted to metric tons, by dividing it by 1000.

The estimated sampled catch, $c_{\bullet jkl}$ (mt), of **species *j*** in **well *k*** in **stratum *l*** is,

$$c_{\bullet jkl} = n_{\bullet jkl} \overline{w}_{\bullet jkl} \tag{3.5}$$

where $n_{\bullet jkl}$ is the estimated total number of fish of species j

$$n_{\bullet jkl} = n_{\bullet\bullet kl} \; p_{\bullet jkl} \,. \tag{3.6}$$

Given the total reported catch (mt) of all species combined $c_{\bullet\bullet kl}$, the estimated total number of fish of all species identified in the well $n_{\bullet\bullet kl}$ is

$$n_{\bullet\bullet kl} = \frac{c_{\bullet\bullet kl}}{\overline{w}_{\bullet\bullet kl}} \tag{3.7}$$

where $\overline{w}_{\bullet\bullet kl}$ is the estimated weighted average weight of all fish in the well,

$$\overline{w}_{\bullet\bullet kl} = \sum_{j=1}^{J} \overline{w}_{\bullet jkl} \; p_{\bullet jkl} \,. \tag{3.8}$$

As mentioned in Section 2.2.4, in some ports, fish are unloaded from wells based on their size and/or species. These wells are called *sorted* wells and differ in how they are sampled. These instructions are included in the Appendix. The unloading staff of a vessel provides the total catch of each sort in a sorted well. Therefore, the total catch by species $c_{\bullet jkl}$ is found by summing up the catch totals of the sorts that contain that species and is not considered an estimate. The total number of fish by species $n_{\bullet jkl}$ is found by estimating the average weight of fish in each sort, dividing that into the given catch total for that sort, then summing over all of the sorts for a given species. The total number of fish in the well $n_{\bullet\bullet kl}$ is found by summing over the $n_{\bullet jkl}$'s for all sorts, and the proportion in number of species *j* is $p_{\bullet jkl} = {}^{n_{\bullet jkl}}\!/\!_{n_{\bullet\bullet kl}}$. The average weight of species *j* in a well is $\overline{w}_{\bullet jkl} = {}^{c_{\bullet jkl}}\!/\!_{n_{\bullet jkl}} * 1000$. The sorted wells are treated the same as the non-sorted wells for the remainder of the estimation process.

The estimates for each **stratum *s*** are carried out similarly to the estimates at the well level. For a given stratum *s*, the estimated number of fish of species *j* $n_{\bullet j \bullet l}$ and of all species combined $n_{\bullet\bullet\bullet l}$ in all sampled wells $\boldsymbol{K_S}$ are calculated by summing over Equations 3.6 and 2.7, respectively

$$n_{\bullet j \bullet l} = \sum_{k=1}^{K_S} n_{\bullet jkl} \tag{3.9}$$

$$n_{\bullet\bullet\bullet l} = \sum_{k=1}^{K_S} n_{\bullet\bullet kl} \,. \tag{3.10}$$

The estimated proportion of species *j*, $p_{\bullet j \bullet l}$ is calculated by dividing Equation 3.9 by Equation 3.10

$$p_{\bullet j \bullet l} = \frac{n_{\bullet j \bullet l}}{n_{\bullet\bullet\bullet l}} \tag{3.11}$$

and the estimated average weight $\overline{w}_{\bullet j \bullet l}$ of species *j* is

$$\overline{w}_{\bullet j \bullet l} = \frac{c_{\bullet j \bullet l}}{n_{\bullet j \bullet l}} \tag{3.12}$$

where $c_{\bullet j \bullet l}$ is the estimated sampled catch of species *j* summed over all wells

$$c_{\bullet j \bullet l} = \sum_{k=1}^{K_S} c_{\bullet jkl} \,. \tag{3.13}$$

The estimated total catch (mt) of **species *j*** in **stratum *l*** is

$$W_{\bullet j \bullet l} = N_{\bullet j \bullet l} \overline{w}_{\bullet j \bullet l} \tag{3.14}$$

where $N_{\bullet j \bullet l}$ is the estimated total number of fish of species *j*

$$N_{\bullet j \bullet l} = N_{\bullet\bullet\bullet l} \; p_{\bullet j \bullet l} \,. \tag{3.15}$$

Given the total reported catch (mt) of all species combined $C_{\bullet\bullet\bullet l}$, the estimated total number of fish of all species identified in the well $N_{\bullet\bullet\bullet l}$ is

$$N_{\bullet\bullet\bullet l} = \frac{C_{\bullet\bullet\bullet l}}{\overline{w}_{\bullet\bullet\bullet l}} \tag{3.16}$$

where $\overline{w}_{\bullet\bullet\bullet l}$ is the estimated weighted average weight of all fish in the well

$$\overline{w}_{\bullet\bullet\bullet l} = \sum_{j=1}^{J} p_{\bullet j \bullet l} \overline{w}_{\bullet j \bullet l} . \tag{3.17}$$

3.4.2 Summary Statistics

From the LFSC database, I calculated average weight and standard deviation of weight by species (yellowfin, skipjack, and bigeye tunas, following the procedure for a stratified two-stage (cluster) random sampling design (Scheaffer, Mendenhall III, & Ott, 1996). I calculated these data for each of the following stratifications:

1. 5^o x 5^o area and year.
2. 5^o x 5^o area for all years combined.
3. IATTC Sampling Area and year.
4. IATTC Sampling Area for all years combined.

I estimated the weights of individual fish by converting the measured length to weight using Equation 3.1. I used these data for descriptive purposes and in the agglomerative cluster analyses.

From the CAE database, I calculated the proportion of catch of each species (yellowfin, skipjack, and bigeye tunas), and the proportion of number of sets by set type (dolphin, unassociated, or floating object) by 5^o x 5^o area and year. I also obtained estimates of the non-adjusted TAC (summary of data provided by the canneries) by species, and for all species combined, by area and year.

To show the distribution of the sampling data, I calculated the total number of samples per 5^o x 5^o area and year. To compare the sampling rate to the catch rate, I calculated the number of samples per 1000 mt of catch by 5^o x 5^o area and year. This information is also useful when interpreting the results of the cluster analyses described in Section 3.4.3.

3.4.3 Cluster Analyses: Defining New Sampling Areas

I conducted two series of cluster analyses (Rousseeuw & Kaufman, 2005). First, I used the data from the CAE database and performed agglomerative cluster analyses (S-Plus 6.1, which follows Rousseeuw & Kaufman, 1990) using all six variables (proportion of catch of the three species and proportion of number of sets by set type, by 5^o x 5^o area) for each year followed by the same analyses for all years combined. Next, I performed agglomerative cluster analyses (using an average linkage and Euclidean distance matrices) on the six variables from the LFSC database (average weights and standard deviations for all 3 species, by 5^o x 5^o area) for each year and for all years combined. For 5^o x 5^o areas that did not contain data for a particular species, the average weights and standard deviations were zero. This may have biased the results in some cases, but it tended to group, for instance the areas with no or minimal bigeye catches, together. For comparative purposes only, I also performed divisive cluster analyses on these same LFSC variables, but do not include the results in this report.

I used the results of the cluster analyses from both datasets to create new sampling areas. I looked at the major groups that were evident in each resulting dendrogram; color coded the groups, and then plotted them on a map. I repeated these steps for each year and for all years combined for both datasets. I used the results of the individual years to assess the inter-annual differences and the results from the combined years to create the new sampling areas. For a 5^o x 5^o area that grouped differently between datasets, I gave precedence to the results from the LFSC data over the CAE data when possible, since the objective is to define homogenous areas by which to collect LFSC samples. Since sampling areas need to be spatially contiguous, there are cases where I grouped 5^o x 5^o areas differently than suggested by the cluster analyses. This process is somewhat subjective, so I created a few new area groupings, and chose the one with the greatest reductions in variance of the TAC estimates by species (discussed in Section 3.4.3). These different area groupings were very similar, but varied by a few 5^o x 5^o areas. I also compared large area stratifications to smaller area stratification. This is discussed in more detail in Section 4.2.

3.4.4 Calculating the Variance of the TAC

In order to test whether the new area stratifications were indeed more homogeneous, I compared the TAC estimates and their variances to those of the original stratification. Due to the complicated structure of the sampling model, the variance calculation is not straightforward. For years, the IATTC staff has used bootstrapping to estimate the TAC's and their variances. The estimation procedure was developed in FORTRAN by

P. Tomlinson of the IATTC and is described in Section 3.4.4.1. The FORTRAN or bootstrapping method is based on stratifying the data stratified by 12 months, 13 areas, and 7 gear types, giving 1092 possible strata, as discussed in Section 2.2.

The second method for estimating the variance of the TAC by species is to derive it from statistical principals. I describe this method in Section 3.4.4.2. Because my objective was to group the 5^o x 5^o data into more homogenous sampling areas, I only stratified the data by area within each year. I did not include the month and gear-type stratifications since their inclusion would render the data too sparse for my analyses without having to devise a substitution scheme as described in Section 2.2.6, something beyond the scope of this paper.

3.4.4.1 IATTC Bootstrap Method

As mentioned in Section 3.4.1, there is a series of FORTRAN programs to do all of the necessary computations to estimate the TAC by species, which includes a bootstrapping method (Efron & Tibshirani, 1993) to calculate the TAC by species and their associated variances(Tomlinson, FORTRAN program, 2002). For each sampled well, the bootstrapping procedure takes a species composition sample (frequencies in number by species) from a trinomial distribution with expected values equal to those observed and obtains new frequencies in number and selects an average weight from a normal distribution with the expected average weight and standard deviation equal to those observed, for each species. These estimates are used to calculate the TAC by species, following the equations in Section 3.4.1. This process is repeated 1000 times, providing the data for computing the variances of the TAC by species (Efron & Tibshirani, 1993).

3.4.4.2 Derived Variance Method

To calculate the estimated variance of $W_{\bullet j \bullet l}$ (Equation 3.14), the variance of $N_{\bullet j \bullet l}$ (Equation 3.15) is needed. $N_{\bullet j \bullet l} \sim \text{trinomial}\left(N_{\bullet\bullet\bullet l}, p_{\bullet j \bullet l}\right)$. An estimate of $N_{\bullet j \bullet l}$ can be obtained by expanding the estimate of abundance in sampled wells to abundance in all wells based on the fraction of catch (mt) sampled

$$N_{\bullet j \bullet l} = \frac{C_{\bullet\bullet\bullet l}}{\sum_{k=1}^{K_S} c_{\bullet\bullet kl}} \sum_{k=1}^{K_S} n_{\bullet\bullet kl} p_{\bullet jkl} = \frac{C_{\bullet\bullet\bullet l}}{\sum_{k=1}^{K_S} c_{\bullet\bullet kl}} n_{\bullet j \bullet l} \tag{3.17}$$

where the estimated variance of $N_{\bullet j \bullet l}$ is

$$\hat{\text{VAR}}\left(N_{\bullet j \bullet l}\right) = \left(\frac{C_{\bullet\bullet\bullet l}}{\sum_{k=1}^{K_S} c_{\bullet\bullet kl}} \right)^2 \text{VAR}\left(n_{\bullet j \bullet l}\right). \tag{3.18}$$

In order to estimate the variance of $n_{\bullet j \bullet l}$, we utilize the variance equation (Seber, 1982, p. 9) that states that for any two random variables x and y,

$$\text{VAR}(x) = \text{E}_Y[\text{VAR}(x \mid y)] + \text{VAR}_Y[\text{E}(x \mid y)]$$

therefore

$$\text{VAR}\left(n_{\bullet j \bullet l}\right) = \text{E}_{\text{n}_{\bullet\bullet kl}} \left[\text{VAR}\left(\sum_{k=1}^{K_S} n_{\bullet\bullet kl} p_{\bullet jkl} \middle| n_{\bullet\bullet kl} \right) \right] + \text{VAR}_{\text{n}_{\bullet\bullet kl}} \left[\text{E}\left(\sum_{k=1}^{K_S} n_{\bullet\bullet kl} p_{\bullet jkl} \middle| n_{\bullet\bullet kl} \right) \right]. \tag{3.19}$$

I derive Equation 3.19 in a few steps. First

$$\text{E}_{\text{n}_{\bullet\bullet kl}} \left[\text{VAR}\left(\sum_{k=1}^{K_S} n_{\bullet\bullet kl} p_{\bullet jkl} \middle| n_{\bullet\bullet kl} \right) \right] = \text{E}_{\text{n}_{\bullet\bullet kl}} \left[\left(\sum_{k=1}^{K_S} n^2{}_{\bullet\bullet kl} \text{VAR}\left(p_{\bullet jkl}\right) \right) + \sum_{k=1}^{K_S} \sum_{\substack{m=1 \\ k \neq m}}^{K_S} n_{\bullet\bullet kl} n_{\bullet\bullet ml} \text{COV}\left(p_{\bullet jkl}, p_{\bullet jml}\right) \right]$$

where $\text{E}\left(n_{\bullet\bullet kl}^2\right) = \text{VAR}\left(n_{\bullet\bullet kl}\right) + \left[\text{E}\left(n_{\bullet\bullet kl}\right)\right]^2$ AND $\text{COV}\left(p_{\bullet jkl}, p_{\bullet jml}\right) = 0$.

So,

$$\text{E}_{\text{n}_{\bullet\bullet kl}} \left[\text{VAR}\left(\sum_{k=1}^{K_S} n_{\bullet\bullet kl} p_{\bullet jkl} \middle| n_{\bullet\bullet kl} \right) \right] = \sum_{k=1}^{K_S} \left[\left(\text{VAR}\left(n_{\bullet\bullet kl}\right) + \left[\text{E}\left(n_{\bullet\bullet kl}\right)\right]^2 \right) \text{VAR}\left(p_{\bullet jkl}\right) \right]. \tag{3.20}$$

Next

$$\text{VAR}_{\text{n}_{\bullet\bullet kl}} \left[\text{E}\left(\sum_{k=1}^{K_S} n_{\bullet\bullet kl} p_{\bullet jkl} \middle| n_{\bullet\bullet kl} \right) \right] = \text{VAR} \sum_{k=1}^{K_S} \left[n_{\bullet\bullet kl} \text{E}\left(p_{\bullet jkl}\right) \right] = \sum_{k=1}^{K_S} \left[\text{E}\left(p_{\bullet jkl}\right) \right]^2 \text{VAR}\left(n_{\bullet\bullet kl}\right) \tag{3.21}$$

Combining Equations 3.20 and 3.21,

$$\text{VAR}\left(n_{\bullet j \bullet l}\right) = \sum_{k=1}^{K_S} \left[\left(\text{VAR}\left(n_{\bullet\bullet kl}\right) + \left[\text{E}\left(n_{\bullet\bullet kl}\right)\right]^2 \right) \text{VAR}\left(p_{\bullet jkl}\right) \right] + \sum_{k=1}^{K_S} \left[\text{E}\left(p_{\bullet jkl}\right) \right]^2 \text{VAR}\left(n_{\bullet\bullet kl}\right). \tag{3.22}$$

To solve Equation 3.22, the variances of $n_{\bullet\bullet kl}$ and $p_{\bullet jkl}$ for each well *k* are needed. The estimated variance from the delta method (Quinn & Deriso, 1999, p. 302-303) of $n_{\bullet\bullet kl}$ is

$$\hat{\text{VAR}}\left(n_{\bullet\bullet kl}\right) \cong \frac{n_{\bullet\bullet kl}^2 \text{VAR}\left(\overline{w}_{\bullet\bullet kl}\right)}{\overline{w}_{\bullet\bullet kl}^2} \tag{3.23}$$

where

$$\hat{\text{VAR}}\left(\overline{w}_{\bullet\bullet kl}\right)=\sum_{j=1}^{J}\left[p_{\bullet jkl}^{2}\text{VAR}\left(\overline{w}_{\bullet jkl}\right)\right] \tag{3.24}$$

and the estimated sample variance of $\overline{w}_{\bullet jkl}$ is

$$\hat{\text{VAR}}\left(\overline{w}_{\bullet jkl}\right)=\left(\frac{n_{\bullet jkl}-m_{\bullet jkl}}{n_{\bullet jkl}}\right)\frac{\sum_{i=1}^{m_{\bullet jkl}}\left(w_{ijkl}-\overline{w}_{\bullet jkl}\right)^{2}}{(m_{\bullet jkl}-1)m_{\bullet jkl}}. \tag{3.25}$$

The estimated variance of $p_{\bullet jkl}$ is

$$\hat{\text{VAR}}\left(p_{\bullet jkl}\right)=\left(\frac{n_{\bullet\bullet kl}-f_{\bullet\bullet kl}}{n_{\bullet\bullet kl}}\right)\left(\frac{p_{\bullet jkl}\left(1-p_{\bullet jkl}\right)}{f_{\bullet\bullet kl}\left(1-f_{\bullet\bullet kl}\right)}\right). \tag{3.26}$$

Therefore, to calculate the variance of $W_{\bullet j\bullet l}$, the estimates for abundance and mean weight are treated as though they are statistically independent and use the identity of

$$\text{VAR}(xy)=\text{VAR}(x)\text{VAR}(y)+[\text{E}(x)]^{2}\ \text{VAR}(y)+[\text{E}(y)]^{2}\ \text{VAR}(x) \tag{3.27}$$

(Goodman, 1960) which yields

$$\begin{aligned}\text{VAR}\left(W_{\bullet j\bullet l}\right)=&\ \text{VAR}\left(N_{\bullet j\bullet l}\right)\text{VAR}\left(\overline{w}_{\bullet j\bullet l}\right)+\left[\text{E}\left(\overline{w}_{\bullet j\bullet l}\right)\right]^{2}\text{VAR}\left(N_{\bullet j\bullet l}\right)\\&+\left[\text{E}\left(N_{\bullet j\bullet l}\right)\right]^{2}\text{VAR}\left(\overline{w}_{\bullet j\bullet l}\right)\end{aligned} \tag{3.28}$$

where the ratio estimator of the average weight $\overline{w}_{\bullet j\bullet l}$ (Scheaffer, Mendenhall III, & Ott, 1996, p. 343), for each species j is

$$\overline{w}_{\bullet j\bullet l}=\frac{w_{\bullet j\bullet l}}{n_{\bullet j\bullet l}}=\frac{\sum_{k=1}^{K_S}w_{\bullet jkl}}{\sum_{k=1}^{K_S}n_{\bullet jkl}}=\frac{\sum_{k=1}^{K_S}n_{\bullet jkl}\overline{w}_{\bullet jkl}}{\sum_{k=1}^{K_S}n_{\bullet jkl}}. \tag{3.29}$$

The estimated variance of $\overline{w}_{\bullet j\bullet l}$ is

$$\hat{\text{VAR}}\left(\overline{w}_{\bullet j\bullet l}\right)=\left(\frac{K_T-K_S}{K_T}\right)\left(\frac{1}{K_S\,\overline{n}_{\bullet j\bullet l}^{2}}\right)s_k^2+\left(\frac{1}{K_sK_T\overline{n}_{\bullet j\bullet l}^{2}}\right)\sum_{k=1}^{K_S}\left(n_{\bullet jkl}\right)^{2}\left(\frac{n_{\bullet jkl}-m_{\bullet jkl}}{n_{\bullet jkl}}\right)\left(\frac{s_m^2}{m_{\bullet jkl}}\right) \tag{3.30}$$

where the total number of wells in the population $\boldsymbol{K_T}$ is estimated by dividing the total reported catch (mt) of all species combined in stratum l by the estimated average catch (mt) in all wells

$$K_T = \frac{C_{\bullet\bullet\bullet l}}{\bar{c}_{\bullet\bullet\bullet l}} \tag{3.31}$$

where

$$\bar{c}_{\bullet\bullet\bullet l} = \frac{\sum_{k=1}^{K_S} c_{\bullet\bullet kl}}{K_S} \tag{3.32}$$

and the estimated average number of fish of species j per well $\bar{n}_{\bullet j \bullet l}$ is

$$\bar{n}_{\bullet j \bullet l} = \frac{n_{\bullet j \bullet l}}{K_S}. \tag{3.33}$$

The estimated sample variances among wells and among fish within each well are

$$s_k^2 = \frac{\sum_{k=1}^{K_S}\left(n_{\bullet jkl}\bar{w}_{\bullet jkl} - n_{\bullet jkl}\bar{w}_{\bullet j \bullet l}\right)^2}{K_S - 1} \tag{3.33}$$

and

$$s_m^2 = \frac{\sum_{i=1}^{m_{\bullet jkl}}\left(w_{ijkl} - \bar{w}_{\bullet jkl}\right)^2}{m_{\bullet jkl} - 1}, \tag{3.34}$$

respectively.

