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Note regarding information reported in this volume:

This document contains a series of reports on current research that may still be in progress, and the data contained within may have been updated since publication. Prior to using data from these reports, it is suggested that you contact the primary author for the latest developments. Staff contact information can be found on the IPHC webpage:https://iphc.int/staff

Foreword

This Report of Assessment and Research Activities (RARA) document is intended to supply progress reports on current projects and monitoring that are underway at the International Pacific Halibut Commission (IPHC). In past years, this document included fishery information, monitoring activities, stock assessment, and research reports about the previous year's activities. Many of the reports that have been routinely included in the past (e.g. the suite of stock assessment documents) are now provided as detailed papers for the Annual Meeting and as such, are listed and linked here with unique document numbers, e.g. IPHC-2018-AM094-01. This allows us to update our documents in real time as data become available ensuring that Commissioners and stakeholders have access to the most recent information possible for the decision-making process at the Annual Meeting. Continuing to be included in their entirety here are summaries of an expanded research effort that has taken place in the past year, as well as pieces of supporting information for the annual meeting documents now on the webpage.

Note that the meeting webpage is organized such that logistical information is at the top and the documents are listed and linked below.

Acronyms commonly used in IPHC reports

ADEC - Alaska Department of Environmental Conservation
ADF&G - Alaska Department of Fish and Game
BBEDC - Bristol Bay Economic Development Corporation
BSAI - Bering Sea and Aleutian Islands
CDFW - California Department of Fish and Wildlife
CDQ - Community Development Quota
CGOARP - Central Gulf of Alaska Rockfish Program
COAC - Clean Otolith Archive Collection
C&S - Ceremonial and Subsistence
CSP - Catch Sharing Plan
CVRF - Coastal Villages Regional Fund
DFO - Fisheries and Oceans Canada
DMR - Discard Mortality Rate
DO - Dissolved Oxygen
EBS - Eastern Bering Sea
EM - Electronic Monitoring
GAF - Guided Angler Fish
HCR - Harvest Control Rule
HARM - Halibut Angler Release Mortality
IFMP - Integrated Fisheries Management Plan
IFQ - United States Individual Fishing Quota
IPHC - International Pacific Halibut Commission
IQ - Individual Quota
IVQ - Canadian Individual Vessel Quota
MP - Management Procedure
MPR - Mortality Per Recruit
MSAB - Management Strategy Advisory Board
MSE - Management Strategy Evaluation
NMFS - National Marine Fisheries Service
NOAA - National Oceanic and Atmospheric Administration
NPFMC - North Pacific Fishery Management Council
NPUE - Numbers-Per-Unit-Effort
NSEDC - Norton Sound Economic Development Corporation
ODFW - Oregon Department of Fish and Wildlife
PAT - Pop-up Archival Transmitting
PDO - Pacific Decadal Oscillation
PFMC - Pacific Fishery Management Council
PHI - Prior Hook Injury
PSC - Prohibited Species Catch
PSMFC - Pacific States Marine Fisheries Commission
QS - Quota Share
RARA - IPHC Report of Assessment and Research Activities
RDE - Remote Data Entry
RI - Rockfish Index
RSL - Reverse Slot Limit
SRB - Scientific Review Board
SPR - Spawning Potential Ratio
WDFW - Washington Department of Fish and Wildlife
WPUE - Weight-Per-Unit-Effort
XRQ - Experimental Recreational Halibut

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1.1 Executive Summary

Jamie Goen

The data collected by the International Pacific Halibut Commission (IPHC) each year from the Pacific halibut fishery add to the time-series stretching back to the beginning of the modern fishery in 1888 and are a vital component of the management of the stock in accordance with the IPHC's mandate. In the fisheries statistics section, we report on Pacific halibut removals from all sectors of the fishery, the sampling and analysis of the commercial catch, and other information related to fishery removals.

Chapter 1.2 documents removals by the different sectors of the Pacific halibut fishery, including the commercial fishery, recreational fishery, subsistence fishery, and bycatch in other fisheries. The commercial and recreational fishery chapters include both landings and estimated discard mortality. The subsistence fisheries are those that are non-commercial and traditionally use Pacific halibut for direct personal, family, or community consumption or sharing as food, or customary trade. Subsistence fisheries include: 1) ceremonial and subsistence removals in the IPHC Regulatory Area 2A treaty Indian fishery, 2) the sanctioned First Nations Food, Social, and Ceremonial (FSC) fishery conducted in British Columbia, 3) federal subsistence fishery in Alaska, and 4) Pacific halibut retained by the Community Development Quota fishery in IPHC Regulatory Areas 4D and 4E for personal use that are less than 32 in or 81.3 cm (i.e., U32).

Chapter 1.3 details the IPHC's program for sampling commercial landings in 2017. The IPHC's port sampling program collects information such as Pacific halibut otoliths, lengths, individual fish weights, tissue samples, vessel logbook information, and final landing weights. This information is used to inform IPHC's stock assessment and other research by providing data on the size, age, and sex composition of the commercial landings; size-at-age; weight per unit effort; and genetics. The IPHC's port sampling improves our understanding of the Pacific halibut resource by providing fishery-dependent information which is used in conjunction with information from the IPHC's annual fishery-independent setline survey.

1.2 Fishery Statistics 2017 (IPHC-2018-AM094-05)

Lara Erikson and Jamie Goen

The following subjects were described in a paper that was prepared for the 2018 International Pacific Halibut Commission Annual Meeting (Paper IPHC-2018-AM094-05). This paper can be found on the IPHC website Annual Meeting page .

Subjects include:
- Commercial fisheries
- Recreational fisheries
- Subsistence fisheries
- Bycatch in other fisheries

1.3 Sampling commercial landings in 2017

Lara M. Erikson and Thomas M. Kong

Abstract

The International Pacific Halibut Commission's commercial catch sampling program for Pacific halibut in Alaska, British Columbia, Washington, and Oregon involves collecting Pacific halibut otoliths, fork lengths, individual fish weights, and tissue samples for genetic sampling, logbook information, and final landing weights. The collected data are used in stock assessment and other research and the collected otoliths provide age composition. Lengths and weights of sampled Pacific halibut provide the basis for size-at-age and sex-at-age analyses. Mean weights are combined with final landing weights to estimate catch in numbers. Logbook information provides weight per unit effort data, fishing location for the landed weight, and data for research projects. Finally, recovered tags provide information on migration, exploitation rates, and natural mortality.

Introduction

The commercial fishery for Pacific halibut takes place off of Alaska, British Columbia, Washington, Oregon, and California. It is managed via an individual fishing quota system in Alaska and British Columbia. While the commercial fishery off of Washington, Oregon, and California is managed with 10-hr derby style openers, as well as an allowance for fisheries targeting salmon or sablefish to retain Pacific halibut caught incidentally. To gather information for the stock assessment and for other research, IPHC Secretariat field staff, called port samplers, sample offloads of Pacific halibut in ports where landings are made and collect logbook information from vessel captains.

Sampling objectives and procedures

One of the primary objectives in sampling landings of commercially caught Pacific halibut is to obtain samples composed of sagittal otoliths and corresponding fork length, and weight measurements, which are representative of all commercial Pacific halibut landings. To accomplish this, random sampling techniques are applied, and an equal proportion of the catch (by weight) is sampled, within each IPHC Regulatory Area over the entire landing period, using prescribed sampling rates that vary among areas and sometimes ports. In addition to sampling the catch, other objectives include collecting recovered tags, and copying information from fishing logs along with the respective landed weights, for as many Pacific halibut trips as possible throughout the entire season.

Inherent in the sampling program is the positioning of field sampling staff in ports where there is an opportunity to sample a majority of the catch for each IPHC Regulatory Area. To ensure that proportional sampling occurs by IPHC Regulatory Area and port, landing patterns are reviewed annually, sampling protocols are established based on the weights landed, and sampling days are assigned to each port. In some cases, different sampling rates for a given IPHC Regulatory Area are assigned by port. Finally, sampling priorities by IPHC Regulatory Area are assigned on a port level to address situations in which multiple concurrent landings preclude the IPHC port sampler's ability to obtain samples from all landings.

Selection of sample days

Sampling protocols maximize the number of landings available for sample selection and ensure that the sampled Pacific halibut are representative of the population of landed Pacific halibut. To this end, the randomized weekly sampling schedule (six days a week; one day off) ensures that catch landed on each day has an equal chance of being selected for sampling. A restriction to the weekly sampling schedule is that one day per week is set aside for logbook collection only.

Small landings

Small landings contribute a substantial proportion of the total landed catch in some ports. The potential impact of not sampling what is considered a small landing (which differs by port) was assessed, differences identified (see Webster et al. 2014), and small landings sampled. For reference, small landings were defined and sampled in the following Alaskan ports: Petersburg, Sitka, and Juneau landings less than 2,000 lb (907 kg); and St. Paul less than 1,000 lb (454 kg).

Sampling rates and priorities

Sampling rates for each IPHC Regulatory Area are port specific (Table 1). The sampling rates are applied to the hailed weight from each trip prior to offload to determine the sample size (in pounds) for that offload. The number of days per week on which sampling should occur for landings from an IPHC Regulatory Area are also port specific. Differences in sampling rates among ports within IPHC Regulatory Areas were due to uneven distributions of projected landings among those ports. Small landings in Petersburg, Sitka, Juneau, and St. Paul, Alaska were sampled on assigned days at 10% of the hailed weight.

Samplers used their own judgment, based on a hierarchy of objectives, to determine which landings to sample when there were conflicts that precluded sampling all of the landings prescribed by their sampling schedule. For example, more than one boat may unload simultaneously from the same IPHC Regulatory Area within a port. In such cases, the vessel with the higher poundage was usually sampled. In instances when this did not occur, a sampler may have been working at a facility where there was a constant stream of Pacific halibut offloads. The sampler may therefore opt to stay at the one plant rather than travel to another location. Sampling conflicts also arose from simultaneous landings of Pacific halibut from different IPHC Regulatory Areas within a port. Sampling priorities by IPHC Regulatory Area were assigned to address these conflicts (Table 1).

Otolith sampling targets

An objective of the catch sampling program is to collect a target number of otoliths and corresponding fish lengths and weights from each IPHC Regulatory Area. Otolith sampling rates are established to optimize work effort and achieve target sample sizes. A target of 1,500 ± 500 otoliths and Pacific halibut fork lengths and lengths was set for each of IPHC Regulatory Areas 2B, 2C, 3A, 3B, 4A, 4B, and Areas 4C and 4D combined (Tables 2a and 2b). In IPHC Regulatory Area 2A, the target was 1,000 otoliths with corresponding fork lengths and weights. The IPHC Regulatory Area 2A target was further subdivided to obtain adequate sample sizes from the Area 2A treaty Indian fisheries and the directed commercial fishery, relative to each fishery component's proportion of the overall Area 2A catch limit. This division resulted in a target of 650 otoliths/

lengths/weights from the treaty Indian fishery and 350 otoliths/lengths/weights from the non-treaty directed commercial fishery and incidental retention of Pacific halibut in the sablefish fishery. The sampling rates detailed above were calculated to meet sampling targets and to obtain otoliths and data from an equal proportion of the catch within areas.

Weight measurements

There is a need to collect data coastwide throughout the season in order to estimate spatial and seasonal variation in the length to weight relationship (Webster and Erikson 2017). Fish may be weighed head-on, washed and unwashed.

In 2017, all samplers were provided with an Intelligent Weighing Technology's[1] TitanH 300/250-16 or 24 scale. All samplers used the same protocol, which integrated weighing into the standard otolith sampling procedure, i.e., for every fish from which an otolith was collected, an associated fork length and weight were also collected. This was an expansion of the 2016 coverage of the weighing procedure coastwide, to include Newport and all tribal samplers in IPHC Regulatory Area 2A.

Commercial sex-marking

A key element missing from the IPHC's stock assessment is the sex ratio of the Pacific halibut in the commercial landings. By regulation, Pacific halibut are to be dressed (eviscerated) before delivery; gonads are therefore unavailable for visual inspection of sex. In 2014, a system of external marking was developed to denote sex: two knife cuts in the dorsal fin for female, a single cut in the white-side gill plate for male (McCarthy 2015). After a small trial in Homer in 2015, which involved three vessels, the project was expanded to the Regulatory Area scale in 2016 and coastwide in 2017. The IPHC approached the fleet and asked its members to voluntarily mark their catch. Port samplers in all ports recorded the external sex mark and took a tissue sample, in addition to the length/weight measurement and otolith collection, during the standard market sampling procedure when possible. A total of 84 sex-marked landings were sampled (Table 7).

Tissue samples

In order to monitor sex ratios within the commercial catch and more accurately model population characteristics, tissue samples were collected coastwide along with otoliths and length and weight measurement data from commercial landings (Loher et al. 2017). The tissue samples will be analysed to assign sex information to each sampled fish.

Electronic log remote data entry (RDE)

Port sampling vessel data collection methods are still based on pencil and paper technology. With recent advancements in the field of ruggedized computing, the IPHC has integrated the new technology to enhance this data collection program in order to eliminate or reduce the need for post-collection data entry and increase the timeliness of data editing. Consequently, the data are provided to the end users (i.e., stock assessment and research scientists) earlier than in the past, allowing more time for data analysis. This also provides greater precision, verification, and timeliness in the collected log data.

[1] Intelligent Weighing Technology, 4040 Adolfo Road, Camarillo, CA 93012, USA.

An electronic tablet was provided to port samplers in each Alaskan port and in Bellingham, WA, for entry of fishing data from the IPHC hard cover logbooks directly into the remote data entry (RDE) application that was designed by IPHC programmers to capture all necessary logbook details. Samplers were tasked with entering data from as many of the logs they collected as priorities and time allowed during the course of their regular port sampling duties. Modifications and enhancements to the application continue.

In British Columbia, samplers were provided with a field version of the log entry program used by the IPHC's data transcription staff in Seattle. The samplers were tasked with entering as many Canadian paper logs as time permitted, though priority was given to other tasks such as biological sampling. In addition, samplers were supplied with Bluetooth-enabled tablets for collection of electronic logs from vessels using Archipelago Marine Research's FLOAT Fishing Log Application for Android.

Modifications to sampled ports

Prior to the season, landings for past years were reviewed, comparing deliveries into sampled and unsampled ports by IPHC statistical area, to ascertain whether any statistical areas were being under-sampled. Good coverage was found in IPHC Regulatory Areas 2B, 2C, 3A, 4C, and 4D. However, there were statistical areas in IPHC Regulatory Area 3B where the proportion of landings into sampled ports was lower than their total contribution to the Area 3B harvest. An additional port, receiving landings from this Area, has been covered in the past and this has proven to be problematic as landings are low and sporadic.

Sampling rate calculations

Sampling rate calculations, the 2017 average Pacific halibut weight, and the proportion of catch landed in sampled ports for 2017 for the different IPHC Regulatory Areas are shown in Tables 2a and 2b. The rates were calculated using the following equations:

$$PG = (TSS \cdot \overline{w}) / (PS \cdot CL)$$

where PG = the overall ratio of the landings to be sampled by IPHC Regulatory Area in sampled ports;
TSS = the otolith target for each respective IPHC Regulatory Area;
$\overline{w}$ = the average Pacific halibut weight for each IPHC Regulatory Area;
PS = the proportion of landings that were expected to be landed in sampled ports;
CL = the available catch limit set by the IPHC; and

$$sr = PG / ps$$

where sr = the sampling rate to be used for each IPHC Regulatory Area;
PG = the overall ratio of the landings to be sampled by IPHC Regulatory Area in sampled ports;
ps = the previous year's proportion of landed weights with otolith sampling.

Sampling results

Alaskan Individual Fishing Quota fishery

To meet Alaskan sampling objectives, the ports of Dutch Harbor, Kodiak, Homer, Seward, Juneau, Sitka, Petersburg, and Bellingham were staffed throughout the entire 2017 Individual Fishing Quota (IFQ) season (11 March through 7 November). St. Paul was staffed from 26 June through 19 August, during the height of the IPHC Regulatory Area 4C Community Development Quota (CDQ) and IFQ fisheries. A sampling effort summary is presented in Table 3. Otolith and length samples for each Alaskan IPHC Regulatory Area met the targets.

Table 4 presents the proportion of sampled weight to landed weight in each sampled port. IPHC Regulatory Area information on a Prior Notice of Landing (PNOL) list aids in minimizing this variation. The PNOL list was compiled from National Oceanic and Atmospheric Administration (NOAA) Restricted Access Management Division data on vessels notifying NOAA's Office of Law Enforcement of their intention to land IFQ fish. The PNOL list included poundage of Pacific halibut and sablefish to be landed by vessel name, along with the accompanying Alaska Department of Fish and Game number, the unloading port, and the unloading location, date, and time. The advance knowledge of which IPHC Regulatory Area the catch was coming from helped samplers set sampling priorities. For landings of catch taken from multiple IPHC Regulatory Areas, the knowledge of the amount of catch from each Regulatory Area for a given landing would further reduce these variations in proportions.

IPHC samplers copied approximately 2,700 Alaskan fishing logs from ports where the IPHC had a presence, and another 300 logs for Alaskan landings delivered to other ports (Table 5). Samplers had an opportunity to collect logs from other locations when they encountered transient Pacific halibut vessels in their own ports.

Canadian Individual Vessel Quota fishery

IPHC samplers staffed the ports of Vancouver, Port Hardy, and Prince Rupert from 11 March through 7 November 2017. Most of the IPHC Regulatory Area 2B catch (94%) was landed in the three sampled Canadian ports combined (Table 2a). The samplers collected otoliths and fork length samples, within the target range of 1,000-2,000 (Table 3). Table 4 presents the proportion of sampled weight to landed weight in each sampled port. IPHC samplers collected 410 Canadian logs from ports where the IPHC has a presence, and few logs for Canadian landings delivered to other ports in British Columbia (Table 5).

Washington and Oregon

Treaty Indian managers worked cooperatively with the IPHC and sampled IPHC Regulatory Area 2A tribal landings. In 2017, the Jamestown S'Klallam, Port Gamble S'Klallam, Swinomish, Lummi, Makah, Quileute, and Quinault tribes in Washington State participated in the IPHC's sampling program. Sampling rates were calculated for each tribe based on the sampling rate calculation used for all non-tribal ports. The sampling rates for the tribes are listed in Table 1. The 2017 otolith/tissue-sample and length/weight collections totaled 670, which were just over the target of 650 otoliths, and the tribal samplers collected otoliths from 50% of the total tribal commercial catch (Table 3). Sampling by the tribes is done opportunistically and is dependent on availability of tribal fisheries staff. The number of fishing logs collected from the treaty Indian fisheries decreased from 161 in 2016 to 111 in 2017 (Table 5).

In 2017, the IPHC Regulatory Area 2A non-treaty commercial sampling collections were 105 above the target of 350 otoliths/tissue-samples (Table 3). The majority (55%) of the IPHC Regulatory Area 2A non-treaty commercial sampling was conducted in Charleston, Oregon, during the 12 and 26 July directed commercial fishery openings. The rest of the samples were obtained in Newport, Oregon during the first directed commercial opener (28 June) and in Bellingham, Washington during the incidental retention of Pacific halibut in the sablefish fishery.

In 2017, samplers collected 66 logs from the directed commercial fishery (Table 5), 30 more than in 2016. In 2017, 15 logs were collected from the incidental retention of Pacific halibut in the sablefish fishery north of Point Chehalis, Washington.

Pacific halibut tag collection

Port samplers collected tags from 14 tagged Pacific halibut. Five of these recoveries were from the 2017 setline U32 wire tagging project; three were recovered in Prince Rupert, and one each in Bellingham and Port Hardy. Two tagged Pacific halibut from the 2015 NMFS trawl survey wire tagging pilot were recovered: one in Petersburg and one in Kodiak. Six tagged fish from the 2013 dummy archival study were recovered in Seward (four fish) and Kodiak (two fish). Lastly, one Pacific halibut from the 2010 Aleutian wire tagging study was recovered in Kodiak. Tag data collected dockside included fork lengths, otoliths, and capture location of the recovered tagged fish. Additional tag information can be found within this volume (Forsberg 2017a, Forsberg 2017b).

Additional biological sampling and data collection projects

This section describes biological sampling projects for which the port samplers were tasked with outside of their typical port sampling collection duties. Details on each project are presented below.

Clean otolith archive collection (COAC)

Otoliths for the Clean Otolith Archive Collection (COAC) will not be used for age determination, but are cleaned, dried, and stored whole in climate-controlled conditions for future analysis (Tobin at al. 2017). The COAC is primarily supplied via the IPHC fishery-independent setline survey; however, in IPHC Regulatory Areas 2A and 4CD the otolith sampling rate for the 2017 survey is 100%. For this reason, samples from the commercial fleet were collected in these three IPHC Regulatory Areas to supply the COAC. In 2017, the target of 100 otoliths was attained or exceeded in IPHC Regulatory Areas 2A and 4CD (Table 6).

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Table 1. 2017 sampling rates and days by IPHC Regulatory Area and port.

Regulatory Area	Sampling Rate (%)	Port(s)	No. Sampling Days Per Week	Priority by Port (1 = highest)
2A Non-tribal	10	Bellingham, Newport	All days	4
2A Tribal	10	Bellingham	As many as possible	4
	10	LaConner		4
	5	Neah Bay, Sequim, Port Angeles		4
	5	Taholah, Westport		4
2B	3.5	Prince Rupert	5 days	4
	1.5	Port Hardy, Vancouver		4
2C	4	All ports	5 days	4
3A	1	Bellingham	3 days	6
	1.5	Sitka	5 days	6
	1	Seward, Kodiak	4 days	6
	1	All other ports	5 days	6
3B	10	Seward, Dutch Harbor	5 days	5
	2.5	All other ports		5
4A	5	All ports	5 days	3
4B	15	Dutch Harbor	5 days	1
	10	All other ports		1
4C&D	6	St. Paul	4 days	2
		All other ports	5 days	2

Table 2a. 2017 otolith targets and data used in determining the sampling rates for IPHC Regulatory Areas 2B, 2C, 3A, and 3B.

	Regulatory Areas			
	2B	2C	3A	3B
Otolith target (no.) (*TSS*)	1,500	1,500	1,500	1,500
2016 Average Pacific halibut weight (lbs) ($\overline{w}$)	22.76	29.81	19.41	22.03
Sample size (000 lb) ($TSS*\overline{w}$)	34.1	44.7	29.1	33.0
2017 Catch limit (000 lb) (*CL*)	6,199	4,212	7,739	3,140
2016 Landings into sampled ports (000 lb)	5,767	2,725	6,227	1,922
Proportion landed in 2016 sampled ports (*PS*)	0.937	0.722	0.828	0.796
Overall ratio to be sampled in 2017 (*PG*)	0.006	0.015	0.005	0.013
Proportion of 2016 landed weight with otolith sampling (*ps*)	0.362	0.452	0.449	0.559
Sampling ratio for estimated weight available for sampling in 2017 (*sr*)	0.016	0.033	0.010	0.024
2017 Final sampling rates (%)	2.0	3.0	1.0	2.5
2017 Average Pacific halibut weight	22.9	30.5	19.5	22.0
2017 proportion landed in sampled ports	0.930	0.701	0.813	0.826

Table 2b. 2017 otolith targets and data used in determining the sampling rates for IPHC Regulatory Areas 2A, 4A, 4B, and 4C&D.

	Regulatory Areas				
	2A Tribal	2A Non-tribal	4A	4B	4C&D[1]
Otolith target (no.) (*TSS*)	650	350	1,500	1,500	1,500
2016 Average Pacific halibut weight (lbs) ($\overline{w}$)	19.37	19.77	23.81	22.56	22.09
Sample size (000 lb) ($TSS*\overline{w}$)	12.6	6.9	35.7	33.8	33.1
2017 Catch limit (000 lb) (*CL*)	436	296	1,390	1,140	1,504
2016 Landings into sampled ports (000 lb)	318	102	976	532	1,040
Proportion landed in 2016 sampled ports (*PS*)	.90	0.26	0.713	0.489	0.801
Overall ratio to be sampled in 2017 (*PG*)	0.032	0.090	0.036	0.061	0.028
Proportion of 2016 landed weight with otolith sampling (*ps*)	0.488	0.595	0.790	0..464	0.501
Sampling ratio for estimated weight available for sampling in 2017 (*sr*)	0.066	0.151	0.046	0.131	0.055
2017 Final sampling rates (%)	5	10	5.0	15.0	5.0
2017 Average Pacific halibut weight	19.9	17.3	22.4	21.4	25.5
2017 proportion landed in sampled ports	0.930	0.839	0.689	0.375	0.773

[1]4C&D includes CDQ

Table 3. Summary of 2017 otolith targets, collected otoliths, landings sampled, and the percentage of the total landed weight, represented by the weight of landings, from which otoliths were sampled.

Regulatory Area	Otolith Target	Collected otoliths	No. landings sampled	Percent of catch sampled
2A Tribal	650	670	101	35
2A Non-tribal	350	455	72	88
2B	1,500	1,347	92	26
2C	1,500	1,405	142	29
3A	1,500	1,466	127	37
3B	1,500	1,467	48	44
4A	1,500	1,038	56	33
4B	1,500	1,816	17	26
4C&D	1,500	1,632	50	41
Totals	**11,500**	**11,296**	**705**	**34**

Table 4. Proportion of total 2017 Pacific halibut landings represented by the weight of landings from which otoliths were sampled, separated by IPHC Regulatory Area, and listed by key ports.

	2A	2B	2C	3A	3B	4A	4B	4C	4D
Charleston	0.55								
Newport	0.40								
Bellingham	1.12			1.27					
Treaty Tribe[1]	0.36								
Port Hardy		0.43							
Prince Rupert		0.23							
Petersburg			0.47	0.31					
Sitka			0.42	0.45					
Juneau			0.38	0.30					
Seward				0.40	0.34				
Homer				0.56	0.69	0.48			
Kodiak				0.50	0.66	0.47	0.59		0.96
Dutch / Unalaska					0.28	0.55	0.80	0.07	0.81
St Paul								0.46	0.86

[1]IPHC Regulatory Area 2A tribes that participated in the commercial sampling program.

Table 5. The number of Pacific halibut fishing logs collected by IPHC port samplers from landings into key ports in 2017, and the total number of logs collected from all ports.

Key Ports	US	Canada	
Charleston	41		
Newport	25		
Bellingham	45		
Treaty Indian[1]	111		
Port Hardy		157	
Prince Rupert		251	
Vancouver		2	
Petersburg	254		
Sitka	473		
Juneau	185		
Seward	352		
Homer	382		
Kodiak	510		
Dutch Harbor	258		
St. Paul	229		**Grand total**
Total key ports	**2,865**	**410**	**3,275**
Total all ports	**3,175**	**412**	**3,587**

[1]IPHC Regulatory Area 2A tribes that participated in the commercial sampling program.

Table 6. Summary of 2017 COAC targets and collections.

Regulatory Area	Otolith Target	Collected otoliths
2A	100	100
4CD	100	151

Table 7. Number of sex-marked landings that were sampled, number of biological samples taken (with sex-mark) for those trips, the weight of offloaded fish represented, and the proportion of sampled weights that were sex-marked, as sampled by IPHC port samplers during 2017.

Regulatory Area	Sex-marked offloads	Sex-marked samples	Sex marked weight (000 lb; t)	Percent sex-marked by weight
2A	36	87	18; 8	6.2
2B	5	70	91; 41	5.3
2C	16	102	110; 50	9.0
3A	10	79	219; 99	7.6
3B	9	237	285; 129	20.3
4A	2	69	34; 15	7.4
4B	2	93	32; 15	10.7
4C	3	79	18; 8	9.1
4D	1	19	16; 7	3.7

2.1 Executive Summary

Josep V. Planas

The research activities performed by the International Pacific Halibut Commission (IPHC) Secretariat staff during 2017 and that are reported here highlight several of the research topics that IPHC has been investigating over the last few years and that are now being contemplated within the 5-year Biological and Ecosystem Science research program. It is worth noting that a great majority of these studies are conducted using the fishery-independent setline survey (FISS) that IPHC conducts annually covering the distribution range of the Pacific halibut and this underscores the importance of the FISS as an essential research platform for IPHC. One of the landmark activities that is performed annually (since 2009) in the FISS is the environmental monitoring effort aimed at collecting oceanographic data from all survey stations in the form of depth, salinity, temperature, dissolved oxygen, pH, and chlorophyll *a* concentration information. In 2017, oceanographic data were successfully collected from 1,281 stations (Sadorus and Walker 2017). The FISS has also allowed for the collection of biological data from Pacific halibut in order to understand the biology of this species, with emphasis on growth, physiological condition, reproduction, and migration, as well as investigating the relationship between capture-related events, physiological condition, and survival of discarded Pacific halibut.

In the present Report of Assessment and Research Activities we report on current studies devoted to describing the changes in reproductive development that take place throughout an entire annual reproductive cycle in female and male Pacific halibut (Planas et al. 2017). The described studies are intended to improve our current staging of reproductive status and update current estimates of maturity-at-age, to provide estimates of skipped spawning, and ultimately to improve our estimates of the effective spawning stock biomass (SSB). Also in relation to improving our estimates of SSB, given that uncertainties regarding the proportion of female and male Pacific halibut captured by the commercial fleet can strongly influence estimates of SSB, we report on the results of a field sex-marking program and the parallel development of genetic methods used for sex identification (Loher et al. 2017). These studies will determine the feasibility and accuracy of sex-marking at sea by commercial vessels in order to estimate the sex ratio of the commercial catch.

In parallel with ongoing studies aimed at understanding the effects of environmental temperature on somatic growth and at developing methods to evaluate different growth trajectories in Pacific halibut, in the present report we provide the age distribution by sex and size of Pacific halibut caught in the FISS and by the directed fishery (Forsberg 2017a, 2017b, respectively). Also, efforts to collect clean otoliths for future trace element studies (Tobin et al. 2017) and to monitor Pacific halibut for contaminants and parasites have continued in 2017 (Dykstra 2017).

We also report on the progress in the sequencing of the Pacific halibut genome and its future importance in providing genomic resolution to genetic markers identified in other projects and in understanding potential genomic regions that determine growth, reproductive, and behavioral characteristics, and that could be subject to evolutionary or direct environmental pressures (Planas 2017).

Continuing our efforts to improve our understanding of the movement and distribution of Pacific halibut, we report on studies on Pacific halibut migration, including a summary of past tagging efforts and current tag recovery success (Forsberg 2017c), the results of the first year of a coastwide effort to tag small Pacific halibut (< 82 cm fork length or "U32") in the FISS (Forsberg 2017d) and a description of the continuation of wire-tagging efforts on the National Marine Fisheries Service trawl survey that is contained in summaries provided in the Report of Assessment and Research Activities Chapter 3 (Sadorus et al. 2017b; Sadorus et al. 2017c). We also report on the first efforts to identify winter spawning locations and seasonal movements of adult fish caught on Bowers Ridge (Regulatory Area 4B) with the use of pop-up archival transmitting (PAT) tags (Loher 2017). In addition, we report on the results of ongoing studies to describe distribution of Pacific halibut larvae and the connectivity of larvae between the Gulf of Alaska and the Bering Sea (Sadorus et al. 2017a).

Finally, we report on our efforts to investigate the relationship between Pacific halibut release practices, physiological condition, injury levels, and post-release mortality in the directed Pacific halibut longline fishery (Dykstra et al. 2017). This study, which also incorporates an electronic monitoring component in its design, will be important for improving current discard mortality rate estimates.

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2.2.1 Reproductive assessment of female and male Pacific halibut

Josep V. Planas, Claude L. Dykstra, Tracee Geernaert, Timothy Loher

Abstract

Current maturity estimates in female Pacific halibut are derived from macroscopic visual examination of the ovaries collected in the field. In order to improve maturity estimates and to provide updated estimates of maturity-at-age, the International Pacific Halibut Commission (IPHC) is conducting studies destined to improve our knowledge on reproductive development in female and male Pacific halibut. In this ongoing study, Pacific halibut of both sexes will be collected on a monthly basis during an entire annual reproductive cycle from the central Gulf of Alaska region. A description of the sample collection protocols and the various reproductive parameters that will be measured, as well as an update on the progress in sample collection, is provided in this report.