3.4.5 Estimating the TAC and Variance by Species

The TAC and variance by species and year for the EPO is found by summing the statistics over all areas. The estimated total catch of species j in the population in numbers and weight, respectively are

$$N_{\bullet j \bullet\bullet} = \sum_{l=1}^{L} N_{\bullet j \bullet l} \tag{3.35}$$

$$W_{\bullet j \bullet\bullet} = \sum_{l=1}^{L} W_{\bullet j \bullet l} \tag{3.36}$$

where ***L*** is the total number of strata, or areas in this case.

The variance of the TAC for each species in the EPO is obtained by summing over the estimates by area found by Equation 3.28.

3.4.6 Comparing the Variances of the TAC by Species

In Section 3.4.4, I discussed two methods for estimating the variance of the TAC by species. In addition to the difference of these two approaches, the results should not be compared statistically since the bootstrap method is based on the data being stratified by year, month, area, gear, and set type, while I applied the derived variance method to the data stratified by year and area only. Therefore, I did not perform statistical tests on the results, but discuss the results in terms of ratios.

I applied both variance estimation procedures to data stratified by the IATTC Sampling Areas and by the Proposed Sampling Areas. There are four possible comparisons. A summary of these comparisons is in Figure 3.1. I calculated the yearly ratios of the two estimation methods (derived to bootstrap) within each of the stratifications (IATTC and Proposed). Next, I compared the estimates resulting from the derived variance method between the two different stratifications. The fourth comparison is the bootstrapping results between the two different stratifications, but this analysis is redundant, and therefore the results are not included

I calculated the ratio of the derived variance method to the bootstrap method for the catches and standard deviations. The ratio of the standard deviations was calculated as the ratio of the squares of the standard deviations, or the ratio of the variances.

To compare the variances of the TAC by species between the IATTC Sampling Areas and the Proposed Sampling Areas resulting from the cluster analyses, I used the Wilcoxon signed-rank test (Ott & Longnecker, 2001, pp. 308-309). For each year and species, I calculated the overall variance of the TAC using the derived variance method (Sections 3.4.4 and 3.4.5) for the IATTC Sampling Areas and the Proposed Sampling Areas. I took the absolute value of the difference (IATTC minus Proposed) of the variance of each year and species, and ranked the differences in increasing order. The null hypothesis for the Wilcoxon signed rank test is that the differences for each species are symmetrical around 0. The alternative hypothesis is that the differences tend to be greater than 0 and the IATTC Sampling Area stratification produces larger variances by species than the Proposed Sampling Area stratification.

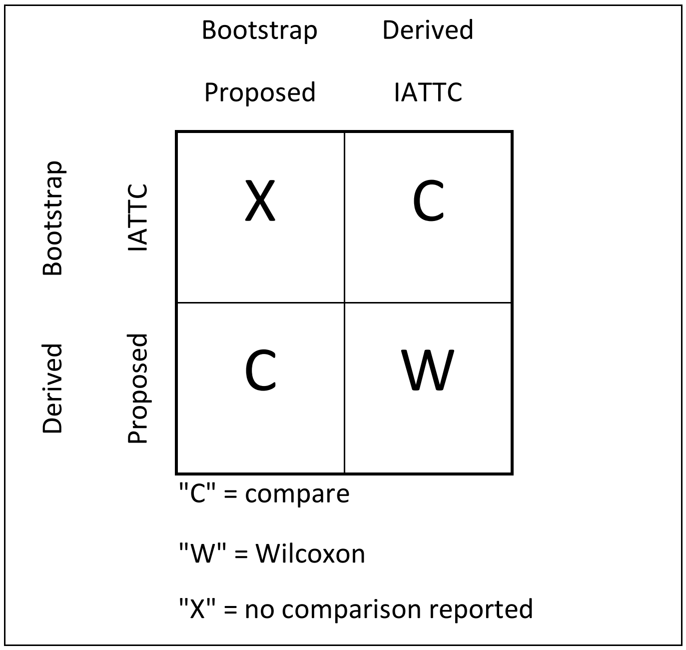

Figure 3.1. Comparisons of the two variance estimation methods within and among the two sampling area stratifications, IATTC and proposed.

CHAPTER 4

RESULTS

In this Chapter, I describe the IATTC Sampling Areas, provide results and interpretations of the cluster analyses, and propose a new area stratification. I provide the results of the variance of the TAC by species by the derived variance method (Section 3.4.4.2) and the standard IATTC FORTRAN method (Section 3.4.4.1), and compare the variances of the TAC estimates calculated by the IATTC Sampling Area stratification and the Proposed Sampling Area stratification. All of the results are based on data for 2000–2006.

4.1 DESCRIBING THE EPO AND THE IATTC SAMPLING AREAS

The EPO is divided into 13 areas for sampling the sizes and species composition of tunas. In this section, I describe these areas in terms of sizes of the tunas caught, proportion of catch by species, and proportion of number of sets by set type.

4.1.1 Total Catches, Number of Samples, and Sampling Rates

The total catches of yellowfin, skipjack, and bigeye tuna summed over all years are greatest between 5^{o}S and 10^{o}N from the coast to approximately 100^{o}W (Figure 4.1). The catches decrease further offshore and north and south of this area.

The number of samples taken and the number of samples per 1000 mt of catch (sampling rate) in each 5^{o} x 5^{o} area, for all years combined, are shown in Figures 4.2 (p. 45) and 4.3 (p. 45), respectively. The correlation between the number of samples and the total catch in each 5^{o} x 5^{o} area is strong, (r = 0.89). The average sampling rate was 1.6 (range: <1–8.3) samples per 1000 mt of catch. There are some 5^{o} x 5^{o} areas at the edges of the fishery for which the sampling rates are inflated due to the small total catches taken in those areas (Areas 10, 11, and 12). The sampling rates in Area 5 are all ≤1 sample per 1000 mt of total catch. The catches in this area are large, but the vessels that fished in this area tended to

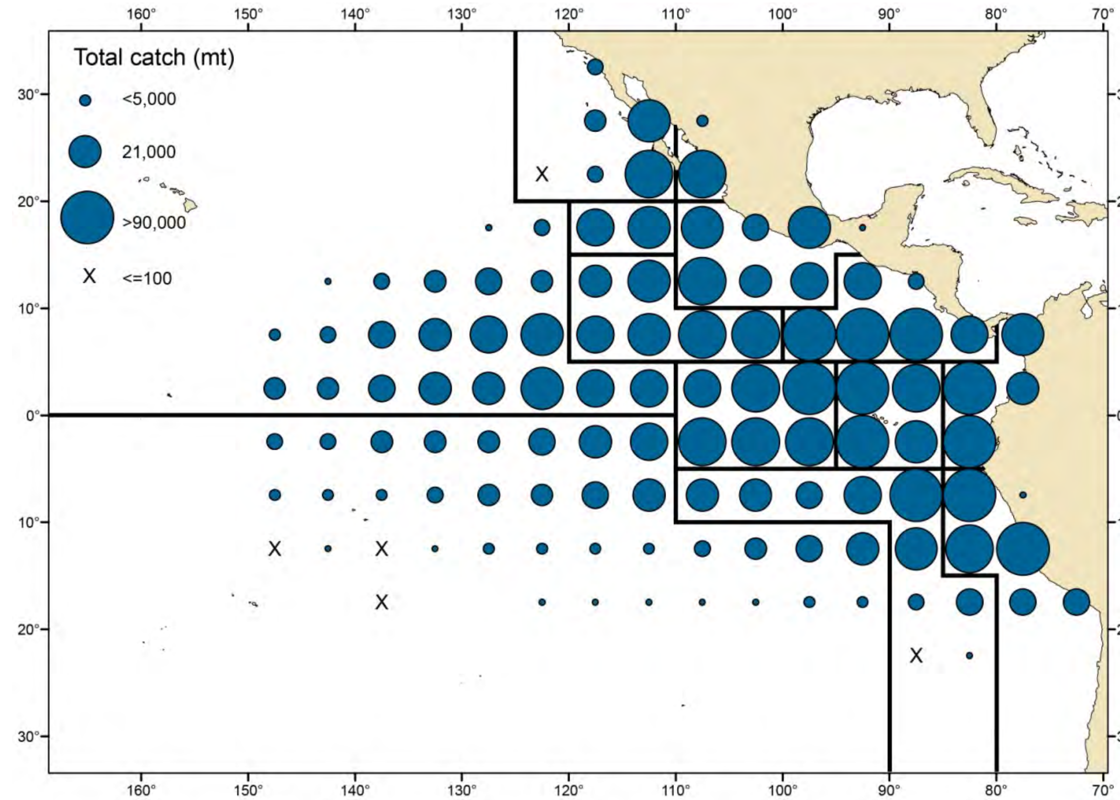

Figure 4.1. Total catches of yellowfin, skipjack, and bigeye tuna combined by 5° x 5° area, 2000–2006 combined.

land in ports where either there is no IATTC field office, or where sampling is logistically difficult. It is assumed that if a vessel landed in a port that the catch was unloaded there. This did not hold true for Areas 3, 4, or 9 for which vessels that fished in these areas tended to land their catches in ports where sampling was very active. These same ports handled 49% and 81% of the vessels catching fish in Area 3 and Area 4, respectively. Eighty-eight percent of the vessels fishing in Area 9 landed their catches in various ports of one country.

4.1.2 Average Weights of Yellowfin, Skipjack, and Bigeye Tunas

The average weight of yellowfin, skipjack, and bigeye tuna by 5° x 5° area are shown in Figure 4.4 (p. 46). On average, the largest yellowfin tuna are caught north of 5°N in areas where dolphin sets are prevalent (discussed in Section 4.1.4). The yellowfin further offshore, in Area 10, tend to be larger than those in the neighboring areas (Areas 2, 3, 4, and 5).

The largest skipjack tuna were caught mostly around the equator in Areas 7 and 9, where they make up large portions of the total catch (Figure 4.5, p. 48). Larger skipjack

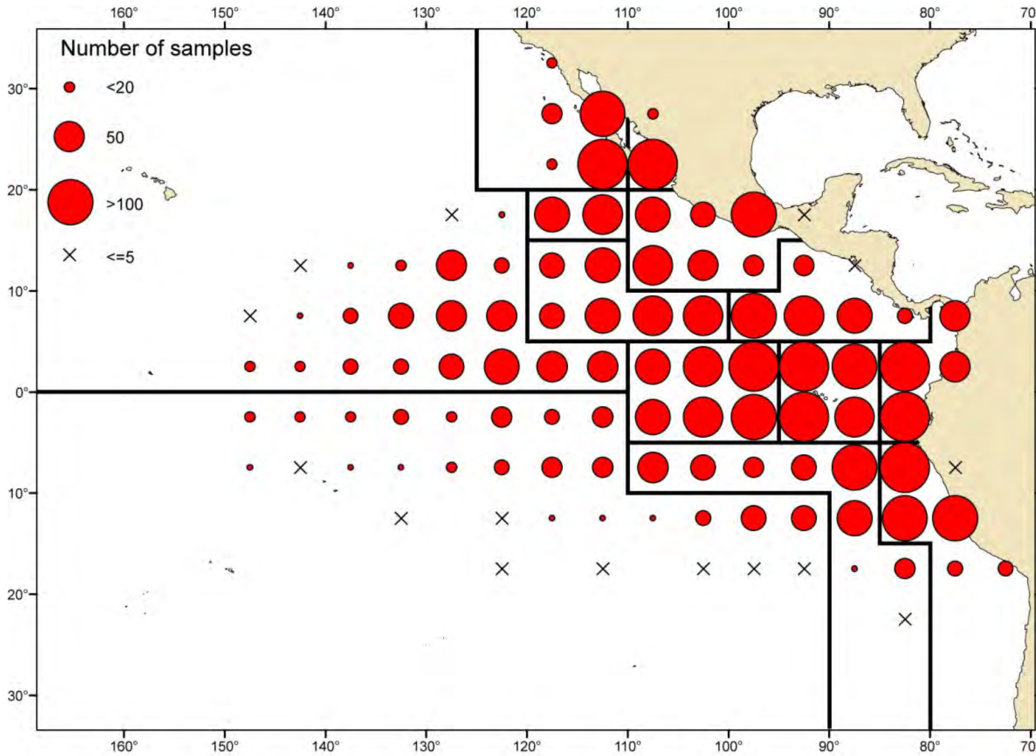

Figure 4.2. Number of samples in each 5° x 5° area, 2000–2006 combined.

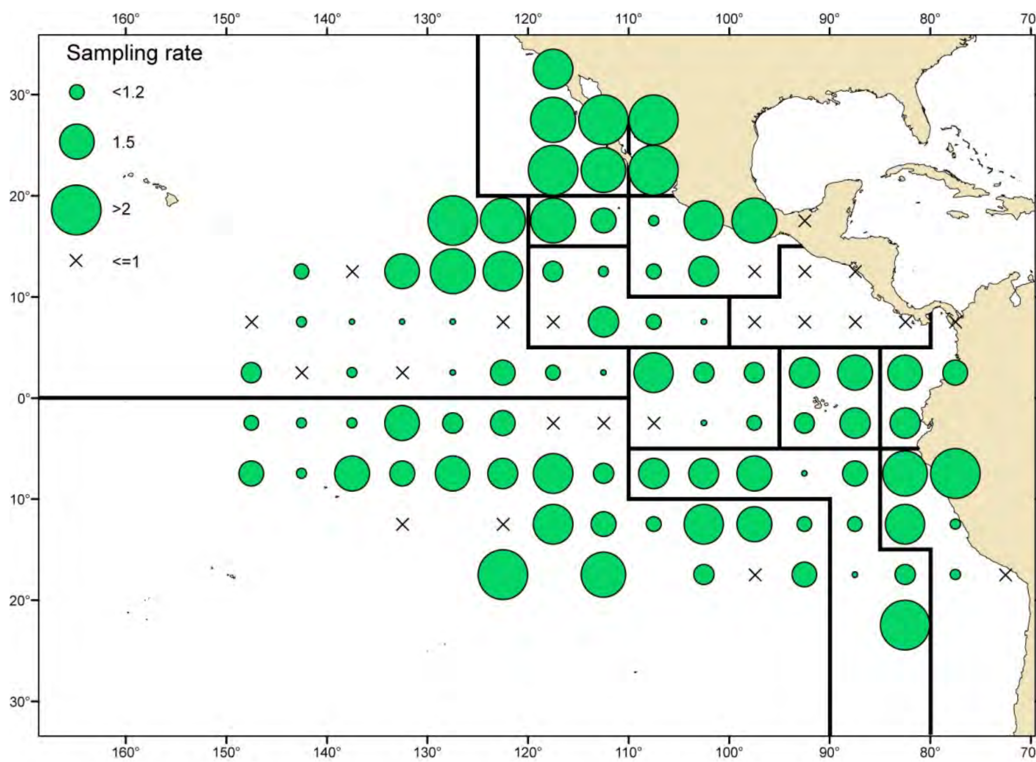

Figure 4.3. Sampling rate (number of samples per 1000 mt of catch) by 5° x 5° area, 2000–2006 combined.

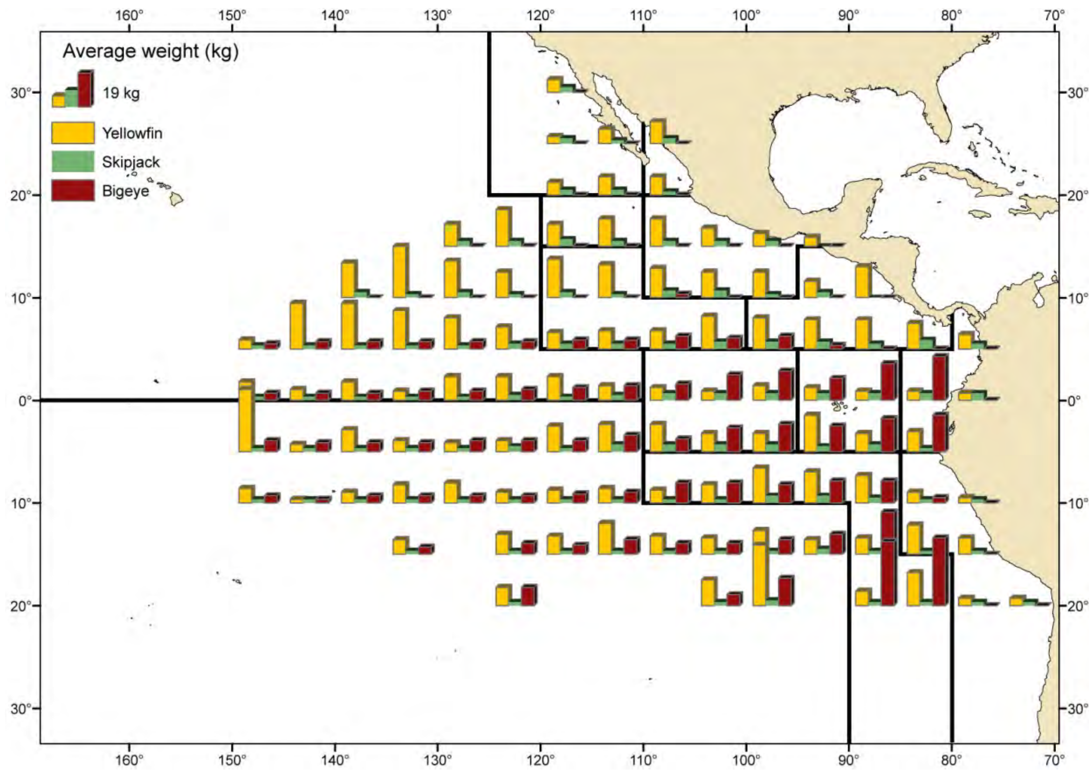

Figure 4.4. Average weights of yellowfin, skipjack, and bigeye tuna by 5^o x 5^o area, 2000–2006 combined.

were also caught in Areas 2 and 5. Since skipjack tuna are smaller than yellowfin and bigeye tuna, it is difficult to see these patterns on the map; however, they are discussed further in Section 4.1.4.

The largest bigeye tuna tended to be caught near the equator in Areas 6, 7, and 9. During 2002, 2003, and 2005, very large bigeye tuna (>50 kg) were caught in the southernmost part of Area 12. More information on sizes of bigeye by sampling area may be found in Section 4.1.4.

4.1.3 Proportion of Catch by Species and Sets by Set Type

The proportion of catch by species and proportion of number of sets by set type are shown in Figures 4.5 (p. 48) and 4.6 (p. 48), respectively. The majority of the yellowfin tuna are caught north of 5^oN, where most of the dolphin fishing occurs. The majority of bigeye and skipjack tuna are caught south of 5^oN, where the fishery is dominated by floating-object sets. Most of the sets made on unassociated schools of fish occur along the coast.

Figures 4.5 and 4.6 are useful when describing the IATTC Sampling Areas (Section 4.1.4) and the Proposed Sampling Areas (Section 4.2.3).

4.1.4 IATTC Sampling Areas

As discussed in Section 2.2.1, sampling tunas in the EPO follows a stratified two-stage sampling model, with area being one of the strata. Before attempting to re-stratify the EPO into new sampling areas it is important to understand the 13 areas as defined in the IATTC sampling guidelines. The statistics referred to in this section are shown in Tables 4.1, 4.2, 4.3, and 4.4 (pp. 49-52).

Area 1 is the northern coastal area of the fishery, off of Mexico. There are six 5^o x 5^o areas that were fished, but only five had samples. The area is dominated by unassociated school fishing (85%), with some dolphin (13%), and a few floating-object sets (2%). Sixty-one percent of the catch by weight was yellowfin, and 39% was skipjack. Bigeye tuna are generally not caught in this area. The average weights of yellowfin and skipjack were 8.9 (± 0.3 SD) kg and 2.5 (± 0.1 SD) kg, respectively.

Area 2 consists of only two 5^o x 5^o areas, south of Area 1, and north of Area 3. Area 2 is an offshore area. Yellowfin comprise 80% and skipjack 20% of the catch. Larger yellowfin and skipjack are typically caught in the dolphin fishery (53% of the sets) in this area. Many skipjack were caught in the unassociated fishery (43% of the sets); however they tend to be smaller than those caught in association with dolphins. The average weights of yellowfin and skipjack tunas were 14.4 (± 1.0 SD) kg and 3.7 (± 0.1 SD) kg, respectively. No bigeye were sampled or reported in the catches. Only 3% of the reported sets were floating-object sets.

Area 3 is an offshore area that lies south of Area 2, west of Areas 4 and 5 (coastal areas), and east of Area 10 (the northern offshore area). It contains six 5^o x 5^o areas, and is mostly a dolphin fishing area (78% of the sets). Twenty percent of the sets are floating-object sets and 2% are unassociated sets. The catch composition is 75% yellowfin, 22% skipjack, and 4% bigeye. The average weights of yellowfin, skipjack, and bigeye tunas were 14.0 (± 0.7 SD), 2.9(± 0.1 SD), and 5.3 (± 0.4 SD) kg, respectively.

Area 4, which includes seven 5^o x 5^o areas, is located off the coast of Mexico. Sixty-two percent of the sets are dolphin-associated sets, 38% are unassociated sets, and about 1%

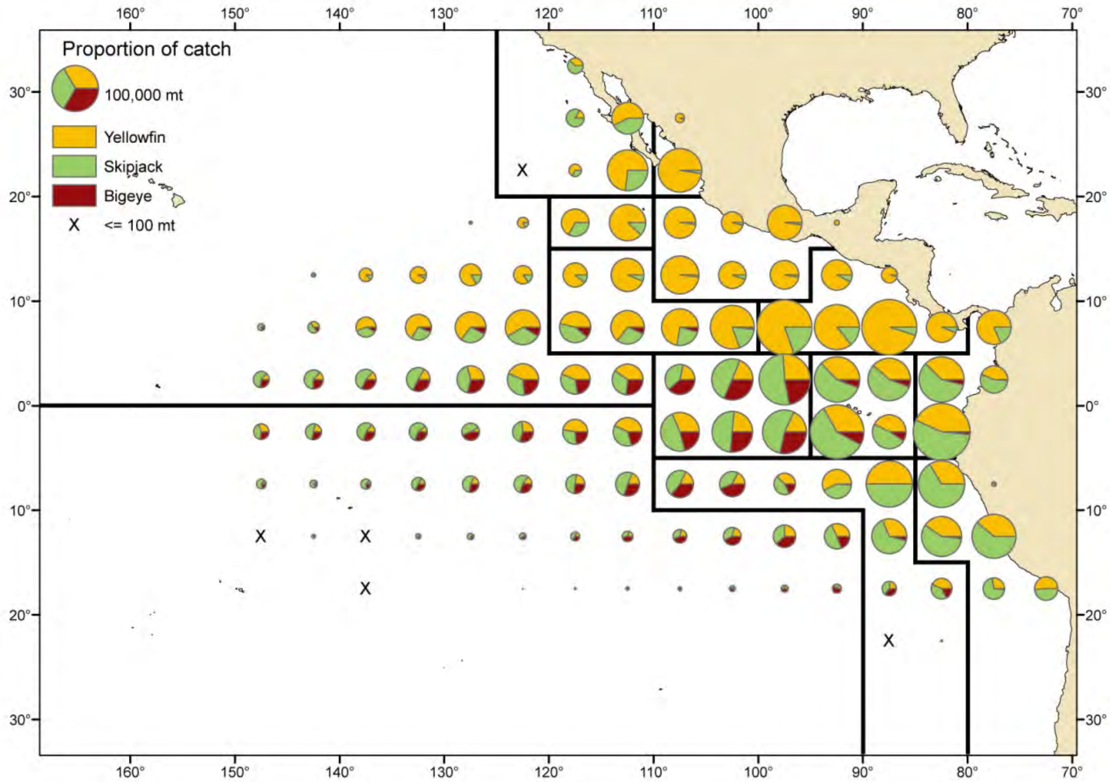

Figure 4.5. Proportion of catch by species and 5° x 5° area, 2000–2006 combined.

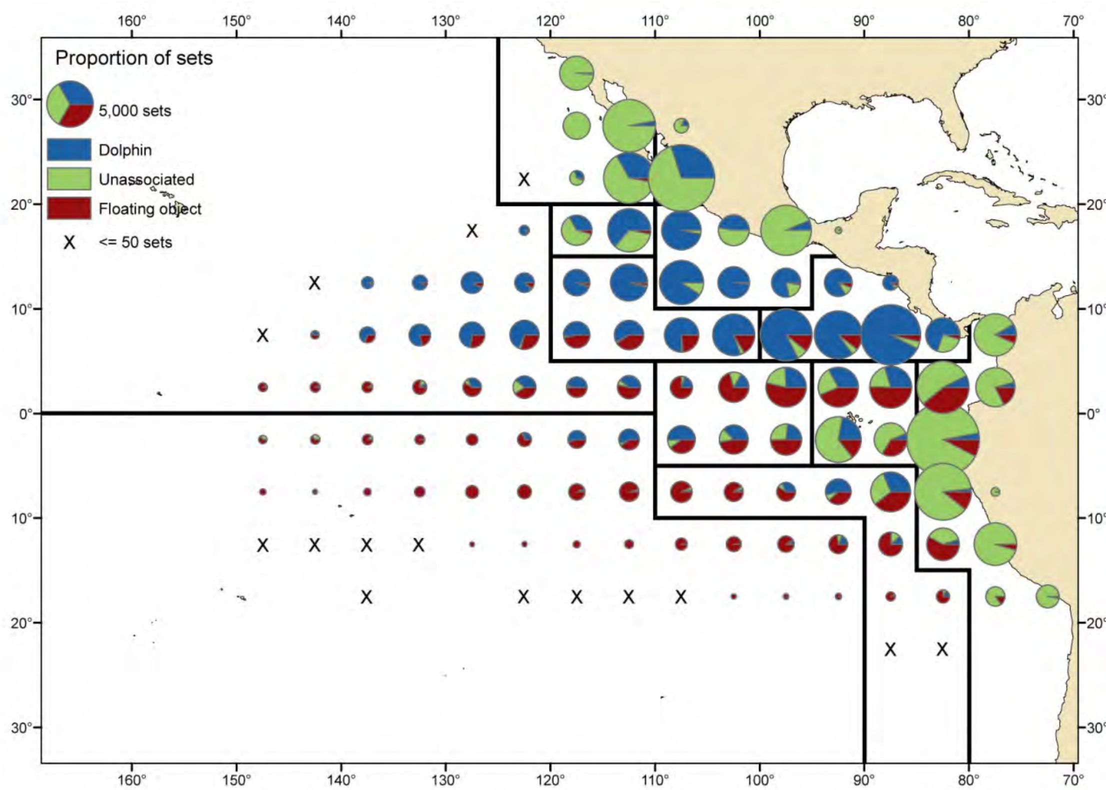

Figure 4.6. Proportion of number of sets by set type and 5° x 5° area, 2000–2006 combined.

Table 4.1. Proportions of Catches by Species for Each of the IATTC Sampling Areas, 2000–2006 and Combined

Area	2000	2001	2002	2003	2004	2005	2006	ALL
Yellowfin								
1	0.96	0.85	0.75	0.78	0.43	0.39	0.55	0.61
2	0.93	0.89	0.83	0.85	0.78	0.77	0.58	0.80
3	0.67	0.69	0.91	0.73	0.80	0.70	0.49	0.75
4	1.00	1.00	1.00	0.95	0.95	0.92	0.97	0.97
5	0.81	0.95	0.95	0.89	0.90	0.75	0.85	0.88
6	0.47	0.66	0.50	0.45	0.71	0.32	0.34	0.48
7	0.25	0.55	0.49	0.35	0.51	0.44	0.18	0.37
8	1.00	1.00	1.00	0.97	0.94	0.95	0.94	0.98
9	0.21	0.35	0.39	0.32	0.23	0.14	0.10	0.23
10	0.64	0.63	0.58	0.57	0.39	0.34	0.29	0.49
11	0.26	0.22	0.29	0.28	0.31	0.21	0.18	0.25
12	0.28	0.56	0.37	0.29	0.32	0.31	0.30	0.39
13	0.40	0.75	0.22	0.35	0.59	0.33	0.14	0.38
ALL	0.49	0.67	0.67	0.57	0.52	0.45	0.33	
Skipjack								
1	0.03	0.15	0.25	0.22	0.57	0.61	0.45	0.39
2	0.07	0.11	0.17	0.15	0.22	0.23	0.42	0.20
3	0.26	0.28	0.07	0.25	0.15	0.24	0.43	0.22
4	0.00	0.00	0.00	0.05	0.05	0.08	0.03	0.03
5	0.19	0.05	0.05	0.11	0.10	0.24	0.15	0.11
6	0.50	0.29	0.48	0.54	0.29	0.67	0.63	0.50
7	0.66	0.38	0.44	0.61	0.44	0.52	0.72	0.56
8	0.00	0.00	0.00	0.03	0.06	0.05	0.06	0.02
9	0.43	0.45	0.36	0.50	0.52	0.53	0.66	0.50
10	0.21	0.24	0.26	0.32	0.41	0.40	0.54	0.34
11	0.36	0.46	0.45	0.44	0.43	0.49	0.51	0.45
12	0.53	0.30	0.55	0.60	0.55	0.52	0.58	0.49
13	0.50	0.22	0.77	0.65	0.41	0.67	0.86	0.62
ALL	0.36	0.24	0.26	0.36	0.37	0.46	0.55	
Bigeye								
1	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.08	0.03	0.02	0.02	0.05	0.05	0.08	0.04
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
6	0.03	0.05	0.02	0.01	0.00	0.01	0.03	0.02
7	0.09	0.07	0.07	0.04	0.05	0.05	0.11	0.07
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.36	0.20	0.25	0.18	0.25	0.32	0.24	0.27
10	0.15	0.13	0.17	0.11	0.20	0.26	0.17	0.16
11	0.38	0.32	0.26	0.28	0.26	0.31	0.32	0.30
12	0.19	0.14	0.08	0.11	0.13	0.17	0.12	0.13
13	0.10	0.03	0.01	0.00	0.00	0.00	0.00	0.01
ALL	0.15	0.09	0.07	0.07	0.10	0.09	0.12	

Table 4.2. Proportions of Numbers of Sets by Set Type for Each of the IATTC Sampling Areas, 2000–2006 and Combined

Area	2000	2001	2002	2003	2004	2005	2006	ALL
	Unassociated							
1	0.92	0.89	0.90	0.70	0.84	0.90	0.83	0.85
2	0.50	0.41	0.52	0.48	0.36	0.37	0.47	0.43
3	0.08	0.02	0.01	0.02	0.01	0.02	0.02	0.02
4	0.53	0.29	0.22	0.46	0.22	0.46	0.47	0.38
5	0.12	0.07	0.11	0.07	0.07	0.05	0.09	0.08
6	0.82	0.75	0.70	0.83	0.81	0.76	0.79	0.79
7	0.59	0.36	0.36	0.27	0.43	0.30	0.42	0.41
8	0.76	0.87	0.84	0.60	0.68	0.62	0.68	0.70
9	0.17	0.06	0.10	0.15	0.24	0.08	0.27	0.17
10	0.03	0.02	0.04	0.06	0.15	0.02	0.03	0.05
11	0.01	0.05	0.13	0.01	0.04	0.01	0.01	0.04
12	0.10	0.19	0.17	0.22	0.17	0.08	0.13	0.16
13	0.13	0.37	0.49	0.75	0.78	0.91	0.91	0.83
ALL	0.47	0.33	0.31	0.39	0.39	0.45	0.48	
	Dolphin-associated							
1	0.07	0.09	0.05	0.29	0.14	0.09	0.16	0.13
2	0.49	0.59	0.42	0.47	0.60	0.62	0.51	0.53
3	0.73	0.67	0.86	0.82	0.83	0.81	0.60	0.78
4	0.46	0.70	0.78	0.54	0.78	0.54	0.52	0.62
5	0.82	0.87	0.84	0.85	0.88	0.84	0.81	0.84
6	0.04	0.01	0.02	0.05	0.11	0.09	0.04	0.05
7	0.21	0.27	0.17	0.21	0.37	0.37	0.11	0.24
8	0.24	0.13	0.16	0.40	0.31	0.38	0.32	0.30
9	0.29	0.26	0.38	0.43	0.34	0.21	0.14	0.29
10	0.79	0.64	0.55	0.66	0.49	0.53	0.45	0.60
11	0.14	0.03	0.05	0.24	0.26	0.20	0.05	0.14
12	0.17	0.29	0.25	0.13	0.25	0.34	0.28	0.26
13	0.13	0.10	0.01	0.02	0.02	0.01	0.00	0.02
ALL	0.36	0.40	0.44	0.42	0.41	0.37	0.26	
	Floating object-associated							
1	0.01	0.02	0.05	0.01	0.02	0.01	0.01	0.02
2	0.00	0.00	0.06	0.05	0.04	0.01	0.02	0.03
3	0.19	0.32	0.12	0.16	0.16	0.18	0.38	0.20
4	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01
5	0.06	0.06	0.05	0.08	0.05	0.10	0.10	0.07
6	0.14	0.24	0.28	0.12	0.08	0.16	0.18	0.16
7	0.20	0.37	0.47	0.52	0.21	0.34	0.47	0.35
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.54	0.68	0.53	0.42	0.41	0.71	0.59	0.54
10	0.17	0.34	0.41	0.28	0.36	0.46	0.51	0.35
11	0.85	0.92	0.81	0.74	0.70	0.79	0.94	0.82
12	0.72	0.52	0.58	0.65	0.58	0.57	0.59	0.58
13	0.74	0.52	0.50	0.23	0.20	0.07	0.09	0.16
ALL	0.17	0.27	0.24	0.19	0.20	0.18	0.26	

Table 4.3. Average Weights of Yellowfin, Skipjack, and Bigeye Tuna in Each of the IATTC Sampling Areas, 2000–2006 and Combined

Area	2000	2001	2002	2003	2004	2005	2006	ALL
Yellowfin								
1	5.9	9.5	14.8	10.6	7.0	9.4	7.4	8.9
2	6.7	14.3	18.0	18.4	14.4	13.5	10.8	14.4
3	17.4	11.1	20.4	13.4	13.4	14.5	5.8	14.0
4	11.8	13.7	15.0	8.3	8.5	6.7	7.8	10.4
5	15.5	17.2	17.4	12.1	13.7	12.6	11.3	14.6
6	5.9	7.0	8.0	9.8	9.7	7.4	4.9	7.3
7	10.9	10.6	5.6	6.9	14.3	12.0	3.8	8.6
8	14.1	11.8	16.8	9.6	12.1	10.8	5.8	10.3
9	8.4	6.5	17.1	10.7	7.5	2.5	3.2	7.6
10	26.5	15.3	18.8	19.0	10.4	9.8	9.7	15.0
11	10.5	8.8	10.7	12.5	14.2	5.8	6.5	9.9
12	16.0	21.3	10.3	7.8	8.7	8.4	13.5	12.8
13	13.2	27.6	8.4	10.2	10.2	5.2	3.5	8.1
ALL	11.6	13.0	14.0	11.1	10.8	8.9	6.8	
Skipjack								
1	2.4	3.0	4.2	3.1	2.0	2.6	2.8	2.5
2	2.7	3.4	5.5	4.8	4.1	3.2	2.9	3.7
3	3.3	3.6	2.5	3.2	2.4	2.6	2.2	2.9
4	5.1	2.9	3.2	3.9	3.1	3.0	2.8	3.3
5	4.8	4.3	3.7	3.7	3.7	3.2	2.1	3.5
6	4.6	4.0	3.3	2.1	2.8	3.3	2.3	2.8
7	4.2	2.9	3.9	3.7	3.8	3.5	2.9	3.6
8	2.6	1.2	nc	5.1	2.4	2.5	2.6	2.5
9	5.5	4.4	3.6	4.7	3.4	3.5	3.2	3.9
10	3.7	3.6	1.6	3.2	2.1	1.8	1.9	2.3
11	4.3	3.2	2.0	2.5	2.3	1.8	1.6	2.2
12	5.4	3.8	2.1	2.3	3.9	3.2	2.2	2.8
13	3.8	2.9	2.2	2.2	2.4	2.3	1.7	2.1
ALL	4.6	3.6	2.5	2.9	2.8	2.6	2.2	
Bigeye								
1	ns	nc	nc	nc	nc	nc	nc	ns
2	nc	nc	nc	nc	nc	nc	nc	nc
3	12.3	6.6	8.8	3.8	5.9	4.9	3.5	5.3
4	2.2	nc	nc	nc	nc	nc	nc	2.2
5	nc	3.9	nc	3.6	2.6	7.7	1.8	6.1
6	9.6	52.5	37.3	26.2	nc	28.4	8.0	24.6
7	34.1	35.5	13.9	19.5	20.4	3.9	9.0	15.8
8	nc	nc	nc	nc	nc	nc	nc	nc
9	28.2	18.9	9.8	13.7	11.6	9.0	8.7	16.2
10	17.3	7.1	4.8	5.0	5.4	4.7	3.8	5.2
11	11.7	7.5	5.5	5.0	5.6	5.8	4.5	5.8
12	19.9	26.4	13.6	7.7	8.1	10.8	7.6	12.3
13	ns	5.4	ns	nc	nc	nc	3.1	3.8
ALL	20.2	11.4	7.0	6.1	7.1	6.3	5.3	