Introduction

Each year, the fishery-independent setline survey (FISS) collects biological data on the maturity of female Pacific halibut that are used in the stock assessment. In particular, the female maturity schedule is used to estimate spawning stock biomass. Currently-used estimates of maturity-at-age indicate that the age at which 50% of female Pacific halibut are sexually mature is 11.6 years on average. However, maturity is estimated with the use of macroscopic visual criteria, implying a relative level of uncertainty associated with the employed semi-quantitative assessment, but the maturity schedules for both sexes have not been revised in recent years and may be outdated. For this reason, efforts need to be put in place to further understand reproductive maturity in female Pacific halibut. Unfortunately, relatively little is known regarding the physiological changes that take place in the ovary during reproductive development leading to spawning in this species. This study aims at describing the progression of reproductive development in both female and male Pacific halibut during an entire annual reproductive cycle. The present study aims at collecting morphological, histological, endocrine, and functional data that will provide us with a better understanding of the temporal and spatial progression of sexual maturation in Pacific halibut, and to better estimate maturity for stock assessment purposes.

Materials and Methods

Sampling schedule and location

Adult male and female Pacific halibut are currently being collected on a monthly basis in the Portlock region in the central Gulf of Alaska on chartered commercial vessels. Fish collection occurs at the beginning of each month, began in September 2017, and will continue until August 2018. The September 2017 and October 2017 fish collection trips were conducted on the *F/V Saint Nicholas* out of Homer, AK. The November 2017 and December 2017 fish collection trips were conducted on the *F/V Kema Sue* out of Kodiak, AK; the *Kema Sue* will continue the monthly collection trips until May 2018. Fish collection trips between June 2018 and August 2018 will be conducted by chartered commercial vessels that will be selected in early 2018. Two experienced sea samplers are placed on board each vessel to record biological measurements and collect biological samples.

Sample collection

Approximately 30 male (>70 cm in length) and 30 female (>90 cm in length) Pacific halibut are sampled per month. From each fish, round weight and fork length are recorded. Blood samples are taken by caudal puncture using heparinized 1 cc syringes with 22G heparinized hypodermic needles and are kept on ice until transferred to a heparinized Eppendorf tube for centrifugation. Blood is centrifuged in a field centrifuge (MiniSpin, Eppendorf, Germany) at 3,000 rpm for 15 min. Once separated, the plasma is removed with the use of a plastic Pasteur pipette, transferred to a separate, non-heparinized Eppendorf tube and stored at - 20C. Fish are sacrificed and the gonads are removed and weighed using a small motion compensated scale in order to calculate the gonadosomatic index (GSI; gonad weight/round weight X 100). Gonadal staging is visually assessed following the same protocols that are used in the FISS and each of the sampled gonads is individually photographed. Small pieces (approx. 1 cm^3) of ovary and testis are excised from the gonad and fixed in 10 ml of 10% formalin in a 15-ml conical tube. In addition, smaller pieces of ovary and testis (approx. 0.5 cm^3) are excised from the gonad and are placed in a 2-ml screw-cap microcentrifuge tube containing 1 ml of RNAlater, an RNA-preserving solution, and stored at - 20C. The pituitary gland is extracted by accessing the base of the brain and is placed in a tube containing RNAlater and stored at - 20C for future extraction of total RNA. Like the gonads, the liver is excised and weighed in order to calculate the hepatosomatic index (HSI; gonad weight/round weight X 100). Fish are measured for fat content using the Fatmeter (Distell, Scottland, UK) device by taking to readings from the musculature above the sharp curvature of the lateral line on the blind side of the fish as described in Briones Ortiz (2017). Finally, the left otolith of each fish is removed for aging.

Results

Female and male Pacific halibut were successfully collected from September 2017 through December 2017. In September 2017, 30 females and 27 males were collected, whereas in October, November and December 2017, 30 females and 30 males were collected. Biological samples collected from these fish are currently being stored at the Kodiak Marine Science Center in Kodiak, AK.

The photographic images of all staged gonads, when combined with GSI and histological data will allow us to revise the morphological criteria currently used for staging the maturity status of the gonads (ovary and testis). The histological assessment of gonadal development will be performed by processing fixed gonad (ovary and testis) samples for histology in paraffin-embedded blocks. Histological blocks will be cut and histological sections will be stained with hematoxylin and eosin to visualize the developmental stage of collected ovaries and testes.

Collected plasma samples will allow us to conduct a thorough endocrinological assessment of reproductive status and development in order to correlate levels of hormones and reproductive genes with morphological and histological assessment of the gonads. The endocrine system is tasked with transmitting environmental information on light and temperature captured by the sensory systems throughout the changing seasons to the organs involved in reproduction: the pituitary gland (also named hypophysis), as the site of the production of gonadotropic hormones; the gonads (ovaries and testes), as the site of the production of sexual steroids (estradiol, testosterone, progesterone, etc.) and, importantly, the gametes (eggs and sperm). Therefore, collected blood samples will be used to measure the levels of reproductive hormones (gonadotropic hormones and sex steroids) throughout the entire reproductive cycle of male and female Pacific halibut. Total RNA extracted from gonadal and pituitary samples collected in RNAlater will be used to measure the transcript (mRNA) levels of important reproductive genes that are expressed in these tissues and that encode key proteins controlling the reproductive process and, therefore, can be used as molecular markers of reproductive function.

Finally, we are collecting functional data on the energy stored in the fish in order to relate energy storage to sexual maturity. Energy storage will be determined by the hepatosomatic index (HSI; liver weight/round weight X 100) and the muscle lipid content as measured with the Fatmeter device.

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2.3.1 Age distribution of Pacific halibut in the 2017 commercial catch

Joan E. Forsberg

Abstract

Pacific halibut (*Hippoglossus stenolepis*) otoliths are collected annually by International Pacific Halibut Commission port samplers to provide age data for use in the stock assessment. Otoliths collected from the commercial catch provide age data that are representative of the directed fishery removals. The age distribution of Pacific halibut sampled from the 2017 commercial catch is summarized from 10,771 otoliths aged thus far. Fish from five to 40 years old were captured, with 12-year-olds comprising the largest age group in the overall catch. Average age for all Regulatory Areas combined was 13.2 years, representing a slight decrease from 2016.

Otolith sampling

Pacific halibut otoliths are collected to provide age data for use in the International Pacific Halibut Commission's (IPHC) stock assessment. IPHC age readers only use the left- or blind-side otolith of the sagittal pair for age determination because the growth patterns of right- or eyed-side otoliths are harder to interpret and the ages derived from right-side otoliths are less accurate (Forsberg 2001). Left-side sagittal otoliths are obtained from Pacific halibut caught on the IPHC's fishery-independent setline survey (setline survey) and on National Marine Fisheries Service (NMFS) trawl surveys, as well as from the commercial fishery. The annual setline survey, which uses standardized methods, gear, and bait, provides catch and biological data (including ages) that are independent of the commercial fishery and can be used to monitor changes in the catch over time, while otoliths from the NMFS trawl survey provide age data for small Pacific halibut that are not captured on longline gear. Age distributions for the setline and NMFS trawl survey collections are presented in Forsberg (2017) and Sadorus et al. (2017a, b).

Otoliths collected from the commercial catch (also called market samples) provide age data that are representative of the directed fishery removals. The commercial otolith-collection target is 1,000 otoliths for IPHC Regulatory Area 2A and 1,500 (±500) per Regulatory Area for each of Regulatory Areas 2B, 2C, 3A, 3B, 4A, and 4B, and Regulatory Areas 4C/4D combined. Otolith targets were met in all Regulatory Areas in 2017. Commercial catch-sampling procedures, including port- and area-specific otolith sampling rates, are detailed in Erikson and Kong (2017).

In 2017, IPHC port samplers reported collecting 11,339 market sample otoliths for stock assessment; however, only 11,296 otoliths had been received in the office at the time of writing. Of the latter, ages could not be determined for 525 otoliths because they were crystallized (i.e., composed of vaterite), right-sided, or badly broken.

An additional 251 sagittal otolith pairs were collected by port samplers for the clean otolith archive collection. These otoliths were not aged but were dried and stored for future elemental or isotopic studies (Tobin et al. 2017). The otolith collection numbers presented in the text and tables of this report do not include clean otolith archive samples.

Age distribution

The 2005 year class (12-year-olds) accounted for the largest proportion (in numbers) of the sampled commercial catch (20%) for all Regulatory Areas combined in 2017 (Table 1). The next most abundant year classes for all Regulatory Areas combined were 2004 and 2006, accounting for 16 and 12% of the sampled catch, respectively. Twelve-year-olds were also the most abundant age class in individual Regulatory Areas in 2017.

The average values for age, length, and estimated weight by Regulatory Area for 2017 are presented in Table 2. Average fork length of sampled Pacific halibut increased in Regulatory Areas 2B, 2C, 3A, 4B, 4C, and 4D in 2017, but decreased in all other Regulatory Areas. Average fork length for all Regulatory Areas combined increased by 0.5 cm in 2017.

The average age of fish sampled from Regulatory Areas 2B, 2C, and 4B increased in 2017 relative to 2016, while average ages from all other Regulatory Areas decreased (Table 3). The average age from all Regulatory Areas combined in 2017 (13.2 years) was slightly lower than it was in 2016.

The youngest and oldest Pacific halibut in the 2017 commercial samples were determined to be five and 40 years old, respectively. One Pacific halibut was determined to be five years old: a 93-cm fish from Regulatory Area 4B. Two fish were aged at 40 years: a 117-cm fish from Regulatory Area 4A and a 131-cm fish from Regulatory Area 4B. The largest Pacific halibut in the 2017 commercial sample was a 208-cm fish from Regulatory Area 3B, which was determined to be 23 years old. The smallest Pacific halibut in the 2016 commercial catch sample was a 74-cm fish from Regulatory Area 4C, aged at 13 years old. Length frequencies by regulatory area for Pacific halibut sampled in the 2017 commercial catch are presented in Table 4.

Quality control

Table 5 contains percent agreement values for quality control (QC) readings. All QC readings from 2002 through 2016 were conducted on burned or baked otolith sections (Forsberg 2001). QC readings for years prior to 2002 were read from either surface ages or burned/baked section ages. Ten percent of each year's market samples are read twice for QC. At the time of writing, QC readings for the 2017 commercial samples were not complete. The remainder of the QC readings of 2017 market samples will be performed over the winter of 2017-18.

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Table 1. Age distribution of commercial catch of Pacific halibut by IPHC Regulatory Area in 2017.

Age	Regulatory Area								
(years)	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4C**	**4D**	**Total**
5							1			**1**
6		7	5	4	17	1			1	**35**
7	1	3	6	9	37	15	1			**72**
8	28	17	26	7	53	25	1	16	6	**179**
9	115	60	56	44	119	112	23	87	58	**674**
10	136	89	77	61	138	90	55	66	71	**783**
11	179	137	163	138	185	110	165	94	90	**1,261**
12	247	280	269	272	279	160	325	163	117	**2,112**
13	168	252	219	207	227	142	292	151	101	**1,759**
14	72	133	144	154	127	124	202	129	103	**1,188**
15	40	91	142	127	81	52	119	75	76	**803**
16	25	58	82	93	61	47	95	23	27	**511**
17	25	61	64	92	33	18	79	8	20	**400**
18	7	46	46	71	25	16	62	9	15	**297**
19	8	26	24	36	12	14	39	3	11	**173**
20	9	24	24	42	8	5	22	1	9	**144**
21	2	6	9	16	4	4	20	1	5	**67**
22	5	3	4	15	4	5	17	1	2	**56**
23	1	6	5	11	3		18	1	5	**50**
24		3	1	11	2	3	24		2	**46**
25	3	3	4	7		3	14			**34**
≥26		4	5	13	3	11	86		4	**126**
Total	**1,071**	**1,309**	**1,375**	**1,430**	**1,418**	**957**	**1,660**	**828**	**723**	**10,771**

Table 2. Statistic associated with 2017 commercial Pacific halibut fishery samples by IPHC Regulatory Area: mean age, mean length, mean net weight, and the number of otoliths collected and aged.

Regulatory Area	Mean age (years)	Mean length (cm)	Mean weight (lbs)[1]	Mean weight (kg)[1]	Otoliths collected[2]	Otoliths aged[3]
2A	12.0	94.6	18.4	8.3	1,119	1,071
2B	13.3	100.5	23.3	10.6	1,396	1,309
2C	13.4	109.8	31.3	14.2	1,405	1,375
3A	14.1	98.2	21.1	9.6	1,466	1,430
3B	12.2	98.9	21.9	9.9	1,467	1,418
4A	12.6	99.8	22.6	10.3	1,038	957
4B	14.9	100.8	23.2	10.5	1,816	1,660
4C	12.4	103.9	25.9	11.8	869	828
4D	13.1	102.4	24.8	11.2	763	723
All Areas	**13.2**	**101.0**	**23.6**	**10.7**	**11,339**	**10,771**

[1]Weights calculated from measured fork lengths for fish aged through December 5, 2017 (excludes otoliths collected for clean archive and extra otoliths collected for sex-marking project).
[2]From market sample data entered through November 30, 2017 (excludes otoliths collected for clean archive and extra otoliths collected for sex-marking project).
[3]Numbers of otoliths aged by December 5, 2017.

Table 3. Mean age (in years), mean length (in centimeters fork length), and estimated mean net weight[1] (in pounds and kilograms) of sampled commercially-caught Pacific halibut by IPHC Regulatory Area, 2008-2017.

Reg. Area		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
2A	Age	12.1	11.5	11.4	11.7	11.5	11.6	11.2	11.1	12.1	12.0
	Length	93.5	95.5	94.2	93.2	92.9	96.1	94.7	93.9	96.9	94.6
	Wgt (lbs)	17.7	19.1	18.3	17.7	17.4	19.6	18.6	18.2	19.9	18.4
	Wgt (kg)	8.0	8.6	8.3	8.0	7.9	8.9	8.4	8.3	9.0	8.3
2B	Age	12.2	11.7	11.6	11.9	12.0	12.6	12.6	12.1	12.8	13.3
	Length	97.0	97.2	98.9	97.9	99.4	103.0	100.8	102.5	99.7	100.5
	Wgt (lbs)	21.2	21.4	22.5	21.5	22.8	25.7	23.9	25.4	22.6	23.3
	Wgt (kg)	9.6	9.7	10.2	9.8	10.3	11.6	10.8	11.5	10.2	10.6
2C	Age	13.1	12.9	12.2	12.7	12.4	13.0	12.9	13.0	13.3	13.4
	Length	106.7	107.5	105.1	106.5	109.2	109.4	110.0	109.1	108.5	109.8
	Wgt (lbs)	28.9	29.6	27.3	28.6	31.0	31.2	31.6	30.7	29.8	31.3
	Wgt (kg)	13.1	13.4	12.4	13.0	14.1	14.1	14.3	13.9	13.5	14.2
3A	Age	15.9	15.1	15.2	15.0	15.0	15.1	14.5	14.7	14.3	14.1
	Length	100.3	99.1	97.5	95.7	95.6	96.7	96.4	96.5	95.9	98.2
	Wgt (lbs)	22.9	22.1	20.9	19.4	19.2	20.2	20.0	20.0	19.4	21.3
	Wgt (kg)	10.4	10.0	9.5	8.8	8.7	9.2	9.1	9.1	8.8	9.7
3B	Age	14.0	12.8	12.7	12.7	12.6	12.8	12.8	12.1	12.6	12.2
	Length	97.1	97.2	96.0	95.2	95.2	95.4	94.2	95.8	99.1	98.9
	Wgt (lbs)	20.3	20.6	19.7	19.1	19.1	19.2	18.4	19.5	21.8	22.0
	Wgt (kg)	9.2	9.3	8.9	8.7	8.7	8.7	8.3	8.8	9.9	10.0
4A	Age	15.6	15.4	13.9	15.6	15.7	15.0	13.8	14.0	13.3	12.6
	Length	103.4	101.2	99.8	103.4	104.1	100.9	98.4	98.8	101.1	99.8
	Wgt (lbs)	25.9	24.0	22.8	26.0	26.3	23.7	21.5	21.7	23.7	22.4
	Wgt (kg)	11.7	10.9	10.4	11.8	11.9	10.7	9.8	9.8	10.7	10.2
4B	Age	15.5	16.7	16.4	16.0	16.3	15.8	15.9	15.1	14.9	14.9
	Length	110.6	107.2	107.5	109.0	105.5	104.4	100.9	100.5	100.1	100.8
	Wgt (lbs)	33.3	29.2	29.6	31.1	27.4	26.8	23.5	23.5	22.8	23.2
	Wgt (kg)	15.1	13.2	13.4	14.1	12.4	12.1	10.7	10.7	10.3	10.5
4C	Age	11.7	12.2	13.2	12.9	12.6	12.5	12.0	12.1	12.9	12.4
	Length	103.8	102.4	101.4	100.4	99.6	99.3	96.8	96.1	102.7	103.9
	Wgt (lbs)	26.3	25.4	23.8	23.3	22.9	23.3	21.0	20.2	25.5	25.9
	Wgt (kg)	11.9	11.5	10.8	10.6	10.4	10.6	9.5	9.2	11.6	11.8
4D	Age	16.1	15.9	16.1	14.7	14.9	15.9	13.8	14.1	14.2	13.1
	Length	103.2	104.3	102.7	99.3	99.2	100.3	98.3	97.7	98.4	102.4
	Wgt (lbs)	25.5	26.5	25.3	22.1	21.7	22.8	21.6	20.6	21.2	24.8
	Wgt (kg)	11.6	12.0	11.5	10.0	9.8	10.4	9.8	9.4	9.6	11.2
Total	Age	14.3	13.7	14.0	13.7	13.8	13.8	13.3	13.3	13.4	13.2
	Length	101.2	100.6	100.8	99.1	100.2	101.1	99.0	99.5	100.5	101.0
	Wgt (lbs)	24.2	23.6	23.8	22.4	23.2	24.0	22.3	22.6	23.1	23.7
	Wgt (kg)	11.0	10.7	10.8	10.1	10.5	10.9	10.1	10.3	10.5	10.7

[1]Weights calculated from measured fork lengths. Excludes samples not aged and samples collected for clean archive.

Table 4. Number of Pacific halibut sampled by 5-cm length category in the 2017 commercial catch by IPHC Regulatory Area (not including samples collected for the clean otolith archive). The 80-84-cm category is further divided to designate the U32/O32 split within that category.

Fork length	Regulatory Area									
(cm)	2A	2B	2C	3A	3B	4A	4B	4C	4D	Total
70-79	2	7			2	1		9		21
[1]80-81	21	27	9	29	28	16	8	15	4	157
[2]82-84	166	130	39	144	189	76	90	53	50	937
85-89	278	243	121	317	279	205	286	107	112	1,948
90-94	222	201	149	277	235	158	327	103	114	1,786
95-99	128	155	162	194	162	133	300	109	126	1,469
100-104	102	128	138	141	144	95	265	96	81	1,190
105-109	69	101	132	105	110	97	171	78	77	940
110-114	55	95	118	73	93	68	126	79	64	771
115-119	43	85	124	57	77	69	76	57	43	631
120-124	15	60	105	37	46	35	43	61	20	422
125-129	11	46	91	32	41	27	31	38	18	335
130-134	4	22	45	15	19	17	28	19	16	185
135-139	1	15	60	27	16	14	20	14	8	175
140-144	1	11	34	9	9	7	14	11	11	107
145-149		8	24	3	8	4	12	10	4	73
150-154	1	5	21	2	4	2	7	4	7	53
155-159		4	7	2	2	1	5	3	3	27
160-164			8		1	1	2	2	2	16
165-169			2				2		1	5
170-174		1				1			1	3
175-179	1	3	1							5
180-184			1	1		1	1	1	1	6
185-189										
190-194							2			2
195-199			1							1
200-204										
205-209					1					1
Total	1,120	1,347	1,392	1,465	1,466	1,028	1,816	869	763	11,266

[1]U32
[2]O32

Table 5. Between-reader percent agreement for Pacific halibut market samples that were aged from 1996-2016 (CV = coefficient of variation, APE = average percent error).

Year	Total aged	No. aged twice	Percent agreement (± 1 year)	CV	APE
1996	13,452	1,839	92.3	2.8	2.0
1997	15,500	2,203	93.6	2.4	1.7
1998	14,395	2,110	91.9	2.6	1.8
1999	12,796	1,117	92.0	2.5	1.8
2000	13,982	1,002	88.8	3.0	2.1
2001	13,181	2,025	86.3	3.9	2.8
2002	17,770	2,135	87.9	3.2	2.3
2003	13,738	984	82.6	3.9	2.8
2004	11,866	809	82.6	3.6	2.5
2005	13,945	1,315	85.9	3.7	2.6
2006	12,330	1,241	88.3	3.5	2.5
2007	13,910	1,488	85.8	3.9	2.8
2008	13,460	1,337	90.3	3.1	2.2
2009	13,718	1,348	91.5	2.9	2.0
2010	16,106	1,617	91.7	2.9	2.1
2011	11,215	1,131	88.4	3.4	2.4
2012	12,981	1,364	90.3	2.8	2.0
2013	11,039	1,259	89.4	2.7	1.9
2014	12,606	1,357	90.9	2.8	2.0
2015	12,312	1,366	91.0	2.4	1.7
2016	11,618	1,641	93.9	2.0	1.4

2.3.2 Age distribution of Pacific halibut in the 2017 IPHC fishery-independent setline survey

Joan E. Forsberg

Abstract

Pacific halibut otoliths are collected annually from the International Pacific Halibut Commission (IPHC) fishery-independent setline survey to provide age data for use in the stock assessment. The annual setline survey provides catch and biological data (including ages) that are independent of the commercial fishery and can be used to monitor changes in the stock over time.

The age distribution of Pacific halibut sampled during the 2017 IPHC fishery-independent setline survey is summarized in this paper. Fish ranging from four to 46 years old were captured, with 12-year-olds comprising the largest age group in the overall catch. Average age was higher and average fork length was lower for males than females in all regulatory areas.

Otolith collections

Samples used for age data

Pacific halibut otoliths are collected annually to provide age data for use in the stock assessment. Otoliths are obtained from three main sources: the International Pacific Halibut Commission (IPHC) fishery-independent setline survey (setline survey), the commercial Pacific halibut fishery, and the National Marine Fisheries Service (NMFS) trawl surveys. Otoliths collected from the commercial catch provide age data that are representative of the directed fishery removals, while otoliths from the NMFS trawl survey provide age data for small Pacific halibut that are not captured on longline gear. Age distributions for the 2017 commercial fishery are presented in Forsberg (2017), the 2016 and 2017 age distributions from the Bering Sea trawl survey are presented in Sadorus et al. 2017a, and the 2015 Gulf of Alaska trawl survey are presented in Sadorus et al. 2017b. The annual setline survey, which uses standardized methods, gear, and bait, provides catch and biological data (including ages) that are independent of the commercial fishery and can be used to monitor changes in the stock over time. The setline survey otolith collection target is 2,000 (± 500) for Areas 2A, 2B, 2C, 3A, 3B, 4A, and 4B, and Areas 4C/4D combined. Targets are achieved by setting otolith sampling rates for each regulatory area based on projected catch rates. Setline survey sampling procedures, including area-specific otolith sampling rates, are described in Goen and Geernaert (2017).

Additional otoliths

Paired otoliths for the IPHC clean otolith archive collection (COAC) have been collected during the setline survey since 2010. Otoliths in this collection are not aged, but are stored dry for use in future studies. In 2017, COAC otoliths were collected from regulatory areas where sampling rates were not already 100%. A total of 504 otolith pairs were collected on the 2017 setline survey (Tobin et al. 2017).

Extra otoliths are also collected along with tissue samples from Pacific halibut that are sampled for environmental contaminants and for parasite studies. These otoliths are aged, but the ages are not included in the setline survey age distribution.

Age distribution

The age distribution of Pacific halibut sampled from the 2017 IPHC setline survey is summarized in Tables 1-3. The 2005 year class (12-year-olds) accounted for the largest proportion (in numbers) of sampled Pacific halibut for all areas and sexes combined (Table 1). The next most abundant year classes were 2004 and 2006 (13- and 11-year-olds, respectively).

Twelve-year-olds were the most abundant age class for female Pacific halibut sampled from all areas combined, as well as for females in all Regulatory Areas except for Area 4A (Table 2). The second and third most abundant age classes for sampled females across all Regulatory Areas were 13- and 11-year-olds, respectively.

The 2005 year class (12-year-olds) was the largest for male Pacific halibut from all areas combined, as well as from Regulatory Areas 2, 3B, 4A, and 4B (Table 3). The second and third most abundant age classes for sampled males across all Regulatory Areas were 13- and 11-year-olds, respectively.

Mean age and fork length (FL) by Regulatory Area of sampled setline survey Pacific halibut for the years 2008-2017 are presented in Table 4. Average length was calculated only from fish that were aged. Average age was higher and average fork length was lower for males than females in all areas for all years with the exception of Regulatory Area 4C in 2008, where the average age was slightly lower for males than females.

The youngest and oldest Pacific halibut in the 2017 setline survey samples were determined to be four and 46 years old (Table 5). There were four fish determined to be four years old: a female from Regulatory Area 3A measuring 53 cm FL; two females from Regulatory Area 3B measuring 53 and 55 cm FL); and one male from Regulatory Area 3B measuring 71 cm FL. The 46-year-old was a male captured in Regulatory Area 4B with a fork length of 119 cm. The maximum fork length recorded for setline survey-caught Pacific halibut in 2017 was 190 cm: a female from Regulatory Area 3A aged at 22 years. The smallest Pacific halibut sampled in the 2017 setline survey measured 33 cm FL: a male from Regulatory Area 4A aged at five years.

Quality control

Ten percent of annual setline survey otoliths are aged a second time by a different reader as a measure of quality control (QC). QC age readings for the 2017 survey otoliths were not complete at the time of writing. Between-reader percent agreement for setline survey ages from 2002 through 2016 is presented in Table 6.

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Table 1. Age distribution (number of individuals sampled) of all Pacific halibut (male, female, and unknown sex combined) collected in the 2017 fishery-independent setline survey. "Sample rate" indicates the percentage of those halibut captured in each Regulatory Area whose otoliths were removed for subsequent aging.

	Regulatory Area									
	2A	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4C**	**4D**	
	Sample rate (%)									
	100	35	33	9	13	78	45	100	100	
Age (years)										**Total**
4				1	3					**4**
5	1	7	9	5	10	9	4	7	2	**54**
6	4	18	26	13	25	34	14	12	7	**153**
7	12	23	21	13	38	40	43	9	10	**209**
8	18	31	43	18	37	86	26	23	29	**311**
9	86	129	117	82	110	222	76	71	92	**985**
10	104	123	145	107	115	172	72	57	130	**1,025**
11	125	204	240	174	183	220	109	69	131	**1,455**
12	193	345	371	287	289	335	228	87	133	**2,268**
13	141	240	349	233	208	331	191	77	106	**1,877**
14	64	105	184	145	144	249	175	50	96	**1,212**
15	47	88	186	140	113	163	113	38	55	**943**
16	20	45	113	94	41	82	62	8	30	**495**
17	14	43	82	97	34	65	55	7	16	**413**
18	10	32	81	95	29	56	41	4	11	**359**
19	11	11	49	47	21	28	38		9	**214**
20	4	13	35	29	6	25	31		11	**154**
21	4	4	13	20	2	12	19		6	**80**
22	1	3	12	17	2	10	11		6	**62**
23	3	3	10	7	1	9	18		6	**57**
24	1		4	2	2	4	13		6	**32**
25	1	2	5	5	2	4	9	1	2	**31**
≥26	1	2	9	3	6	31	60	2	59	**173**
Total	**865**	**1,471**	**2,104**	**1,634**	**1,421**	**2,187**	**1,408**	**522**	**953**	**12,565**

Table 2. Age distribution (number of individuals sampled) of female Pacific halibut collected in the 2017 fishery-independent setline survey. Note that halibut are not sampled at the same rate in all Regulatory Areas (see rates in Table 1), and that there are not separate sampling rates by sex within an area.

	Regulatory Area									
Age	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4C**	**4D**	**Total**
4				1	2					**3**
5	1	6	7	4	8	5	3	7	2	**43**
6	3	9	16	7	22	28	7	10	4	**106**
7	11	15	14	10	26	28	30	6	9	**149**
8	15	19	29	11	18	54	15	19	17	**197**
9	65	83	80	51	60	101	37	66	66	**609**
10	84	91	97	72	47	95	37	46	97	**666**
11	101	125	179	122	77	93	57	64	97	**915**
12	158	230	285	202	126	164	116	79	106	**1,466**
13	118	159	279	152	100	172	103	65	84	**1,232**
14	52	65	131	89	59	139	71	47	73	**726**
15	38	44	142	77	36	83	44	31	40	**535**
16	11	22	87	43	9	42	14	7	23	**258**
17	12	19	57	39	9	26	20	4	10	**196**
18	6	9	53	31	11	28	14	3	6	**161**
19	10	3	29	12	4	11	3		5	**77**
20	1	2	23	7		14	6		7	**60**
21	3	1	8	5		3	4		1	**25**
22	1	2	8	2		5	3		4	**25**
23	3		6	2		4	2		3	**20**
24	1		2			2	3		4	**12**
25		1	5			1	2	1	1	**11**
≥26		2	4	2		9	9		23	**49**
Total	**694**	**907**	**1,541**	**941**	**614**	**1,107**	**600**	**455**	**682**	**7,541**

Table 3. Age distribution (number of individuals sampled) of male Pacific halibut collected in the 2017 fishery-independent setline survey. Note that halibut are not sampled at the same rate in all Regulatory Areas (see rates in Table 1), and that there are not separate sampling rates by sex within an area.

	Regulatory Area									
Age	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4C**	**4D**	**Total**
4					1					**1**
5		1	1	1	2	4	1			**10**
6	1	9	9	6	3	5	7	2	3	**45**
7	1	8	5	2	12	12	12	3	1	**56**
8	3	12	14	6	18	31	11	4	12	**111**
9	21	45	35	30	49	119	38	5	26	**368**
10	19	32	45	34	65	77	33	11	33	**349**
11	22	78	58	46	106	125	50	5	33	**523**
12	34	113	85	82	159	169	109	8	26	**785**
13	21	77	69	80	103	156	84	11	21	**623**
14	11	40	53	52	82	108	104	3	23	**476**
15	9	43	44	63	76	79	67	7	15	**403**
16	9	23	26	50	32	39	47	1	7	**234**
17	2	23	24	58	25	38	33	3	6	**212**
18	4	23	28	63	18	27	27	1	5	**196**
19	1	8	20	35	17	16	34		4	**135**
20	3	11	12	22	6	11	24		4	**93**
21	1	3	5	15	1	9	15		5	**54**
22		1	4	15	2	5	7		2	**36**
23		3	4	5	1	5	16		3	**37**
24			2	1	2	2	10		2	**19**
25	1	1		4	1	3	7		1	**18**
≥26	1		5	1	5	21	51	2	36	**122**
Total	**164**	**554**	**548**	**671**	**786**	**1,061**	**787**	**66**	**268**	**4,905**

Table 4. Mean age (in years) and mean fork length (in centimeters) of sampled Pacific halibut caught on standard survey skates by sex and Regulatory Area (CLS = Bering Sea closed area), 2008-2017 (F = female, M = male).

Reg.		2008		2009		2010		2011		2012[1]		2013		2014		2015		2016		2017	
Area		F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
2A	Age	11.3	11.4	10.3	11.0	11.0	11.1	11.4	12.0	11.8	12.0	11.2	11.6	10.5	11.4	10.6	11.1	10.8	11.8	12.0	12.4
	Length	90.3	78.8	89.5	79.4	93.1	79.1	95.6	81.5	95.1	80.1	94.7	80.4	95.8	81.3	93.0	80.5	92.1	78.5	100.7	81.1
2B	Age	10.6	11.1	11.2	11.8	10.9	11.4	11.1	11.6	11.4	12.3	11.4	12.3	11.2	12.6	11.3	12.4	11.5	12.3	12.0	12.8
	Length	91.0	77.2	93.5	77.4	93.8	78.2	94.6	78.5	95.2	79.8	94.4	79.1	92.1	78.8	91.8	78.7	93.4	78.1	95.6	80.0
2C	Age	11.4	11.5	10.9	11.7	11.0	11.5	11.9	12.0	11.2	11.6	11.9	12.4	11.7	12.3	11.9	12.3	12.7	13.2	13.1	13.4
	Length	93.4	78.8	90.6	78.2	91.0	77.0	96.9	79.8	95.8	80.1	96.4	79.4	97.0	80.0	97.7	80.4	96.7	81.0	100.7	82.9
3A	Age	12.9	16.0	11.7	14.6	12.1	15.0	12.2	14.9	12.2	14.6	12.7	14.3	11.8	13.8	11.8	13.7	12.8	14.6	12.8	14.7
	Length	93.7	81.8	89.5	79.6	89.4	78.7	87.6	78.3	90.1	78.6	89.4	76.4	87.7	75.5	88.5	75.3	90.4	76.0	92.0	77.2
3B	Age	11.1	14.4	10.6	13.5	10.7	13.0	10.8	12.9	10.7	12.5	11.3	13.3	10.9	12.7	11.3	12.8	11.5	12.4	11.6	12.8
	Length	83.0	78.1	82.3	77.6	81.8	75.9	81.5	74.2	81.7	74.9	80.3	73.3	80.5	73.4	82.3	72.2	83.9	71.2	87.8	73.2
4A	Age	10.7	13.5	10.5	12.6	10.6	12.7	10.8	13.2	11.1	13.2	11.3	13.4	12.3	14.7	11.5	13.9	12.3	13.0	12.5	13.0
	Length	82.4	78.6	84.1	77.6	82.6	76.6	83.4	76.5	82.8	76.6	85.8	78.3	88.2	79.7	84.7	77.0	89.1	74.1	88.0	74.1
4B	Age	12.6	15.8	13.1	15.9	12.2	14.9	12.2	15.2	11.8	13.9	11.0	13.6	11.2	13.7	11.0	13.6	11.4	13.6	12.8	15.3
	Length	103.4	92.1	103.8	92.7	100.3	90.3	98.4	89.7	96.6	86.5	89.4	84.1	92.0	84.1	94.6	86.2	91.1	82.1	96.7	85.3
4C	Age	10.5	10.4	9.6	10.8	10.2	10.8	10.4	11.2	11.3	13.2	10.6	11.2	11.3	11.4	10.7	11.4	11.7	12.1	11.5	12.3
	Length	88.0	72.7	84.1	75.1	84.3	73.8	82.0	72.8	86.3	78.8	80.7	74.2	84.7	72.9	83.1	72.2	87.0	74.9	93.9	74.3
4D	Age	13.4	16.1	13.8	16.6	14.4	17.4	13.2	14.9	12.0	13.7	13.8	15.2	12.3	13.1	12.5	13.3	13.3	14.2	12.8	15.1
	Length	93.8	85.3	94.4	86.7	96.6	87.3	88.4	80.9	86.6	78.5	91.9	81.5	88.2	77.6	88.2	77.6	88.1	77.7	93.7	80.6
4E	Age	----	----	----	----	----	----	----	----	----	----	----	----	----	----	10.1	12.5	----	----	----	----
	Length	----	----	----	----	----	----	----	----	----	----	----	----	----	----	89.0	79.9	----	----	----	----
CLS	Age	----	----	----	----	----	----	----	----	----	----	----	----	----	----	10.4	11.2	----	----	----	----
	Length	----	----	----	----	----	----	----	----	----	----	----	----	----	----	86.9	73.4	----	----	----	----

[1]Does not include otoltihs from fish sampled on experimental bait skates that were fished concurrently with standard survey skates during 2012 bait study (Webster et al. 2013).

Table 5. Maximum and minimum age (in years) and fork length (in centimeters) of Pacific halibut for which sex was determined, collected in the 2017 fishery-independent setline survey, by Regulatory Area and sex.

Reg. Area	Sex	Max. age	Min. age	Max. length	Min. length
2A	Female	24	5	145	60
2A	Male	33	6	113	57
2B	Female	30	5	174	55
2B	Male	25	5	127	56
2C	Female	31	5	186	57
2C	Male	32	5	139	54
3A	Female	28	4	190	48
3A	Male	27	5	147	51
3B	Female	19	4	161	50
3B	Male	31	4	127	48
4A	Female	34	5	155	50
4A	Male	37	5	121	33
4B	Female	36	5	174	53
4B	Male	46	5	134	57
4C	Female	25	5	180	56
4C	Male	36	6	106	53
4D	Female	32	5	175	57
4D	Male	42	6	134	34

Table 6. Between-reader percent agreement for fishery-independent setline survey ages 2002-2016. (CV = coefficient of variation, APE = average percent error, % -bias = % of ages where the second age estimated for a fish (age 2) was younger than the intially-estimated age (age 1), % +bias = % of ages where age 2 > age 1.)

Year	Total aged	Number aged twice	% agreement (± 1 year)	CV (%)	APE	% -bias	% +bias
2002	13,635	2,229	81.2	4.3	3.0	24.8	33.6
2003	12,613	1,633	83.3	4.3	3.0	22.0	29.3
2004	14,474	1,257	83.3	4.8	3.4	18.5	38.8
2005	14,552	1,361	85.1	3.9	2.8	20.4	30.2
2006	14,977	1,556	90.4	3.2	2.2	23.7	18.8
2007	16,022	1,566	87.2	4.5	3.2	28.1	28.6
2008	15,545	1,579	89.5	3.4	2.4	25.8	21.3
2009	15,706	1,567	91.1	3.4	2.4	26.2	19.0
2010	14,080	1,407	92.8	2.8	2.0	23.7	19.5
2011	14,451	1,448	89.8	3.7	2.6	30.3	19.3
2012	[1]17,459	[1]1,751	91.7	3.5	2.5	26.0	21.1
2013	12,717	1,438	91.9	2.6	1.8	16.9	17.7
2014	16,193	1,848	90.6	2.9	2.0	14.6	19.2
2015	16,023	2,044	86.8	3.5	2.5	10.1	26.7
2016	15,724	2,741	95.1	1.8	1.3	14.1	11.2

[1]Includes extra otoliths collected on standard skates and experimental bait skates from 2012 bait study (Webster et al. 2013).

2.4.1 2017 Discard mortality rates in the directed longline fleet

Claude L. Dykstra, Timothy Loher, Ian J. Stewart, Allan C. Hicks, Josep V. Planas

Abstract

In 2017, the IPHC conducted a field experiment investigating the relationship between Pacific halibut release practices, physiological condition, injury levels, and post-release survival in an effort to improve discard mortality rate estimates in the directed Pacific halibut longline fishery. Longline gear was deployed southeast of Chignik, AK to collect Pacific halibut smaller than 84 cm (33 in), subject them to different hook-release techniques, measure physiological conditions, and possibly tag them to determine factors that affect discard mortality. Physiological parameters collected included information on condition status at capture (round weight, fat reserves) and post-handling stress levels (blood stress hormones). Electronic monitoring equipment was also deployed during the project to collect data on the accuracy of its ability to capture release methods. Over two trips and 38 sets, 79 Pacific halibut were fitted with accelerometer pop-up archival transmitting tags to assess near-term (96 days) survival, and 1,048 fish were wire tagged to investigate longer-term survival. Vitality (injury and condition) profiles by hook-release method will be developed as a proxy for discard mortality rates on EM trips.

Introduction

Due to regulatory requirements, all Pacific halibut that are caught as bycatch or that are of sublegal size in the targeted fishery cannot be retained and must be returned to the sea with minimal injury. However, through the process of capture and release, Pacific halibut incur a range of injuries and are subjected to a variety of factors that will affect their survival potential after release. Individual variability in terms of mortality after release to the sea will be expected depending on the level of injuries and stresses incurred during the discarding process as well as on the basal physiological condition of the fish. Therefore, an accurate understanding of the types and relative levels of injuries and stresses that fish are exposed to during the discarding process in relation to the biological characteristics of the fish can be instrumental in helping better estimate the probability of survival during the discarding process.

Discard mortality rates (DMRs) are calculated from data collected by observers from the release vitality or injury characteristics of Pacific halibut post-capture and are used to estimate the percentage of incidentally-caught fish that are expected to die after release. Currently, post-capture DMR estimates are based on qualitative assessments of the physical condition of the fish (e.g., minor/moderate/severe/dead for longline gear) and have a certain degree of uncertainty associated with them, which in turn is a source of uncertainty in the estimation of total mortality within current International Pacific halibut Commission (IPHC) stock assessment models. In practice, assigned DMRs and their uncertainty translate into *a priori* adjustments to expected mortality in each upcoming year, and to the catch limits that are thereafter assigned to each harvest sector. Given current low halibut yields relative to long-term mean productivity, uncertain estimates can result in undue hardship on some harvest sector(s) relative to others. Therefore, there is an urgent need to improve our estimates of DMR as well as to provide strategies to improve survival of incidentally-caught Pacific halibut after release.

It has been well recognized that fish condition assessments that incorporate additional levels of information on the physiological characteristics of captured fish have improved the power to predict survival in discarded fish (Davis, 2010; ICES, 2014). It is important to indicate, on one hand, that the physiological condition of the captured fish may influence their susceptibility to the stress associated with capture and handling events and, hence, their potential for survival after release. On the other hand, different capture and handling procedures can elicit different physiological responses in the fish to cope with the ensuing stress, which may also influence their survival after release. These two aspects are important because they drive most of the variability associated with discard mortality. Therefore, it is important to measure physiological indicators of stress and condition in a quantitative manner in relation to capture and handling events in order to understand their influence on mortality after release. Full condition assessments incorporating physiological parameters can then be used as a predictive tool to estimate DMRs if properly calibrated with the results of direct survival or behavioral studies (e.g., tagging and telemetry studies).

Traditional observer programs require examining the animal (which includes looking at both sides of the fish, testing muscle tone and opercular responses) to determine vitality; something that cannot be achieved with cameras. Development of electronic monitoring (EM) systems as an alternative to human observers highlights a need to develop the capability to convert imagery into actionable data. It has been demonstrated (Smith et al. 2017) that EM provides information on Pacific halibut hook-release techniques (e.g., careful shake, gangion cut, hook stripper) for close to 95% of events, however the suite of vitalities incurred by each hook-release technique is unknown. This project will provide a quantitative summary of injuries by release method.

There are two main goals of this research. First, to develop an understanding of the relationship between hook-release practices and fish physical and physiological condition. The second goal is to understand the post-capture probability of mortality based on hook-release technique, as assessed by tagging. This research will help to better estimate post-release mortality of incidentally-caught Pacific halibut in directed and non-directed (bycatch) longline fisheries, and provide data to develop a proxy for EM to associate DMRs to hook-release methods.

Experimental design and sampling procedures

The 2017 discard mortality rate study was conducted on the F/V Kema Sue in an area southeast of Chignik, AK, bounded between the following points (56°05’N, 158°10’W), (56°05’N, 157°25’W), (55°26’N, 156°23’W), (54°55’N, 157°15’W), (54°55’N, 158°10’W), and (55°40’N, 158°50’W) as depicted in Figure 1 (with the exception of several sets that were made outside the area to avoid severe weather conditions). Sets consisted of eight skates of conventional longline gear, each 1,800 feet (549 m) long with 100 hooks (#3 (16/0 Mustad) at 18’ (5.5 m) intervals, on 24 to 48 inch (61 cm to 122 cm) gangions. The vessel’s hauling station was located amidships with a chute, roughly 1 foot (0.3 m) above sea-level and an in-chute roller placed in-board of the rail roughly 1 foot (0.3 cm) above the slide to enable the release of fish onto area slide where they could be gently slid to an area to be assessed, tagged, and released. Gear was baited with 0.25 lb to 0.33 lb (0.11 kg to 0.15 kg) of chum salmon (*Oncorhynchus keta*). Two to three sets were made daily beginning at or after 6:30 AM, and the gear was soaked for at least three hours before hauling. Soaking the gear at night was avoided, when possible, to minimize sand flea infestation of the study fish. An EM system was installed by Archipelago Marine Research Ltd. (Victoria, British Columbia, Canada) in the same configuration as is used under the Exempted Fishing Permit program of the US National Oceanic and Atmospheric Administration (NOAA), underway in Alaska.

The first day of the experiment (2 sets) involved finalizing sampling protocols and four treatments were applied: the three releases mandated in IPHC regulations (i.e. careful shake, hook straightening, and gangion cutting), as well as a fourth treatment (hook stripping) for those fish that made it past the release point. Each treatment was randomly assigned to a whole skate of gear. It was quickly determined that hook straightening was not a feasible treatment as sublegal Pacific halibut do not have enough mass to straighten a #3 (16/0) circle hook; furthermore, this method is not practiced to release sublegal Pacific halibut in the fishery.

The full experiment began on the second day and involved the random assignment of hook-release methods (5 skates of careful shaking, 2 skates of hook stripping, and 1 skate of gangion cutting). All captured Pacific halibut were measured, weighed, assessed for current hooking injury, and evaluated for vitality (or release condition). Pacific halibut less than or equal to 84 cm (33 inches)[1] fork length (FL) were subjected to fat measurements using a FatMeter (Distell, Fauldhouse, Scotland), blood draw, genetic sampling (fin clip), and body temperature prior to being tagged and released. Water temperature was recorded using Minilog-II-T temperature data loggers (Vemco, Nova Scotia, Canada) attached to each set of gear. Fish temperature was collected with a hand held Ceenwes GM 550 infrared thermometer (Ceenwes, Shenzhen Guangdong, China). Survivorship pop-up archival transmitting tags (sPAT) tags (Wildlife Computers, Redmond, Washington, USA) containing accelerometer sensors were deployed randomly on Pacific halibut ≤ 84 cm FL in excellent release condition. Wire tags (Floy Tag, Seattle, Washington, USA) were deployed on Pacific halibut ≤ 84 cm of any condition. To manage the work load, a maximum number of 65 wire tags were deployed per set and 10 sPATs per day. For the same reason, blood collection was conducted on only half of the wire-tagged fish, whereas time on deck was recorded for all sPAT fish but only for 25% of the wire-tagged fish (random start and every 4th fish thereafter).

Results

The *F/V Kema Sue* successfully completed 38 experimental sets between 18 October; 2017 and 2 November, 2017. A total of 79 Pacific halibut were tagged with sPAT tags, and 1,048 with wire tags. At the time of writing this, samples are still being processed, and data from this project have not yet been entered or analyzed.

Acknowledgements

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[1] N.B. As the focus of the study was on the survival of Pacific halibut released from the gear in the directed longline fishery (fish less than 32 inches (81.3 cm) fork length), and as it is likely that some Pacific halibut are released that are slightly above this size limit, this study looked at survival of fish less than or equal to 84 cm (33 inches) fork length).

conditions and long days, and to IPHC sea samplers Danielle Vracin, Kaitlin Johnson, and Nathan Willse for their attention to detail and positive attitudes.

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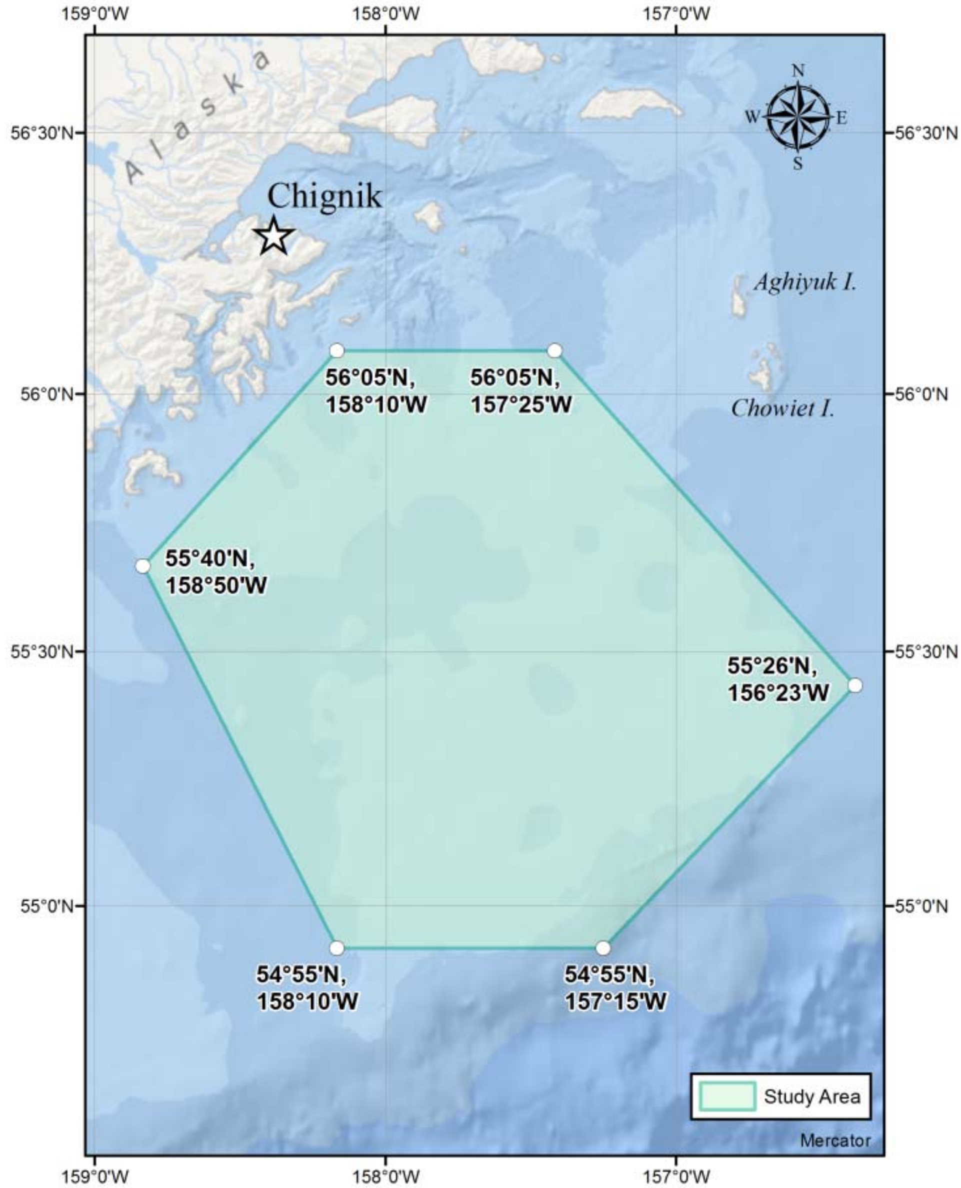

Figure 1. Discard mortality study area (southeast of Chignik, AK).

2.5.1 Pacific halibut tagging studies

Joan E. Forsberg

Abstract

Since the International Pacific Halibut Commission (IPHC) began tagging studies in 1925, over 465,000 tagged Pacific halibut (*Hippoglossus stenolepis*) have been released and more than 51,000 of these releases have been recovered. Pacific halibut are tagged to study migration, age, growth, and mortality. The IPHC conducted five tagging experiments in 2017 in which 4,545 fish were tagged and released. Thirty-seven tagged Pacific halibut, representing recoveries from several different IPHC experiments and sport tag releases, were recaptured in 2017. Otoliths were collected from 15 of these recaptured fish. An additional three tags recovered in previous years were reported in 2017.

Introduction

Since the International Pacific Halibut Commission (IPHC) began tagging in 1925, over 465,000 tagged Pacific halibut have been released. To date, more than 51,000 of these releases have been recovered. Pacific halibut are tagged to study migration, age, growth, and mortality. Of the recovered tagged Pacific halibut, over 39,000 were measured for length when recovered, and over 31,000 had otoliths collected for age determination.

Tag releases

IPHC tag experiments

The IPHC tagged and released 3,396 U32 Pacific halibut (<82 cm fork length) with plastic-coated wire opercular tags in 2017 in the third year of a long-term effort to tag young halibut. A total of 1,927 U32 Pacific halibut were tagged on 11 vessels participating in the IPHC fishery-independent setline survey (setline survey) in 2017 (Forsberg 2017) and a total of 1,469 U32 fish were tagged on three vessels conducting the National Marine Fisheries Service (NMFS) trawl surveys in the Bering Sea (n=756), Sadorus et al. (2017a) and the Gulf of Alaska (n=713, Sadorus et al. 2017b).

An additional 1,048 Pacific halibut ≤ 84 cm were wire-tagged as part of a discard mortality study in Regulatory Area 3B (Dykstra et al. 2017). Tagged fish in this study were subjected to different hook release and handling methods. Future recovery rates by hook release method can be used to improve discard mortality rates in the commercial longline fisheries.

The IPHC also tagged and released 101 Pacific halibut with pop-up satellite transmitting archival (PAT) tags in two different studies. Twenty-two PAT tags were released on the Bowers Ridge expansion stations that were part of the setline survey in Regulatory Area 4B in 2017 (Loher 2017). Reporting from these tags will provide information on seasonal and interannual dispersal of Pacific halibut in this region. Seventy-nine accelerometer PAT tags were released during the discard mortality study in Regulatory Area 3B. These tags will provide information on short-term post-release survival of longline-caught Pacific halibut subjected to different methods of hook release.

Sport tag releases

The IPHC continued to provide tags on a cost-recovery basis for two Alaskan sport fishing derbies in 2017. The Homer Jackpot Halibut Derby tagged and released 77 fish and the annual Seward Halibut Tournament tagged and released 41 fish. Both the Homer and Seward sport derbies use plastic-coated wire opercular tags. These tags are printed with the year, Derby/Tournament name, and tag number.

Other releases

For the second year, IPHC issued a permit to Gray FishTag Research (GFTR)1, in conjunction with a local fishing charter group, to tag Pacific halibut out of Seward, AK. GFTR was authorized to tag up to 80 Pacific halibut; however, no tagging was conducted in 2017. GFTR is interested in looking at local movement of the fish they tag.

Tag recoveries

Tag recoveries from a total of 27 Pacific halibut from various IPHC tagging experiments were reported in 2017, as well as 13 tags from sport tagging programs. Otoliths were collected from 15 of the IPHC-tagged Pacific halibut recovered. Recoveries by experiment or tag type are discussed below. Total release and recovery numbers for the most recent major IPHC tagging experiments are presented in Table 1. Current-year recoveries of tagged Pacific halibut from sport tagging programs are presented in Table 2. Sport-tagged halibut are usually measured when recovered but otoliths are not collected.

Recoveries from experiments using wire tags only

In 2017, three tags were recovered from the 2010 Aleutian wire tagging experiment, a study designed to identify potential future tagging sites for archival tag releases in Regulatory Area 4B (Loher 2011). Eight Pacific halibut tagged during the 2015 pilot study on the NMFS trawl survey were recovered (Forsberg et al. 2016); two fish had been recaptured in 2016 and six were recovered in 2017. The remaining wire tags recovered in 2017 were part of the U32 tagging effort. Two fish tagged on the 2016 NMFS trawl survey were recovered (one in 2016 and one in 2017). Six tags were recovered from Pacific halibut tagged on the 2017 setline survey (Forsberg 2017) and one tagged halibut released on the 2017 NMFS trawl survey in the Gulf of Alaska was recovered.

Recoveries from archival and dummy archival tag experiments

Tags from seven fish from the 2013 dummy archival tag experiment in Regulatory Area 3A (Loher and Geernaert 2014) were returned in 2017. Six of these fish had been tagged with both a dummy archival dart tag and a plastic-coated wire cheek tag, and one had been tagged with only an external dummy archival tag attached to the operculum; the purpose of this study was to evaluate different attachment methods for archival tags.

Sport tag recoveries

Three tags from the 2017 Homer Derby were recovered. Additionally, six tags from previous Homer Derby releases were recovered in 2017: four from the 2015 derby and two from the 2016 derby. All of the Homer Derby tags recovered in 2017 were recovered by sport fishers out of Homer during the Derby.

Four tags from the 2017 Seward Halibut Tournament were recovered by sport fishers during the tournament.

Recoveries from Gray FishTag releases had not been reported at the time of writing.

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Table 1. Total recovery rates for the most recent major Pacific halibut tagging experiments.

Experiment	Reg. Area of release	Release year(s)	Number released	Number recovered to date	Number reported in 2017	Recov. rate
Longline mortality	3A, 3B	1993-94	13,096	1,123	0	9%
Trawl mortality	3A	1995	4,852	178	0	4%
Wire/PIT double-tagging (3A)	3A	2001	281	30	0	11%
Wire/PIT double-tagging (2B)	2B	2003	2,661	731	0	27%
PIT tagging (coastwide)	2A through 4D	2003	43,999	2,266	0	5%
PIT tagging (2B and 3A)	2B, 3A	2004	23,437	1,179	0	5%
PAT tagging Gulf spawning	2B, 2C, 3A, 3B	2002	12	0*	0	0%
PAT tagging Bering Sea spawning	4C, 4D	2002	12	0*	0	0%
PAT tagging Bering Sea spawning	4B	2004	25	1*	0	4%
PAT tagging Gulf migration timing	2B, 2C, 3A, 3B	2005	49	15*	0	31%
PAT tagging Bering Sea spawning	4A, 4D	2006	24	2*	0	8%
PAT tagging Area 2 dispersal	2A, 2B	2006	78	12*	0	15%
PAT tagging Bering Sea dispersal	4A, 4B, 4C, 4D	2008	115	7*	0	4%
PAT tagging Bering Sea dispersal	4A, 4C, 4D	2009	17	1*	0	6%
Archival tagging (2B)	2B	2008	166	22	0	13%
Wire/dummy archival double-tagging	3A	2009	200	48	0	24%
Aleutian wire tagging	4B	2010	773	50	3	7%
Geomagnetic-sensing archival	2C, 3A	2011	30	2	0	7%
External dummy archival attachment	3A	2013	901	100	7	11%
PAT tagging Salish Sea dispersal	2A	2014	12	3*	0	25%
Gulf of Alaska NMFS trawl tagging	2C, 3, 4A	2015	1,491	12	7	<1%
Bering Sea NMFS trawl tagging	4A, 4CDE, CLS	2015	485	5	1	1%
Bering Sea NMFS trawl tagging	4A, 4CDE, CLS	2016	425	1	1	<1%
Aleutian Islands NMFS trawl tagging	4B	2016	170	1	1	<1%
Setline survey U32 wire tagging	4D	2016	169	0	0	0
PAT tagging Bering Sea spawning	4D	2016	20	0*	0	0
PAT tagging Bering Sea dispersal	4D	2016	15	0*	0	0
Setline survey U32 wire tagging	2BC, 3, 4A, 4B	2017	1,927	6	6	<1%
Bering Sea NMFS trawl tagging	4A, 4CDE, CLS	2017	756	0	0	0
Gulf of Alaska NMFS trawl tagging	2C, 3, 4A	2017	713	1	1	<1%
PAT tagging Bowers Ridge dispersal	4B	2017	22	0*	0	0
PAT tagging short-term survival	3B	2017	79	0*	0	0
Longline discard mortality wire	3B	2017	1,048	0	0	0

* refers to physical recovery of tagged fish, not pop-up data broadcast to satellite

Table 2. Recoveries of sport-tagged Pacific halibut in 2017.

Release source	Number recovered in 2017
Homer Jackpot Halibut Derby	9
Seward Halibut Tournament	4

2.5.2. Deployment and reporting of pop-up archival transmitting (PAT) tags to study seasonal and interannual dispersal of Pacific halibut on Bowers Ridge (Area 4B)

Timothy Loher

Abstract

The International Pacific Halibut Commission (IPHC) has conducted a series of pop-up archival transmitting (PAT) tag studies in the Bering Sea and Aleutian Islands (BSAI) region in order to identify winter spawning locations, determine the timing of seasonal movements, and investigate mixing within the BSAI and between the Bering Sea and Gulf of Alaska. However, neither PAT nor PIT (passive integrated transponder) tagging has been conducted on Bowers Ridge (IPHC Regulatory Area 4B), because this region has not been previously surveyed by the IPHC. In 2017, we took advantage of setline survey expansion in order to generate data for this unstudied region that will complement prior work. From 5-10 July 2017, 22 Pacific halibut ranging from 115-170 cm fork length (FL) were tagged with Wildlife Computers miniPAT pop-up archival transmitting tags. Sixteen tags were programmed to detach from their host fish to report their location and download environmental data to passing Argos (Advanced research and global observation system) satellites during the 2017-2018 spawning season, on 15 January 2018; 6 tags were programmed to detach and report after 365 days at liberty, in July of 2018. In addition to determining the length of the tagged Pacific halibut, blood samples were obtained for future analysis of plasma hormone levels that might be predictive of individual migratory behavior, and ultrasound was employed to determine sex and the likelihood that tagged females (n = 13) were mature.

Introduction

The International Pacific Halibut Commission (IPHC) has a considerable history of conducting pop-up archival transmitting (PAT) tag studies in the Bering Sea and Aleutian Islands (BSAI) region in order to investigate both seasonal and inter-annual dispersal. In total 188 tags have been deployed in the BSAI region in previous studies, covering the historically-surveyed range of Pacific halibut (*Hippoglossus stenolepis*) throughout IPHC Regulatory Area 4. These studies have been designed to identify winter spawning locations, gain greater understanding of the timing of movements within this stock component, and investigate mixing among regulatory areas in a fishery-independent manner. Taken together, they have resulted in an understanding of population function that is generally consistent with the spatial structure of the IPHC's Area-as-Fleets stock assessment model (Stewart and Martell 2016).

Studies of seasonal migration and winter distribution were initiated in 2002 in the shallow nearshore waters of Regulatory Area 4C (Seitz et al. 2007), expanded to Regulatory Area 4B in 2004 (Seitz et al. 2008), and to the northern and southern extents of the IPHC's Bering Sea continental shelf-edge survey grid in 2006 (Seitz et al. 2016). The result was an integrated 5-site design spanning from Attu Island in the west to Unimak Pass in the east, and northward to Pervenets Canyon. With respect to stock structure, the results indicated considerable mixing on the eastern continental shelf in conjunction with relative isolation within Regulatory Area 4B (Seitz et al.

2011). Additionally, the results suggested that the stock's spawning range is considerably broader than had been traditionally assumed. Prior to the initiation of the IPHC's PAT-tagging program, the best available evidence indicated that Pacific halibut in the eastern Pacific Ocean concentrate their winter spawning activity at submarine canyons from southern British Columbia to Pribilof Canyon in the southeastern Bering Sea, with no indication of spawning along the Aleutian Ridge (St. Pierre 1984). PAT tag data suggest a spawning distribution that extends latitudinally from at least Cape Johnson, Washington (Loher and Blood 2009) northwards to Pervenets Canyon, and westward to Attu Island (Seitz et al. 2016). Still, the full range of potential spawning habitats has not been studied.

From 2008-2010, a large PAT-tagging experiment was conducted in the Bering Sea to examine inter-annual dispersal of Pacific halibut (Loher and Clark 2010). This was designed as a fishery-independent complement to an earlier large-scale Passive Integrated Transponder (PIT)-tagging study (Webster et al. 2013) that had relied upon the directed commercial fishery to recapture tags. Results of the inter-annual dispersal experiment were consistent with both seasonal PAT tagging and large-scale PIT tagging in demonstrating relative isolation of Regulatory Area 4B from the remainder of the stock and a relative discontinuity in north-south dispersal across the Aleutian Ridge. With respect to the latter, Pacific halibut that were tagged in Regulatory Area 4A were found to be more likely to move into Regulatory Area 3 if they had been tagged south of Unimak Pass than if tagged in Regulatory Area 4A north of Unimak; i.e., movement of commercially-recruited sizes was considerably more prevalent within the western Gulf of Alaska (GOA) than was movement of Pacific halibut from the Bering Sea into the GOA. Additionally, results of the study suggested reduced east-west dispersal (Loher and Clark 2010) of adult Pacific halibut across deep Aleutian passes, consistent with recent population genetic analyses that suggest the existence of significant stock structure to the west of Amchitka Pass (Drinan et al. 2016). However, as with examinations of spawning distribution, geographic gaps occur in both the PIT- and PAT-tag data due to survey coverage that has not extended to the limits of the managed range; in particular, near the Russian border and along Bowers Ridge north of the Aleutian Islands. Here, we take advantage of ongoing setline survey expansion in order to begin filling these gaps in understanding. In the current study, PAT tags were deployed at Regulatory Area 4B expansion stations on Bowers Ridge.

Tag specifications and biological sampling

The miniPAT (manufactured by Wildlife Computers, Redmond, WA) is a cast epoxy satellite-transmitting archival tag (Fig. 1) that is shaped somewhat like a microphone, with a body diameter of 1.8 cm (0.75 in), float diameter of 3.7 cm (1.5 in), a total body length of 11.5 cm (4.5 in). The body of the tag contains temperature (nominal recording range of -40° to 60° C; accuracy of 0.1° C at 0.05° resolution), pressure (depth; 0-1700 m, accurate to 1% of recorded values at 0.5-m resolution) and light (ranging from 5 x 10^{-12} W cm^{-2} to 5 x 10^{-2} W cm^{-2}) sensors as well as programming circuitry and a satellite transmitter. The tag weighs 60 g in air.