Note: nc = no catch, ns = no sample

Table 4.4. Standard Deviations of Weights of Yellowfin, Skipjack, and Bigeye Tuna by IATTC Sampling Area, 2000–2006 and Combined

Area	2000	2001	2002	2003	2004	2005	2006	ALL
Yellowfin								
1	0.6	0.6	1.3	0.9	0.8	0.6	0.6	0.3
2	1.3	2.5	2.3	3.0	3.8	1.6	1.6	1.0
3	2.1	1.4	2.0	1.7	1.9	1.2	1.0	0.7
4	0.9	0.9	0.8	0.6	0.8	0.4	0.8	0.3
5	1.1	0.8	1.2	1.2	2.0	1.7	1.4	0.5
6	0.6	1.1	1.4	1.3	2.4	1.8	0.7	0.4
7	1.5	2.2	1.0	1.6	3.7	2.4	0.8	0.6
8	1.7	0.7	1.7	0.6	1.8	1.5	0.6	0.4
9	1.5	1.0	3.9	3.1	2.9	0.4	0.5	0.7
10	2.3	1.8	2.8	2.2	1.7	1.8	1.5	0.9
11	1.9	1.3	1.8	2.6	3.3	0.8	0.7	0.7
12	2.4	2.2	1.6	1.6	2.7	2.6	4.3	1.0
13	4.3	0.9	3.0	1.7	1.2	0.4	0.2	0.5
ALL	4.7	4.2	5.0	4.7	5.4	4.2	3.8	
Skipjack								
1	0.6	0.1	0.2	0.1	0.2	0.1	0.1	0.1
2	0.2	0.4	0.4	1.1	0.2	0.1	0.1	0.1
3	0.3	0.2	0.4	0.2	0.4	0.2	0.2	0.1
4	0.0	0.0	0.3	0.2	0.3	0.5	0.4	0.3
5	0.4	0.5	0.7	0.3	0.6	0.3	0.2	0.2
6	0.2	0.3	0.3	0.1	0.3	0.1	0.1	0.1
7	0.2	0.2	0.2	0.1	0.2	0.3	0.1	0.1
8	0.3	0.0		0.5	0.5	0.1	0.0	0.2
9	0.2	0.2	0.3	0.1	0.4	0.2	0.2	0.1
10	0.3	0.3	0.1	0.2	0.2	0.1	0.1	0.1
11	0.3	0.2	0.1	0.2	0.1	0.1	0.1	0.1
12	0.6	0.2	0.1	0.2	0.5	0.3	0.2	0.1
13	0.1	0.2	0.1	0.1	0.1	0.0	0.0	0.0
ALL	1.9	1.7	1.8	1.8	2.0	1.5	1.3	
Bigeye								
1	ns	nc	nc	nc	nc	nc	nc	ns
2	nc	nc	nc	nc	nc	nc	nc	nc
3	6.0	2.6	0.1	0.8	1.3	0.4	0.3	0.4
4	0.0	nc	nc	nc	nc	nc	nc	0.0
5	nc	0.0	nc	0.0	0.0	0.3	0.4	1.4
6	4.5	6.0	1.9	0.0		0.0	3.8	7.3
7	2.3	5.1	1.3	2.4	3.2	1.4	1.3	1.6
8	nc	nc	nc	nc	nc	nc	nc	nc
9	1.0	1.7	1.0	1.3	1.8	1.1	0.6	0.6
10	3.0	0.9	0.4	0.4	0.5	0.3	0.2	0.2
11	1.3	0.6	0.5	0.3	0.5	0.5	0.2	0.2
12	1.7	2.8	3.0	1.5	1.7	1.7	0.9	1.0
13	ns	3.1	ns	nc	nc	nc	0.0	0.8
ALL	8.7	9.5	4.0	3.2	4.3	2.6	4.2	

Note: nc = no catch, ns = no sample

are floating-object sets. Ninety-seven percent of the catch is yellowfin, and 3% is skipjack. Although no bigeye tuna were reported in the catch statistics, a small number were sampled in the catches of floating-object sets in 2000. The average weights of yellowfin, skipjack, and bigeye were 10.4 (± 0.3 SD), 3.3 (± 0.3 SD), and 2.2 kg, respectively.

Area 5, which is located off the southern tip of Mexico, where it borders Guatemala, south to Costa Rica, is comprised of six 5^o x 5^o areas. The set type predominately used in this area is dolphin (84%), with some unassociated (8%) and floating-object (7%) sets. The majority of the catch was yellowfin (88%), with some skipjack (11%), and no reported bigeye, although, as in Area 4, some were sampled in floating-object sets in all years but 2000 and 2002. The average weights of yellowfin, skipjack, and bigeye were 14.6 (± 0.5 SD), 3.5 (± 0.2 SD), and 6.1 (± 1.4 SD) kg, respectively. The yellowfin and skipjack were, on average larger, probably due to the predominance of the dolphin sets in this area.

Area 6, which is comprised of five 5^o x 5^o areas, is located along the coast from Costa Rica, south to northern Peru. Seventy-nine percent of the sets in this area are on unassociated schools of tuna, mainly of yellowfin (48%) and skipjack (50%). There is a coastal floating-object fishery, which accounts for 16% of the sets made, and the remaining 5% are dolphin sets. A small amount of bigeye (2%) was caught in this area. Smaller than average yellowfin (7.3 ± 0.4 SD kg) and skipjack (2.8 ± 0.1 SD kg) were caught in this area; however, the bigeye were quite large (24.6 ± 7.3 SD kg).

Area 7 is just west of Area 6, along the same latitude, and encompasses four 5^o x 5^o areas. Area 7 is a mixed-fishing area with 41% unassociated sets, 35% floating-object sets, and 24% dolphin sets. The catch composition is 56% skipjack, 37% yellowfin, and 7% bigeye tuna. As in Area 6, the yellowfin tended to be small (8.6 ± 0.6 SD kg); however, the skipjack and bigeye tunas were larger, with average weights of 3.6 (± 0.1 SD) and 15.8 (± 1.6 SD) kg, respectively.

Area 8 is the smallest area, consisting of only two partial 5^o x 5^o areas. Average-sized yellowfin (10.3 ± 0.4 SD kg) make up 98% of the catch of this area, caught mainly in unassociated sets (70%). The other 30% of the sets are dolphin sets. Smaller skipjack (2.5 ± 0.2 SD kg) account for the remaining 2% of the catch. Few or no floating-object sets are made and no bigeye are generally caught in this area.

Area 9 lies west of Area 7 on the same latitude. It consists of six 5° x 5° areas. All three species occur in this area, although the catch of bigeye (27%) is much greater than that of Area 7, but the fish are slightly smaller (10.0 ± 0.6 SD kg). This is due to the increased occurrence of floating-object sets (54%). Of the remaining sets, 29% were dolphin and 17% were unassociated. Forty-five percent of the catch consisted of large skipjack (4.0 ± 0.1 SD kg) and 28% was smaller yellowfin (7.7 ± 0.7 SD kg).

Area 10 is a large offshore area, north of the equator. All three species occur in this area, as do all three set types. The majority of the catch (49%) was large yellowfin (15.0 ± 0.9 SD kg) mostly taken in dolphin sets (60%). Floating-object sets, which accounted for 35% of the sets, occurred mostly between 0° and 10°N. Only 5% of the sets were made on unassociated schools. Thirty-four percent of the catch was small skipjack (2.3 ± 0.1 SD kg) and 16% was small bigeye (5.2 ± 0.2 SD kg).

Area 11 is the large offshore area south of the equator. Fishing on floating-objects (82%) made up most of the effort in this area, with some dolphin fishing (14%) occurring in the northeast corner. There was also a scattering of unassociated sets (4%) in this area. The catch consisted of 45% small skipjack (2.2 ± 0.1 SD kg), 30% small bigeye (5.8 ± 0.2 SD kg), and 25% average-sized yellowfin (9.9 ± 0.7 SD kg) tuna.

Area 12 is a Z-shaped area, nestled between Areas 11 and 13. It consists of eight main 5° x 5° areas, although occasionally fishing occurs south of 20°S. This is a mixed-fishing area, consisting of 58% floating-object, 26% dolphin, and 16% unassociated sets. Average-sized skipjack (2.8 ± 0.1 SD kg), make up 49% of the catch, followed by larger yellowfin (39%) and bigeye (13%) tuna with average weights of 12.8 (± 1.0 SD) and 12.3 (± 1.0 SD) kg, respectively.

Area 13 is the southernmost area along the coasts of Peru and Chile. A large portion of the sets made in this area were on unassociated schools (83%), followed by floating-object sets (16%), and few dolphin sets (2%). The catch consisted of 38% small yellowfin (8.1 ± 0.5 SD kg) and 62% small skipjack (2.1 ± 0.0 SD kg) tunas. The 1% of small bigeye tuna (3.8 ± 0.8 SD kg) were reported in the catches of 2000 and 2002, but were encountered during sampling in 2001 and 2006.

4.2 Defining New Sampling Areas

The process for defining new sampling areas was discussed in Section 3.4.3. To review, I used agglomerative cluster analyses on data from the LFSC and CAE databases, summarized at the 5^o x 5^o area level. I used these data in conjunction with other fishery data (Section 4.1) to define new sampling areas. I describe these areas in terms of sizes of fish, proportion of catch by species, and number of sets by set type, and compare these new Proposed Sampling Areas to the IATTC Sampling Areas. 5^o x 5^o areas are referred to by the latitude and longitude of the southeast corner of the square. For instance, 0^o x 80^oW refers to the 5^o x 5^o area that is bounded by 0^o and 5^oN in latitude, and 80^oW and 85^oW in longitude.

4.2.1 Results of the Cluster Analyses

The dendrogram resulting from the analyses of the LFSC and CAE data sets grouped the 5^o x 5^o areas into six and five main clusters as shown in Figure 4.7 (p. 56) and Figure 4.9 (p. 57), respectively. The average weights and standard deviations of the LFSC clusters are shown in Figure 4.8 (p. 56). The proportions of catches by species and numbers of sets by set type for the CAE clusters are shown in Figure 4.10 (p. 57). Three of the clusters resulting from the LFSC analysis had obvious subgroups. There were also a few outliers in each analysis.

I color coded the 5^o x 5^o areas in Figures 4.7 and 4.9 to somewhat match the colors used for identifying species in Figure 4.5. The red and pink (and orange–LFSC only) colors identify 5^o x 5^o areas that are fished predominately by setting on schools of fish associated with floating objects where the majority of the bigeye tunas are caught. The green 5^o x 5^o areas along the coast are where yellowfin and skipjack tunas are generally caught in sets made on unassociated schools of fish. The catch in the yellow 5^o x 5^o areas consists mainly of yellowfin caught in sets associated with dolphins. I used different shades of these colors to represent the subgroups resulting from the LFSC analysis (Figure 4.7). The CAE analysis produced two outliers and the LFSC analysis produced four outliers, shown in grey. The medium-yellow 5^o x 5^o areas (10^oS x 95^oW, 5^oS x 145^oW, 5^oN x 135^oW, 5^oN x 140^oW, 10^oN x 130^oW) shown on the LFSC map (Figure 4.7) did not cluster with the neighboring 5^o x 5^o areas because yellowfin caught there were much larger, on average, than in any of the other areas. The 5^o x 5^o areas in orange were not spatially contiguous either. The orange group

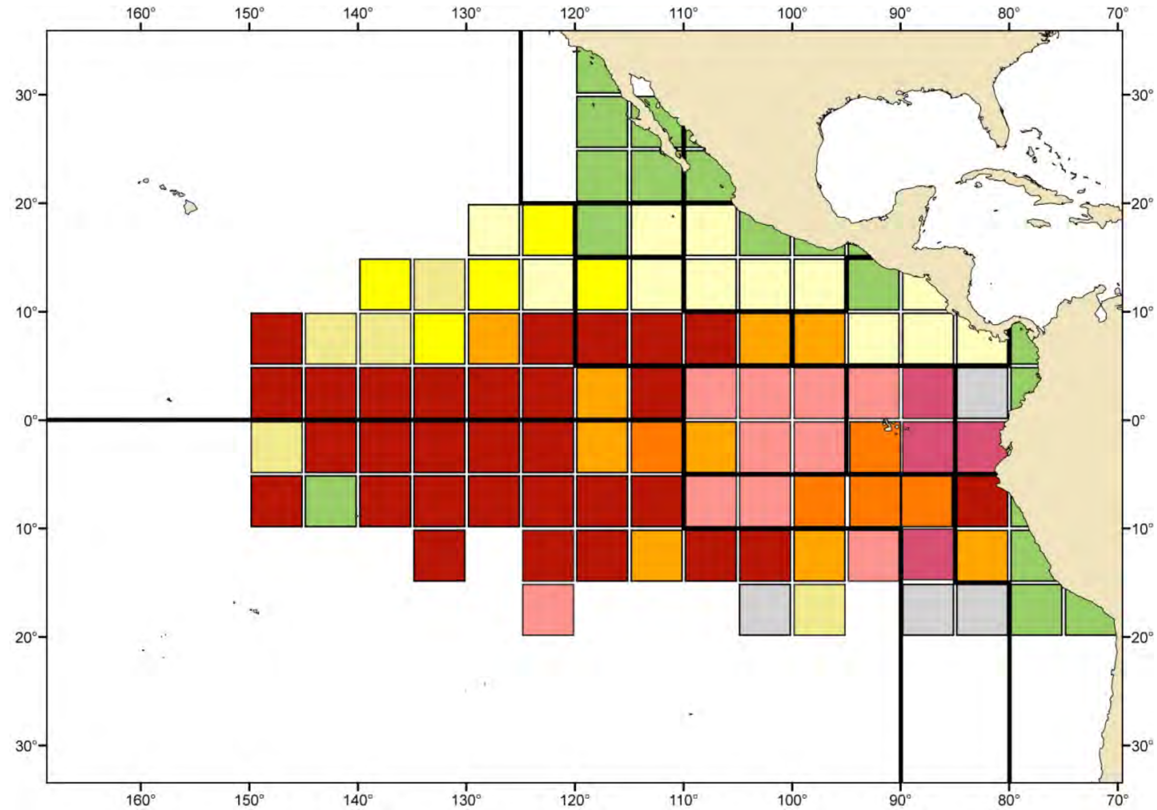

Figure 4.7. Results of agglomerative cluster analysis on the averages and standard deviations of weight of yellowfin, skipjack, and bigeye tuna, 2000–2006 combined.

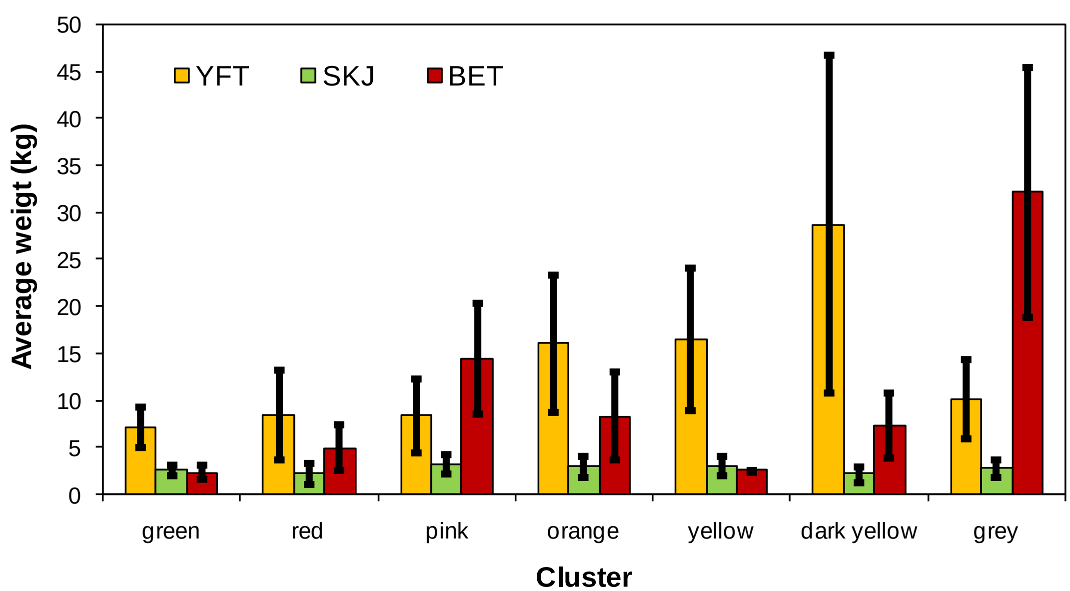

Figure 4.8. Averages weights (± 2 SD) of yellowfin, skipjack, and bigeye tuna in the clusters resulting from the LFSC analysis, 2000–2006 combined.