The tags were attached to Pacific halibut via a dart and leader assembly composed of a 10-cm (4.5-in) leader constructed of 300-lb (136-kg) test nylon monofilament line covered in black adhesive-lined shrink-tubing secured to a titanium dart. The darts were embedded into the dorsal musculature so as to rest against the uneyed-side of the fish's pterygiophores, with their leaders extending roughly 4 cm (1.5 in) medial to the dorsal fin where the body begins to taper towards the tail. After pre-programmed deployment period, the tags will be released from their leaders and float to the surface, where data transmissions will begin. Data will be transmitted to the US National Oceanic and Atmospheric Administration's (NOAA) polar-orbiting satellites, administered by the Advanced Research and Global Observation System (ARGOS). Wildlife Computers miniPAT tags are equipped with surface-detect capabilities, and so tags that detach from their host fish prematurely will broadcast upon surfacing. Upon broadcast, each tag's endpoint position will be determined from the Doppler shift of its transmitted radio frequency in successive uplinks received during one satellite pass (Keating 1995) and during these uplinks, daily summary data for temperature and depth, along with daylight curves that are derived from onboard data processing and can be used to produce at-liberty geoposition estimates, will be remotely downloaded. If a tagged fish is captured and its tag retrieved before the tag pop-up date, or if a tag is found awash following detachment from a fish, the full archival data records for each recorded parameter can be accessed.

Tags deployed in this study were programmed to release from their host Pacific halibut within one of two treatment groups: a) reporting on 15 January 2018 (i.e., summer-to-winter); b) reporting after 365 days at liberty (i.e., summer-to-summer). The January reporting date was chosen to correspond to the peak spawning period for Pacific halibut in the GOA (Loher and Seitz 2008) and is inferred to be roughly equivalent in the Bering Sea (Seitz et al. 2011).

All Pacific halibut were captured using standardized commercial longline gear during the IPHC's 2017 fishery-independent setline survey (Henry et al. 2017). Briefly, gear was composed of six skates of groundline tied end-to-end, with each skate measuring 549 m (1800 ft) and fitted with 100 16/0 circle-hooks secured via 0.6-1.2 m (2-4 ft) gangions spaced 5.5 m (18 ft) apart. Each hook was baited with #2 of semi-bright chum salmon (*Oncorhynchus keta*). Gear was never set before 0500 hours and was allowed to soak for a minimum of five hours before being hauled.

Fish selection protocols for each treatment group followed methods that were used in the prior research that these data are intended to complement. Summer-to-winter tags were deployed on Pacific halibut ≥105 cm FL because individuals of both sexes of this size have a high probability of being mature and therefore undergoing seasonal spawning migrations (*sensu* Seitz et al. 2011). Summer-to-summer tags were applied to any Pacific halibut of any commercially-legal size (≥ 32 in (O32) or 81.3 cm FL) without *a priori* regard to sex in order to reflect the demographics of regional exploitable biomass (*sensu* Loher and Clark 2010).

Upon capture, Pacific halibut were measured to the nearest centimeter FL and examined for physical condition. Individuals were tagged only if they were in excellent condition: not substantially injured during capture, showed no evidence of predation by sand fleas (gammarid amphipods), and displayed considerable strength and opercular reflex. Sex and ovarian length were determined prior to tagging via veterinary ultrasound following the methods described in Loher and Stephens (2011). A small tissue sample was taken from the tip of the caudal fin (tail) of each individual and immediately preserved in 100% ethanol. Blood samples were extracted from the caudal vein (DFO 2004), accessed through the caudal peduncle, using pre-heparinized hypodermic needles. Following collection, blood samples were centrifuged at 1600 rpm for 15 minutes in order to separate the plasma, and the resulting plasma samples were frozen for storage and transport.

Tag deployments

A total of 22 Pacific halibut were tagged in this study in IPHC Regulatory Area 4B on Bowers Ridge (Fig. 2). Tagging occurred on dates ranging from 05-10 July 2017 (Table 1). Sixteen Pacific halibut (four male, 11 female, and one of unknown sex) ranging from 117-170 cm FL were tagged with PAT tags scheduled to detach and report on 15 January 2018. Six Pacific halibut (four male, two female) ranging from 117-144 cm FL were tagged with PAT tags programmed to detach after 365 days, resulting in scheduled reporting dates of 5 and 10 July 2017.

Biological sampling

Maximum posterior ovarian extent (MPOE; Loher and Stephens 2011) was determined for all of the known-female Pacific halibut (Table 1). MPOE is an index of the length of the ovary, in which the listed value represents the ventral fin-ray number immediately above which the ovary terminates posteriorly. MPOEs of the tagged fish ranged from 27-35. Given that prior research (Loher and Stephens 2011) has estimated that 50% maturity in the Pacific halibut population in the GOA occurs at MPOE = 18, and that >90% maturity occurs at MPOEs ≥22, all of the individuals tagged in the current study are likely to have been mature. Blood plasma samples were obtained for all tagged individuals.

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Table 1. Deployment details for Lotek Wireless PSATflex satellite-transmitting archival tags deployed on Pacific halibut in the eastern Bering Sea during the IPHC's 2016 setline survey (see also Fig. 2). For longitude, negative values indicate west longitude and positive values east. For sex, "F" = female, "M" = Male, "MPOE" = Maximum Posterior Ovarian Extent; "n.a." = not applicable (males). MPOE is an index of the posterior length of the ovary; the listed value represents the ventral fin-ray number immediately above which the ovary terminated. In prior research (Loher and Stephens 2011), 50% maturity was estimated to occur at MPOE = 18 and >90% maturity at MPOE ≥ 22.

Tag #	Deploy date	Programmed tag-reporting date	Latitude (N)	Longitude	Sex	Length (cm FL)	MPOE
S-17001	07/05/17	07/05/18	54.833°	178.634°	F	118	32
S-17002	07/05/17	07/05/18	54.833°	178.634°	F	144	33
S-17003	07/10/17	07/10/18	54.000°	-179.967°	M	116	n.a.
S-17004	07/10/17	07/10/18	54.000°	-179.967°	M	115	n.a.
S-17005	07/10/17	07/10/18	54.000°	-179.967°	M	115	n.a.
S-17006	07/10/17	07/10/18	54.000°	-179.967°	M	111	n.a.
S-17011	07/05/17	01/15/18	54.833°	178.634°	F	128	27
S-17012	07/05/17	01/15/18	54.833°	178.634°	F	148	33
S-17013	07/05/17	01/15/18	54.833°	178.634°	M	118	n.a.
S-17014	07/05/17	01/15/18	54.833°	178.634°	M	123	n.a.
S-17015	07/05/17	01/15/18	54.833°	178.634°	F	147	36
S-17016	07/09/17	01/15/18	54.334°	179.466°	M	137	n.a.
S-17017	07/10/17	01/15/18	54.000°	179.750°	F	150	33
S-17018	07/10/17	01/15/18	54.000°	179.750°	F	170	31
S-17019	07/10/17	01/15/18	54.000°	-179.967°	M	125	n.a.
S-17020	07/10/17	01/15/18	54.000°	-179.967°	F	152	35
S-17021	07/10/17	01/15/18	54.000°	-179.967°	F	108	27
S-17022	07/10/17	01/15/18	54.000°	-179.967°	F	142	38
S-17023	07/10/17	01/15/18	54.000°	-179.967°	F	117	29
S-17024	07/10/17	01/15/18	54.000°	-179.967°	F	117	32
S-17025	07/10/17	01/15/18	54.000°	-179.967°	F	133	28
S-17026	07/10/17	01/15/18	52.666°	-179.420°	unk	117	n.a.

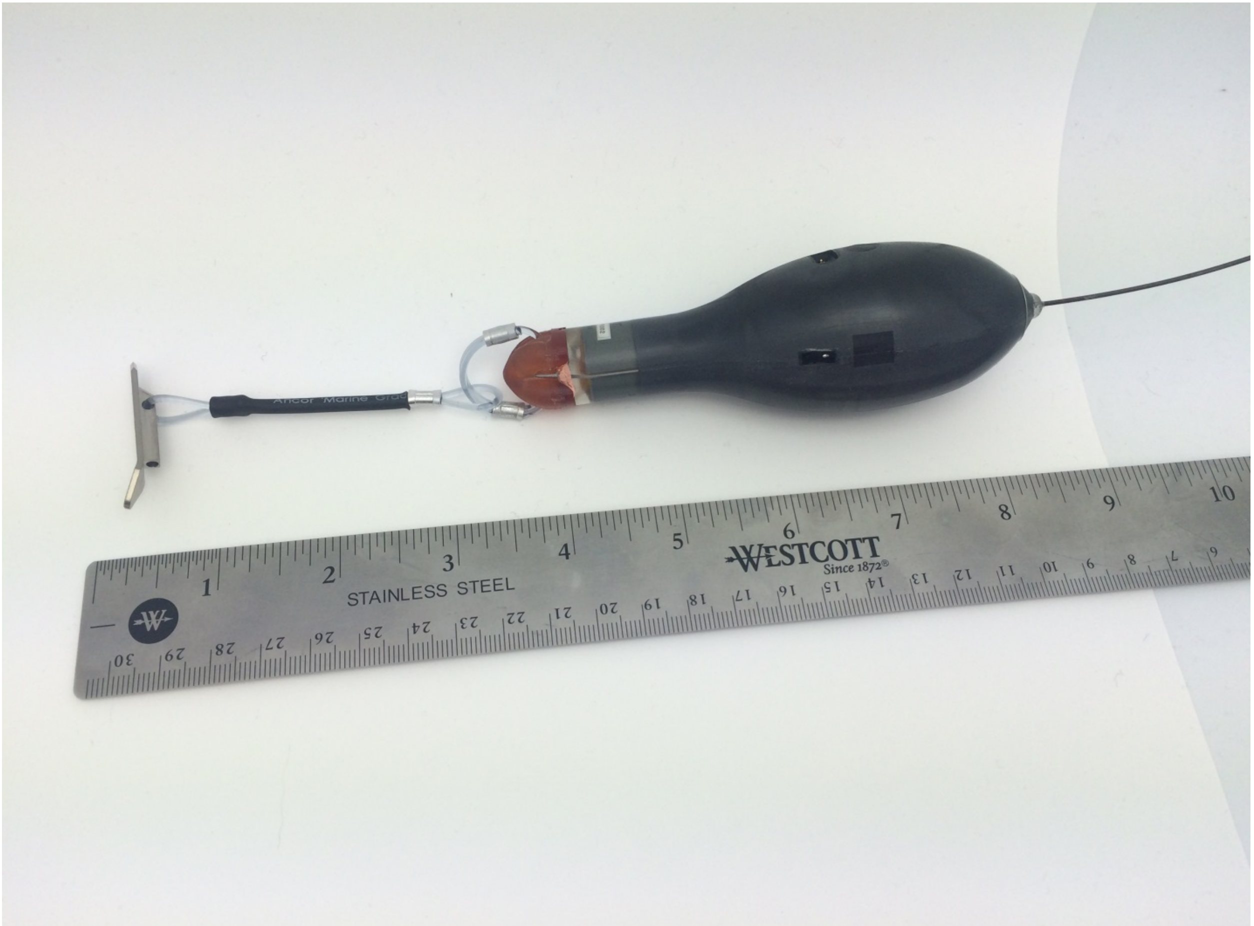

Figure 1. A Wildlife Computers miniPAT satellite-transmitting archival tag.

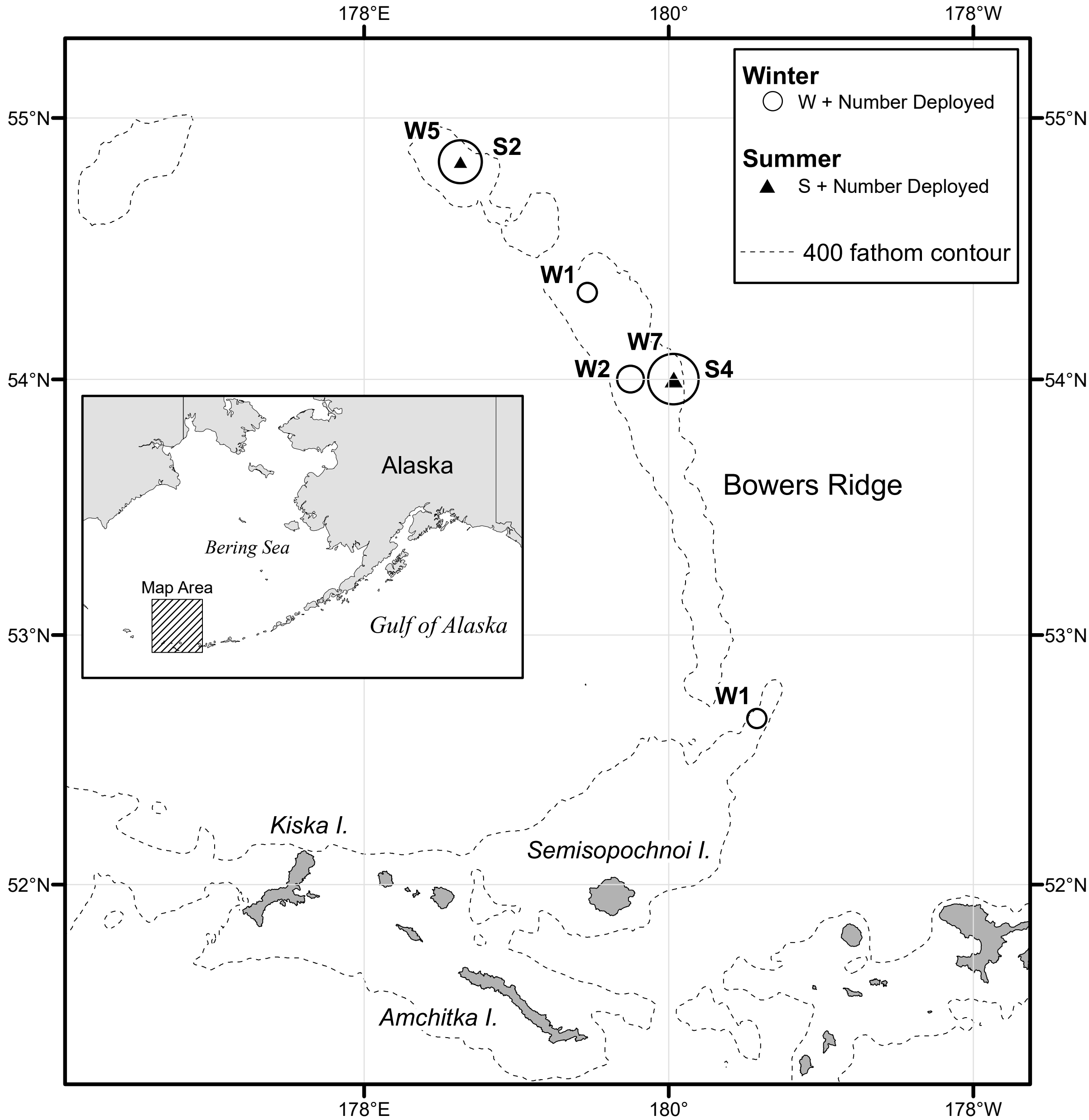

Figure 2. Deployment locations for Wildlife Computers (Redmond, WA) miniPAT satellite-transmitting archival tags deployed on Pacific halibut on Bowers Ridge during the IPHC's 2017 fishery-independent setline survey. Circles indicate summer-to-winter tags deployed to examine seasonal migration and spawning locations; triangles are summer-to-summer tags deployed to investigate interannual dispersal.

2.5.3 Evaluating Pacific halibut larval connectivity between the Gulf of Alaska and Bering Sea: Project update

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This study is currently ongoing with final results for the first portion expected in 2018. Following is a brief summary of the project objectives and preliminary findings with a description of plans for future work.

Introduction

Pacific halibut (*Hippoglossus stenolepis*) is a long-lived flatfish that spends the majority of its life living on or near the ocean bottom. However, the larval stage, which encompasses the first six months of life, is spent in the pelagic zone and the success of these larvae is highly dependent on favorable environmental conditions. While a larval Pacific halibut can somewhat control its position vertically in the water column within a few weeks after hatch (McFarlane et al. 1991), horizontal distribution of larvae is determined by the currents accessed as well as the strength and direction of those currents.

In the past, it was thought that each ocean basin contained a unique stock of Pacific halibut (Thompson and Van Cleve 1936), but later tagging studies showed that there is connectivity between the Gulf of Alaska (GOA) and Bering Sea by way of actively migrating fish through Aleutian Island passes (Webster et al. 2013, Skud 1977). The migration of adult and juvenile Pacific halibut has been studied extensively, but much less is known about the larval stages and the extent of dispersal both within and between basins.

While currents could feasibly carry larvae through any of the Aleutian Island passes (refer to map in Sadorus et al. 2015, page 387), this study focuses on basin connectivity via Unimak Pass, which is the main connection between the GOA and the Bering Sea continental shelves. The Alaska Coastal Current (ACC) flows through this pass from the GOA to the Bering Sea and once it enters the Bering Sea, its direction is determined by a combination of current strength and season, i.e. the flow can continue westward and follow the 50 or 100 m isobath, or turn sharply to the northeast into Bristol Bay (Stabeno et al. 1999).

Objectives for the initial phase of this study are to: 1) update and redefine larval distribution in the GOA and Bering Sea, 2) investigate the likelihood and magnitude of larval connectivity between the GOA and the Bering Sea, and 3) identify possible environmental factors that influence larval year class strength, organism size, degree of connectivity between basins, and recruitment to demersal stages, and 4) define parameters for the modeling phase of the project.

Data sources

This study utilizes 43 years of National Oceanic and Atmospheric Administration (NOAA) icthyoplankton survey data from 1972-2015. These data include both standardized catch, which was used as a proxy for abundance, and individual lengths of a subset of the data. Because there are no surveys that routinely capture Pacific halibut from settlement to about age-2, survival of the larvae to the adult form is gauged using data collected on 2-year-olds caught during the annual National Marine Fisheries Service groundfish trawl surveys in the Bering Sea.

Environmental data included sea surface temperatures for both January and May, summer bottom temperature in the Bering Sea, annual anomaly data for both the Pacific Decadal Oscillation (PDO; Mantua et al. 1997) and the North Pacific Index (Trenberth and Hurrell 1994), and sea ice cover extent. All environmental data were downloaded from freely accessible NOAA databases available on their website.

Preliminary results and conclusions

A map of larval occurrence over the 43 yr-sampling period provides strong anecdotal evidence that larval transport through the pass may be significant (Fig. 1). Mapping exercises of occurrence data by month along with catch totals by month, indicated that Pacific halibut larvae are widely detected in the water column from February to June and largely absent from the water column by about mid-summer forward. Given that spawning is known to occur in the winter months, it is likely that larvae are also present in the water column in December and January, but very little to no sampling has occurred during those months. These results agree with earlier accounts (Thompson and Van Cleve 1936), and mean that larval transport through Unimak Pass is most likely to occur from the winter to the early summer. Vertical distribution data are largely lacking, but in the few data points that were available, Pacific halibut larvae were at depths > 300 m at the smallest sizes and found within 100 m of the surface when the yolk sac was estimated to be fully absorbed (Liu et al. 1993) and feeding commenced. Unimak Pass is relatively shallow, ranging from about 70-160 m depth (Stabeno et al. 2002) and larvae moving through the pass are occupying the more shallow depths and so have likely already surpassed a major hurdle to survival and are actively feeding.

A series of linear regression analyses were performed to try and identify possible predictors of larval abundance. While none of the predictors chosen, significantly described GOA larval abundance, a significant result was found using GOA larval abundance and the North Pacific Index to describe Bering Sea larval abundance (Adj R^2= 0.20, p-value=0.031). Also significant was GOA larval abundance to predict age-2 abundance in the Bering Sea (Adj R^2=0.11, p-value=0.039) but, notably, Bering Sea larval abundance was not a predictor of age-2 Pacific halibut abundance in the Bering Sea.

To compare larval abundance and recruitment between warm and cold years, two temperature stanzas were chosen for comparison using sea surface temperature in the Bering Sea. Warm years were defined as the period 2001-2005 and cold years as the period 2007-2013. There were distribution differences between stanzas of both larvae in the Bering Sea and resulting 2 year olds. In warm years, larvae were concentrated in the east over Bering and Pribilof Canyons and in cold years, larvae were more dispersed along the continental shelf edge extending to the west. Two year olds (those that hatched during the stanzas) showed the opposite pattern and were more widely dispersed in Bristol Bay extending westward in warm years and concentrated to the east in cold years. A t-test indicated that average Bering Sea larval catch was higher during cold years compared to warm years, but the difference was not significant. In the GOA, the opposite was true, i.e. that average larval catch appeared higher in warm years compared to cold years but the difference again was not significant. However, an F-test showed that the difference in variance between the two stanzas was significant, i.e. variability was greater in warm years than in cold years (p-value=0.002). Both abundance and variance differences of 2-year-old fish were significant (p-value=0.034 and p-value=0.013, respectively) in the Bering Sea with warm years resulting in higher abundance and variability than cold years.

A preliminary examination of size at age of 2-year olds over time showed a significant positive relationship between size and temperature experienced by the animal at age 1 (R^2=0.595, p-value=0.0002). Neither larval size nor temperature at year 0 was a significant predictor.

Given the results of the first phase, there is correlative evidence to suggest that GOA larvae are significant contributors to the eastern Bering Sea stock. There is also reason to hypothesize that the strength of the ACC may play a role in both the magnitude of larvae that are transported through Unimak Pass, as well as their final destination upon entrance to the Bering Sea. Temperature positively affects length of newly settled Pacific halibut and warm years produced significantly more Pacific halibut than cold years suggesting that fish may be moving more quickly through their most vulnerable stages in warm years compared to cold years, resulting in increased survivability.

Future work

The first phase of this project is nearly complete and the next phase will be to examine movement of larvae using a NOAA-produced oceanographic transport model. The process of producing parameters for the model is underway and this work is scheduled to take place in 2018.

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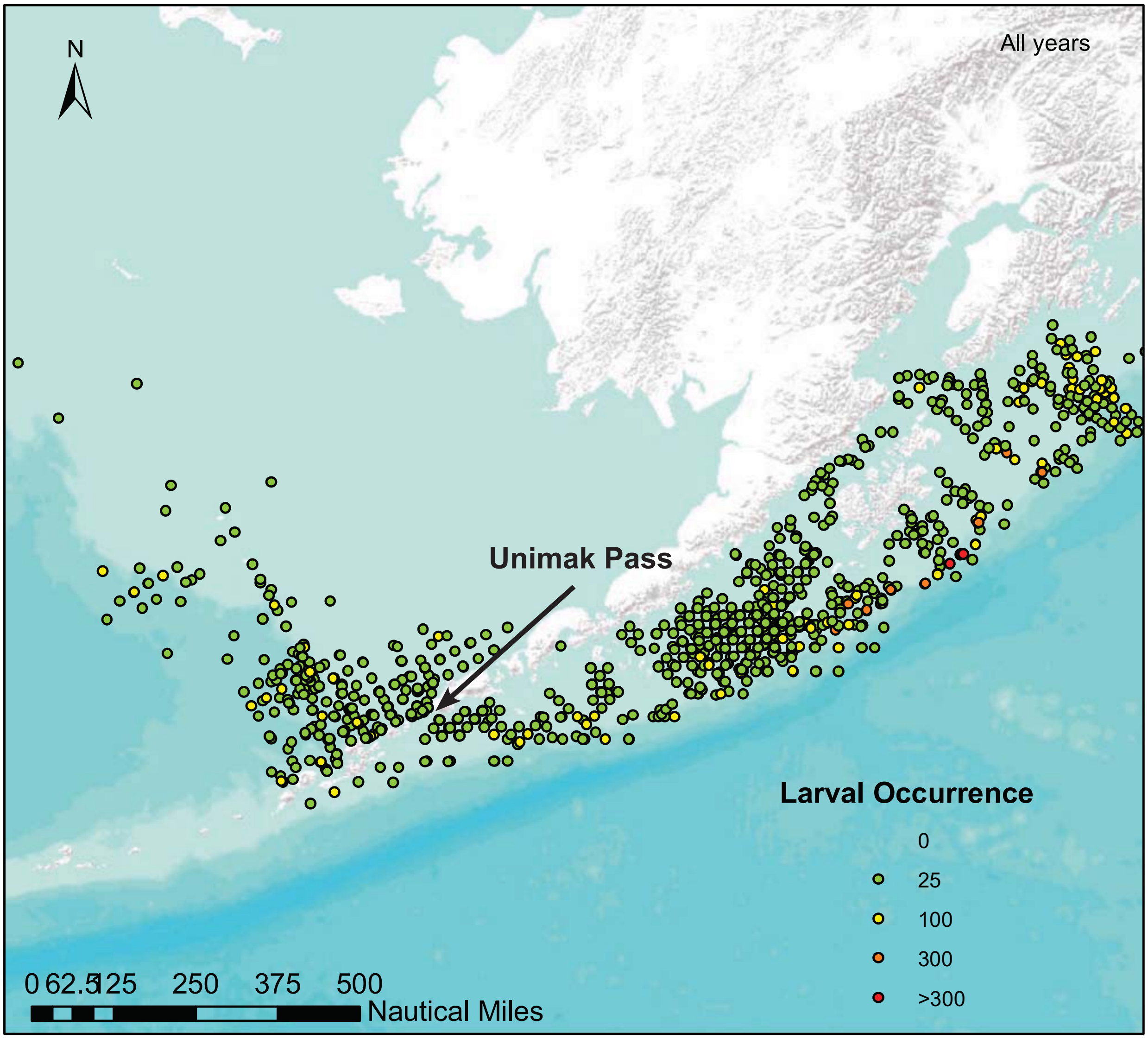

Figure 1. Occurrence of larval Pacific halibut captured during NOAA icthyoplankton surveys from 1972-2015 in the western Gulf of Alaska and eastern Bering Sea. Note that only those stations where Pacific halibut catch was > 0 are shown.

2.5.4 Wire-tagging on the fishery-independent setline survey

Joan E. Forsberg

Abstract

Following a successful wire-tagging pilot study in a single survey region in 2016, the International Pacific Halibut Commission expanded the tagging effort to additional regions of the annual fishery-independent setline survey in 2017. A total of 1,927 small Pacific halibut (< 82 cm fork length) were tagged and released and tissue samples were collected from 1,918 of these tagged fish.

Introduction

In 2015, the International Pacific Halibut Commission (IPHC) began a long-term effort to wire-tag young Pacific halibut with a pilot study on the National Marine Fisheries Service (NMFS) groundfish trawl surveys (Forsberg et al. 2016). The main goal of the trawl tagging effort was to provide data on juvenile Pacific halibut movement and growth. Migration information on adult Pacific halibut has been well documented in recent tagging studies, but less is known about juvenile Pacific halibut movement. The 2015 trawl survey tagging pilot was successful and the decision was made to continue the project into the foreseeable future on the NMFS trawl surveys and to test the feasibility of expanding the tagging effort to small Pacific halibut captured on the IPHC fishery-independent setline survey (setline survey).

Not all Pacific halibut are sampled for otoliths on the IPHC setline survey; otolith sampling rates are assigned by regulatory area to achieve a target of 2,000 otoliths per area. Pacific halibut that are of the minimum commercial size or greater (fork length ≥ 81.3 cm (> 32 inches) or *O32*) and are not sampled for otolith collection are measured and kept for sale. Pacific halibut that are below the minimum commercial size (fork length < 81.3 cm (< 32 inches) or *U32*) and not sampled for otolith collection are measured and released alive. Wire-tagging non-sampled U32 Pacific halibut on the existing setline survey platform is an inexpensive way to increase the number of small Pacific halibut tagged as well as the likelihood of recoveries in the future. Additionally, a small tissue sample (fin clip) from each tagged fish will enable the IPHC to know the sex of the animals tagged, even if they are later recovered in the commercial fishery where the sex may be unknown.

The 2016 setline survey tagging pilot was limited to Regulatory Area 4D where catches of small Pacific halibut were expected to be relatively low and where tagging could be incorporated into the workflow without compromising other survey objectives. The pilot study was successful and U32 tagging was expanded in 2017 to all survey areas for which the otolith sampling rate was less than 100%. Tagging was conducted in Regulatory Areas 2B, 2C, 3A, 3B, 4A, and 4B in 2017.

The number of Pacific halibut encountered in the different survey regions varies greatly. In order to incorporate U32 tagging into other sampling duties, a target number of 500 tags per regulatory area was established and a tag sampling rate was set for each regulatory area to achieve this target (Table 1).

Methods

Determining Pacific halibut to be tagged

Tagging and tissue sampling instructions were incorporated into the 2017 setline survey manual (IPHC 2017). Samplers on vessels in Regulatory Areas with otolith sampling rates less than 100% instructed vessel crew to land all U32 Pacific halibut carefully (i.e., without gaffing the fish in the body or gills). All U32 Pacific halibut were measured dark-side-up to minimize potential damage to the eyes in the event the fish was selected for tagging. Samplers used electronic tablets for data collection in 2017. Random sampling algorithms were programmed into the tablet to select Pacific halibut for otolith removal or tagging. Because only U32 Pacific halibut were to be tagged, the sampling rate for potential tagged fish was adjusted (i.e., increased) to factor in the predicted proportion of U32 to O32 fish expected for each Regulatory Area. The expected proportion of U32 to O32 was based on proportions observed in 2016. Of the U32 Pacific halibut that were selected for potential tagging, only individuals that were in viable condition based on U.S. federal fishery observer criteria (AFSC 2017) (*Excellent, Moderate,* or *Poor*) were tagged. A fin tissue sample was also collected for each tagged Pacific halibut before release. The tissue samples provided genetic material for determining sex (Drinan et al. 2017).

Tags

Pacific halibut were tagged on the eyed-side operculum (cheek) using conventional plastic-coated wire tags. The IPHC has used plastic-coated wire tags in many tagging experiments. Tags used in this project were manufactured by Floy Tag[1] using 0.5 mm diameter stainless steel wire covered with colored polyolefin tubing for an overall diameter of 1.8 mm. Each tag was 16.5 cm long and was labeled with a unique number as well as the IPHC's contact information (Fig. 1). Samplers were provided with tag applicators made of hollow stainless metal tubing attached to a solid shank, which curve and taper to a point (Fig. 1). Samplers could make adjustments to the curve of the shank using pliers.

Data collected from tagged fish prior to release

In addition to data usually collected on the setline survey: fork length (FL) and prior hooking injury (PHI), samplers also assessed and recorded the release condition and tag number and type for each tagged fish. Release condition was determined using the criteria used by NMFS observers on longline vessels for assessing Pacific halibut viability. The criteria include four categories: *Excellent* (E), *Moderate* (M), *Poor* (P), and *Dead* (D) (Table 2). Those assessed *Dead* were not tagged or sampled for fin tissue, but samplers recorded length, sex, and maturity. Only Pacific halibut that were scored as *Excellent, Moderate,* or *Poor* were tagged and released. Each unique tag number was recorded in its entirety. Wire tags are assigned a tag type code based on tag thickness and color. Tags used in 2017 were type "Y" (fluorescent yellow) and "C" (pink).

Tagging procedure

Samplers were instructed to use the tags in numerical order if possible. Tags were pre-bundled in groups of 25 tags with consecutive numbers. Each sampler was equipped with a plastic block with 50 holes that allowed them to sort and hold tags while on deck. Tags were sorted and loaded

[1] Floy Tag (www.floytag.com/) 4616 Union Bay Pl NE, Seattle, WA 98105, (206) 524-2700

into the plastic block, in numerical order, prior to the gear being hauled. Tags were applied by first inserting the tag into the hollow shaft of the applicator. The sharpened end of the applicator was then inserted between the pre-opercular and the opercular bone of the cheek at an angle which permitted the applicator to pass between the two bones. The curvature of the solid shank of the applicator caused it to pass around the pre-opercular bone and come out through the edge of the cheek. The tag was then pulled through the opening created by the applicator, and the two ends of the tag were folded together and twisted a minimum of five times so a closed loose loop (allowing for growth) was created around the pre-opercular bone. Any excess tag beyond the twist was cut off. The tagging procedure is illustrated in Figure 2.

Fin tissue sample

After a fish was tagged, a small sample of fin tissue was collected and transferred to filter paper that was pre-printed with a 50-cell grid. Samplers were provided with biopsy punches and wire cutters or "clippers" for collecting the fin tissue (Fig. 3a, b). The biopsy punch consisted of a hollow tube and plunger/ejector assembly with a 7-mm circular cutting edge at the tip. The biopsy punch was used to collect a small piece of fin tissue from the outer portion of the fin by simultaneously pressing down and rotating the punch. Composite biopsy cutting mats were used under the fin while cutting the sample to protect the cutting tip from damage. Samplers using the wire cutters clipped off a small piece of tissue from the corner of the tail or pectoral fin. For either method, samplers were instructed to deposit each tissue sample in a separate printed grid cell on the filter paper and to record the tag number in the same cell. The wet fin tissue adheres to the paper and remains in place as it dries (Fig. 4). The tissue sampling equipment was cleaned with 70% isopropanol between fish to avoid cross contamination between samples. Once a sheet was filled and tissue samples were dry, the sheets were stored individually inside plastic sheet protectors with silica gel desiccant packs to ensure samples stayed dry.

Results

A total of 1,927 Pacific halibut were tagged and released among six Regulatory Areas (Table 3). Most of the tagged Pacific halibut (76%) were assessed as *Excellent* (Table 3). Release condition was not recorded for 28 tagged fish, but would have been *Excellent, Moderate,* or *Poor* since fish assessed as *Dead* were not tagged. Nineteen Pacific halibut selected for tagging were assessed as *Dead* and were not tagged. Fork length of the tagged fish ranged from 45 to 82 cm (Table 4) with 87% of the tagged fish measuring between 65 and 81 cm FL. One fish measuring 82 cm FL was inadvertently tagged in Regulatory Area 2B, and one fish was tagged and released in Regulatory Area 3A without an accompanying length measurement. All but six tagged fish were examined for PHIs. Most of the tagged fish (n=1,847, or 96%) had no PHI, 56 fish (3%) had minor injuries, and 18 tagged fish (<1%) had moderate PHIs. Tissue samples were collected for all but 9 wire-tagged Pacific halibut in 2017 (>99%).

Project evaluations

The biologists in the field were encouraged to provide feedback with respect to the impact of the additional time involved in tagging and collecting tissue samples on the rest of the survey workload for samplers and vessel crew. This feedback will be used to better streamline the process on future surveys, and to adjust the tagging rates if necessary.

Samplers were able to easily incorporate the tagging of U32 Pacific halibut into the workflow in most cases; samplers in regions with extra projects were challenged on sets with high catches. Catch rates of Pacific halibut of all sizes were lower than anticipated, and the target of 500 tagged U32 fish was not met in any regulatory area. Several samplers suggested an addition to the tablet software that will give advance notice of a fish to be potentially selected for tagging (similar to the current "upcoming otolith" feature). The maximum number of U32 Pacific halibut tagged in a set in 2017 was 19.

Samplers on all vessels found the wire cutters easier to use than the biopsy punches and most fin tissue samples were collected using wire cutters. The wire cutters supplied in 2017 were not made of stainless steel and they tended to rust. Sea samplers will be provided with stainless steel wire cutters in 2018.

Future of the project

The IPHC plans to continue the U32 wire-tagging effort on the fishery-independent setline survey for the foreseeable future. Tagging as many Pacific halibut as possible over the next several years will increase the chance of meaningful recoveries. Samplers will also continue to collect tissue from all tagged fish for genetic sexing.

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Table 1. Regulatory Area-specific tagging rates used in 2017.

Regulatory Area	Tagging Rate
2A	no tagging
2B	0.281
2C	0.328
3A	0.040
3B	0.053
4A	1.000
4B	0.416
4CD	no tagging

Table 2. Viability criteria used to assess release condition (criteria are listed in order of importance).

Excellent: Injuries, if any, are slight and inconsequential to health of the fish. (*observer code Minor*)

1. Injuries around the mouth from the hook and hook removal are slight.
    - *A hook entrance/exit hole around the jaw or in the cheek.*
    - *The lip (skin covering the external portion of the jaw) may be torn and hanging.*
    - *The hook and some length of residual gangion may be hanging from the mouth if the gangion was cut.*
2. Very little bleeding, if any.
    - *Bleeding is seen only in the area surrounding the jaw.*
    - *Bleeding may have stopped, or may be continuing very slowly a few drops at a time.*
3. No penetration of the body or head by sand fleas.
    - *Membranes surrounding eyes and anus are intact, without any holes from sand fleas.*
    - *A few sand fleas may be seen on body and can be wiped off with your hand. Typically, no penetration has occurred when only a few (e.g., <10) sand fleas are found on the body.*

Moderate: Injuries are present, but are not severe. (*observer code Moderate*)

1. Injuries may have been inflicted to the jaw, cheek, eye, or body.
    - *Lower jaw may be broken into 2 pieces at the snout, but each is still attached at the base of the jaw.*
    - *Jaw is torn on one side or the other, possibly extending through the cheek.*
    - *Hook may have punctured the eye or eye socket.*
    - *Wounds on head and abdomen limited to surface scratches on skin*
    - *No wounds of any kind to abdominal organs. Abdominal cavity wall not punctured.*
    - *Wounds in body consist of puncture holes in skin, with possibly a flesh tear.*
2. Bleeding is occurring but not from gills.
    - *Blood may be seen around mouth and jaw.*
    - *Blood is not flowing profusely, but is oozing continuously.*

(Table 2. continued next page)

Table 2. continued

3. No penetration of the body or head by sand fleas.

   - *Membranes surrounding eyes and anus are intact, without any holes from sand fleas.*
   - *A few sand fleas may be seen on body and can be wiped off with your hand. Typically, no penetration has occurred when only a few (e.g.,<10) sand fleas are found on the body.*

Poor: Severe life-threatening injuries can be seen. (*observer code Severe*)

1. Injuries to the head and/or jaw have occurred. Any of the following will be present, individually or in combination:

   - *Skin on head (forward of preopercle) is ripped and torn deeply, exposing tissue and internal organs.*
   - *Side of the head, possibly including the jaw, has been torn loose and missing from the fish.*
   - *Lower jaw has been torn away and is missing.*
   - *No wounds of any kind to abdominal organs. Abdominal cavity wall not punctured.*

2. No penetration of the body or head by sand fleas.

   - *Membranes surrounding eyes and anus are intact, without any holes from sand fleas.*
   - *A few sand fleas may be seen on body and can be wiped off with your hand. Typically, no penetration has occurred when only a few (e.g.,<10) sand fleas are found on the body.*

Dead: Fish is lifeless, sand flea predation, severe bleeding. (*observer code Dead*)

1. Fish is already dead when brought to the surface on the gear.

   - *Fish is in rigor and lifeless, even if no apparent injuries.*
   - *Gills appear completely devoid of blood (light pink or white in color).*

2. Marine mammals have taken bites out of the fish.

   - *Usually taken out of the back of the fish or from the abdominal cavity.*

3. Sand fleas have penetrated the body via the eyes, fins, or anus.

   - *Membrane surrounding eye may be partially or completely missing.*
   - *Dorsal and/or anal fin membranes may be eaten away, leaving fin rays exposed. Skin on the body is separated from tissue where sand fleas have eaten.*

4. Bleeding is severe, especially from the gills.

   - *Blood is flowing freely and continuously in large quantity.*
   - *Bleeding is occurring from a torn or severed gill arch.*

5. Internal organs are damaged, possibly by a gaff.

   - *Abdominal cavity wall is punctured or torn.*
   - *Viscera are visible and exposed, and may be protruding*

Table 3. Number of Pacific halibut tagged in the 2017 setline survey by Regulatory Area and release condition category. Fish in the unknown category were those for which release condition was not recorded.

Reg. Area	Moderate	Excellent	Poor	Unknown	Total
2B	55	232	1	3	291
2C	96	292	13	6	407
3A	51	275	9	6	341
3B	86	221	21	4	332
4A	66	235	6	5	312
4B	29	195	16	4	244
Total	**383**	**1,450**	**66**	**28**	**1,927**

Table 4. Number of Pacific halibut tagged in the 2017 setline survey by 10-cm fork length category and Regulatory Area.

	Regulatory Area						
Fork length category (cm)	2B	2C	3A	3B	4A	4B	Total
<46				1			**1**
46-55	1		3	3	9		**16**
56-65	21	29	27	51	77	13	**218**
66-75	125	191	149	193	143	110	**911**
76-82	144	187	161	84	83	121	**780**
Total	**291**	**407**	**340***	**332**	**312**	**244**	**1,926**

*Excludes one fish tagged in 3A for which length was not recorded

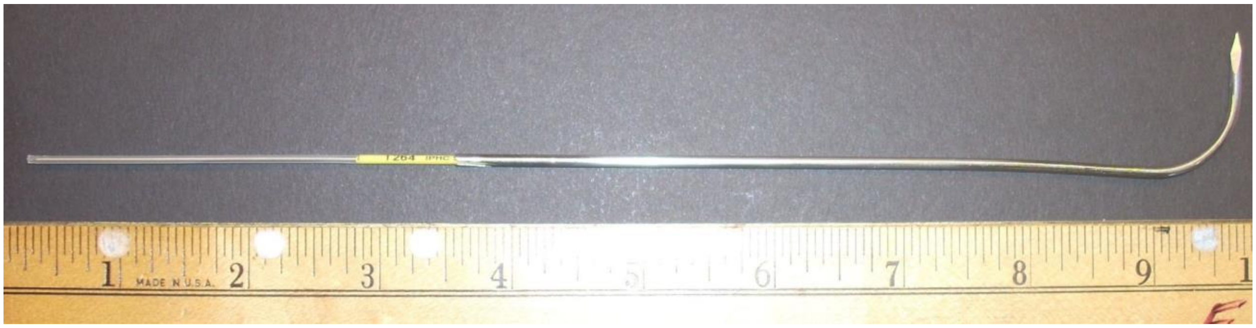

Figure 1. Wire tag inserted in hollow end of tag applicator.

Figure 2. Illustration of the opercular wire tagging procedure used on halibut

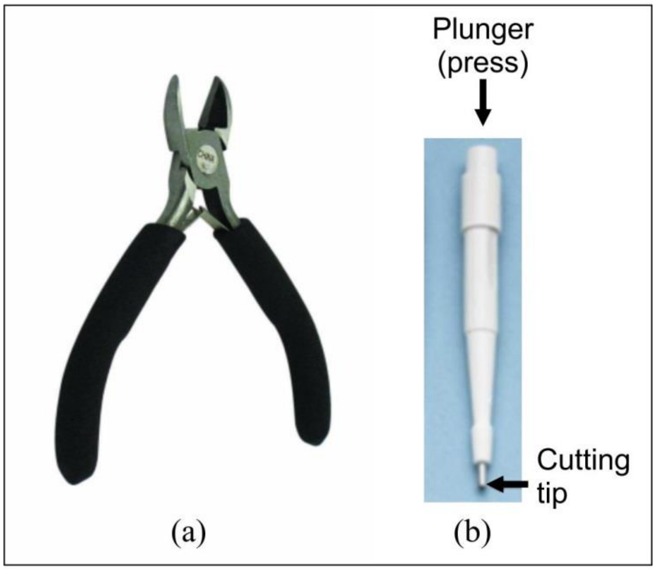

Figure 3. (a) wire cutters and (b) biopsy punch used for taking fin tissue samples.

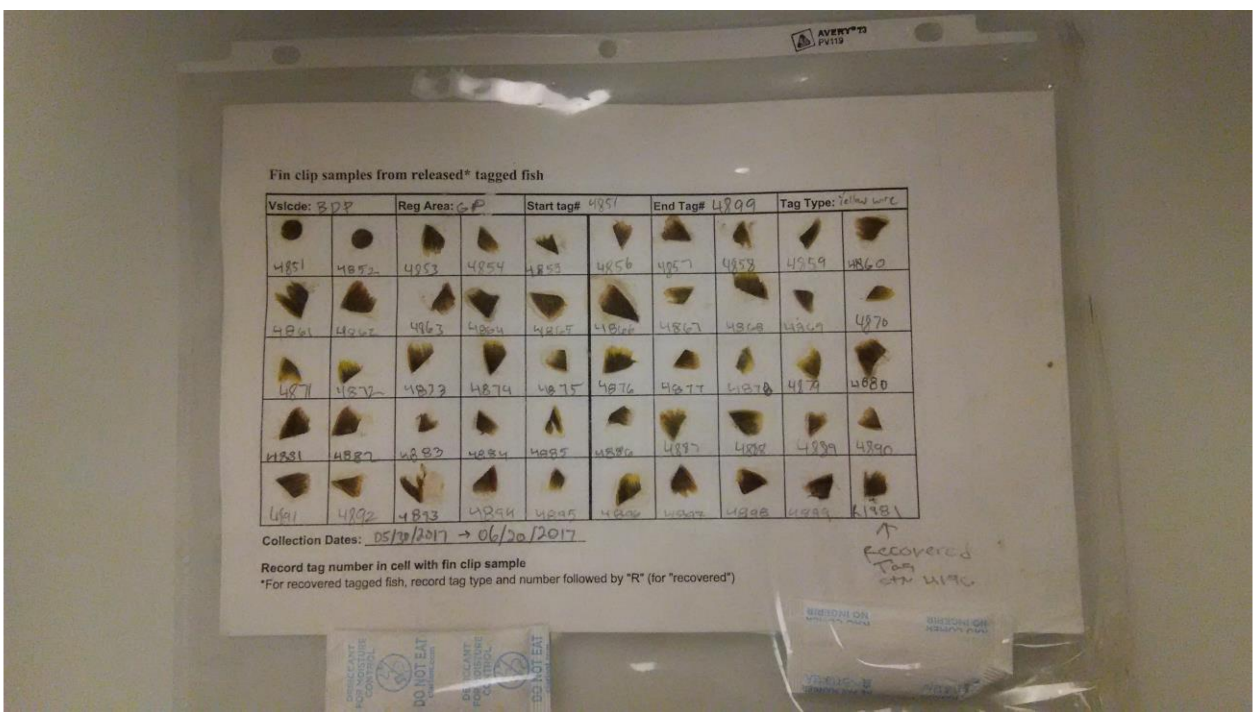

Figure 4. Fin tissue samples on filter paper inside plastic sleeve. The samples in the upper left two cells were taken with a biopsy punch, the rest were taken with the wire cutters.

2.5.5 Otolith archive collection for elemental and isotopic studies

Robert S. Tobin, Joan E. Forsberg, Dana M. Rudy

Abstract

Recent trends in otolith research include analysis of trace element constituents of the otolith. Samples used in these types of analyses need to be free of contaminants, such as glycerin. The International Pacific Halibut Commission's otolith collection has primarily been composed of otoliths collected for age determination, which have been stored in a glycerin/thymol solution to increase readability. A separate collection of paired otoliths for use in future elemental and isotopic studies was started in 2010 (the "clean" otolith archive). A total of 755 otolith pairs were added to the clean otolith archive collection in 2017.

Background

With the advent of new technologies, fisheries researchers have the ability to study the elemental constituents incorporated in the microstructure of the otolith. Otoliths are composed primarily of calcium carbonate (in the form of aragonite) in a protein matrix. Otoliths grow through the life of the fish through gradual accretion. Crystals of aragonite as well as trace amounts of other elements are added to the outer surfaces of the otolith in discrete increments that are stable over time. The most commonly measured elements are those that fall under the alkali, alkaline earth, and transition metals categories of the periodic table, which include, but are not limited to, beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), and manganese (Mn). It is possible to detect and measure extremely small concentrations of these elements in otoliths, however any contaminants in the sample, such as glycerin (1, 2, 3-propanetriol), can make these measurements difficult to interpret.

The International Pacific Halibut Commission (IPHC) otolith collection has, by and large, been comprised of samples collected for age determination as a data input into the annual stock assessment. These structures have been stored in a solution of glycerin and thymol (2-isopropyl-5-methylphenol) that allows for increased readability. As useful as it has been, this collection has limitations for other research purposes. Otolith-based research has seen a shift from age and growth studies to isotopic and elemental analyses of otoliths (Campana 2005). Oxygen isotope analysis can be used to reconstruct thermal history, and stable isotope analysis (carbon and nitrogen) can provide information on a fish's dietary history. Trace elements in the otoliths can be used in conjunction with other sampling to identify nursery origin by analyzing the trace element composition of the core. Analyzing trace element composition over time within an otolith (by sampling material from sequential annuli along a transect of a sectioned otolith) can provide information useful to understanding migration (Campana and Thorrold 2001, Gao and Noakes 2012). A glycerin/thymol solution maintains readability in stored otoliths, enabling age determination; however, it renders these structures unusable for research involving some isotopic and all elemental analyses. While methodological problems with measurement of otolith trace elements remain (Geffen et al. 2013), it is likely that studies involving otolith elemental and isotopic analyses will become more useful as the technologies that underlie these studies become more reliable. To make structures available for future chemical analyses, a clean otolith archive collection (COAC) program was initiated in 2010.

Collection

The COAC is composed of structures from IPHC otolith collection programs and other research opportunities, including: the fishery-independent setline survey (setline survey), commercial port sampling program, National Marine Fisheries Service (NMFS) trawl survey, and special charters that sacrifice Pacific halibut for research. These otoliths are collected along with any associated data, such as capture location and fork length, following the established collection procedures of the applicable program. Otoliths from the COAC are not used for age determination. They are wiped clean of blood and tissue, dried, and stored whole in climate-controlled conditions for future analysis.

There are separate annual COAC sampling goals for Pacific halibut caught on the setline and the NMFS trawl survey platforms. For Pacific halibut caught with longline gear (setline survey and commercial sampling program), the annual COAC sampling goal is to collect a random sample of 100 otolith pairs from each of IPHC Regulatory Areas 2A through 4B, and 100 pairs from Regulatory Areas 4C, 4D, and 4E combined. Ideally, all of these otoliths would come from the setline survey, because sex and exact capture location are available. However, in areas of lower catch, the setline survey otolith sampling rate may already be 100% to achieve the otolith target necessary for age determination. For these areas, COAC otoliths are collected from commercial deliveries. For the NMFS trawl survey, annual COAC sampling goals have ranged between 210 and 250 otolith pairs, depending on the survey regions for a given year. Parts of the NMFS trawl survey occur in IPHC statistical areas not covered by the setline survey; in addition, the trawl survey encounters small Pacific halibut that are not caught on setline gear. A total of 755 otolith pairs were collected for the COAC in 2017.

Setline survey

Sampling for the COAC began on the setline survey in 2010. To achieve a per-area target of 100 otolith pairs, setline survey otolith sampling rates were increased by approximately 5% for each regulatory area, excluding those areas that required a 100% sampling rate to meet the otolith target for age determination. In 2017, otoliths were collected for the COAC from Regulatory Areas 2B through 4B. Selection of fish to be sampled was determined from area-specific random number tables for both the COAC and age determination otolith collections. COAC otoliths were placed in black Tray Bien™ storage trays to prevent confusion with the standard blue Tray Biens™ utilized for the setline survey. COAC totals for the setline survey were 504 otolith pairs. Pairs collected by vessel are listed in Table 1 by vessel code as defined in the 2017 IPHC survey manual (IPHC 2017a).

Commercial sampling program

The COAC from the commercial fishery began in 2011. These otoliths are only collected from deliveries of Pacific halibut caught in regulatory areas where COAC sampling cannot be fully conducted on the setline survey. The number of otoliths targeted from commercial deliveries varies from year to year and depends on the availability of otoliths from the setline survey in a given Regulatory Area. In 2017, COAC samples from the commercial fishery were requested from

Regulatory Areas 2A and 4CD, and 100 and 151 otolith pairs were collected respectively from these areas (Table 1). These otoliths were collected by samplers in Newport, OR, Bellingham, WA, and La Conner, WA (Regulatory Area 2A); and St. Paul, AK (Regulatory Area 4C). Sampling protocol and rates were established by port and Regulatory Area prior to the start of sampling in those ports (IPHC 2017b). In Bellingham, La Conner and Newport, most of the COAC samples were taken from the same deliveries sampled for age and length data to be used in the stock assessment, but a few came from deliveries not sampled for age determination. In St. Paul, the samplers collected COAC otoliths on days when commercial samples for the assessment were not being collected.

NMFS trawl survey

The NMFS conducts an annual trawl survey in the Eastern Bering Sea and biennial surveys on alternate years in the Gulf of Alaska and Aleutian Islands. Due to the nature of the trawl survey, a large portion of the catch consists of small Pacific halibut that are not represented in the setline survey or commercial port sampling collections. COAC sampling took place on the NMFS trawl surveys between 2011 and 2014. Trawl survey COAC sampling has been suspended since 2015 when a Pacific halibut wire tagging project was implemented (Forsberg et al. 2016). Although the IPHC expects to continue tagging over the next several years, samplers may resume COAC sampling on future trawl surveys.

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Table 1. Number of COAC otoliths collected by regulatory area, vessel code, and collection type in 2017. Collection type: FISS (fishery-independent setline survey) and CSP (commercial sampling program).

		Regulatory Area									
Vessel Code	**Collection Type**	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4C**	**4D**	**Total**
PEN	FISS		31								
VNI	FISS		39								
PEN	FISS			76							
STW	FISS			24							
BDP	FISS				26						
CLD	FISS				14						
STN	FISS				25						
STW	FISS				18						
ALL	FISS					30					
CLD	FISS					13					
FTW	FISS					15					
PRE	FISS					14					
FTW	FISS						114				
KSU	FISS							5			
NCR	FISS							60			
	CSP	100								151	
Total		100	70	100	83	72	114	65		151	**755**

2.6.1 At-sea marking and the development of genetic techniques for determination of sex in routine catch sampling of commercially-harvested Pacific halibut

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Abstract

Pacific halibut (*Hippoglossus stenolepis*) is an important commercial species with an annual harvest valued at U.S. $100–170 million in the eastern portion of its range. Over the past four decades, size at harvest has declined dramatically (by ~20 pounds) and, coupled with sexually-dimorphic growth and size limits on commercial catches, suggests that commercial harvests are becoming increasingly biased towards females. Understanding the annual contribution of both sexes to the commercial harvest is important for predicting population dynamics and setting catch limits, but there has been no reliable way to determine sex in the commercial harvest, given that Pacific halibut are eviscerated at sea. Here, we describe efforts to develop an at-sea marking program in which the sex of individual Pacific halibut would be identified during the course of dressing the catch; and the development of genetic assays for accurate sex identification of individuals using field-collected tissue samples. The program began in 2014 with the development of methods to mark Pacific halibut at sea; a pilot test of those methods was conducted in 2015 at the port of Homer, Alaska; in 2016, voluntary at-sea marking was conducted by the commercial fleet throughout IPHC Regulatory Area 2B; and voluntary marking was scaled to coastwide in 2017. Data from at-sea sex marking suggest that commercial vessels may encounter a higher proportion of female Pacific halibut across commonly-encountered ages than does the IPHC's fishery-independent setline survey. Genetic assay development employed restriction-site associated DNA sequencing and identified 40,308 sequences, with 56 sequences (containing 70 single nucleotide polymorphisms) linked to sex, and three loci limited to females. All loci linked to sex in the Pacific halibut were observed on a single chromosome, as is also true for the Atlantic halibut (*Hippoglossus hippoglossus*), which suggests that we have identified the sex-determining chromosome. Assays were developed from a subset of sex-linked loci.

Introduction

Trends in mean weight-at-age, in concert with variance in underlying sex ratios and changing age-distribution over time, can have substantial effects on the demographics of fishery landings and influence population structure as individual cohorts progress through their fisheries. For Pacific halibut (*Hippoglossus stenolepis*) in US and Canadian waters, the average individual weight of harvested fish is estimated to have varied more than two-fold over the last 80 years; increasing from approximately 20 pounds to over 40 pounds between the 1940s and the mid-1970s, then steadily declining to ~20 pounds by 2011 (Stewart and Monnahan 2016). In many regions, the largest decline was observed from 1995-2005 and was most strongly observed for age-10 Pacific halibut and older: age-classes primarily comprising the directed fishery (Stewart and Monnahan 2016). In conjunction with sexually-dimorphic growth, in which female Pacific halibut are typically larger at-age than males (Stewart and Monnahan 2016), longline selectivity tends to subject Pacific halibut to increased vulnerability to harvest with increasing size (Stewart and Martell 2014). A minimum commercial size limit has remained constant since 1973 (Stewart and Monnahan 2016), resulting in an expectation that the sex composition of commercial catches has become increasingly female-biased over the last two to three decades. Given an assessment framework that predicts that both selectivity and natural mortality may vary according to sex (Stewart and Martell 2016), it is important to correctly estimate population sex ratios in order to conduct long-term policy analyses. For example, recent sensitivity analyses have indicated that uncertainty regarding sex ratios within commercial harvests can strongly influence estimates of female spawning stock biomass (SSB_f), with 10% variance in estimated sex ratio translating into roughly 50 million pounds of estimated SSB_f (I. Stewart, IPHC, unpublished). Such uncertainty may be exacerbated if age-specific sex compositions vary in space and time (*sensu* Clark 2004) as recent analyses suggest (Loher et al. 2016).

Unfortunately, there is presently no reliable way to determine the sex of commercially-harvested Pacific halibut at landing because they are eviscerated at sea. Efforts have been undertaken to determine the feasibility of invoking a regular at-sea sex-marking program for the directed Pacific halibut fleet, in which retained catch would be marked by commercial fishers as either male or female during the dressing process (McCarthy 2015, Loher et al. 2017). Such a program would be conceptually similar to Atlantic lobster fisheries in which fishers “V-notch” gravid females prior to releasing them (Acheson and Gardner 2011) and add considerably to the IPHC’s assessment and policy analyses. However, as such marks would not represent direct observations of sex, portside sampling would need to be accompanied by an empirical method to validate sex ratios as well as to monitor sex ratios within components of harvest for which at-sea marking might not be practical. Therefore, genetic assays have been developed from a subset of single-nucleotide polymorphisms (SNPs) found to be associate with sex. SNPs are highly reproducible and modern screening methods allow high throughput screening of SNPs at low costs. Recent advances in sequencing technologies have made the identification of SNPs in non-model species, such as Pacific halibut, feasible (Baird et al. 2008). The current report summarizes the sampling that has been conducted during the at-sea sex-marking program and the completion of the SNP-based sex assays.

At-sea sex marking

Methods

The IPHC’s at-sea sex marking program was launched in 2014 and has been composed of four stages of activity over a four-year period, as follows:

1) Development of methods to mark Pacific halibut at sea, conducted on the IPHC’s setline survey platform (2014).
2) Pilot-testing of the chosen marking methods in a limited commercial setting (2015).
3) Initiation of voluntary at-sea marking by the commercial fleet within IPHC Regulatory Area 2B (2016).

4) Scale up of voluntary at-sea marking by the commercial fleet to include all IPHC regulatory areas (2017).

Brief summaries of each of these stages are found in the subsections that follow.

Development of at-sea marking methods

At-sea marking methods were developed and tested in 2014 by IPHC student intern Orion McCarthy, in a dual-phase study that began in the Alaskan ports of Homer and Dutch Harbor and was completed during the IPHC setline survey aboard the F/V *Kema Sue*. The objective of McCarthy's work was to develop a method for sex-marking halibut that would be easy for fishermen to accomplish while dressing their catch, would not damage their catch from a commercial perspective, and would allow our port samplers to distinguish between female and male marks easily and accurately. Nine marks were initially tested portside, including cuts to various fins, the tail, and the gill plate (operculum). With feedback from the port samplers, fishers offloading the halibut, and local buyers, each potential mark was ranked according to its ease and practicality. From the original nine marks, the top three were then tested to determine which would be easiest for the port samplers to identify while also taking length data and collecting otoliths. The two "winning" marks were then used by the crew of the *F/V Kema Sue* to mark all retained catch from six days of survey fishing, during which the crew provided feedback on the ease of marking, and improvement in their marking accuracy through experience was evaluated by the intern through the trip. After retained fish were dressed and marked by the crew, and then sampled for biological information (including sex) by the IPHC sea samplers, they were inspected by the intern for the presence/absence of the knife cuts and tagged with a unique fish identity number (ID). These unique fish ID numbers were matched with the sample data for each individual fish and used to keep a record of each fish's true sex, the sex marking, and where the fish was caught including station and skate number. During the offload, the IPHC port sampler in Dutch Harbor examined all the Pacific halibut in the catch and recorded the sex based on the mark as well as the individual fish ID. The sex ratio of the catch was estimated from the marks counted by the port sampler and compared with the sex ratio of the catch as marked by the crew as well as to the known true sex ratio for the trip.

The two marks that were chosen were as follows: for females, two cuts made in the dorsal (upper) fin; for males, a single cut through the white-side gill plate (Fig. 1). The vessel crew marked ~85% of the catch correctly. Roughly two thirds of incorrectly-marked fish had either not been given a mark or were given a mark that couldn't be identified later; fewer than 5% of the fish were marked as the wrong sex. Ultimately, the proportion of female halibut in the offload as estimated from crew's sex-marks was ~3% greater than its known composition (i.e., 85% female versus a true proportion of ~82%). These results indicated that an at-sea sex-marking program would have considerable promise for providing sex-ratio data at the resolution required for assessment purposes, given that both accuracy and precision could be measured and monitored over time. This was especially true considering that the crew became more comfortable with the process and increasingly accurate as the trip progressed; suggesting that sex-marking should become easier and potentially more accurate than estimated as the project is scaled upwards and the fleet gains experience with it. For additional details regarding this project component, please see McCarthy (2015).

Pilot test of at-sea marking on commercial trips

During April and May of 2015, the IPHC's Homer port sampler, Jessica Marx, enlisted the cooperation of two vessels in the local fleet to conduct a voluntary field test of the marking method described above. Sex markings to accompany age and length data were obtained from 228 Pacific halibut representing five offloads. For each of these offloads, the crew marked all of their catch, but somewhat fewer total samples were obtained because IPHC port-sampling protocols may stipulate that not all fish from a given offload are to be sampled for age and length.

Feedback from the skippers and crew of the vessels regarding the ease of the process was positive, and a summary analysis of the sex ratio in their catches further highlighted the importance of collecting these data. Although the sample was relatively small and the sex markings were not verified, the data suggested that the vessels encountered a much higher proportion of female Pacific halibut across commonly-encountered ages than our setline survey data would have predicted based on similar sample sizes (Fig. 2). This was most pronounced for Pacific halibut age 9-13, over all landed sizes. Whereas random samples of equivalent sample size and over the same age classes taken from the IPHC's Area 3A setline survey catches had been about 60-70% female, the commercial samples were more than 90% female.

Voluntary at-sea marking by the Area 2B fleet

In advance of the 2016 commercial fishing period, IPHC staff met with representatives of the Pacific Halibut Management Association of British Columbia (PHMA) to discuss logistical considerations associated with a regulatory-area-wide voluntary sex marking program and to receive their input regarding the most efficient way to generate interest from the fleet. A laminated informational flyer (Fig. 1) was produced to assist crew members in distinguishing between male and female Pacific halibut, and to describe the sex-marking procedure. The flyer was provided to PHMA who included it in their pre-season mailing to all Area 2B commercial license holders; i.e., 435 vessels. Subsequently, the IPHC's port samplers in Prince Rupert, Port Hardy, and Vancouver served to communicate and clarify the project's intent, answer any questions that fleet members might have, distribute reward hats to the crews of participating vessels to acknowledge their help with the project, and solicit their feedback as the season progressed.

Over the course of the season, 28 sex-marked landings were sampled representing approximately 13% of the area's entire sampled catch (Table 1). These samples represented just under 4% of 2B's 7.3 million pound (3,311 metric ton) catch limit. Feedback from participants indicated that marking was not disruptive of normal fishing activity, nor did it have any adverse effects on marketability of these fish.

Coastwide voluntary at-sea marking

In advance of the 2016 commercial fishing period, IPHC staff met with and provided informational materials to the Pacific Halibut Management Association of British Columbia (PHMA), Fishing Vessel Owners Association (FVOA), Alaska Longline Fishermen's Association (ALFA), and Central Bering Sea Fishermen's Association (CBSFA) for distribution to their members. The IPHC's port samplers served in all coastwide ports to further communicate and clarify the project's intent, answer any questions that fleet members might have, distribute reward hats, and solicit feedback.

Over the course of the season, a total of 84 sampled offloads were sex-marked, yielding 929 individual samples (fish) for which otoliths and an accompanying fin clip were obtained (Table 1).

Percentage of the sampled catch that was composed of sex-marked fish varied from area-to-area, from a low of 3.7% of the Area 4D's sampled offloads to a high of 20.3% in Area 3B.

Continuation of at-sea marking

Tissue samples collected during the 2017 fishing season have been archived but validation of individual sexes and sex ratios within the samples offloads has not yet been conducted. Genetic sex of the sampled individuals will be determined in 2018 (see next section). Following those assays, the sex-mark data will be compared to the validation results to determine the accuracy associated with the at-sea marking program to-date, and make a determination regarding the degree to which the program as-conceived will satisfy assessment needs, or will require modifications. We will not pursue at-sea marking during the 2018 fishing season, but will refine the program for 2019 as informed by the aforementioned analyses.