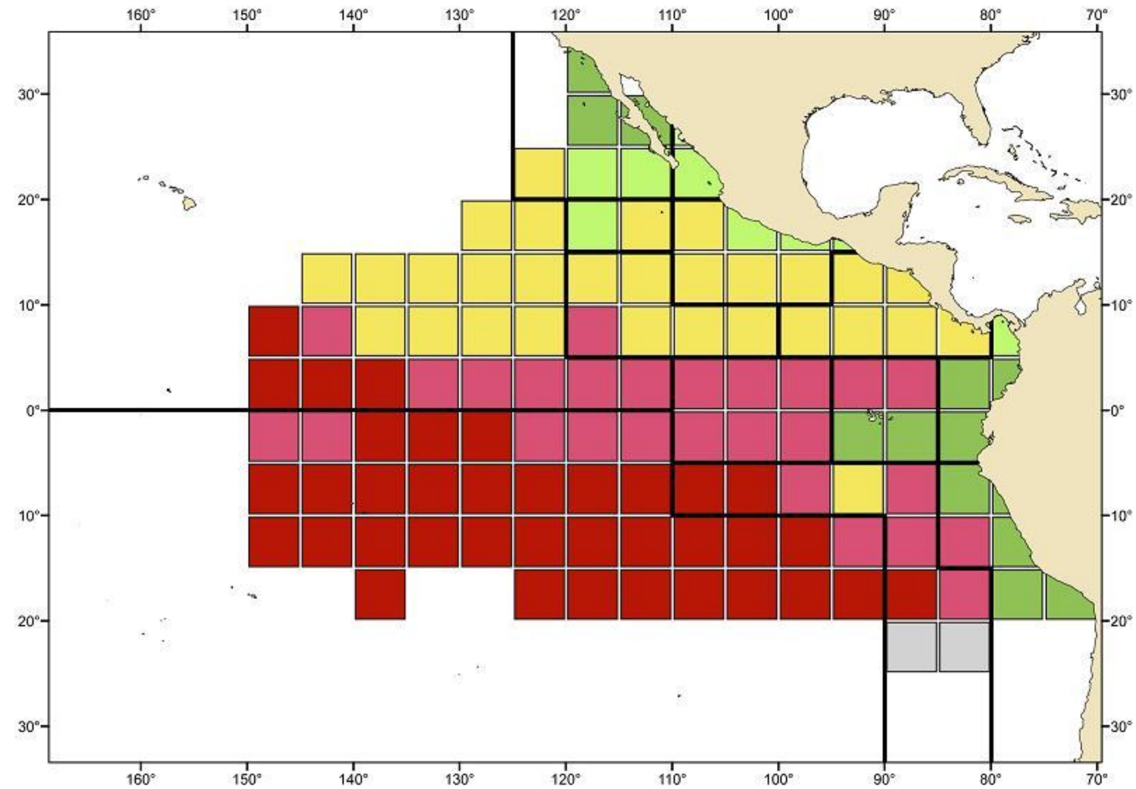

Figure 4.9. Results of agglomerative cluster analysis on the proportion of catch by species (yellowfin, skipjack, and bigeye tunas), and proportion of number of sets by set type (dolphin, floating object, and unassociated), 2000–2006 combined.

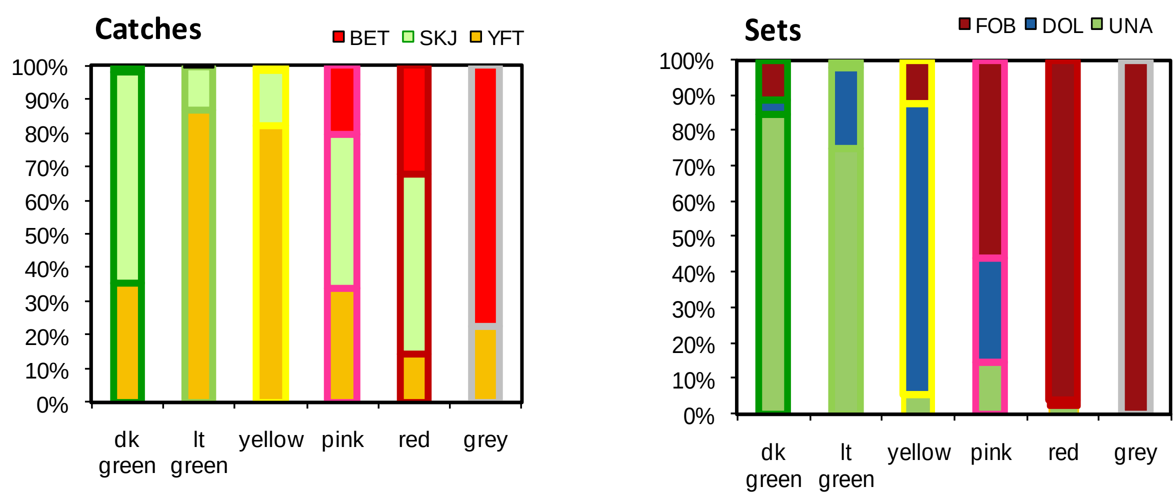

Figure 4.10. Proportion of catch (left) and number of sets by set type in the clusters resulting from the CAE analysis, 2000–2006 combined.

consisted of larger yellowfin and skipjack and medium bigeye tunas. Most of these 5^o x 5^o areas were in areas where the floating-object and dolphin fisheries overlapped (see Figure 4.6), so the average weights of yellowfin tended to be the same as those in the yellow cluster (Figure 4.8). This holds true for skipjack, but the sizes of bigeye were larger in the orange cluster than in the yellow one (Figure 4.8). These same 5^o x 5^o areas associated with various clusters in the CAE analyses, too, indicating the sampling areas with which these 5^o x 5^o areas should join with.

4.2.2 Defining New Areas

As mentioned in Section 3.4.3, the process for defining new area stratifications is subjective. While agglomerative cluster analysis is a useful tool for defining groups in data, the resulting groups of 5^o x 5^o areas were not always spatially contiguous. Information about the EPO fisheries, such as that presented in Figures 4.1 through 4.5 was helpful when interpreting the maps of the results of the two cluster analyses shown in Figures 4.7 and 4.9, and then proposing the new sampling areas shown in the bottom panel of Figure 4.11.

I made two assumptions when creating the Proposed Sampling Areas, how to group the outliers, and how to group the 5^o x 5^o areas that clustered with areas that were not neighbors (non-contiguous). Most of the outliers were at the southern extent of the fisheries (CAE outliers: 25^oS x 80^oW and 25^oS x 85^oW, LFSC outliers: 20^o S x 80^oW, 20^oS x 85^oW, and 20^oS x 100^oW). These were easily joined to the areas that bordered them to the north. However, in the LFSC results, one 5^o x 5^o area along the equator (0^ox 80^oW) did not group with its neighbors. Because very large bigeye tuna were caught in this area during 2001–2003, while few or no very small bigeye tunas were caught in that area during the other years of the time series, which greatly inflated the standard deviation of the average weight. In this case, the CAE data were useful when deciding to group it with Area 7 to the west, instead of Area 6 to the east.

The non-contiguous 5^o x 5^o areas were more difficult to classify. I used abnormalities in the average weights or standard deviations and peculiarities in the clustering results for the individual years for a particular area. Next, I looked at the CAE results, and to the number of samples and sampling rates. This information combined with Figures 4.7 and 4.9 indicated whether a boundary of an IATTC Sampling Area should be changed.

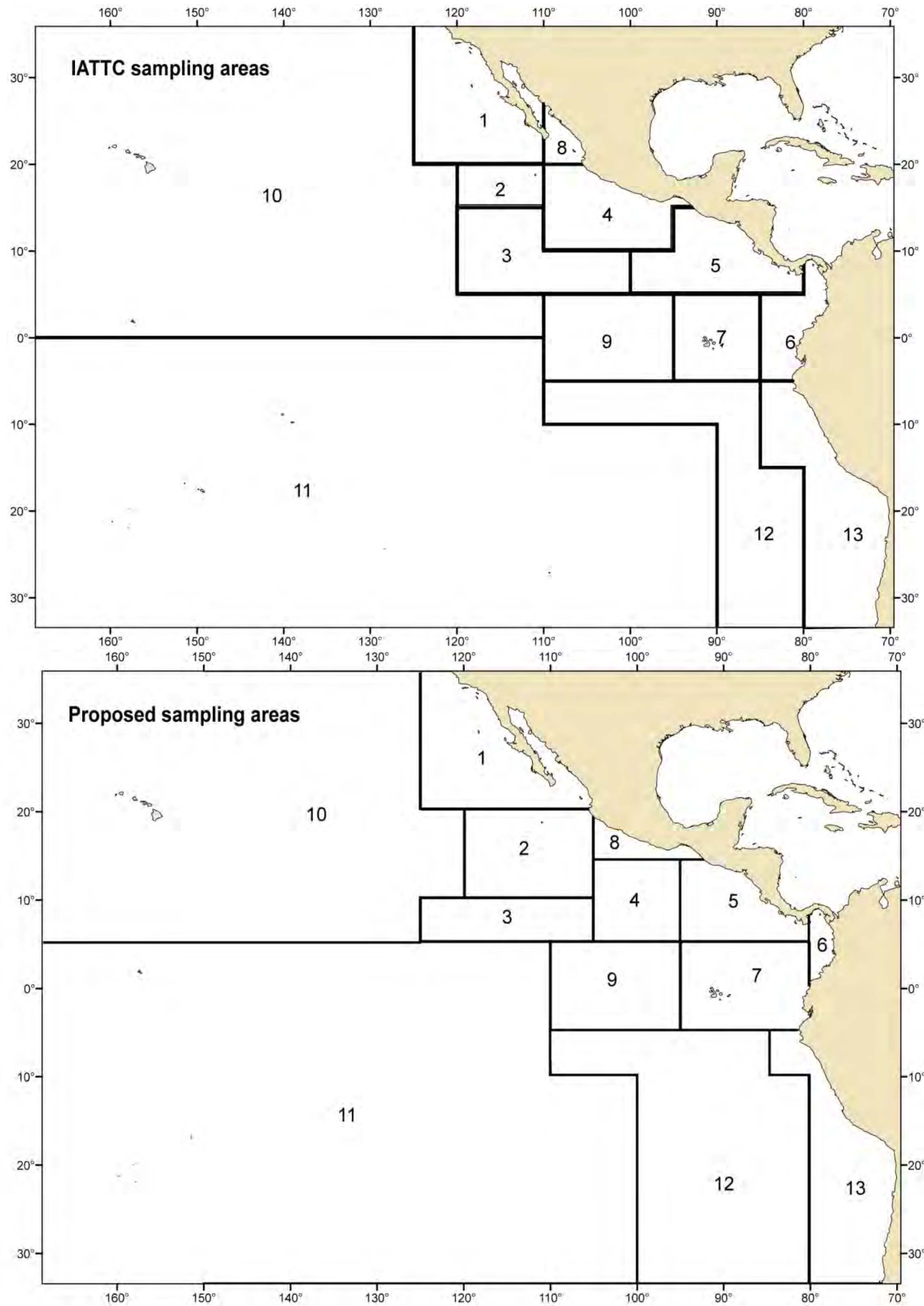

Figure 4.11. The IATTC Sampling Areas (top panel) and Proposed Sampling Areas (bottom panel).

4.2.3 Describing the New “Proposed” Areas

I used the results of the cluster analysis and an understanding of the fishery for tunas in the EPO to re-stratify the 5° x 5° areas into 13 new Proposed Sampling Areas. I also further combined the 13 Proposed Areas into larger area strata; this, however, led to too much loss of information and resulted in larger estimates of the variance of the TAC by species. All of the IATTC Sampling Areas were adjusted, or completely changed, with the exception of Area 9. For the Proposed Areas that were spatially similar to the IATTC Sampling Areas, I discuss the similarities and differences of the estimates of average weights and proportions of catches and numbers of sets by set type. For the Proposed Areas where 50% or more of the 5° x 5° areas differ from the IATTC Sampling Areas, I explain the major geographical differences, the statistics for those areas, and the reasons for the changes. In the following paragraphs, I have provided descriptions of the Proposed Sampling Areas in a format similar to that for the IATTC Sampling Areas in Section 4.1.4. All of the statistics reported in this section are presented in Tables 4.5 through 4.8.

Proposed Area 1 encompasses the old Areas 1 and 8. This increased the proportion of yellowfin and decreased the proportion of skipjack overall, since the catches were 98% yellowfin in IATTC Area 8. The average weight of yellowfin tuna increased overall (from 8.9 to 9.6 kg), in all years except for 2006. The standard deviation of the average weight (0.3 kg) of all years combined remained the same, but fluctuated slightly among years. The overall average weight of skipjack remained steady at 2.5 (± 0.1 SD) kg, although there were slight fluctuations among years.

Proposed Area 2 increased from two to six 5° x 5° areas, and now includes its original two 5° x 5° areas, plus two 5° x 5° areas each from IATTC Area 4 to the east and IATTC Area 3 to the south. These changes caused this area to be more dominated by larger yellowfin tuna (15.6 ± 1.0 SD kg) that comprised 91% of the catch. Skipjack catches decreased to 9% of the total, and the fish were slightly smaller (3.4 ± 0.1 SD kg). Dolphin sets increased to 80%, while unassociated sets decreased to 18%, and floating-object sets decreased to 2%.

Proposed Area 3 contains four 5° x 5° areas, losing its two northern 5° x 5° areas to Proposed Area 2, its eastern 5° x 5° area to Proposed Area 4, but gaining one 5° x 5° area from IATTC Area 10. This area is dominated by yellowfin (61%) and skipjack (31%), with a

Table 4.5. Proportions of Catches by Species for Each of the Proposed Sampling Areas, 2000–2006 and Combined

Area	2000	2001	2002	2003	2004	2005	2006	ALL
	Yellowfin							
1	0.98	0.91	0.84	0.89	0.53	0.50	0.67	0.74
2	0.98	0.95	0.95	0.92	0.89	0.84	0.78	0.91
3	0.50	0.58	0.82	0.66	0.65	0.55	0.35	0.61
4	0.75	0.92	0.97	0.76	0.86	0.71	0.59	0.84
5	0.92	0.96	0.94	0.92	0.93	0.81	0.91	0.92
6	0.49	0.75	0.61	0.77	0.85	0.51	0.64	0.67
7	0.32	0.56	0.48	0.36	0.55	0.36	0.22	0.39
8	1.00	1.00	1.00	0.98	0.91	0.92	0.99	0.97
9	0.21	0.35	0.39	0.32	0.23	0.14	0.10	0.23
10	0.90	0.84	0.70	0.77	0.71	0.55	0.46	0.70
11	0.36	0.32	0.38	0.31	0.27	0.18	0.16	0.28
12	0.32	0.60	0.35	0.24	0.30	0.26	0.26	0.38
13	0.48	0.70	0.23	0.39	0.67	0.36	0.15	0.37
ALL	0.49	0.67	0.67	0.57	0.52	0.45	0.33	
	Skipjack							
1	0.02	0.09	0.16	0.11	0.47	0.50	0.33	0.26
2	0.02	0.05	0.05	0.08	0.11	0.16	0.22	0.09
3	0.39	0.38	0.13	0.30	0.24	0.32	0.54	0.31
4	0.24	0.08	0.03	0.24	0.14	0.28	0.37	0.15
5	0.08	0.04	0.06	0.08	0.07	0.19	0.09	0.08
6	0.49	0.24	0.39	0.22	0.15	0.49	0.36	0.33
7	0.60	0.36	0.47	0.62	0.42	0.60	0.70	0.56
8	0.00	0.00	0.00	0.02	0.09	0.08	0.01	0.03
9	0.43	0.45	0.36	0.50	0.52	0.53	0.66	0.50
10	0.09	0.14	0.26	0.21	0.22	0.37	0.45	0.25
11	0.30	0.40	0.36	0.43	0.47	0.48	0.56	0.44
12	0.47	0.28	0.54	0.63	0.57	0.60	0.61	0.49
13	0.51	0.25	0.77	0.60	0.33	0.64	0.85	0.63
ALL	0.36	0.24	0.26	0.36	0.37	0.46	0.55	
	Bigeye							
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.11	0.04	0.05	0.03	0.12	0.13	0.11	0.07
4	0.00	0.01	0.00	0.00	0.01	0.01	0.04	0.01
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.01
7	0.07	0.07	0.05	0.03	0.03	0.03	0.08	0.05
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.36	0.20	0.25	0.18	0.25	0.32	0.25	0.27
10	0.01	0.02	0.04	0.02	0.07	0.07	0.09	0.05
11	0.34	0.28	0.26	0.26	0.26	0.34	0.28	0.28
12	0.20	0.12	0.11	0.13	0.13	0.14	0.14	0.13
13	0.01	0.05	0.00	0.00	0.00	0.00	0.00	0.00
ALL	0.15	0.09	0.07	0.07	0.10	0.09	0.12	

Table 4.6. Proportions of Numbers of Sets by Set Type for Each of the Proposed Sampling Areas, 2000–2006 and Combined

Area	2000	2001	2002	2003	2004	2005	2006	ALL
Unassociated								
1	0.85	0.88	0.87	0.64	0.80	0.83	0.79	0.79
2	0.17	0.18	0.19	0.18	0.12	0.19	0.21	0.18
3	0.07	0.02	0.01	0.02	0.01	0.01	0.01	0.02
4	0.25	0.02	0.03	0.01	0.04	0.05	0.06	0.07
5	0.09	0.09	0.14	0.09	0.08	0.05	0.05	0.09
6	0.84	0.86	0.78	0.82	0.81	0.73	0.80	0.82
7	0.70	0.50	0.54	0.66	0.60	0.58	0.60	0.61
8	0.87	0.72	0.81	0.92	0.56	0.91	0.79	0.82
9	0.17	0.06	0.10	0.15	0.24	0.08	0.26	0.17
10	0.01	0.00	0.02	0.01	0.02	0.02	0.02	0.01
11	0.02	0.04	0.12	0.07	0.14	0.01	0.02	0.07
12	0.09	0.22	0.15	0.20	0.19	0.19	0.21	0.19
13	0.33	0.40	0.70	0.81	0.90	0.95	0.94	0.91
ALL	0.47	0.33	0.31	0.39	0.39	0.45	0.47	
Dolphin-associated								
1	0.15	0.11	0.10	0.36	0.19	0.17	0.21	0.20
2	0.82	0.81	0.78	0.79	0.86	0.80	0.78	0.80
3	0.63	0.52	0.71	0.75	0.65	0.67	0.44	0.65
4	0.67	0.87	0.93	0.87	0.88	0.84	0.69	0.84
5	0.87	0.87	0.80	0.85	0.88	0.86	0.88	0.86
6	0.05	0.01	0.03	0.05	0.15	0.12	0.11	0.07
7	0.12	0.14	0.09	0.10	0.24	0.19	0.07	0.13
8	0.12	0.28	0.18	0.08	0.44	0.08	0.21	0.18
9	0.29	0.26	0.38	0.43	0.34	0.21	0.14	0.28
10	0.94	0.86	0.75	0.84	0.79	0.74	0.65	0.80
11	0.42	0.21	0.16	0.29	0.23	0.18	0.10	0.22
12	0.20	0.24	0.21	0.10	0.19	0.25	0.19	0.20
13	0.00	0.02	0.00	0.02	0.02	0.01	0.00	0.01
ALL	0.36	0.40	0.44	0.42	0.41	0.37	0.28	
Floating object-associated								
1	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.01
2	0.01	0.01	0.03	0.03	0.02	0.02	0.02	0.02
3	0.30	0.45	0.28	0.23	0.34	0.32	0.55	0.33
4	0.08	0.11	0.03	0.12	0.08	0.11	0.25	0.10
5	0.03	0.04	0.06	0.06	0.04	0.09	0.07	0.06
6	0.11	0.13	0.19	0.12	0.04	0.14	0.09	0.12
7	0.18	0.36	0.38	0.24	0.16	0.23	0.33	0.26
8	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.54	0.68	0.53	0.42	0.41	0.71	0.59	0.55
10	0.05	0.14	0.23	0.15	0.20	0.24	0.32	0.19
11	0.56	0.75	0.72	0.63	0.63	0.81	0.88	0.72
12	0.71	0.54	0.64	0.71	0.62	0.56	0.59	0.61
13	0.67	0.58	0.29	0.16	0.08	0.04	0.06	0.08
ALL	0.17	0.27	0.24	0.19	0.20	0.18	0.25	