Genetic sex assays

Complete documentation of the development of assays for genetic sex in Pacific halibut and additional discussion of sex-determination in the species can be found in Drinan et al. (in press). Here, brief summaries of sample collection, laboratory techniques, and assay development will be provided.

Sample collection

Samples were collected between 2003 and 2007 aboard IPHC-chartered longline vessels at five locations representing the IPHC-managed range of the species: from British Columbia (Haida Gwai) in the south to Attu Island in the western Aleutians and Pribilof Canyon in the southeastern Bering Sea; and at two additional sites (Adak Island and Petrel Bank) in the central Aleutians (Fig. 3). Full details of sample collection can be found in Drinan et al. 2016. Briefly, for each Pacific halibut sampled, sex was determined via macroscopic gonad examination, the fish was measured to the nearest centimeter fork length, and its sagittal otoliths and a fin tissue sample were collected. Tissue samples were preserved and stored in 100% ethanol. Ninety-five individuals, 55 morphological females and 40 morphological males, were used to develop the sex assays.

Laboratory techniques

Single nucleotide polymorphisms were identified using restriction-site associated DNA sequencing (RADseq) techniques (Baird et al. 2008). RADseq is a reduced representation library technique that sequences individuals at thousands of loci spread throughout the genome, and is ideal for identifying genomic regions linked to phenotypic differences in species with few genomic resources. In this study, DNA from each fin tissue sample was extracted using DNeasy Blood & Tissue Kit (Qiagen, Hilden, Germany) prepared for RADseq using standard laboratory techniques (Baird et al. 2008). The *Sbf-I* restriction enzyme was used to create the RAD library with sequencing performed on the Illumina HiSeq 4000.

Using the resulting sequence data, a baseline set of putative loci and consensus sequences were identified using the STACKS v1.35 pipeline (Catchen et al. 2011, 2013) and the sequence aligners BOWTIE2 v2.1.0 (Langmead and Salzberg 2012) and BLAST v2.2.30 (Altschul et al. 1990). Loci identified in individuals were then compared to the catalog (*sstacks*) and genotypes were produced (*populations*: -m 5, -r 0.25, and -p 3 [of 5]). A locus was retained if at least 25%

of individuals had a sequencing depth of five or more reads in at least three sampling locations. From each retained locus, a consensus sequence was identified to create a temporary database of putative loci. Next, loci in the temporary database were quality filtered to remove loci with repeat regions in the genome or those containing repetitive elements using the same alignment based on the methodologies of Brieuc et al. (2014). Loci that aligned exclusively to themselves using both aligners were retained as a final baseline of putative loci present in Pacific halibut.

Genotypes were estimated for each individual at each locus in the final baseline of putative loci by first removing PCR duplicates from the raw reads using *clone filter* within STACKS, and non-duplicated reads were then aligned to the putative set of loci using BOWTIE2. A catalog was then created using the most deeply-sequenced female and male from each stock (*cstacks*: -g), and all individuals were compared to the catalog to identify loci present in each individual (*sstacks* and *populations*: -m 8 and -r 0.5). A SNP was retained for further analyses if at least 50% of individuals within each sample had a read depth of eight or more sequences, and a minor allele frequency > 0.1. Loci linked to sex were identified using genetic differentiation between sexes, measured by F_{ST} using Genepop v4.2.1 (Raymond and Rousset 1995, Rousset 2008). Lastly, high-throughput TaqMan® assays (Thermo Fisher Scientific, Waltham, Massachusetts, USA) were developed. Loci used for the development of assays were selected based on SNP position (the middle of the sequence was preferred), number of SNPs in the locus (fewer was preferred), and differentiation among males and females (greater differentiation was preferred).

Assay development

Sequencing resulted in 163,212,521 sequence reads, with an average of 1,542,009 reads per sample (standard deviation = 733763.1 reads; minimum = 157,282; maximum = 2,059,192). From these reads, a baseline set of 40,308 putative loci was identified. Two loci (*Hs23885* and *Hs10183*) were developed into TaqMan® assays, and their efficacy was tested on 199 individuals that were morphologically sexed previously. Each genetic assay was in agreement with the morphological identification of 194 (97.5%) samples, and both genetic assays as well as the morphological identification were in agreement for 192 (96.5%) samples. In five individuals (3.5%), the genetic assays were in agreement with each other, but differed from the morphological assessment. Four of the five individuals for which the genetic and morphological tests disagreed were genetically assigned as females, but morphologically determined to be males. The converse was true in the fifth individual. Lastly, two individuals (1%) were genetically assigned as a female at one locus and a male at the other. Morphologically, one of these individuals was identified as a male and the other a female.

The efficacy of these genetic assays was comparable to assays in other fish (Palaiokostas et al. 2013, Larson et al. 2016, Utsunomia et al. 2017) and are an improvement, both in terms of analysis time, repeatability, and costs (~$0.60-0.70 US per reaction), over prior genetic tests in Pacific halibut (Galindo et al. 2011). However, differences between the morphological and genetic sex assignments were observed. Beyond inaccurate data collection, alleles may not be fixed between the sexes due either to low levels of recombination or to the recent evolution of sex chromosomes in Pacific halibut. Low levels of recombination may occur in chromosomal regions that are distal to the sex-determining gene in the early stages of sex chromosome evolution (Ellegren and Carmichael 2001). Additionally, environmental conditions may affect sex determination and could contribute to the disagreement between morphological and genetic sex assignment. Sex determination is a highly complex process and has been observed to be affected by environmental conditions, particularly water temperature, in other flatfishes (Luckenbach et al. 2009, Montalvo et al. 2012, Mankiewicz et al. 2013). Additional research would be required to investigate the causes of the discrepancies observed here.

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Table 1. Number of sex-marked commercial Pacific halibut offloads that were sampled, number of biological samples taken (i.e., sagittal otoliths and accompanying tissue samples) for those trips, the weight of offloaded fish represented by the sex-marked offloads, and the proportion of sampled weights that were sex-marked, as sampled by IPHC port samplers during the 2016 and 2017 commercial fishing seasons.

Regulatory Area	2016				2017			
	Sex-marked offloads	Sex-marked samples	Sex-marked weight (1000 lbs; metric tons)	% sex-marked by weight	Sex-marked offloads	Sex-marked samples	Sex-marked weight (1000 lbs; metric tons)	% sex-marked by weight
2A	-	-	-	-	36	70	18; 8.2	6.2
2B	130	1,905	274.5; 124.5	13.1	5	84	91; 41.3	5.3
2C	-	-	-	-	16	116	110; 49.9	9.0
3A	-	-	-	-	10	113	219; 99.3	7.6
3B	-	-	-	-	9	292	285; 129.3	20.3
4A	-	-	-	-	2	77	34; 15.4	7.4
4B	-	-	-	-	2	95	32; 14.5	10.7
4C	-	-	-	-	3	63	18; 8.2	9.1
4D	-	-	-	-	1	19	16; 7.3	3.7

Sex-marking of halibut aboard commercial fishing trips

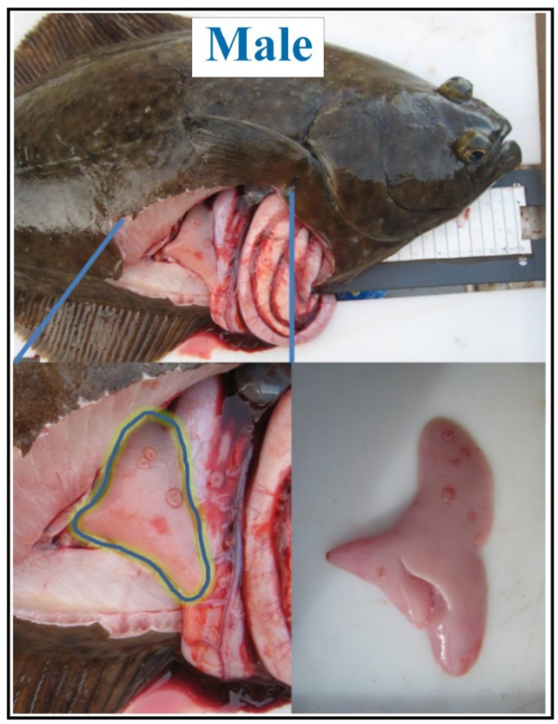
The IPHC requests your help during the 2016 fishing season, as we work to develop standard protocols for determining the sex of halibut that are landed by the commercial fishery. Accurate sex-ratio information is necessary for stock assessment - most notably, for accurately estimating and monitoring spawning stock biomass. You can help by marking the sex of the fish that you catch, while dressing them, using the identification-cuts that are described below.

First: Determine whether you have a female or a male halibut.

Female halibut have ovaries that are elongated (funnel-shaped) triangles (**see below, left**). These take up the rear portion of the gut cavity, farthest from the head, and extend back into to body. The ovaries are smooth and sac-like, with a blutly rounded front edge. Inside, the ovaries may contian develoiping eggs; the outer surface may have well-developed blood vessels. For fish of any given size, ovaries tend to be much larger than testes.

Male halibut have testes that are pale pink and relatively triangular (**see below, right**), with a sharly-tapered front edge, and lacking visible blood vessels on the outer surface. The testes are made up of overlapping lobes (a bit like a liver) that produce fine notches and crevices in the surface. They are also in the rear of the gut cavity, farthest from the head.

Female halibut: ovary location and shape. Ovaries have an elongated funnel-shape, and are a smooth sac with a rounded front edge.

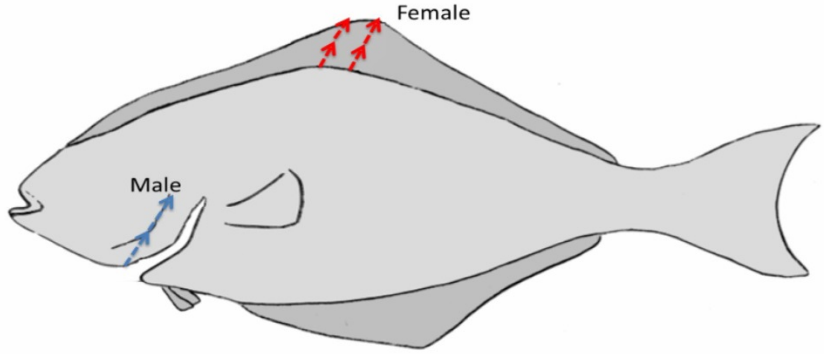


Male halibut: testis location and shape. Testes are more triangular than ovaries, are composed of overlapping lobes, and have a sharper front edge.

over →

Figure 1a. Page 1 of the laminated flyer distributed to the Area 2B fleet for the 2016 commercial fishing season, describing the difference between female and male Pacific halibut.

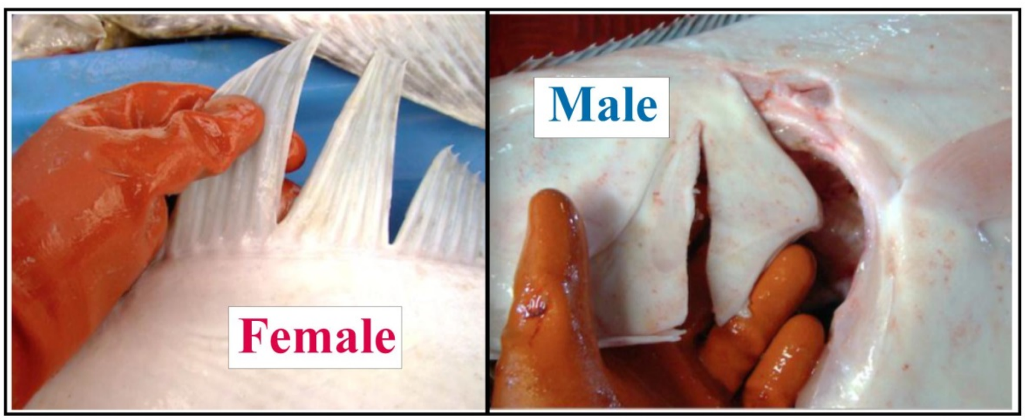
Then: Mark the fish as either female or male, using your gutting knife.



Locations on a halibut for marking it as either female or male

Female: Make two parellel cuts through the top (dorsal) fin (**see below, left**), being sure to make your cuts using an upward stroke, away from the animal, to avoid damaging the flesh. Two cuts must be made, so that the sex-marks cannot be confused with pre-existing injuries to the fin. Note that only the top (dorsal) fin can be marked; any marks found in the lower fin will be ignored when the fish is sampled in port.

Male: Make a single cut through the gill-plate (operculum) on the fish's white side (**see below, right**). Make the cut using an upward stroke, making the cut parallel to the rear edge of the operculum. The cut should extend about 3/4 of the way up the plate, so that the "flap" that you create will remain attached to the plate.



Female: Make two parallel cuts in the top (dorsal) fin.

Male: Make one cut through the white-side gill plate (operculum).

Please mark 100% of your catch!

Your effort is greatly appreciated!

Figure 1b. Page 2 of the laminated flyer distributed to the Area 2B fleet for the 2016 commercial fishing season, demonstrating how to mark halibut as either male or female while dressing them.

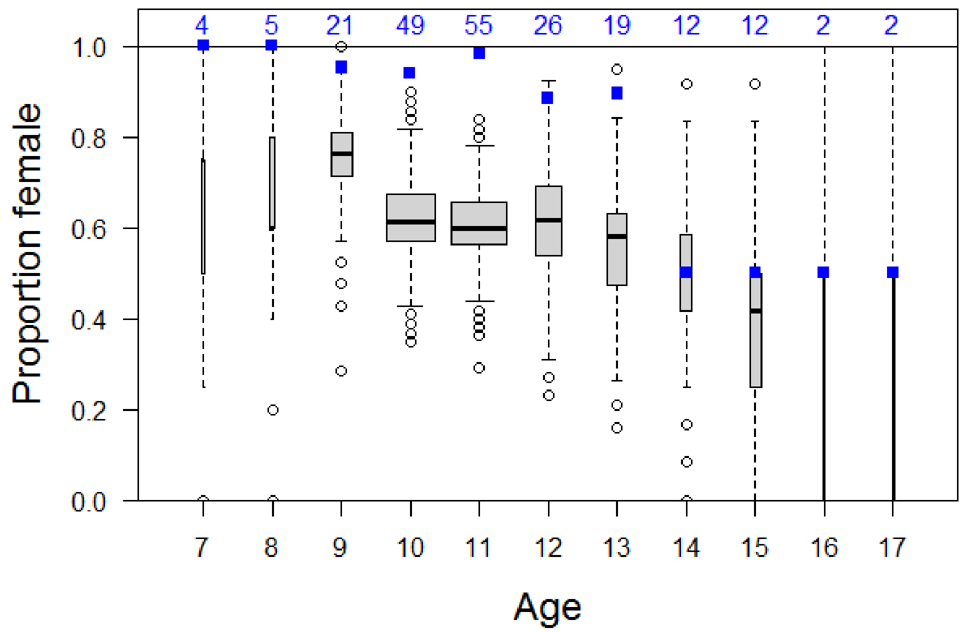


Figure 2. Based on voluntary at-sea marking of commercially-harvested Pacific halibut (n=207) landed in Homer, Alaska in 2015, proportions of female halibut at-age within those landings (small blue squares) relative to what would have been epected from similar sample sizes based on results of the IPHC fishery-independent setline survey (box and whisker plots) during 2015 in Regulatory Area 3A. In the box and whisker plots, the horizontal lines indicate the median values; the gray boxes contain the central 50% of expected values around those medians; the dashed line the 95% interval; and the dots beyond the expected variation indicate unlikely-yet-possible "outlier" values. Sample sizes by age are denoted in the top margin. Note that for halibut <14 years of age, the sampled commercial trips were composed of considerably more females than would have been expected.

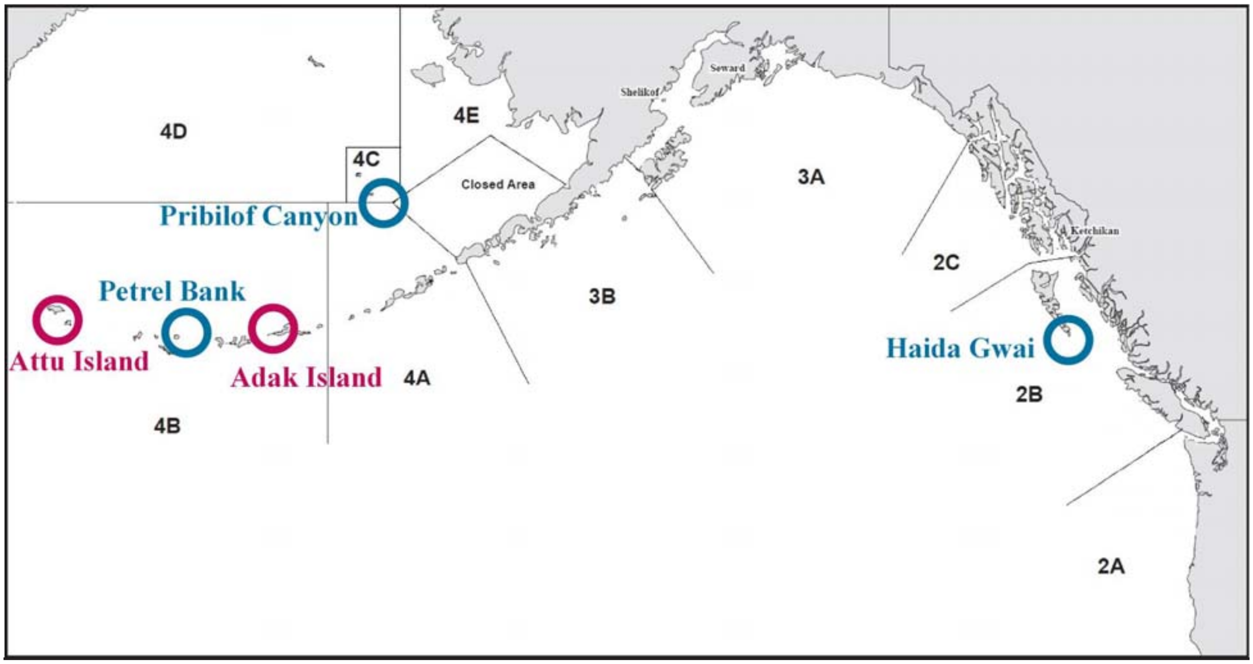


Figure 3. Locations at which Pacific halibut samples were obtained for the development of genetically-based assays of sex. Locations depicted in red were sampled during the summer (i.e. on halibut feeding grounds) and those in blue during the winter (on spawning grounds).

2.6.2 Sequencing of the Pacific halibut genome

Josep V. Planas and Timothy Loher

Abstract

One of the most important biological resources for a fish species with high socio-economic importance and a fascinating life history such as the Pacific halibut is the sequenced genome. Through the genome we can understand the genetic basis of biological processes such as growth or reproduction as well as describe genetic and evolutionary changes in Pacific halibut that occur in response to environmental and fisheries-related influences. At the International Pacific Halibut Commission efforts have begun to generate a first draft of the genome of the Pacific halibut.

Introduction

The genome of an organism is the collection of genes that are organized into chromosomes and that contain the genetic material necessary for its development, growth, and maintenance. The genome sequence therefore contains information on all of the genes present in the genome, namely their DNA sequence and location in the genome. The purpose of this project is to generate a first draft of the genome of the Pacific halibut. Through the sequencing of the Pacific halibut genome we will be able to identify genomic regions and genes that are responsible for temporal and spatial adaptive and phenotypic characteristics of the species. This will provide a better understanding of genetic and evolutionary changes in Pacific halibut that occur in response to environmental and fisheries-related influences. Therefore, the genome sequence will be essential for understanding possible changes in the genetic constitution of the Pacific halibut population. Importantly, the genome sequence will also allow us to understand the genetic basis of growth, reproductive performance, or migratory behavior in the Pacific halibut. In the short term, the Pacific halibut genome sequence will allow us to effectively map and capitalize information derived from the identified single nucleotide polymorphisms (SNPs) associated with sex that are being derived through RAD sequencing as well as the transcripts generated from our current RNA sequencing efforts.

Materials and Methods

Sample

A DNA sample from a Pacific halibut female whose sex was verified morphologically (QCI_F060) was extracted from fin tissue using a Qiagen (Hilden, Germany) DNA extraction kit. The resulting DNA was treated with RNAse in order to remove contaminating RNA. The DNA concentration obtained, as determined by spectrophotometry, was 15 ng/µl and the quality and integrity of DNA was confirmed by BioAnalyzer (Agilent Technologies, Santa Clara, USA). Approximately 1.4 µg of DNA in a volume of 95 µl were sent to the MGX Platform (Universite Montpellier, France) for sequencing.

Sequencing

Pacific halibut DNA was used to build a True Seq DNA nano library. The genomic library was sequenced on half a lane of an Illumina (San Diego, USA) HiSeq 2500 genome sequencer in 2 x 250 pair end mode. The obtained genomic sequences were subjected to quality control. In the absence of a reference genome, a *de novo* assembly (i.e. reconstruction of the genome sequence from overlapping DNA sequences) strategy was applied by using the DISCOVAR software (https://software.broadinstitute.org/software/discovar/blog/). Library construction, genome sequencing and sequence assembly was performed at the MGX Platform.

Results

De novo assembly of the Pacific halibut genomic sequences yielded a predicted genome size of approximately 700 megabases (Mb), as indicated by the total size of the generated contigs (i.e. continuous assembled sequences devoid of gaps) and of the generated scaffolds (i.e. sets of ordered and oriented contigs that may contain gaps) (Table 1). The N50 metric of the assembly was 45 kilobases (Kb), indicating that half of the genome is contained in scaffolds larger than 45 Kb in size. The longer scaffold was 700 Kb and the mean and median scaffold size were 1.5 Kb and 242 base pairs, respectively, indicating that a large proportion of scaffolds were of small size. Similar results were obtained regarding the contigs.

Discussion

Through a first round of preliminary and fragmented genome sequencing, we estimated that the genome size of the Pacific halibut is approximately 700 Mb, a genome size that is comparable to the genomes of other flatfish species such as the half-smooth tongue sole (*Cynoglossus semilaevis*; 477 Mb) and the turbot (*Scophtalmus maximus*; 568 Mb) (Chen et al. 2014; Figueras et al. 2016). Although the N50 metric indicated that the assembly strategy was successful considering the limited sequencing effort performed, the resulting incomplete *de novo* assembly of the Pacific halibut genome is evidenced by comparing the obtained scaffold N50 size of 45 Kb in contrast with that of the half-smooth tongue sole (867 Kb) and the turbot (4.3 Mb). Future efforts will be devoted to expanding and improving the sequencing coverage with other types of sequencing platforms that can produce much longer sequences and that, therefore, can produce much better assemblies, such as Oxford Nanopore (Oxford, UK). These strategies will be highly dependent on our ability to collect, store, and extract high molecular weight genomic DNA.

Although the completion of the Pacific halibut genome will still require additional sequencing and improved assembly of longer sequencing reads, the obtained genome, although fragmented, can be extremely useful for a variety of applications. First, it can be used to map the small sequences obtained from RADseq (Loher et al. 2018) onto the genome and identify genome contigs harboring potential sex marker sequences. Second, the partial genome can be used to design primers to develop PCR-based molecular tools for particular genetic characteristics in Pacific halibut, such as sex identification, geographic origin, etc. Third, the partial Pacific halibut genome can be used to perform comparative genomics studies with good quality genomes of other flatfish species with fully-sequenced genomes (e.g., half-smooth tongue sole and turbot). Finally, the partial Pacific halibut genome can be used to map the transcripts obtained by RNA sequencing of growth (liver and muscle) and reproductive tissues (ovary, testis) (Planas and Dykstra 2017) and identify genome contigs, and therefore the gene composition of growth- and reproductive-regulatory regions in the Pacific halibut genome.

Acknowledgements

We would like to thank Dr. Yann Guiguen (INRA-Rennes, France) for his help and guidance with this project and Dr. Dan Drinan (University of Washington) and Dr. Lorenz Hauser (University of Washington) for providing the Pacific halibut DNA sample for genome sequencing and for their involvement in this project.

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Table 1. Metrics of the first genome sequencing in the Pacific halibut (size in base pairs or nucleotides, nt).

Number of scaffolds	467660	
Total size of scaffolds	709887856	
Longest scaffold	699452	
Shortest scaffold	61	
Number of scaffolds > 1K nt	41649	8.9%
Number of scaffolds > 10K nt	9913	2.1%
Number of scaffolds > 100K nt	1231	0.3%
Number of scaffolds > 1M nt	0	0.0%
Number of scaffolds > 10M nt	0	0.0%
Mean scaffold size	1518	
Median scaffold size	242	
N50 scaffold length	45579	
L50 scaffold count	3526	
scaffold %A	28.96	
scaffold %C	21.05	
scaffold %G	21.03	
scaffold %T	28.89	
scaffold %N	0.07	
scaffold %non-ACGTN	0.00	
Number of scaffold non-ACGTN nt	0	
Percentage of assembly in scaffolded contigs	38.5%	
Percentage of assembly in unscaffolded contigs	61.5%	
Average number of contigs per scaffold	1.0	
Average length of break (>25 Ns) between contigs in scaffold	100	
Number of contigs	472607	
Number of contigs in scaffolds	8079	
Number of contigs not in scaffolds	464528	
Total size of contigs	709393156	
Longest contig	426312	
Shortest contig	61	
Number of contigs > 1K nt	46595	9.9%
Number of contigs > 10K nt	13314	2.8%
Number of contigs > 100K nt	662	0.1%
Number of contigs > 1M nt	0	0.0%
Number of contigs > 10M nt	0	0.0%
Mean contig size	1501	
Median contig size	244	
N50 contig length	29898	
L50 contig count	5744	
contig %A	28.98	
contig %C	21.06	
contig %G	21.04	
contig %T	28.91	
contig %N	0.00	
contig %non-ACGTN	0.00	
Number of contig non-ACGTN nt	0	

2.7.1 IPHC oceanographic monitoring program 2017

Lauri L. Sadorus and Jay Walker

Abstract

This was the ninth consecutive year of the International Pacific Halibut Commission (IPHC) coastwide oceanographic data collection program. Oceanographic data are collected using water column profilers during the IPHC fishery-independent setline survey that spans the area from southern Oregon in the U.S.A. to British Columbia and into the Gulf of Alaska, Bering Sea, and Aleutian Islands. The IPHC has operated profilers since 2000 on a limited basis, and coastwide since 2009. Oceanographic data were successfully collected at a total of 1,281 stations out of a possible 1,420 in 2017. The coldest near-bottom water (-0.82^{o}C) was detected around St. Matthew Island in the Bering Sea. The warmest near-bottom water (13.85^{o}C) was found at a shallow station off of southern Oregon. For the first time in several years, profiler data indicated a severe hypoxic zone off of the Washington coast with dissolved oxygen levels measured as low as 0.069 ml/L.

Introduction

Since the expansion of its fishery-independent setline survey (survey) in 1997 to monitor the Pacific halibut (*Hippoglossus stenolepis*) population, the International Pacific Halibut Commission (IPHC) has annually conducted fishing operations at more than 1,200 stations ranging geographically from the U.S. West Coast to the Bering Sea. Following a pilot program in the 2000s in which oceanographic data were collected coincident with survey fishing, the effort was expanded to all survey stations in 2009 and has since taken place annually (Sadorus et al. 2016). Oceanographic data are collected using water column profiling units manufactured by Sea-bird Electronics[1] that collect a suite of oceanographic data including pressure (depth), conductivity (salinity), temperature, dissolved oxygen, pH, and fluorescence (chlorophyll concentration).

All survey stations are located on the continental shelf and are arranged on an equidistant 10 nmi (18.52 km) grid (except for the Bering Sea flats area and a few stations in southeast Alaska) (Fig. 1). In addition to the standard grid used in the survey, stations in areas not normally surveyed are occasionally added on a temporary basis in response to specific biological and/or management questions or concerns. The profilers are typically deployed at these additional stations, provided that the expected depth is ≤ 500 m. Stations > 500 m are not profiled due to depth limitations of the rigging. A multi-year survey expansion was in its fourth year in 2017, and included additional stations in the Bering Sea, Salish Sea, and U.S. West Coast.

Expansion of the profiler program in 2009 was made possible through grants from the Oregon Department of Fish and Wildlife Restoration and Enhancement Program, and the National Oceanic and Atmospheric Administration (NOAA). The NOAA grant expired in September 2012 and ongoing maintenance costs are currently borne by the IPHC.

[1] Sea-bird Electronics Inc. 13431 NE 20th Street, Bellevue, WA 98005.

Methods

Instruments

The models currently used are SBE19*plus*V2 CTD units with auxiliary sensors to record dissolved oxygen (SBE 43), pH (SBE 18), and chlorophyll *a* concentration (WETlabs ECO-FLRTD). Sensor specifications are described in Sadorus et al. (2016). The sensors are protected by a stainless steel cage, 96 cm tall and specially designed for each unit. The primary units (pressure, conductivity, temperature) have titanium housings and are rated for deployment to depths of 7,000 m. The auxiliary sensors have maximum depth ratings ranging from 1,000-7,000 m which is sufficient for all standard IPHC survey stations. Part of the survey expansions that started in 2014 included stations with an estimated average depth as deep as 730 m. As a precautionary measure, the profilers are deployed at standard survey stations and expansion stations with a posted depth of up to 500 m only.

To adapt the profiler for deployment from a Pacific halibut fishing vessel, a system was designed using weights and floats that permits the profiler to descend rapidly enough through the water column to collect valid data and also ensures that the unit will not crash into or become permanently attached to the ocean bottom (Hare 2001). A sustained descent rate of 1-2 m/s is the target, and the weight of the assembly in the water is sufficient that, if the unit is allowed to free fall, the target descent rate is achieved.

A 15-meter anchor line is attached to the bottom of the profiler cage and a 40-pound longline anchor or cannonball is attached to the end of the line. A section of gangion line separates the profiler from the anchor line and acts as a weak link in case the anchor cannot be freed from the bottom. To the top of the cage, floats are attached that effectively offset the weight of the anchor in water. The floats are attached to standard buoy line which is almost neutrally buoyant (Sadorus et al. 2016).

Deployment

A profiler unit was deployed at each eligible survey station just prior to hauling the fishing gear. To deploy the unit, the anchor was lowered into the water followed by the profiler, then the buoy line and buoys, and the line was threaded through the gurdy. After a minimum 90-second acclimation period at the surface, the line was released, and the full setup allowed to free fall to the bottom. Each profiler took measurements from the surface to depth at a rate of four per second and a pump ensured consistent water flow past the sensors. Once the anchor hit the bottom, the remainder of the unit ceased descent shortly afterward due to the strong positive buoyancy of the floats. On board the vessel, it was usually evident when the anchor hit bottom because of a noticeable slackening of the line. At that time, the profiler was immediately hauled back aboard via the vessel's gurdy. Once on deck, a series of protocols were executed to clean the sensors and store the unit until the next deployment, as outlined in the Seacat operation manual (IPHC 2017.).

Data capture

Each profiler was shipped into the field with a dedicated laptop computer. Approximately once per day, the profiler was connected to the computer, data were uploaded, and the profiler unit was then reset for the next day's casts. The data were sent remotely or via data storage cards back to the Seattle office after each trip. To facilitate quicker retrieval and processing of the data, beginning in 2013 a cloud storage service has been used to transmit the data more efficiently to the

IPHC office. Specifically, when the vessels arrived in port after each trip, the samplers (whenever possible) connected the laptops to the internet whereby data were automatically uploaded to a secured storage location in the cloud and were immediately accessible to office staff.

Results in 2017

Two replacement profilers were purchased in 2015 and 2016 to replace units lost at sea earlier in the program, bringing the total available to 15 units. One profiler was lost in 2017 off the northern Washington coast on August 26. A replacement profiler was sent to the vessel and ultimately only a few stations were not profiled. Several of the profilers had mechanical issues with the dissolved oxygen sensor and those issues will be addressed by Seabird prior to the 2018 survey.

Data collection

In 2017, a total of 12 fishing vessels were chartered to complete the survey and each vessel was outfitted with a profiling unit, a laptop computer, and accessory gear. Out of a possible 1,420 stations coastwide, 1,281 useable casts of environmental data were collected (Table 1), resulting in a 90% success rate. Note that possible stations included those within the sensor depth range of 0-500 m, but there were a total of 1,496 scheduled stations for 2017.

Occasionally, data collection was unsuccessful or not attempted, and there were several reasons for this. The vessel captain and lead biologist together decided whether it was prudent to launch the profiler, given the conditions at each station. Poor weather and strong tides periodically resulted in missed casts. On stations where tides were strong but the station was otherwise deemed viable, the samplers were allowed to incorporate up to 60 pounds (27 kg) total to the bottom of the assembly to achieve a more vertical descent. Periodically, moisture seeped under the endcaps which caused the profiler to shut down mid-cast. In these cases, samplers dried the endcap components and replaced them if necessary.

The original laptop computers, most purchased in 2008, have exceeded their expected lifespan, due largely to the careful handling of these units by the field staff. Systematic replacement began in 2015 and will continue as needed. In 2017, the survey transitioned from paper forms to electronic tablets for field data capture. Ideally, profiler data capture will be an added feature in the future and the laptops will be discontinued, but this transition is not yet scheduled.

Environmental conditions on the Pacific halibut grounds

The sample area encompasses a wide range of environmental conditions. Off the U.S. West Coast, particularly off the Oregon and Washington coast, there has often been areas of hypoxic water (< 1.4 ml/L), but since 2013, the hypoxic events in the area have been relatively mild. In 2017, however, the profilers recorded a large severe hypoxic event off of the Washington coast when surveying those stations in August (visible in Fig. 2b). Catches of Pacific halibut within the low oxygen area were either very low or zero. The lowest near-bottom dissolved oxygen concentration detected (0.069 ml/L) was off the coast of Washington just south of La Push.

Near-bottom temperatures coastwide ranged from below zero to nearly 14°C. The coldest near-bottom temperature (-0.82°C) was found once again off of St. Matthew Island in the Bering Sea. Waters in that area are typically close to zero or below in summer. The warmest near-bottom temperature (13.85°C) was measured at a shallow station off the U.S. west coast near Coos Bay, Oregon.

Figures 2-4 contain a series of plots produced using Ocean Data View software (Schlitzer 2010) illustrating bottom temperature and dissolved oxygen conditions during the survey in the summer of 2017. Figure 2 contains information for the U.S West Coast, Figure 3 for the Gulf of Alaska, and Figure 4 for the Bering Sea and Aleutian Islands. The data are illustrated as iso-surface plots, which are continuous surfaces that use the observed point values to interpolate values at locations between those observations. Survey stations (i.e., where measurements were actually taken) are denoted as black dots.

Data processing and availability

A primary goal of this project is to make the survey profiler data available to scientists worldwide. The IPHC is working with the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) at the University of Washington and NOAA's Pacific Marine Environmental Laboratory to process the oceanographic data and make them publicly accessible. Completed profiles are available at: http://www.ecofoci.noaa.gov/projects/IPHC/efoci_IPHCData.shtml

For the first time since the inception of the coastwide profiler project, all of the bottom readings for temperature and dissolved oxygen from 2009 to the most recent year (in this case 2017) are available for use in analyses by IPHC staff. These data have undergone an internal edit and questionable values were removed in the interim pending further examination by NOAA personnel. The near real-time availability of these data allows for their use in distribution studies, the spatial model that has been developed for the stock assessment, and others.

Acknowledgments

The success of the profiler project depends on the efforts and cooperation of many contributors. We would like to acknowledge the IPHC fishery-independent survey program staff for competently incorporating the profiler project into the survey protocols, Jason Taylor for making sure the gear was ready for the field, IPHC sea samplers for their hard work and attention to detail in collecting the data, the survey vessel captains and crews for making sure the profilers were safely retrieved after every cast, Chris Johnston for his assistance organizing and pre-editing the data, and Peggy Sullivan at NOAA/JISAO for her tireless work on the data and website.

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Table 1. Number of profiler casts completed during the 2017 standardized stock assessment survey, by IPHC regulatory area, survey region, and vessel.

		Stations		
Survey region	**Reg. area**	**Profiled**	**Possible**	**Vessel**
N. California	**2A**	**23**	**38**	Pacific Surveyor
Oregon		40	54	Pacific Surveyor
Washington		68	83	Pacific Surveyor
Puget Sound		10	14	Pacific Surveyor
Vancouver	2B	36	41	Vanisle
Goose Island		43	43	Vanisle
St. James		39	42	Vanisle
Charlotte		40	44	Pender Isle
Ketchikan	2C	31	41	Star Wars II
Ommaney		40	40	Pender Isle
Sitka		33	42	Pender Isle
Fairweather	3A	48	49	Star Wars II
Yakutat		51	51	Star Wars II
Prince William Sound		43	45	Bold Pursuit
Seward		44	48	Bold Pursuit
Gore Point		45	45	Bold Pursuit
Portlock		44	46	St. Nicholas
Albatross		45	45	Clyde
Shelikof		42	45	St. Nicholas
Trinity	3B	45	47	Clyde
Chignik		41	45	Allstar
Shumagin		42	44	Allstar
Sanak		44	48	Free to Wander
Semidi		44	47	Predator
Unalaska	4	66	66	Free to Wander
4A Edge		52	57	Free to Wander
4D Edge		48	68	Kema Sue
Andreanof		42	44	Norcoaster
Amchitka		41	35	Norcoaster
North Bowers Ridge		8	8	Kema Sue
South Bowers Ridge		17	17	Norcoaster
Near Island		26	38	Kema Sue
Total regions: 32		**1,281**	**1,420**	**Total vessels: 12**

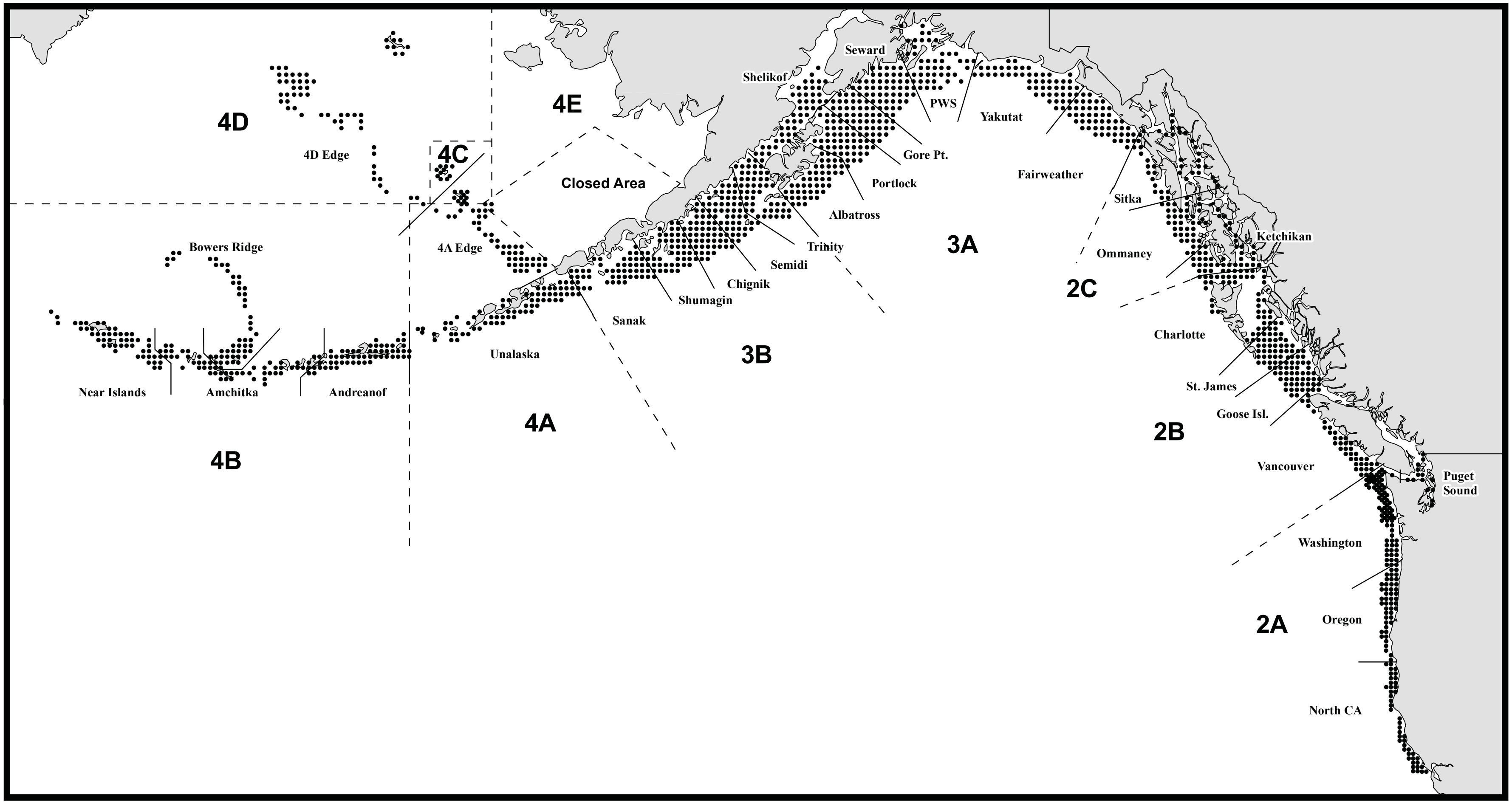

Figure 1. Stations surveyed and profiled during the 2017 IPHC fishery-independent survey. Figure reproduced from IPHC Staff (2017).

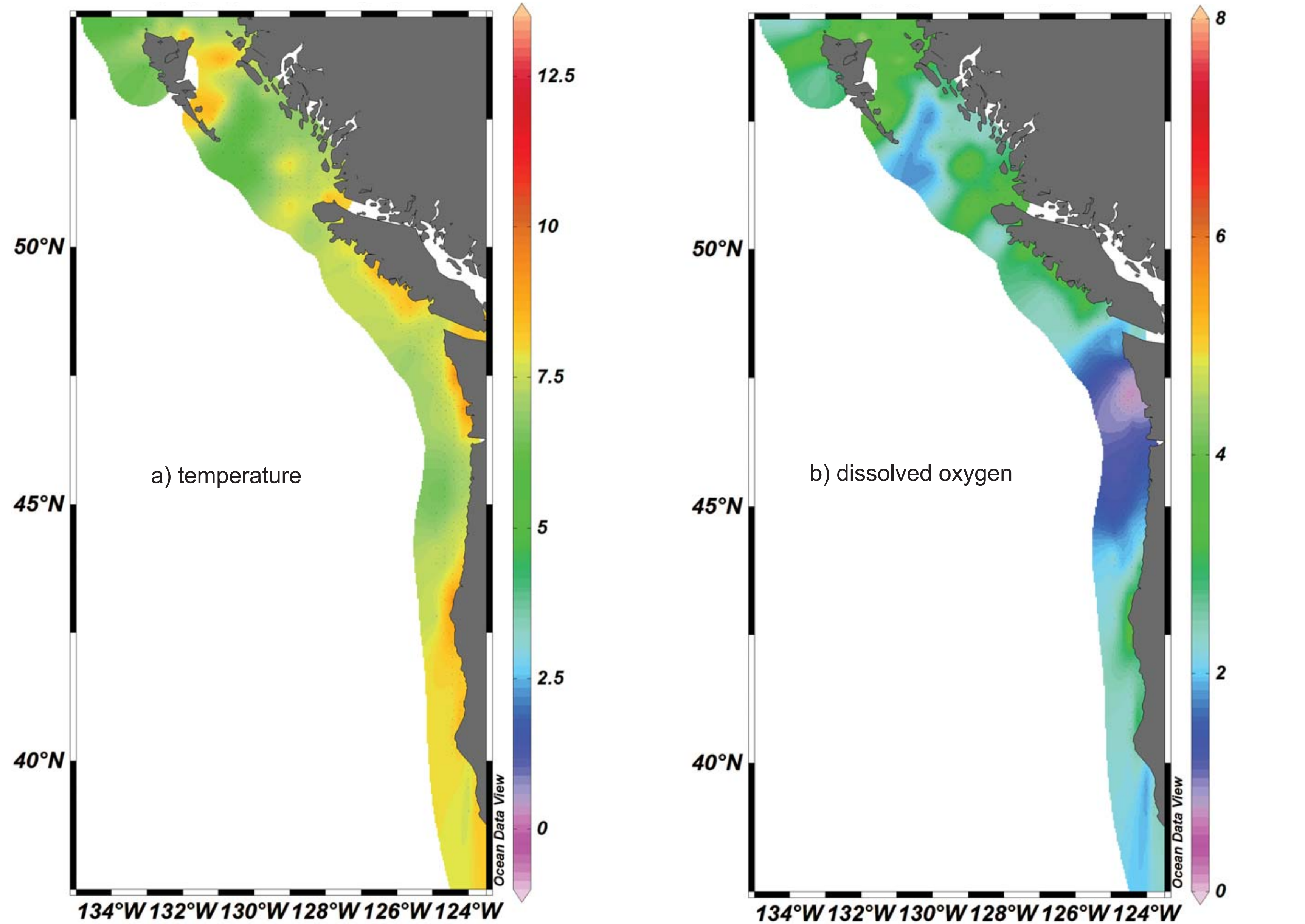

Figure 2. Iso-surface map of near-bottom a) temperature (°C) and b) dissolved oxygen (ml/L) off the U.S. West Coast during the IPHC fishery-independent setline survey.

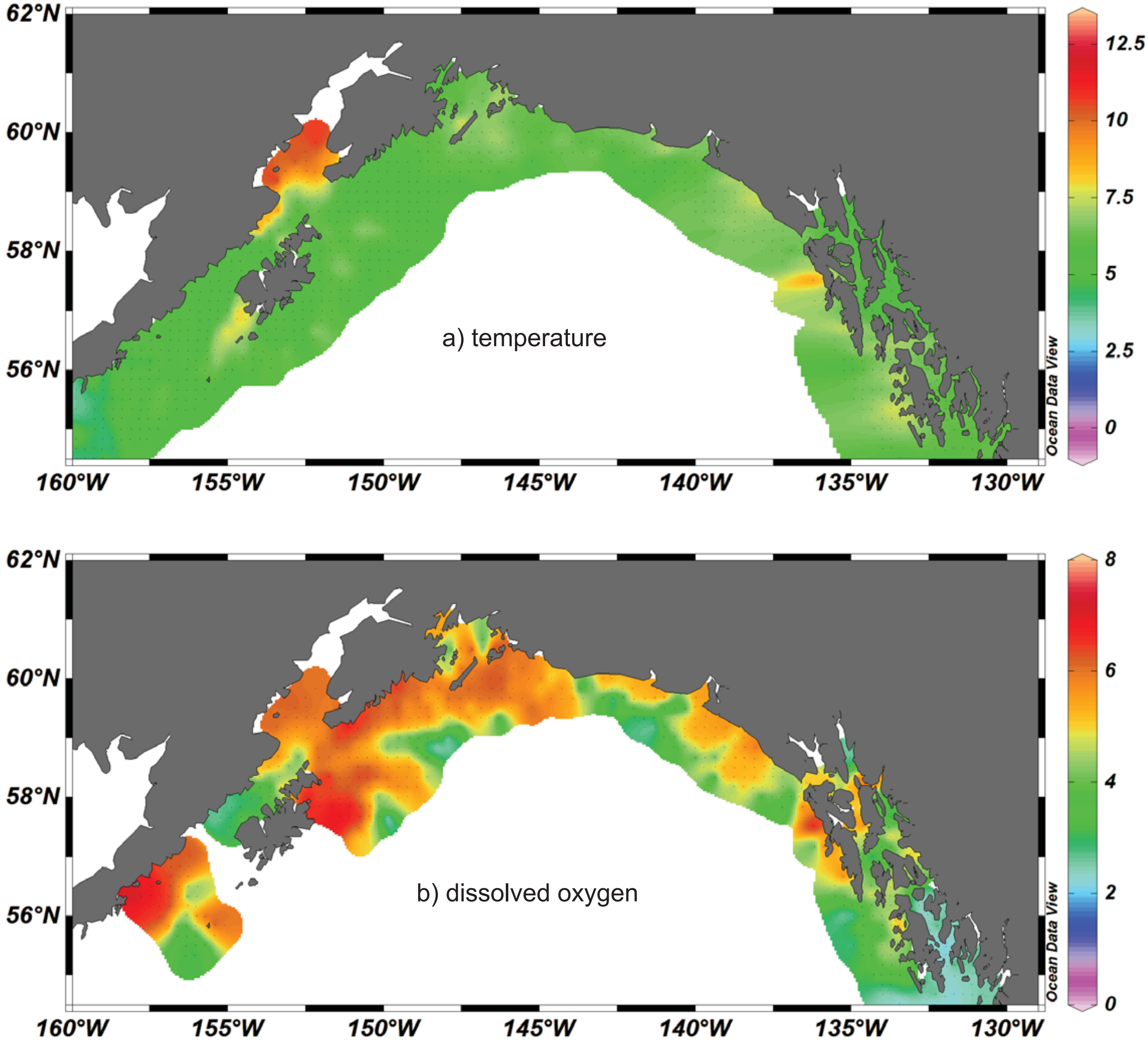

Figure 3. Iso-surface map of near-bottom a) temperature (°C) and b) dissolved oxygen (ml/L) in the Gulf of Alaska during the IPHC fishery-independent setline survey.

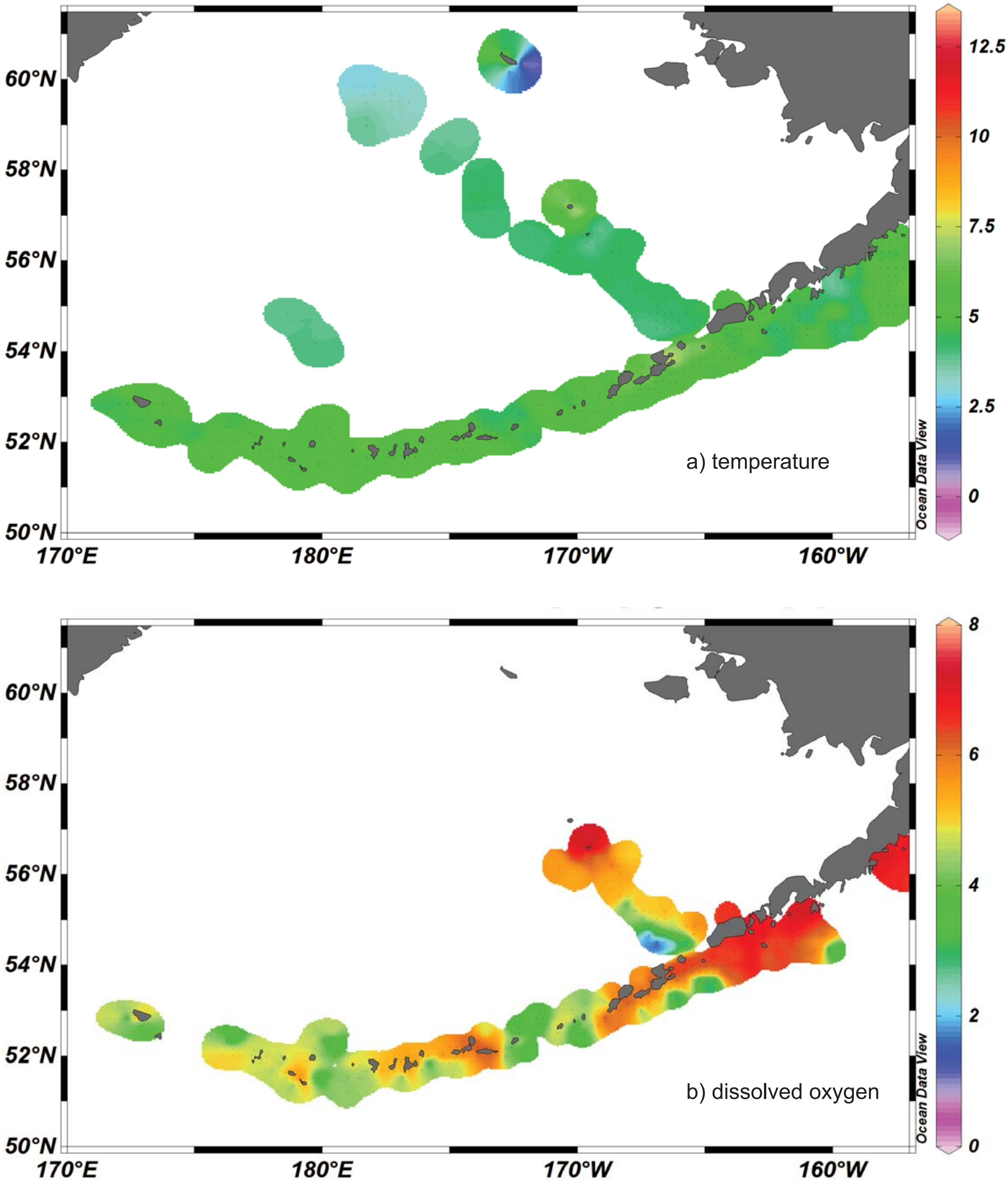

Figure 4. Iso-surface map of near-bottom a) temperature (°C) and b) dissolved oxygen (ml/L) in the Bering Sea and Aleutian Islands during the IPHC fishery-independent setline survey.

2.7.2 Contaminant and parasite monitoring of Pacific halibut

Claude L. Dykstra

Environmental contaminant sampling

The IPHC has been working cooperatively with the Alaska Department of Environmental Conservation (ADEC), to investigate the presence of heavy metals (arsenic, selenium, lead, cadmium, nickel, mercury, and chromium) and persistent organic pollutants (POPs) in Pacific halibut (*Hippoglossus stenolepis*) caught in Alaskan waters since 2002. Results from these studies are used to identify ADEC's future research needs.

Through 2016, a total of 2,744 samples have been tested by ADEC. The mean level of total mercury for these samples has been 0.3 ppm, ranging from non-detectable to 2.0 ppm. For comparison, the U.S. Food and Drug Administration (FDA) limit of concern is based on methyl mercury (~85% of total mercury) levels of 1.0 ppm, and the U.S. Environmental Protection Agency (EPA) and Canadian Food Inspection Agency (CFIA) level of concern is 0.5 ppm. Results from analysis of POPs (i.e. pesticides, selected PCB congeners, polybrominated diphenyl ethers (PBDE's – found in plastics as fire retardants) dioxins, and furans etc.) found that in general these compounds are either undetectable in Pacific halibut or well below the levels found in other marine fish species. This finding is consistent with the fact that the majority of POP chemicals are fat-soluble, and Pacific halibut have lower fat content compared to other species.

In 2017 IPHC samplers collected Pacific halibut muscle and liver samples from survey stations that corresponded to high commercial catch within the target site, with a goal of collecting samples from 20 petite (P; <80cm), 20 small (S; 80-89 cm), 20 medium (M; 90-112 cm), 20 large (L; 113-148 cm), and 10 extra-large (XL; >148 cm) Pacific halibut in three survey regions.

In 2017 eighty five samples were collected in the Bowers Ridge/Amchitka region (20 P, 20 S, 20 M, 5 XL), 60 samples were collected in the Gore Pt. region (15 P, 19 S, 20 M, 6 L), and 83 samples were collected in the Unalaska charter region (20 P, 20 S, 20 M, 20 L, 3 XL).

Samples will be tested for a broad suite of environmental contaminants, including organochlorine pesticides, dioxins, furans, polybrominated diphenyl ethers, polychlorinated biphenyl congeners, methyl mercury, and heavy metals (arsenic, selenium, lead, cadmium, nickel, and chromium). Additional small muscle and liver tissue samples were collected to be examined for genetic expression of genes that are responsive to contaminant load. Continued collaborative work with ADEC is anticipated.

Ichthyophonus sampling

In 2017 the IPHC continued investigating *Ichthyophonus* incidence in Pacific halibut. *Ichthyophonus* is a protozoan parasite from the class Mesomycetozoea, a highly diverse group of organisms with characteristics of both animals and fungi, and has been identified in many marine fish. The project resampled the three geographically distinct areas (Oregon, Prince William Sound (PWS) and 4D Edge (Bering) charter regions) that have been sampled since 2011, to investigate temporal stability of *Ichthyophonus* prevalence. Prevalence in these samples was similar to previous years with PWS being much higher than the other areas (2011-2016 average: Oregon=26.73%, PWS=67.3%, and Bering=27.1%; 2017: Oregon=15.2%, PWS=75.4%, and Bering=12.8%). Genetic and histology results for these samples are still pending.

It is important to note that there is no historical data on *Ichthyophonus* infection in Pacific halibut and it is unknown if *Ichthyophonus* is a new or long-term symbiote of Pacific halibut. Additionally, it is not known what effect, if any, *Ichthyophonus* may be having on the health of individual Pacific halibut, and on population (mortality) or growth dynamics.

2.7.3 Trends in seabird counts from the IPHC fishery-independent setline surveys (2002-17)

Tracee O. Geernaert

Abstract

Counts of live seabirds, taken immediately following gear retrieval, have been conducted during International Pacific Halibut Commission (IPHC) fishery-independent setline surveys since 2002. The Convention waters, extending from off California northward to Alaska and the border of the Exclusive Economic Zone (EEZ) with Russia, are surveyed annually between late May and early September. A total of 20,921 seabird counts have been conducted over the last 16 years, with 1,368 occurring in 2017. More than 916,000 observations of seabirds have been recorded since 2002.

Northern fulmars (*Fulmarus glacialis*), glaucous-winged gulls (*Larus glaucescens*), black-footed albatross (*Phoebastria nigripes*), and fork-tailed storm petrels (*Oceanodroma furcata*) represent the most commonly observed species. The observed number of unidentified gulls has decreased, inversely correlated with an increased number of observations of glaucous-winged gulls and herring gulls (*L. argentatus*). This shift was likely the result of increased emphasis on gull identification during annual IPHC field biologist training. A total of 389 endangered short-tailed albatross (*P. albatrus)* sightings have been recorded overall, with an average of 24 observed annually since 2002.

Introduction

In 2002, the International Pacific Halibut Commission (IPHC), in collaboration with Washington Sea Grant, developed a sampling protocol for collecting seabird occurrence data on the IPHC fishery-independent setline survey (FISS). This was initially a collaborative project between the IPHC, Alaska Department of Fish and Game (ADFG), and the National Marine Fisheries Service (NMFS) sablefish (*Anoplopoma fimbria*) survey group. The purpose of the project was not only to establish a seabird database for Alaska that could be analyzed for population purposes, but also to make recommendations for regulatory changes to the seabird avoidance requirements for commercial fishing vessels. Several reports that evaluated seabird occurrence using these data were published between 2002 and 2013 (Melvin et al. 2004, 2006; Piatt et al. 2006; Guy et al. 2013). Although the collaboration ended in 2004, the IPHC incorporated the seabird data collection protocols into its annual FISS. Observations were conducted between the end of May and the beginning of September, on IPHC FISS stations (Fig. 1). Field biologists aboard each survey vessel counted the number of seabirds in the vicinity of the vessel's stern immediately following gear retrieval/hauling. Sampling seabird occurrence after the haul addresses the question of where and when certain seabird species occur during hauling events. It also aids in the assessment of individual species at risk by providing information on their population trends over time.

Methods

A detailed description of the IPHC FISS, including seabird observation protocols can be found in the IPHC Fishery-Independent Setline Survey Manual (IPHC 2017). Briefly, seabird counts have been conducted since 2002 at all IPHC stations, as well as experimental stations not used for assessment purposes (expansion survey stations were not included). After hauling operations were completed at each station, biologists recorded the abundance of seabirds by taking a snapshot estimate of seabirds within the count zone, which is a 50-meter radius hemisphere from the vessel's stern (Fig.2). The counts are similar in concept to performing a terrestrial bird feeder count. Counts are not conducted when poor visibility prohibits the accurate identification of the seabirds (i.e., in fog or darkness). Binoculars and field guides are provided on all vessels, and the IPHC conducts annual training in seabird identification with slide presentations and field guide reviews. Seabird counts were recorded on forms and entered into the setline survey database, along with the other data collected. Seabird count data examined in this report are from grid and experimental stations fished on the annual IPHC FISS only, and do not include other agency data, or records from winter surveys, special projects conducted by the IPHC, or seabirds caught on setline gear.

Results

A total of 20,921 counts have been conducted on the IPHC FISS over the last sixteen years (2002-2017). Seabird counts were taken at 99% of the IPHC stations during this time period; 166 sets were not observed because of poor visibility. The average number of seabird counts conducted each year was 1,308 (Table 1). More than 916,000 seabird sightings (composed of 36 unique species) were recorded. The average number of unique species observed annually is 21 and the percentage of the times the species appeared each year ranges from 6-100% (Table 1). Start dates for each year's survey ranged from 25 May to 7 June and the end dates from 27 August to 14 September, but the bulk of the surveys took place from June to August (Fig. 3) and most of the counts took place in the Gulf of Alaska (Fig. 4).

The most common species observed in the counts during all years is the northern fulmar (*Fulmarus glacialis*), making up 71% of the cumulative sightings. Glaucous-winged gulls (*Larus glaucescens*) and black-footed albatross (*Phoebastria nigripes*) made up ten and eight percent of the overall sightings, respectively (Fig. 5). Fork-tailed storm petrels (*Oceanodroma furcata*), and mixed shearwater species each represented two percent of all sightings where Laysan albatross (*P. immutabilis*) sightings made up one percent (Fig. 5). Counts per year have remained relatively consistent since 2002 with the average at 1,308 (Table 1). The relative abundance of four of the top five most frequently observed seabirds, northern fulmars, black-footed and Laysan albatross and fork-tailed storm petrels, are plotted over the 16-year period (Fig. 6). Northern fulmar numbers dropped slightly over the last two years to 37,462 and 37,673 respectively, from 2015's high of 46,383. Laysan albatross numbers have been increasing and the all-time high of 1,469 was observed in 2017. Fork-tailed petrel numbers remained nearly unchanged over the last 3 years. A total of 389 sightings of the endangered short-tailed albatross (*P. albatrus)* were recorded during the counts over the 16-year period and this year we saw a record 55 birds seen during the counts (Table 1) with the average of 24 seen annually.

The number of glaucous-winged gull sightings has increased by over 25 percent while the unidentified gull numbers decreased by a factor of 5 from last year (Fig. 7). The ratio of unidentified seabirds to total number of individual seabirds (Fig. 8) has decreased over the time series as well.

When the various unidentified species are examined (excluding unidentified gulls), we see that the unidentified shearwaters make up a large component of the unidentified seabirds (Fig. 9).

Discussion

The number of unidentified seabirds within the survey count zones has decreased since the start of the seabird data collection program in 2002, indicating that the IPHC biologists have improved their identification skills. The change in glaucous-winged gull numbers over time demonstrates this learning curve. Observation rates of glaucous-winged gulls were inversely correlated with observation rates of unidentified gulls such that, as glaucous-winged gull sightings increased, unidentified gull sightings decreased (Fig. 7). The unidentified seabirds numbers also decreased this year after a slight increase in 2016. The field biologists have become more skilled at identification over this time period with our survey field staff training focusing on improving identification to the species level especially among shearwaters and gulls.

Population sizes of many seabirds species vary from year to year, and trends up or down can be indicative of a change in diet, weather, and/or timing of chicks fledging from the nest. Though the FISS offers only a window in time of seabird occurrence, they are broad in geographic scope (conducted coastwide) and are repeated in the same spatial pattern annually. By continuing to accumulate data, it is hoped to eventually determine how observations relate to actual abundance levels; specifically, for seabirds of concern such as the albatrosses. The endangered short-tailed albatross have been seen in increasing numbers since 2002 with a record 55 recorded this year. These data are of particular importance because the short-tailed albatross is a rare species and one of considerable interest to management agencies. Their populations have rebounded and the increase we are seeing in our counts helps substantiate the recovery reported in the literature (Deguchi et al. 2014).

With continued, consistent gathering of these data for all species seen, trends in abundance may be determined that will help predict a species' decline or recovery.

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Table 1. Number of seabirds in 2017; average, total since 2002; and percent presence since 2002.