Table 4.7. Average Weights of Yellowfin, Skipjack, and Bigeye Tunas in Each of the Proposed Sampling Areas, 2000–2006 and Combined

Area	2000	2001	2002	2003	2004	2005	2006	ALL
Yellowfin								
1	8.6	10.5	15.9	9.9	8.4	9.8	6.7	9.6
2	15.2	14.5	19.1	15.2	14.2	14.2	14.9	15.6
3	14.6	8.5	13.0	12.3	7.9	11.0	4.6	10.5
4	15.5	19.2	21.6	9.4	11.6	15.3	8.3	15.8
5	14.5	16.3	14.1	11.9	15.8	13.4	11.8	13.9
6	4.5	7.2	11.9	7.8	6.1	3.8	5.7	6.2
7	8.4	8.6	6.2	8.8	14.9	10.9	4.3	8.3
8	9.2	8.9	9.7	5.6	5.9	5.2	6.3	7.0
9	8.4	6.5	17.1	10.7	7.5	2.5	3.2	7.6
10	32.5	21.8	25.4	27.3	15.7	18.3	11.4	19.8
11	15.6	9.7	16.5	14.5	7.8	4.6	5.9	10.3
12	13.7	23.6	9.2	7.4	8.6	8.0	8.5	13.0
13	18.3	17.3	29.5	11.1	10.6	5.2	3.5	6.9
ALL	11.3	13.2	13.9	11.0	10.7	9.3	6.8	
Skipjack								
1	2.5	2.8	4.2	3.1	2.0	2.6	2.7	2.5
2	3.3	3.1	5.4	4.5	3.3	3.1	2.9	3.4
3	3.8	3.7	1.9	3.0	1.9	2.4	2.2	2.7
4	4.4	4.4	3.6	3.6	4.7	3.6	2.0	3.5
5	5.8	4.0	4.6	4.4	2.8	3.1	2.0	3.5
6	4.5	3.6	3.4	2.9	5.2	4.2	3.9	3.9
7	4.3	3.1	3.7	2.5	3.4	3.3	2.7	3.1
8	nc	2.9	3.5	ns	3.1	2.4	2.8	2.7
9	5.5	4.4	3.6	4.7	3.4	3.5	3.2	3.9
10	2.9	3.1	1.9	2.9	2.0	1.7	1.8	2.2
11	4.2	3.2	1.8	2.8	2.2	1.8	1.8	2.3
12	5.2	3.7	2.1	2.2	3.1	3.0	1.9	2.6
13	3.7	2.5	2.3	2.4	2.8	2.3	1.8	2.1
ALL	4.6	3.5	2.5	2.8	2.8	2.7	2.2	
Bigeye								
1	ns	nc	nc	nc	nc	nc	nc	ns
2	2.2	nc	nc	nc	nc	nc	nc	2.2
3	8.8	5.7	5.0	3.9	5.6	5.0	3.3	4.9
4	nc	9.6	nc	3.7	2.6	7.7	5.1	6.5
5	nc	nc	nc	nc	nc	nc	1.5	1.5
6	ns	ns	nc	nc	nc	nc	nc	ns
7	29.6	40.7	14.7	20.3	20.4	5.2	8.9	16.2
8	nc	nc	nc	nc	nc	nc	nc	nc
9	28.2	18.9	9.8	13.7	11.6	9.0	8.7	12.9
10	ns	2.9	4.7	5.8	4.8	4.2	3.5	3.9
11	14.1	7.4	4.5	4.9	5.2	5.2	4.2	5.6
12	18.8	25.1	11.1	7.7	8.8	11.2	7.2	11.3
13	ns	ns	nc	nc	nc	nc	3.1	3.1
ALL	19.6	11.5	6.9	6.2	7.1	6.4	5.4	

Note: nc = no catch, ns = no sample

Table 4.8: Standard Deviations of Weights of Yellowfin, Skipjack, and Bigeye Tunas by Proposed Sampling Area, 2000–2006 and Combined

Area	2000	2001	2002	2003	2004	2005	2006	ALL
	Yellowfin							
1	0.7	0.5	1.1	0.5	0.8	0.6	0.4	0.3
2	2.2	1.6	1.0	1.2	1.3	1.0	2.0	1.0
3	2.0	1.4	2.2	1.7	2.6	1.7	0.9	0.6
4	1.6	0.9	1.0	1.4	2.0	1.7	1.5	0.5
5	1.1	0.8	1.3	1.9	2.6	2.3	1.6	0.5
6	0.7	1.5	5.9	1.3	1.3	1.1	1.7	0.4
7	0.8	1.3	0.8	1.3	3.1	1.9	0.5	0.6
8	0.7	0.8	0.7	0.3	0.7	0.2	0.3	0.4
9	1.5	1.0	3.9	3.1	2.9	0.4	0.5	0.7
10	3.5	3.0	3.0	3.1	3.1	3.0	2.3	1.1
11	2.7	1.2	2.8	2.5	1.6	0.7	0.8	0.7
12	2.1	1.5	1.2	1.3	1.9	1.9	2.0	1.0
13	0.2	2.0	4.1	2.0	1.3	0.4	0.2	0.4
ALL	6.4	5.4	9.8	6.7	7.6	5.5	4.8	
	Skipjack							
1	0.4	0.2	0.2	0.1	0.2	0.0	0.0	0.1
2	0.5	0.2	0.4	0.7	0.4	0.1	0.1	0.1
3	0.3	0.3	0.2	0.2	0.3	0.2	0.2	0.1
4	0.4	0.4	0.9	0.2	0.3	0.5	0.3	0.3
5	0.1	0.6	0.3	0.1	0.4	0.2	0.2	0.2
6	0.2	0.4	0.7	0.3	0.2	0.4	0.3	0.1
7	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.1
8	nc	0.0	0.2	ns	0.3	0.1	0.4	0.3
9	0.2	0.2	0.3	0.1	0.3	0.2	0.2	0.1
10	0.4	0.2	0.2	0.3	0.4	0.2	0.1	0.1
11	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1
12	0.5	0.2	0.1	0.1	0.3	0.2	0.1	0.1
13	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0
ALL	1.1	1.0	1.4	0.9	1.1	0.8	0.7	
	Bigeye							
1	ns	nc	nc	nc	nc	nc	nc	ns
2	0.0	nc	nc	nc	nc	nc	nc	
3	3.5	2.3	0.8	0.4	1.0	0.4	0.2	0.4
4	nc	6.4	nc	0.1	0.0	0.3	0.7	4.2
5	nc	nc	nc	nc	nc	nc	0.0	0.0
6	ns	ns	nc	nc	nc	nc	nc	ns
7	3.8	4.8	1.4	2.6	3.2	1.9	1.2	1.7
8	nc	nc	nc	nc	nc	nc	nc	nc
9	1.0	1.7	1.0	1.3	1.8	1.1	0.6	0.6
10	ns	0.3	1.5	1.1	0.2	0.5	0.3	0.2
11	1.3	0.5	0.2	0.2	0.4	0.3	0.2	0.2
12	1.7	2.5	1.6	1.2	1.5	1.7	0.8	0.9
13	ns	ns	nc	nc	nc	nc	0.0	0.6
ALL	5.7	8.9	2.9	3.3	4.1	2.9	1.8	

Note: nc = no catch, ns = no sample

small portion of bigeye (7%) caught mainly in dolphin (65%) and floating-object (33%) sets. Only 2% of the sets were unassociated sets. The average weights of yellowfin, skipjack, and bigeye tunas were 10.5 (± 0.6 SD), 2.7 (± 0.1 SD), and 4.9 (± 0.4 SD) kg, respectively.

Proposed Area 4 contains two of its original 5° x 5° areas, plus one each from IATTC Areas 3 and 5. The northern half of IATTC Area 4 became Proposed Area 8. The catch composition changed to contain fewer yellowfin (84%), more skipjack (15%), and < 1% bigeye tuna. Sets on fish associated with dolphins (84%) were most prevalent, with lesser numbers of floating-object (10%) and unassociated sets (7%). Yellowfin and skipjack caught is this area were larger than average (15.8 ± 0.5 SD and 3.5 ± 0.3 SD kg, respectively). Bigeye tuna averaged only 6.5 kg, but that was variable (SD = ± 4.2 kg), probably due to the fact that bigeye are rarely caught in this area.

Proposed Area 5 is similar to its original size, losing only one 5° x 5° area to Proposed Area 4. The catch and set type compositions shifted slightly. Yellowfin comprised 92% of the catches in this area, and the remaining 8% were skipjack catches. No bigeye tuna catch was reported in this area; however a few very small fish (1.5 ± 0.0 SD kg) were sampled in 2006. Eighty-six percent of the sets were made on schools associated with dolphins, with smaller percentages of floating-object (6%) and unassociated (9%) sets.

Proposed Area 6 is one of the smallest areas, losing its two westerly 5° x 5° areas to Proposed Area 7. Eighty-two percent of the sets in this area are on unassociated schools of fish. Yellowfin catches increased to 67%, while skipjack decreased to 33% of the total catch. There are small floating-object (12%) and dolphin (7%) fisheries in this area. A small amount of bigeye (1%) was caught in this area. Smaller-than-average yellowfin (6.2 ± 0.4 SD kg) and larger-than-average skipjack (3.9 ± 0.1 SD kg) were caught in this area, and no bigeye samples were taken.

Proposed Area 7 increased from its original area due to the addition of two 5° x 5° areas from Area 6. Area 7 remained a mixed-fishing area, but the addition of the two 5° x 5° areas increased the portion of unassociated sets to 61%, decreasing the portions of floating-object sets (26%) and dolphin sets (13%). The catch composition was similar: 56% skipjack, 39% yellowfin, and 5% bigeye tuna. As in Area 6, the yellowfin and bigeye tended to be small (8.3 ± 0.6 SD kg) and (5.3 ± 1.7 SD kg), respectively, but the skipjack were medium sized (3.6 ± 0.1 SD kg).

Proposed Area 8 does not overlap IATTC Area 8. Proposed Area 8 is a small area, consisting of three partial 5^o x 5^o areas, southwest of the coast of Mexico (formerly the northeastern section of IATTC Area 4). Small yellowfin (7.0 ± 0.6 SD kg) make up 97% of the catch of this area caught mainly in unassociated sets (82%). The other 18% of the sets are dolphin sets. Smaller skipjack (2.7 ± 0.3 SD kg) account for the remaining 3% of the catch. Few or no floating-object sets are made and no bigeye are generally caught in this area.

Proposed Area 9 is the same as IATTC Area 9.

Proposed Area 10 remains the offshore northwestern sampling area, but decreased in size, mostly due to its southern boundary shifting 5^o north. One other 5^o x 5^o area was included in Proposed Area 3. This area is now dominated by large yellowfin (19.8 ± 1.1 SD kg) catches (70%) likely taken in dolphin sets (80%). Floating-object sets accounted for 19% of the sets that occurred mostly between 5^o and 10^oN. Only 1% of the sets were made on unassociated schools. Twenty-five percent of the catch was small skipjack (2.2 ± 0.1 SD kg) and 5% was bigeye (12.9 ± 0.3 SD kg).

Proposed Area 11 shifted 5^o to the north to encompass more of the offshore floating-object fishery, and west to allow the expansion of Proposed Area 12. The catch composition remained nearly the same, but the percentages of set types shifted to include more dolphin (22%) and fewer floating-object sets (72%). Forty-four percent of the catches were small skipjack (2.2 ± 0.1 SD kg), 28% small bigeye (5.8 ± 0.2 SD kg), and 28% average-sized yellowfin (9.9 ± 0.7 SD kg) tuna. There was also a scattering of unassociated sets (7%) in this area.

Proposed Area 12 shifted west to include the eastern section of IATTC Area 11. It consists of approximately 13 main 5^o x 5^o areas, although occasionally fishing occurred south of -20^o S. This was a mixed-fishing area consisting of 61% floating-object, 20% dolphin, and 19% unassociated sets. Average-sized (2.6 ± 0.1 SD kg) skipjack made up 49% of the catch, followed by yellowfin (38%) and small bigeye (13%) tunas with average weights of 13.0 (± 1.0 SD) and 5.6 (± 0.9 SD) kg, respectively.

Proposed Area 13 decreased by only one 5^o x 5^o area to Proposed Area 12. The large portion of the sets made on unassociated schools increased to 94%, while the portion of floating-object sets decreased to 8%, and the number of dolphin sets (1%) remained the same. The catch consisted of small yellowfin (37%) and skipjack (63%) tunas, with average weights of 6.9 (± 0.4 SD) and 2.1 (± 0.0 SD) kg, respectively. Small amounts of bigeye tuna were reported in the catches in 2001 and 2002, but were also encountered during the unloading of a vessel and sampled in 2006 (3.1 ± 0.0 SD kg).

4.3 Estimates of the TAC and Variance by Species

In Section 3.4.4, I discussed two methods for estimating the variance of the TAC by species. The method used by IATTC staff is based on a bootstrapping technique (Tomlinson, FORTRAN program, 2002). The method I developed for this research was derived from sampling and statistical theories. The techniques I used to compare these results are explained in Section 3.4.6.

For the IATTC Sampling Area stratification, the differences between the TAC estimates obtained with the bootstrapping method versus the derived variance method were greatest for bigeye in all years except 2000 (Table 4.9). The TAC estimates for yellowfin and skipjack were similar in 2000, 2001, and 2006. The greatest differences were in 2003, because the yellowfin catches are so much greater than those of bigeye tunas (2.2-8.4 times as great), even a 1% difference in the estimate of the yellowfin catch for a year between the two methods can change the bigeye catch dramatically. For example, in 2002, both the yellowfin and skipjack catch estimates based on the derived variance method were only 1% greater than those calculated with the bootstrap method; however, this caused the bigeye catch estimate to drop by 11%.

The standard deviations of these TAC estimates obtained by the two methods were very different. The estimates for yellowfin, for example, were from 6-23 times as great as those obtained from the derived variance method. This is most likely because I did not stratify the data by set type in my analyses. Yellowfin caught in dolphin sets tend to be much larger, on average, than those caught in floating-object sets. Therefore in mixed-fishing areas (those where multiple set types are used) where set type is ignored during the estimation process, the estimates are probably biased.

For the Proposed Sampling Area stratification, the differences between the TAC estimates obtained with the bootstrapping method versus the calculation method were greatest for bigeye, especially during 2003–2005 (Table 4.10, p. 68). The catches of

Table 4.9. Estimates of Total Annual Catch (and Standard Deviation) by Species from the Bootstrap versus the Derived Variance Method for the IATTC Sampling Areas

	BOOTSTRAP			DERIVED VARIANCE			RATIO		
Year	Yellowfin	Skipjack	Bigeye	Yellowfin	Skipjack	Bigeye	Yellowfin	Skipjack	Bigeye
	Catch estimate (mt)								
2000	258,125	207,213	91,507	261,993	202,926	91,932	1.01	0.98	1.00
2001	396,479	140,088	53,212	376,135	152,049	61,596	0.95	1.09	1.16
2002	415,530	145,162	64,120	420,689	147,017	57,106	1.01	1.01	0.89
2003	410,912	251,706	48,798	350,027	301,325	60,064	0.85	1.20	1.23
2004	280,874	190,235	66,777	262,207	201,545	74,139	0.93	1.06	1.11
2005	269,376	265,655	66,971	243,314	282,637	76,070	0.90	1.06	1.14
2006	164,969	306,972	75,260	164,812	297,906	84,484	1.00	0.97	1.12
	Standard deviation								
2000	3,164	5,401	4,751	8,854	4,254	3,553	7.83	0.62	0.56
2001	3,508	3,889	3,046	10,903	3,623	2,741	9.66	0.87	0.81
2002	2,968	3,597	2,694	14,308	3,286	2,896	23.25	0.83	1.16
2003	4,328	5,191	3,010	13,738	5,019	2,359	10.08	0.93	0.61
2004	4,265	5,350	4,247	14,535	6,799	4,833	11.61	1.61	1.30
2005	4,000	4,898	3,093	9,773	4,397	3,433	5.97	0.81	1.23
2006	2,522	3,272	2,717	7,206	4,521	2,672	8.16	1.91	0.97

Note: The ratio is the derived variance method divided by the bootstrap method.

Table 4.10. Estimates of Total Annual Catch (and Standard Deviation) by Species from the Bootstrap versus the Derived Variance Method for the Proposed Sampling Areas

	BOOTSTRAP			DERIVED VARIANCE			RATIO		
Year	Yellowfin	Skipjack	Bigeye	Yellowfin	Skipjack	Bigeye	Yellowfin	Skipjack	Bigeye
	Catch estimate (mt)								
2000	263,713	198,970	94,162	258,011	201,893	96,945	0.98	1.01	1.03
2001	394,627	140,774	54,377	380,471	150,142	59,165	0.96	1.07	1.09
2002	412,527	155,877	56,407	417,643	148,901	58,267	1.01	0.96	1.03
2003	401,980	260,302	49,135	366,343	290,316	54,757	0.91	1.12	1.11
2004	273,132	200,377	64,376	264,615	197,997	75,279	0.97	0.99	1.17
2005	272,663	268,726	60,615	247,154	280,392	74,471	0.91	1.04	1.23
2006	165,184	301,985	80,033	160,211	302,657	84,335	0.97	1.00	1.05
	Standard deviation								
2000	3,262	5,556	5,106	8,884	4,083	3,963	7.42	0.54	0.60
2001	3,667	4,027	3,617	10,292	3,552	2,541	7.88	0.78	0.49
2002	3,076	4,023	2,989	13,156	3,280	2,900	18.29	0.66	0.94
2003	3,512	4,665	3,408	14,401	5,091	2,149	16.81	1.19	0.40
2004	4,681	5,557	4,174	14,299	6,533	4,798	9.33	1.38	1.32
2005	4,292	5,164	2,990	9,878	4,260	3,536	5.30	0.68	1.40
2006	2,422	3,628	3,058	7,250	4,678	2,760	8.96	1.66	0.81

Note: The ratio is the derived variance method divided by the bootstrap method.

yellowfin and skipjack tunas obtained by the two methods were similar in all years but 2001 (skipjack only), 2003 (both species), and 2005 (yellowfin).

The results of the standard deviation estimations were similar to those resulting from the IATTC Sampling Area stratification. The standard deviations of the yellowfin estimates using the derived variance method ranged from 5-18 times as great, relative to the bootstrap method.

These types of comparisons may be useful when testing the different levels of stratification, but, that was not my intention for this project. The interesting point is that the catch estimates were comparable in most cases.

4.4 Comparing the Variances of the TAC by Species Obtained by the IATTC and Proposed Area Stratifications

The ratios of the TAC by species and derived variance estimates under the Proposed Area stratification relative to the IATTC Area stratification are shown in Table 4.11. The catch estimates are similar for all species; however differ slightly in both directions. The relative variation of the catch estimates was 1-5% for yellowfin, 1-4% for skipjack, and 0-9% for bigeye tuna. The relative variation of the derived variance estimates ranged from 1-18% for yellowfin, 0-7% for skipjack, and 1-21% for bigeye.

As mentioned in Section 3.4.6, I used the Wilcoxon signed-rank test (Ott & Longnecker, 2001, pp. 308-309) to compare the derived variances of the TAC's by species between the IATTC Sampling Areas and the Proposed Areas. The null hypothesis is that the differences are symmetrical around 0, for each species. The alternative hypothesis is that the differences tend to be >0, and the IATTC Sampling Area stratification produces greater variances by species than the Proposed Sampling Area stratification. The critical value, $T_{\alpha(0.5)}$ = 3 (Ott & Longnecker, 2001, Table 6, p. 1098-1099), so in order for any of the species to have a significant difference, the sum of the negative ranks T_{-} would have to be <3.

There were no significant differences in the derived variance estimates of the TAC by species, and therefore the null hypothesis cannot be rejected (Table 4.12, p. 70). However, for yellowfin, the variance was smaller in 2001, 2002, and 2004 in the Proposed Area stratification. The variance of the skipjack catch was reduced under the Proposed Area three stratification in four out of seven years (equal in2002), and those for bigeye were reduced in out of seven years (equal in 2002). The only year in which the estimates for all three species decreased was 2004.

Table 4.11. Estimates of Total Annual Catch (and Standard Deviation) by Species from the IATTC Areas and the Proposed Sampling Areas

	IATTC AREAS			PROPOSED AREAS			RATIO		
Year	Yellowfin	Skipjack	Bigeye	Yellowfin	Skipjack	Bigeye	Yellowfin	Skipjack	Bigeye
	Catch estimate (mt)								
2000	261,993	202,926	91,932	258,011	201,893	96,945	0.98	0.99	1.05
2001	376,135	152,049	61,596	380,471	150,142	59,165	1.01	0.99	0.96
2002	420,689	147,017	57,106	417,643	148,901	58,267	0.99	1.01	1.02
2003	350,027	301,325	60,064	366,343	290,316	54,757	1.05	0.96	0.91
2004	262,207	201,545	74,139	264,615	197,997	75,279	1.01	0.98	1.02
2005	243,314	282,637	76,070	247,154	280,392	74,471	1.02	0.99	0.98
2006	164,812	297,906	84,484	160,211	302,657	84,335	0.97	1.02	1.00
	Standard deviation								
2000	8,854	4,254	3,553	8,884	4,083	3,963	1.01	0.92	1.24
2001	10,903	3,623	2,741	10,292	3,552	2,541	0.89	0.96	0.86
2002	14,308	3,286	2,896	13,156	3,280	2,900	0.85	1.00	1.00
2003	13,738	5,019	2,359	14,401	5,091	2,149	1.10	1.03	0.83
2004	14,535	6,799	4,833	14,299	6,533	4,798	0.97	0.92	0.99
2005	9,773	4,397	3,433	9,878	4,260	3,536	1.02	0.94	1.06
2006	7,206	4,521	2,672	7,250	4,678	2,760	1.01	1.07	1.07

Note: The Ratio is the Proposed Area divided by the IATTC Area.

Table 4.12. The Difference of the Variance of the Total Annual Catches by Species from the IATTC Areas Minus the Proposed Sampling Areas, and Results of the Wilcoxon Signed Rank Test

	Difference			Rank		
Year	Yellowfin	Skipjack	Bigeye	Yellowfin	Skipjack	Bigeye
2000	532,405	(1,429,773)	3,080,237	1	5	7
2001	(12,967,302)	(511,397)	(1,056,699)	5	2	6
2002	(31,643,927)	(36,955)	25,294	7	1	1
2003	18,657,647	730,141	(948,505)	6	3	5
2004	(6,812,212)	(3,546,677)	(336,355)	4	7	2
2005	2,048,385	(1,182,043)	716,394	3	4	4
2006	645,572	1,442,770	477,033	2	6	3
	sum of positive ranks (T_+)			12	9	15
	sum of negative ranks (T_-)			16	19	13
	$T_{\alpha\ (0.5)} = 3$, so reject if $T_- \leq T_\alpha$			**accept Ho**	**accept Ho**	**accept Ho**

Note: The difference is the IATTC minus Proposed variance

CHAPTER 5

DISCUSSION

The discrepancies in the maps of the distributions of catches and effort plotted against the IATTC Sampling Areas (see Figures 4.5 and 4.6) provoked me to ask the following questions. How were the IATTC Sampling Areas derived and when? How do these strata affect the estimates TAC of various species?

To answer these questions, I first reviewed the history of the sampling program and its relationship to changes in the fishery (Objective 1). Next, I examined the geographical distributions of the LFSC and CAE data in relationship to the IATTC Sampling Areas statistically by using cluster analysis (Objectives 2 and 3). Based on these results, I proposed new sampling areas and assessed these areas by comparing estimates of the TAC by species obtained by stratifying the data into the Proposed Sampling Areas to those obtained by stratifying the data by the existing IATTC Sampling Areas (Objectives 4 and 5). To do the comparison in Objective 5, I derived a method to calculate the variance of the TAC by species (Objective 6). In this chapter, I discuss my results in terms of these objectives.

5.1 Objective 1: The History of the Fishery and IATTC Sampling Program

My first research objective was to review the history of the fishery and the sampling program, emphasizing the importance of the area stratification and how it was derived. I reviewed the literature published by the IATTC pertaining to the sampling program and major changes or shifts in the fishery, filled in missing information by interviewing various IATTC staff members, and then summarized my findings. The IATTC staff has studied different design features of the sampling program over the years, and this is the first comprehensive report that includes all of these studies. I did not re-examine the hypotheses proposed by other researchers, but provide herein documentation of the IATTC LFSC sampling program to date. Previous researchers examined the importance of the other two levels of stratification. Hennemuth (1957) evaluated stratification by month to account for growth of fish over time, and Wild (1994) assessed set-type stratification. Other aspects of the sampling program have also been evaluated, and these are discussed in Sections 2.2 and 2.3.

This report is the first evaluation of the area stratification for sampling tunas of the EPO. The IATTC Sampling Area stratification presently used is based on a two-species (yellowfin and skipjack) and two-set-type (dolphin and unassociated) fishery derived by observing differences in sizes of fish in different areas or by drawing borders through areas with lesser amounts of catches. The first stratification of the EPO into sampling areas was adopted in 1957 (IATTC, 1979), when the fishery was dominated by pole-and-line vessels fishing close to shore and a few offshore islands and banks. By 1968, purse seiners dominated the fishery for tunas, and 13 sampling areas were adopted, 11 of which were inside the CYRA (Figure 1.1), a boundary which is no longer used to manage tunas in the EPO. Currently, yellowfin and skipjack dominate the purse-seiners fisheries, but bigeye catches have increased substantially since the 1990s.

Sampling the tuna catches of purse-seine and pole-and-line vessels began in 1954, and therefore a very long time series of information exists. The basic sampling scheme was designed in the early years of the sampling program, and it has been updated as the fishery changed and expanded and as the vessel unloading procedures changed. However, sometimes updating the sampling program lagged behind changes in the fishery. The expansion of the floating-object fishery in the 1990's and resulting increased catches of bigeye and skipjack tunas was a major change to the tuna fishery in the EPO, and should be considered in the design of the sampling program. Forty years have passed since the current IATTC Sampling Areas were defined and it is important to periodically assess whether they suitably represent the current fisheries.

5.2 OBJECTIVES 2 AND 3: GEOGRAPHICAL DISTRIBUTIONS OF THE LFSC AND CAE DATA IN RELATIONSHIP TO THE IATTC SAMPLING AREAS BASED ON AGGLOMERATIVE CLUSTER ANALYSES

Tunas caught in different set types tend to be of different sizes (Broadhead & Orange, 1960); Calkins, 1965; Wild, 1994). The spatial distributions of the sizes of fish by species is shown in Figure 4.4, and the estimated average weights and standard deviations for each species by year and IATTC Sampling Area are shown in Tables 4.3 and 4.4. Agglomerative cluster analysis of these data resulted in distinct groups, but with a large degree of variability. The variability is probably the result of the following factors. Multiple cohorts of fish of all three species exist in the EPO at any given time (IATTC, 2006). The sample size and sampling rates (Figures 4.2 and 4.3) for some 5^o x 5^o areas may have been too small to account for these multi-modal distributions. Further, using average weights and standard deviations do not sufficiently describe multiple modes of sizes if they are present. Also different gear or set types select for different sizes of fish, and I did not stratify the data by gear/set type for this analysis. With the exception of IATTC Sampling Areas 1 and 8, no sampling areas contained 5^o x 5^o areas that were all in the same cluster in the LFSC analysis (Figure 4.7). The important result was that the main clusters in both analyses could be classified as either yellowfin and skipjack areas or areas where all three species were caught. This was expected in the CAE results since the variables were proportion of catch by species and proportions of sets by set type, but this trend was also evident in the LFSC results.

There was less variability in the CAE data, as shown in Figure 4.9. Some 5^o x 5^o areas had more fish caught by mixed gear types than others, and the data for those areas clearly clustered together. Because the CAE data exist for over 90% of the trips made in the EPO in recent years, there is enough information to capture the spatial patterns in the data, especially at the 5^o x 5^o area level. Although identifying sampling areas based on the cluster results of the CAE data would appear to solve this issue, these areas are too large and would not include the spatial patterns of the size data, and therefore would not reduce the variance of the estimates of TAC by species. IATTC Sampling Areas 5 and 9 were the only areas that contained 5^o x 5^o areas that all clustered together. Similar to the LFSC results, most IATTC Sampling Areas contained 5^o x 5^o areas from different clusters.

Both yellowfin and bigeye tunas are considered to be single stocks of fish in the EPO (IATTC, 2006), yet at any given time, multiple cohorts of fish occur. Yellowfin and bigeye tunas have the potential to spawn daily when the sea-surface temperature is above 24^o C (Margulies *et al.*, 2007; Schaefer, 1998; Schaefer *et al.*; 2005), which is a normal temperature in tropical waters. Therefore, at any given time in the EPO, there is a potential for catching many different sizes of fish of the same species. However, since set type or gear type are size-selective, there is a tendency for larger fish to be caught in areas where certain gears are prevalent, thus creating geographical patterns in the size (Figure 4.4) and in catch and effort data (Figures 4.5 and 4.6).

In the EPO, this is especially true for yellowfin and bigeye tunas. Yellowfin caught in sets associated with dolphins (and by longline vessels) tend to be much larger than those caught in the unassociated and floating-object fisheries (IATTC, 2006). The majority of the catch of yellowfin is taken in dolphin sets, with the exception of the coastal areas where large portions are taken in unassociated sets. Only a small fraction of the yellowfin tuna catch is taken in floating-object sets (IATTC, 2006). The largest yellowfin were caught north of 5^{o}N in IATTC Sampling Area 10, although those caught in neighboring areas (Areas 2, 3, 4, and 5) were also larger than average. Yellowfin tuna catches have been regulated in many years due to the large amount of fishing effort exploiting the stock (IATTC, 2006).

Before the expansion of the floating-object fisheries in the EPO during the 1990s, bigeye tunas were caught mostly by longline vessels. Since then, catches of bigeye tuna from the purse-seine fishery have exceeded those from the longline fishery in some years (see Table 1.1) (Harley & Suter 2007). The floating-object fishery targets skipjack tuna, and incidental catches include smaller, less valuable bigeye tuna (50-80 cm) than those caught by the longline fishery (110-160 cm) (Harley & Suter 2007). This has possible implications for the longline fishery, because the smaller, younger bigeye that are removed in the floating-object fisheries do not get the opportunity to grow large enough to be caught by the longline fishery. This has resulted in regulations imposed on the bigeye catches by purse-seine vessels in recent years (IATTC, 2006) and has increased awareness of the importance of estimating the TAC by species and gear type as precisely as possible.

During the study period, larger skipjack and bigeye tunas were taken near the equator mostly by the floating-object fisheries in IATTC Sampling Areas 7 and 9. The largest skipjack tunas tend to be caught in floating-object and dolphin fisheries north of the equator in IATTC Sampling Areas 2, 4, and 5. These trends are apparent in Figure 4.4. Skipjack are an important component of the purse-seine catch in the EPO, but recent stock assessments suggest no management concerns for skipjack at this time, except for the associated catch of bigeye in floating-object sets (IATTC, in press). Skipjack tuna are much smaller than yellowfin and bigeye tunas, ranging from about 30-80 cm, compared to 40-160 cm for yellowfin and bigeye in the purse-seine fishery. This size difference affects the results of both cluster analyses. The proportion of catch in the CAE analysis was based on weight, rather than on numbers of fish, and the average-sized skipjack weighs far less than the average yellowfin and bigeye. If the catches were converted to numbers of fish, the clusters may have formed differently. In the LFSC analysis, the average size (and standard deviation) of skipjack in almost all 5^o x 5^o areas was smaller than those of yellowfin and skipjack, and therefore the magnitude of the dissimilarity matrix calculation will be affected by the larger sizes of yellowfin and bigeye tunas. Standardizing the average weights would account for these size discrepancies. These issues may have biased the results of the cluster analysis somewhat, and should be addressed in future analyses.

Further discussion of the results of the cluster analyses in relationship to the IATTC Sampling Areas and the changes I proposed are in Section 5.3.

5.3 Objectives 4 and 5: Assessment of the Proposed Sampling Area Stratification and the Estimates of the Total Annual Catches

The IATTC Sampling Areas were drawn well before bigeye tuna became important in the EPO purse-seine catches. Areas designed exclusively for monitoring bigeye catches would look much different than those used for sampling yellowfin or skipjack. Nearly all of the bigeye taken by purse-seine vessels were caught south of 10^oN and west of 90^oW, where they made up 20-30% of the catches, the largest proportions being in IATTC Sampling Areas 9 and 11. In these areas, the fish caught in Area 9 were larger than those in Area 11. The sizes of bigeye caught in Area 11 tend to be closer in size to those caught in Area 10. Since only a few floating-object sets are made north of 5^oN, a better boundary between IATTC Sampling Areas 10 and 11 would be 5^oN. This is the delineating area between the large yellowfin caught in dolphin sets in Area 10 and those caught in floating-object sets. This may affect the skipjack data since the sizes of fish caught in Area 10 and 11 are quite similar. The results of the cluster analyses on both the LFSC and CAE data provide further support for this change.

Another noteworthy result of the cluster analyses was the similarity of all of the coastal 5^o x 5^o areas (see the green areas in Figures 4.7 and 4.9). However, due to the jagged configuration of the coastline, some of these 5^o x 5^o areas were not contiguous. Many of these 5^o x 5^o areas belong to IATTC Sampling Areas that have mixed sizes of fish caught in different types of sets. The opposite was true for IATTC Areas 1 and 8, which I proposed be combined into one area. I proposed a new coastal area (Proposed Area 8), which was the northern part of IATTC Area 4, along the southern coast of Mexico. The data in these 5^o x 5^o areas clustered together in both of the analyses. Along the coasts of Panama, Colombia, and northern Ecuador is IATTC Area 6, which I proposed to decrease to the two 5^o x 5^o areas that border the coast. Smaller-than-average yellowfin and skipjack were caught mostly in unassociated sets (82%) in this area. South of Proposed Area 6 is Proposed Area 7, which I expanded to include two former 5^o x 5^o areas from IATTC Area 6. Large bigeye were caught in these 5^o x 5^o areas and were similar in size to those in the neighboring 5^o x 5^o areas to the west (IATTC Area 7). Along the coastline of Peru and Chile is the southern coastal fishing area. I proposed to change this area by moving one 5^o x 5^o area (15^oS x 80^oW) that contained catches of larger bigeye tuna to Proposed Area 12.

Further off the coast in the northern hemisphere, I re-distributed the 5^o x 5^o areas of IATTC Sampling Areas 2, 3, 4, and 5 into new geographical clusters. The majority of the yellowfin catch was taken mainly in dolphin sets, but the sizes of fish varied somewhat. There are some discrepancies between the results of the CAE and LFSC analyses, and so I took this into account, but gave the LFSC results higher priority, especially when creating Proposed Area 3. The Proposed Area shares three 5^o x 5^o areas with its former self, plus includes one neighboring 5^o x 5^o area from IATTC Area 10. The longitudinal band between 5^oN and 10^oN is a transitional area in which the dolphin and floating-object fisheries overlap. When data are examined on a smaller scale, such as 1^o x 1^o areas (Watters, 1999), more detail is apparent compared to the 5^o x 5^o stratification level. However, even if the data show that the demarcation between the northern and southern offshore sampling area should be set somewhere between 5^oN and 10^oN, say at 8^oN, it may not be practical to implement this.

Proposed Area 2 was created to include four 5^o x 5^o areas in which the sizes of yellowfin and skipjack caught were similar, although there was a greater proportion of unassociated sets made in the two northern 5^o x 5^o areas than in the other two 5^o x 5^o areas. The results of the LFSC analyses do not entirely support this decision, but this process is somewhat subjective.

Proposed Area 4 is similar to Proposed Area 2 in that it contains catches of similar-sized fish (yellowfin and skipjack) caught mostly in dolphin sets. Bigeye tuna were taken in the two southern 5^o x 5^o areas and in very small amounts in the two northern 5^o x 5^o areas that together make up Area 4. This is apparent in the results of the LFSC analysis.

Proposed Area 5 is another coastal area however; due to the large proportion of dolphin sets made in this area, it did not cluster with the other coastal areas (see Figures 4.7 and 4.9). As is the case for Areas 3 and 4, the southern portion of this area overlaps with the floating-object fishery, but the catches of bigeye tunas are negligible here.

Proposed Areas 7 and 9 are around the equator. Proposed Area 9 is the same as IATTC Area 9. Proposed Area 7 includes two 5^o x 5^o areas that were formerly part of IATTC Area 6. Both of these areas have large catches of skipjack tuna. The proportion of floating-object sets increased further off the coast as did the catches of bigeye tuna. The results of both the LFSC and CAE analyses included three of the four 5^o x 5^o areas of Proposed Area 7 in one cluster group. However, the 5^o x 5^o area that was not included was different in the two analyses. I did not change IATTC Area 9, since the groupings resulting from the two analyses were in agreement.

Proposed Area 12 is similar in shape to IATTC Area 12; however, I moved the southwestern boundary further west. Because this area is at the southern edge of the fishery, some of the outliers from both analyses were here. This is due to the small number of samples taken from a smaller amount of catch.

5.4 OBJECTIVE 6: DISCUSSION OF THE METHOD DERIVED TO CALCULATE THE VARIANCE OF THE TAC BY SPECIES

As described in detail in Section 2.2, the sampling frame is a stratified two-stage (cluster) random sampling design with first-stage units varying (unequal) in size (Tomlinson *et al.*, 1992). The model is highly stratified, with 1092 possible strata resulting from 12 months, 12 areas, and 7 gear types (see Table 2.2). Since my objective was to evaluate the area stratification used for sampling tunas in the EPO and propose more homogenous sampling areas, I stratified the sampling data only by year and area.

During sampling, two independent samples are taken from a well (first-stage cluster) as per the instructions included in the Appendix and explained in Section 3.2. The first is a sample of lengths of fish and the second is a sample of the species composition of the catch in the well. The information from both of these samples is used to estimate the total catch by species in a well, as described in Section 3.4.1. Even though the samples are independent (the same fish measured for lengths are not used for the species composition sample), to estimate the species composition in a given stratum seems a bit circuitous. This makes it difficult to directly calculate the variance of the catch by species *j* in stratum *l*. To estimate the variance of the catch of species *j* in stratum *l*, I first estimated the variances of the total number of fish ($N_{\bullet j \bullet l}$) and average weight ($\bar{w}_{\bullet j \bullet l}$) of species *j* in stratum *l*. The variance of $N_{\bullet j \bullet l}$ is dependent on the variances of two other variables, the total number of fish of all species combined in stratum *l* ($n_{\bullet\bullet\bullet l}$), and the proportion of species *j* in stratum *l* ($p_{\bullet j \bullet l}$). These steps are shown in Section 3.4.3.2. These variances at the stratum level are then dependent on the variances of the similar variables at the well level, $n_{\bullet\bullet kl}$ and $p_{\bullet jkl}$, thus yielding a multi-step process for estimating the variance of the catch.

Currently, the IATTC staff uses the bootstrapping procedure described in Section 3.4.3.1 to calculate the variance of the TAC by species. Bootstrapping is a widely accepted method for calculating variance, and is especially useful for complex models where the variance is difficult to derive. The development of a derived variance method for estimating the variance of the TAC by species will provide IATTC scientists a technique to validate the bootstrapping procedure. The stock assessment models used by IATTC and other fisheries scientists rely on the estimates of the TAC by species and therefore, it is important to have accurate estimates of all of the input variables (Crone, 1995).

5.5 Limitations of this Research and Future Recommendations

There are many variables and types of analyses to choose from when attempting to describe a multivariate system. Some limitations are due to the data itself. Data are not always available at a scale fine enough to really answer the question at hand. In sampling, there are often constraints that prohibit true random sampling and many assumptions must be made.

Catch, effort, and average sizes are some of the most common variables used for fisheries stock assessments. Others, such as catch per unit of effort (CPUE) and environmental variables, such as sea-surface temperature, weather conditions, or wind speed, are also important. Because I was interested in the stratification of the sampling areas, I used only the basic variables. This might have resulted in some important patterns being missed. Because of this, in future analyses with the CAE data, I propose to use the proportion of catch of each species in each set type, to yield nine variables instead of six.

Average weight may not be the best variable to describe the distribution of the size data since the distribution of sizes of fish tend to be multi-modal, given the presence of more than a single cohort of fish at any given time. Converting fish size to age and incorporating cohort analysis could be preferable for describing the size distributions.

Another multivariate technique such as classification or regression tree analysis may provide more detailed results of this problem. Watters and Deriso (2000) used regression trees and simulated annealing to study the distribution of CPUE of bigeye tuna from the Japanese longline fishery, and proposed nine regions that best described the CPUE data. They proposed using simulated annealing for designing tagging experiments. They also suggested comparing the annealing results to those obtained by cluster analyses.

5^{o} x 5^{o} areas may be too large to effectively capture some of the differences in the EPO fisheries, but in most cases, the sampling data cannot be obtained at a finer level due to the method used to lad fish on vessels. Each vessel has multiple storage wells onboard. The amount of fish caught in most sets are less than the capacity of a typical well, so many wells contain multiple sets of fish. As per the sampling instructions (see Appendix and Section 3.2), a well may be sampled only if it contains fish that were all caught in the same calendar month, the same IATTC Sampling Area, and by the same type of set. Yet many of the IATTC Sampling Areas are large and often two or more different sets in the same well were not caught in the same 1^{o} x 1^{o} area or even 5^{o} x 5^{o} area, within a sampling area.

I did not apply the variance calculation to all of the strata used in the IATTC sampling instructions. I was interested in parsing out the effect of the area stratification on the estimates of the TAC by species, and therefore chose to ignore the month and set-type strata. In future analyses it will be useful to include the full stratification (year-month-area-set type) and either revise the substitution scheme to handle strata for which there is catch but no sample, or derive a new method to deal with missing data.

Other avenues of research pertaining to this problem that could be explored are post-stratification of the sampling data by area. For example, it may be more productive to use different strata for a given time frame, such as a year. However, this would involve changing the sampling instructions. Instead of choosing wells that contain fish from the same sampling area, the rule could be that the sets would have to be in spatially contiguous 5^o x 5^o areas. This may seem difficult to implement; however, the samplers already have to evaluate the observer or logbook data at a fine level to determine if the well is suitable for sampling, so this technique would not necessarily increase their workload, but rather change their approach.

Another issue pertaining to the actual sampling scheme that should be further addressed is the impact that sorted wells have on the estimates of TAC by species. It would be prudent to study the spatial distribution of these samples and identify any potential biases they may have on the estimates of the TAC by species.

CHAPTER 6

CONCLUSIONS

Estimating the total catch of the various species of tuna in the EPO has become more important in recent years due to increased fishing pressure by several types of gear. Stock assessments rely largely on the data collected from the fishery, so it is prudent to learn as much as possible about the variability of the estimates. In recent years, the IATTC staff has been able to compile better estimates of the landed catches from more nations that fish for tunas in the EPO, from small artisanal vessels off the coasts of the Americas to the large longline vessels from various Asian and European countries (IATTC, 2006). In addition, reporting the scientific estimates instead of cannery estimates of the TAC by species for the purse-seine and pole-and-line fleets has given a broader view of the exploitation of these resources. There are still many unknown variables, and possibly more unreported catches. However, the increased participation of many of the nations that fish for tunas in the EPO to collect data and maintain better databases has allowed for better estimates of the TAC by species.

Despite these better estimates, there is still room for improvement. Creating more homogenous sampling areas that represent the current fisheries for tunas in the EPO is an important update to the sampling scheme. Stratifying the data by the Proposed Sampling Areas produced smaller variance estimates of the TAC by species in more cases than not (see Table 4.12). Though the reductions were not significant, the methodology used in this research may be improved by incorporating different variables into the analyses and it may be possible to decrease the variance estimates even further.

Area stratification may not be the most important component affecting the variability of the TAC estimates; however, it is one of the strata defined in the sampling protocols. Without some sort of spatial stratification, it would be difficult to implement the sampling protocols in the field. Further research regarding the optimal spatial stratification is necessary.

An improved method for estimating the variance of the TAC by species is also crucial. Bootstrapping is a useful tool often used to estimate the variance of populations; however, it is important to understand the intricacies of the variance components, especially in complex systems such as the multi-species, multi-gear type fisheries for tunas that exist in the EPO and many other ocean areas around the world.

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APPENDIX

IATTC SAMPLING INSTRUCTIONS

IATTC SAMPLING INSTRUCTIONS

The following is an excerpt of Chapter 6 of a draft of the IATTC Field Office Manual and is included to give a better understanding of the how LFSC samples are obtained. The tables, figures (except Figure 5), and appendices referred to in this section are not provided.

6.0. LENGTH FREQUENCY AND SPECIES COMPOSITION SAMPLING

Two objectives of the IATTC are to estimate the total catch of tuna for each species and to estimate the size composition of the catches for each species made by the surface fleet (purse seine and baitboat) in the eastern Pacific Ocean. These estimates are based on data collected from selected wells during the unloading process of fishing vessels. The fork length (Figure 5) of samples of the target species (yellowfin, skipjack, bigeye, bluefin and black skipjack) is measured and a species composition sample is taken from selected wells by counting and identifying individual fish. The selected wells should contain catches made within a calendar month and sampling area (Figure 6) and, for purse seiners, from a single type of set (dolphin, unassociated school, or floating object); wells containing fish caught in more than one set type are not sampled.

6.1. General Instructions

6.1.1. Sampling of purse-seine catches (all set types):

Prior to sampling, abstract the fishing information from the observer records, or if the trip did not have an observer on board, from the logbook. Determine which wells contain fish caught with a single set type within a single sampling area and a single month. Only wells with catches meeting all these criteria should be sampled. Do not sample wells with tunas from more than one month, more than one sampling area, or mixed set types. Determine from the reported catches whether there is one or more species in a well.

6.1.2. Sampling of pole-and-line catches:

Prior to sampling, abstract the fishing information from the logbook. Determine which wells contain fish caught within a single sampling area and single month. Only wells meeting both these criteria should be sampled. If the whole vessel meets these criteria, you can consider the vessel as a well. Determine from the reported catches whether there is one or more species in a well.

6.2. Sampling procedures

- Do not measure or count tunas from the top 10% or the bottom 10% of the well selected for sampling.
- If any non-target species are encountered in the well during sampling, make a note in the Comments section of the species type and estimated tonnage.
- Choose the fish for both measurement and species composition sampling **AT RANDOM.**

Obtain fork length measurements and species composition samples as follows:

A. For wells expected to contain only ONE tuna species (**all purse-seine set types and pole-and-line**):

1. Measure 25 tunas.
2. Count and identify by species 50 tunas.
3. Measure 25 additional tunas.
4. Count and identify by species 50 more tunas.

A sample from a well expected to contain only one tuna species should consist of 50 fish measured and 100 fish counted and identified by species. If a second tuna species is encountered during sampling, follow the instructions under section (B) or (C) below. Measurement and counting/identifying should be independent of each other: in other words, do not count fish which have been measured, and conversely do not measure fish which were counted.

B. For wells expected to contain MORE THAN ONE tuna species (**purse-seine floating object or unassociated school sets and pole-and-line**):

1. Measure all tuna species encountered until 25 tunas of **one** species are measured.
2. Count and identify by species 200 tunas.
3. Return to measuring until 50 tunas of one species have been measured.
4. Count and identify by species an additional 200 tunas.
5. Return to measuring until 50 tunas of each species have been measured, when possible. If there are very few of the secondary (or tertiary) species present or if the species composition appears to change as the well is further unloaded, count and identify an additional 200 fish. If it is not reasonable to obtain 50 measurements of each species present, try to measure at least 25 of each species. Use your discretion

as when to stop sampling and note the reason in the Comments section of the sampling form.

For purse-seine floating object or unassociated school sets and baitboats, a sample from a well containing more than one tuna species should therefore consist of 50 tunas measured **of each species**, plus 400 tunas counted and identified by species. As in (A), do not count fish which have been measured, and conversely do not measure fish which were counted. In cases when the secondary (or tertiary) species is rare, it is possible to have a species composition count of 600 fish and measurements of less than 50 fish of each species present. Use your discretion as when to stop sampling.

C. For wells expected to contain MORE THAN ONE tuna species (**dolphin sets only**):

1. Measure all tuna species encountered until 25 tunas of **one** species are measured.
2. Count and identify by species 100 tunas.
3. Return to measuring until 50 tunas of one species have been measured.
4. Count and identify by species an additional 100 tunas.
5. Return to measuring until 50 tunas of each species have been measured, when reasonable. If there are very few of the secondary species present or if the species composition appears to change as the well is further unloaded, count and identify an additional 100 fish. If it is not reasonable to obtain 50 measurements of each species encountered in the well, try to measure at least 25 of each species. Use your discretion as when to stop sampling and note the reason in the Comments section of the sampling data form.

A sample from a well (dolphin sets) containing more than one tuna species should therefore consist of 50 tunas measured **of each species**, plus 200 tunas counted and identified by species. As in (A), do not count fish which have been measured, and conversely do not measure fish which were counted. In cases when the secondary (or tertiary) species is rare, it is possible to have a species composition count of 300 fish and measurements of less than 50 fish of each species present. Use your discretion as when to stop sampling.

D. For wells that are SIZE AND/OR SPECIES SORTED during unloading (**<u>all</u> purse-seine set types and pole-and-line**):

Size sorted or species sorted wells should only be sampled if individual well information by size class and species can be obtained from vessel representatives, canneries or the chief engineer. Attempt to measure fish in all of the size groups noted by the chief engineer.

1. If the fish are sorted into 2 size groups, measure 25 fish of each species <u>in every size group.</u> Count and identify 200 fish for each size group containing two or more species. Forego counting and identifying those size groups with only one species.
2. If the fish are sorted into 3 or more size groups, measure 25 fish of each species <u>in every size group.</u> Count and identify 100 fish for each size group containing two or more species. Forego counting and identifying those size groups with only one species.
3. If fish are separated by species in addition to size, measure 25 fish from each group, but forego counting and identifying.
4. If fish are separated by species, but not sorted into size groups, measure 50 fish of each species, and forego counting and identifying.

6.3. Instructions for filling out the Length Frequency and Species Composition Sampling Form

For vessels with observers on board, use the set summary form (Figure 7) to determine which wells meet the three sampling criteria. If observer information is not available, use the logbook abstract to determine which wells to sample from. Use a plastic sheet to record lengths and counts while sampling. Write legibly on the plastic sheet so that a clear photocopy can be made. Attach the photocopy of the plastic sheet to the Length Frequency and Species Composition Sampling form. Also include a copy of the observer set summary form and/or the original Logbook Abstract with the sampling data.

Please fill out the sampling form completely! Examples of sampling forms for different sampling scenarios are provided in Appendix C.

6.3.1. Length Frequency and Species Composition Sampling Form Header. See Appendix C.

Vessel:.	Enter the complete vessel name
Trip No.:	Enter the trip number as described in Logbook Abstracting 1.1.6.
Sample Port:	Enter the name of the port where the sample is taken.
Sampling Area:	Enter the sampling area (Figure 6, formerly MMA)
Gear:	Enter the abbreviation for gear type (Table 9).
Set Type:	For purse-seine vessels, enter the set type (unassociated school, floating object, or dolphin).
Sample Date:	Enter the date that the sample is taken in the format "YYMMDD".
Unloading Method:	Briefly describe the type of unloading, such as "floated out", "dry" or "using winch".
Data Source:	Enter the data source(s) (observer, logbook, engineer's log) used to determine which wells to sample from.

6.3.2. Well Data

Well No.:	Enter the number of the well(s) and the location, port or starboard, of the well sampled (e.g. P1, S1, PS1).
Set No.:	If the data source is the observer (set summary sheet), enter the set number(s) that are contained in the well being sampled. If the data source is logbook, leave it blank.
Tons in Well:	Enter the total tons in the well and indicate whether the data is recorded in metric tons (M/T) or short tons (S/T).
Sample Method:	Enter the sampling method code (Table 8)
Well Loading Start Date and End Date:	Enter the start and end dates for when the well was loaded
Section Measured /Section Counted:	Indicate the section of the well where sample was taken from for both lengths and species composition. (Table 7)
Measured by /Counted by:	Enter the name of the sampler who measured fish and the name of the sampler who counted fish.

6.3.3. Sampling Data

Use this section for all unloading types except for those that are size sorted. If the fish are size sorted during unloading, leave this section blank and use the section labeled Size Sorting Data (described below.)

Species:	Enter each species type (YFT, SKJ, BET, BFT or BSJ) encountered in the well.
Total Meas.:	Enter the total number of fish measured for each species encountered in the well
Total Count:	Enter the total number of fish counted for each species encountered in the well.

6.3.4. Size Sorting Data

Use this section only for size-sorted unloadings. If the fish are not size sorted during unloading, leave this section blank and use the section 6.3, Sampling Data. If there are more than four species/size class combinations, use a second sampling form to note the additional information. See the example in Appendix C.

Species: Enter each species type (e.g. YFT, SKJ, BET, PBF or BKJ) encountered in the well.

Size Class: Enter the size class associated with each species type. It is possible that there are multiple size classes and/or multiple species types (e.g. YFT small, YFT med, YFT large or SKJ small and SKJ large, etc)

Total Meas.: Enter the total number of fish measured for each species/size class combination encountered in the well.

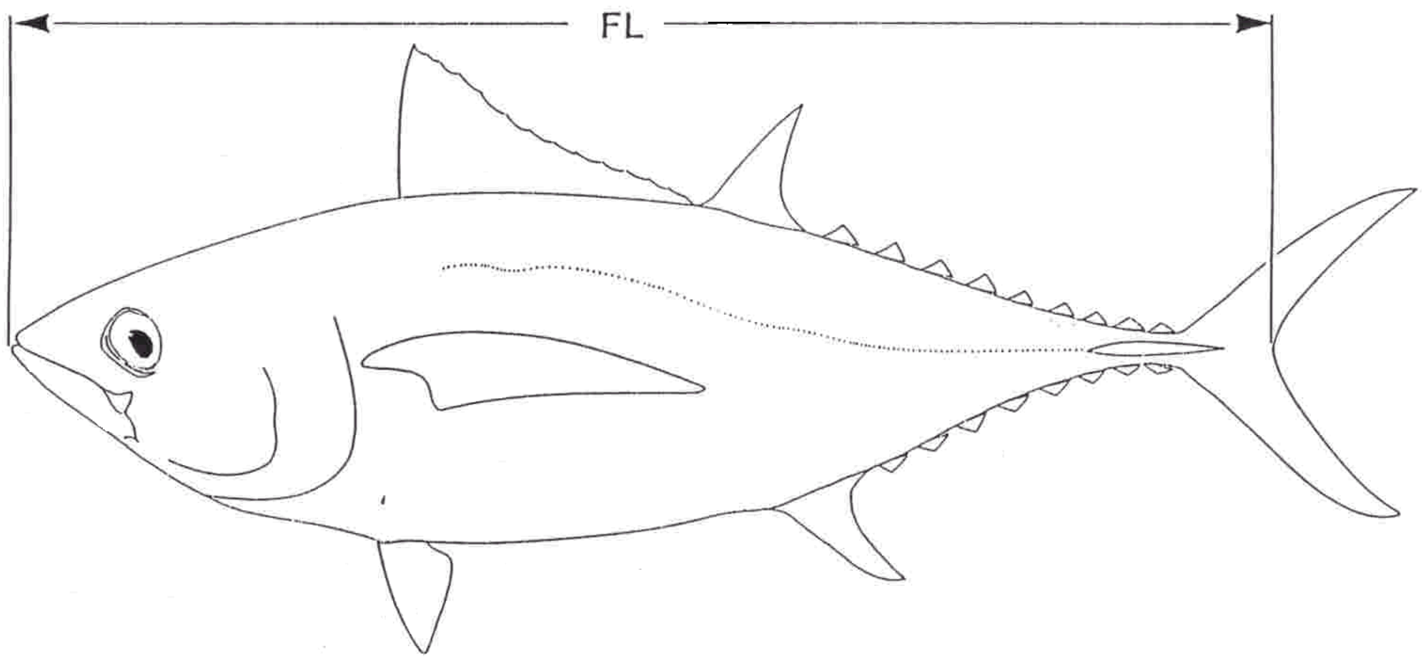
Total Count: Enter the total number of fish counted for each species/size class combination encountered in the well.

Start Time/ End Time Enter the time you begin and finish sampling the well.

6.3.5. Comments

Note anything unusual, observations, or any problems you encounter during the unloading process.

Figure 5 – Fork Length Measurement



Fork Length (FL): the distance between the tip of the upper jaw and the outside center of the caudal fin