Species	2017	Average 2002-17	Total	Percent presence
Northern fulmar	37,673	40,640	650,247	100%
Black-footed albatross	3,941	4,339	69,424	100%
Laysan albatross	1,469	861	13,783	100%
Short-tailed albatross	55	24	389	100%
Glaucous-winged gull	9,593	5,711	91,380	100%
Herring gull	233	300	4,505	94%
Western gull	607	411	1,642	25%
Mew gull	-	23	115	19%
Glaucous gull	204	45	405	50%
Heermann's gull	2	14	95	44%
Sabine's gull	4	3	23	44%
Slaty-backed gull	-	2	7	6%
Ring-billed gull	1	4	19	25%
Bonaparte's gull	-	2	6	14%
Unidentified gull	286	2,195	35,114	100%
Arctic tern	-	1	3	13%
Unidentified tern	-	4	30	31%
Ruddy turnstone	-	3	8	6%
Pomarine jaeger	-	4	50	81%
Parasitic jaeger	1	3	38	81%
Long-tailed jaeger	-	4	21	25%
Unidentified jaeger	1	5	42	57%
South polar skua	-	1	3	13%
Fork-tailed storm petrel	660	1,134	18,150	100%
Leach's storm petrel	6	49	783	100%
Unidentified storm petrel	10	319	5,096	100%
Black-legged kittiwake	780	428	6,846	100%
Red-legged kittiwake	4	10	162	100%
Unidentifed kittiwake	-	61	971	99%
Short-tailed shearwater	-	154	2,304	88%
Sooty shearwater	463	245	3,923	100%
Pink-footed shearwater	41	53	534	63%
Flesh-footed shearwater	-	1	2	6%
Unidentified shearwater	1,028	576	9,222	100%
Common murre	15	8	63	50%
Thick-billed murre	1	10	31	13%
Unidentified murre	4	19	310	100%
Rhinoceros auklet	-	1	2	13%
Parakeet auklet	-	1	2	6%
Tufted puffin	6	7	107	94%
Horned puffin	3	2	11	38%
Unidentified puffin	1	11	174	100%
Unidentified alcid	1	13	80	31%
Bald eagle	-	1	2	13%
Unidentified cormorant	-	1	11	38%
Unidentified bird	-	15	135	57%
Grand total	57,093	57,267	916,270	
Number of counts	1,362	1,308	20,921	
Number of unique species	22	21	36	

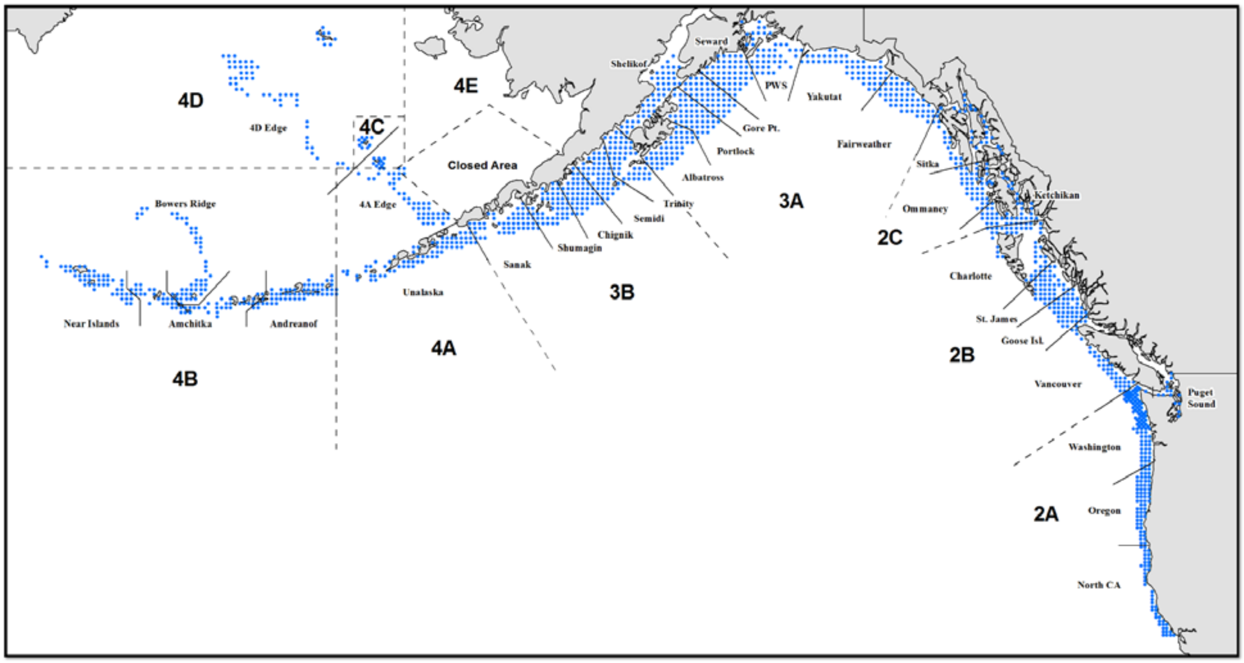

Figure 1. 2017 IPHC fishery-independent setline survey stations with regulatory area (two-character codes) and charter region (formal names) divisions.

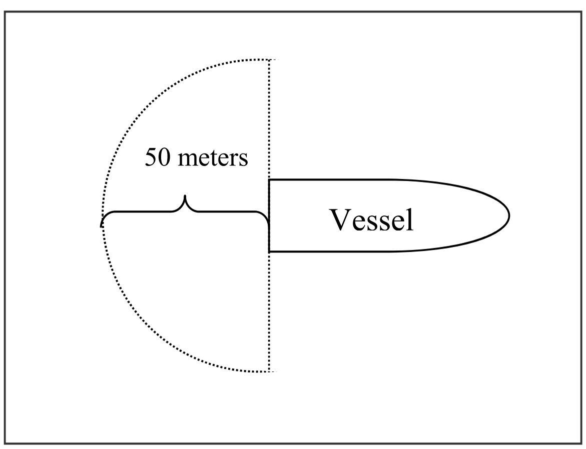

Figure 2. Diagram of the seabird 50-meter hemisphere (count zone) at the stern of the vessel where seabird counts were conducted.

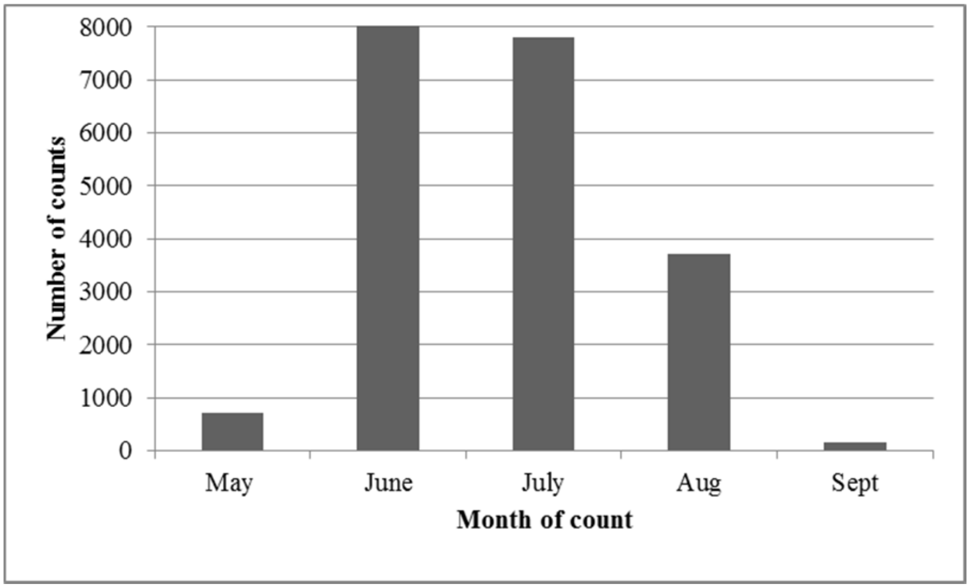

Figure 3. Overall seabird counts conducted on IPHC fishery-independent setline surveys by month, 2002-2017.

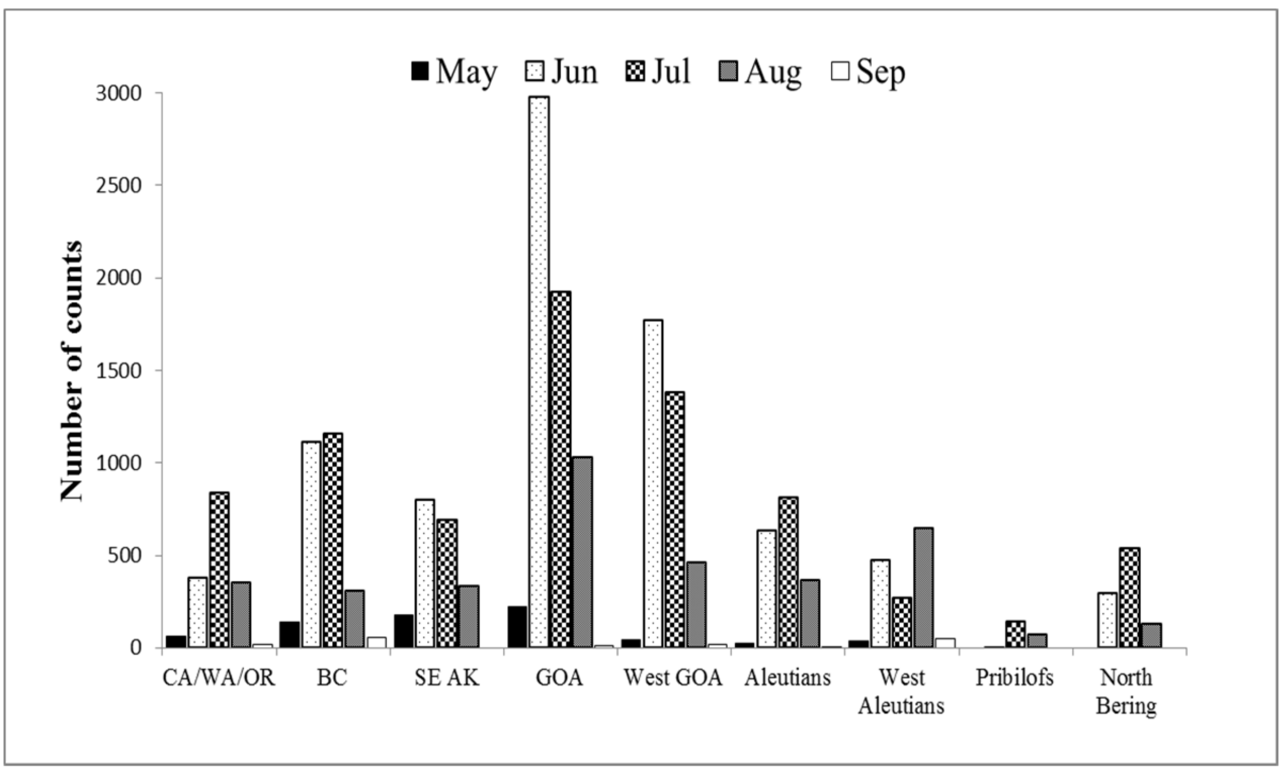

Figure 4. Total number of seabird counts conducted on IPHC fishery-independent setline surveys, by area and month, 2002-2017. Abbreviated locations are as follows: CA/WA/OR = California, Oregon, and Washington; BC = British Columbia; SE AK = southeast Alaska; GOA = central Gulf of Alaska; West GOA = western Gulf of Alaska.

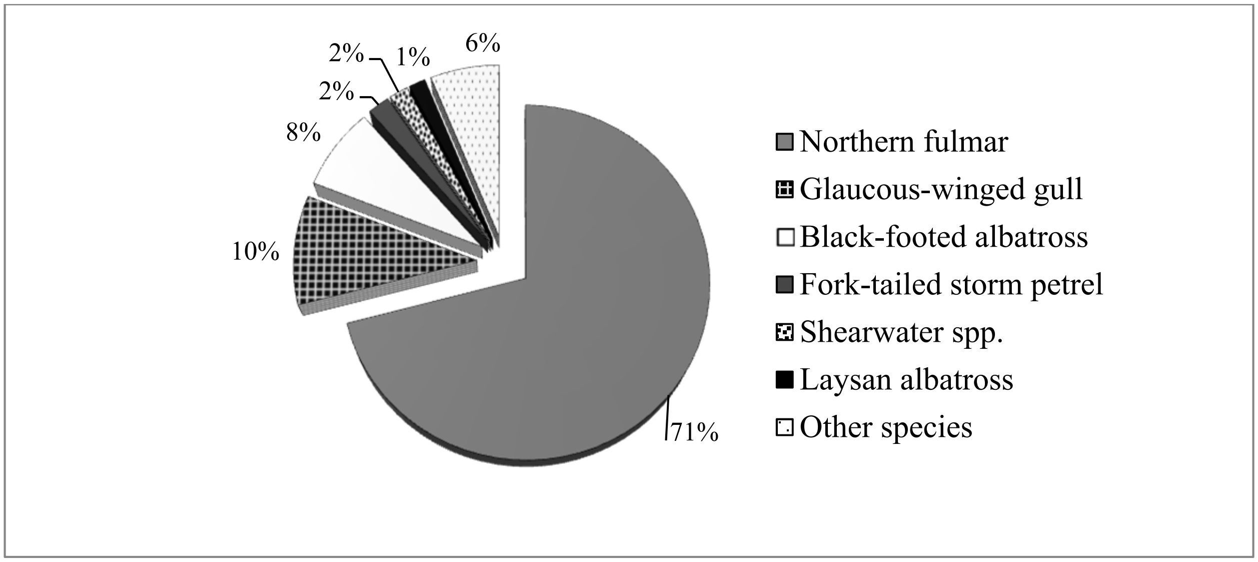

Figure 5. Most common seabird species by overall percentage occurence in counts on IPHC fishery-independent setline surveys, 2002-2017.

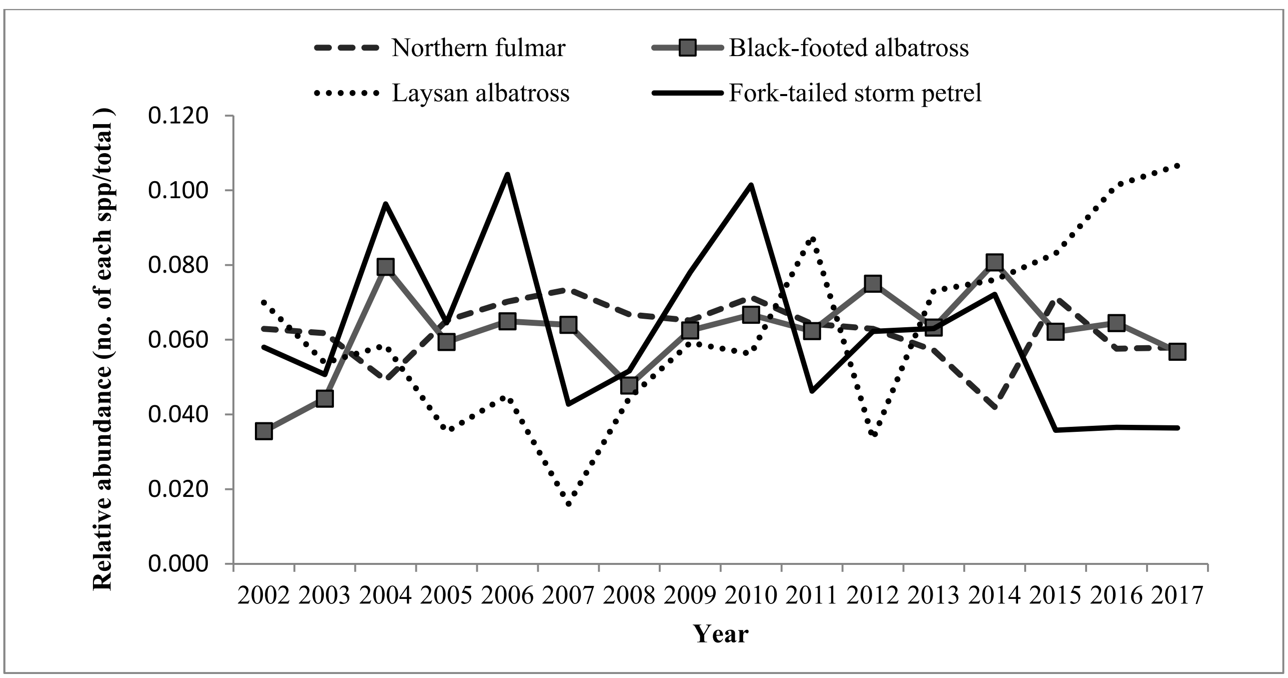

Figure 6. Relative abundance of the four most common seabird species observed on IPHC fishery-independent setline surveys, 2002-2017.

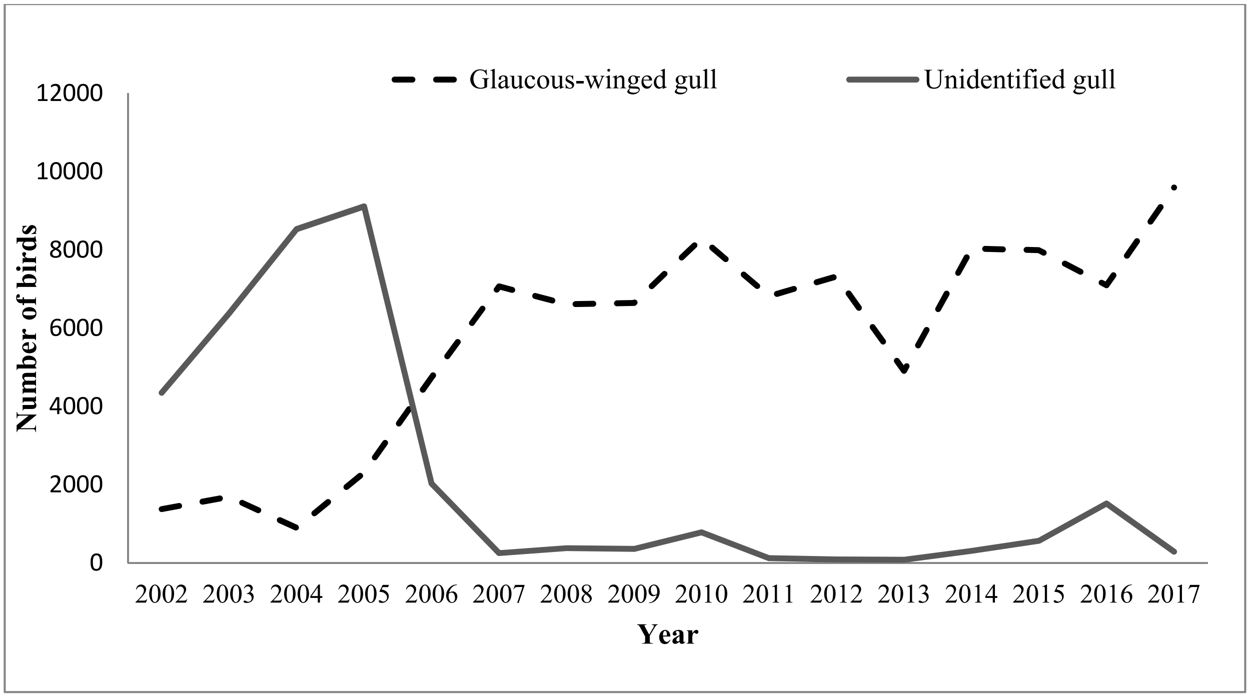

Figure 7. Glaucous-winged gull numbers versus unidentified gull numbers observed on IPHC fishery-independent setline surveys, 2002-2017.

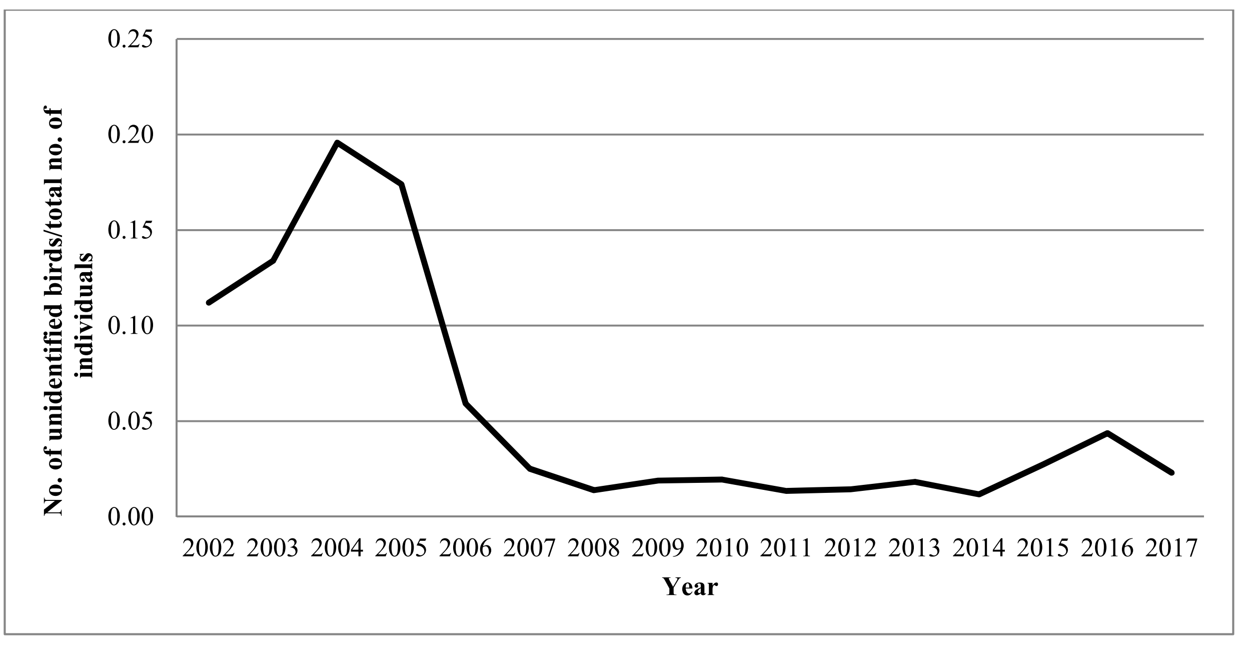

Figure 8. The ratio of number of unidentified seabirds to total individuals observed on IPHC fishery-independent setline surveys, 2002-2017.

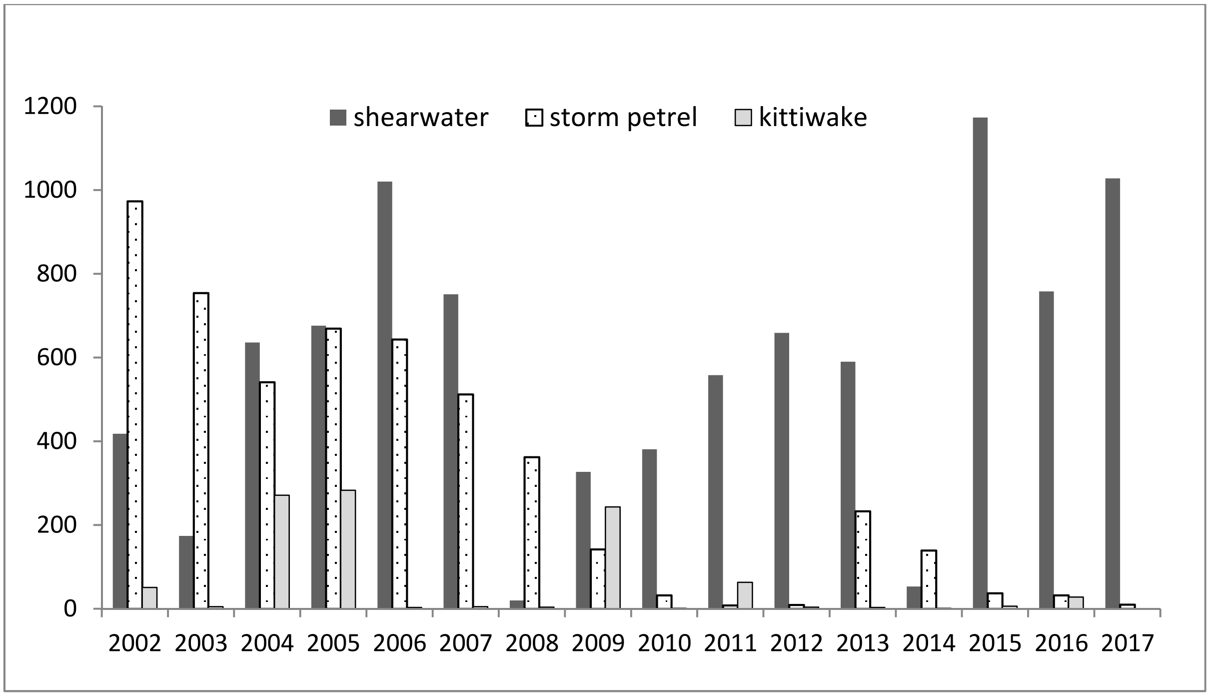

Figure 9. The most common unidentified seabird species by year, 2002-2017.

3.1 Executive Summary

Jamie Goen

Fishery-independent surveys produce important, high-quality abundance and trend information for assessment and management of the Pacific halibut stock. The International Pacific Halibut Commission (IPHC or Commission) has conducted fishery-independent setline surveys (FISS) in selected areas during most years since 1963, and has carried out a coast-wide survey with a consistent sampling design since 1998. The IPHC has also taken part in the National Marine Fisheries Service (NMFS) Bering Sea groundfish trawl survey since 1998 and the NMFS Aleutian Islands trawl survey since 2012. These two NMFS surveys contribute Pacific halibut data from areas either poorly covered or not covered by the Commission's own fishery-independent survey. In Chapter 3.1, we report on the results of the IPHC and the NMFS surveys, as well as analysis of data derived from them.

In Chapter 3.2, we document the IPHC fishery-independent setline survey for 2017, including design, implementation, and a synopsis of the additional special research projects conducted during the survey. The IPHC fishery-independent setline survey completed the fourth year in a series of planned survey expansions that will eventually cover all regulatory areas. For 2017, the expanded survey was in IPHC Regulatory Areas 2A and 4B. Chapter 3.3 describes the results of the IPHC's space-time modeling of weight per unit effort (WPUE) and numbers per unit effort (NPUE) from the IPHC's fishery-independent setline survey, including these expansions. This modeling approach was introduced in 2016 and is a clear improvement over the previous empirical method, as it makes greater use of the information within the data, and better accounts for uncertainty in the estimation. Chapter 3.3 also includes an evaluation of the need for future survey expansions in IPHC Regulatory Areas 2A and 4A.

Finally, data on Pacific halibut from the two NMFS trawl surveys in the Bering Sea and the Gulf of Alaska are described in Chapter 3.4.

3.2 Fishery-Independent Setline Survey (FISS) design and implementation in 2017, including current and future expansions (IPHC-2018-AM094-06)

Jamie Goen, Tracee Geernaert, Ed Henry, Eric Soderlund, Aaron Ranta, Tom Kong, Joan Forsberg

This paper was prepared for the 2018 International Pacific Halibut Commission (IPHC) Annual Meeting (IPHC-2018-AM094-06) and can be found on the IPHC website Annual Meeting page.

3.3 Space-time modelling of IPHC fishery-independent setline survey data (IPHC-2018-AM094-07)

Raymond Webster

The following subjects were described in a paper that was prepared for the 2018 IPHC Annual Meeting (IPHC-2018-AM094-07) and can be found on the IPHC website Annual Meeting page.

Subjects include:

- Results of space-time modelling of WPUE and NPUE time series
- Results of fishery-independent setline survey expansions in Regulatory Areas 2A and 4B in 2017
- Evaluating the need for future fishery-indpendent setline survey expansions in Regulatory Areas 2A and 4A.

3.4.1 Results from the Bering Sea NMFS trawl survey in 2017

Lauri L. Sadorus[1], Robert Lauth[2], Aaron Ranta[1]

[1]International Pacific Halibut Commission
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Abstract

The National Marine Fisheries Service groundfish trawl survey has taken place since 1979 and the International Pacific Halibut Commission (IPHC) has participated in the survey on an annual basis since 1998 by directly sampling Pacific halibut from survey catches. The 2017 standard survey took place aboard two vessels from 31 May to 7 August and an additional trip to sample the northern Bering Sea extended the survey to 31 August. IPHC field biologists were deployed on the *F/V Vesteraalen* for all trips. Lengths were collected for all Pacific halibut, and wire-tagged fish were released from the *Vesteraalen* and the *F/V Alaska Knight*. On the vessel staffed by IPHC, a total of 1,259 Pacific halibut were encountered. The Pacific halibut caught were randomly divided into two groups: one for biological sampling and and another one for tagging. In the tagging group, only those fish < 82 cm fork length were tagged and released while the remainder were measured and released as soon as possible. A total of 619 Pacific halibut otoliths were collected along with sex, maturity, and prior hooking injury information, and 503 fish were tagged and released. Tagging on the non-IPHC staffed vessel was more opportunistic due to logistical issues, and resulted in 252 Pacific halibut released. One hundred ninety-nine tissue samples for energetics analysis were obtained from a portion of the fish sampled for otoliths and fin clips for genetic analysis were obtained from both those energetics sample and all tagged Pacific halibut on the IPHC-staffed vessel. The Bering Sea abundance estimate was 53 million fish which represents a decline from 2016. The total biomass was estimated at 279 million pounds which continues a declining trend that began in 2011.

Introduction

The National Marine Fisheries Service (NMFS) has conducted annual bottom trawl surveys on the eastern Bering Sea (EBS) continental shelf since 1979. The survey was standardized in 1982 and an International Pacific Halibut Commission (IPHC) field biologist has been deployed on the survey every year since 1998 to collect Pacific halibut (*Hippoglossus stenolepis*) samples. The IPHC operates a coastwide longline survey as the primary fishery-independent source of data for the Pacific halibut stock assessment (Henry et al. 2017). However, Pacific halibut occupy a vast area of the Bering Sea shelf for which the IPHC lacks the financial resources to sample in its entirety on a regular basis. Therefore, in most years, the NMFS trawl survey is the only measure of abundance for much of this area. This paper presents abundance and biomass estimates for the EBS for the years 1982-2017, age composition for 2016 and 2017, and results from the 2017 survey.

Survey trawl gear has different size selectivity than setline gear, making it necessary to apply a selectivity curve to include these data directly in the Pacific halibut stock assessment that is generated by the IPHC. Pacific halibut are vulnerable to the trawl from about 20-100 cm fork length (FL)

(Clark et al. 1997), but a substantial portion of the commercial-sized population (O32 or ≥ 81.3 cm FL) exceeds 100 cm. In 2006, and again in 2015, the IPHC added shelf stations to its setline survey in the Bering Sea region in order to compare information from these stations with data collected on the NMFS trawl survey. After the study in 2006, the IPHC staff concluded that the trawl survey, along with periodic IPHC survey calibrations, provided an adequate accounting of Pacific halibut biomass on the EBS shelf (Clark and Hare 2007) and is a useful tool for constructing a population-density index for the IPHC stock assessment (Webster 2014). The 2015 calibration confirmed this earlier finding. In addition to its use as a stock assessment tool, trawl survey information is useful as a forecasting tool for cohorts approaching recruitment into the commercial fishery.

In 2017, an IPHC sampler was placed aboard the EBS trawl survey for the 20th consecutive year. Two chartered fishing vessels, *F/V Vesteraalen* and *F/V Alaska Knight*, were each staffed by six scientific crew members. The scientists carried out objectives related to stock assessment and year-class strength estimation for numerous species. The IPHC biologist was deployed on the *F/V Vesteraalen* to sample the Pacific halibut caught and to help NMFS personnel achieve their survey goals.

Objectives

The main objectives for the IPHC biologist in 2017 were:

- Record the fork length on 100% of the Pacific halibut caught on all standard groundfish tows;
- Collect sex, maturity, and prior hooking injury (PHI) data on 50% of the catch;
- Assess viability using NMFS observer criteria on the other 50% of the catch, and subsequently wire tag and release all those individuals that were determined to be viable and that were < 82 cm fork length. Measure and release those ≥ 82 cm fork length as soon as possible;
- Obtain tissue samples from a subsample of Pacific halibut for energetics analysis;
- Obtain fin clips from all tagged Pacific halibut and from the subsample of Pacific halibut selected for tissue samples.

The primary NMFS objective was to continue the annual series of crab and groundfish assessment surveys for the eastern Bering Sea to provide information to the following groups:

- The North Pacific Fishery Management Council for understanding the distribution, abundance, and biological condition of important groundfish and crab resources;
- The U.S. fishing industry for catch-per-unit-effort and size composition of commercially important groundfish species; and
- Stock assessment scientists to support ongoing studies on the biology, behavior, and dynamics of key ecosystem components.

Survey design, vessels, and itinerary

The current standard trawl survey includes 376 stations on a 20 nmi (1 nmi = 1.852 km) square grid design extending from inner Bristol Bay to St. Matthew Island, within the 200 m depth contour. The stations are placed at the center of each grid square, and additional stations are placed at the corners of grid cells in areas surrounding St. Matthew and the Pribilof Islands to better assess blue king crab (*Paralithodes platypus*) density. Additionally, in 2017, the survey extended into the northern Bering Sea which extended the range from St. Matthew Island to Norton Sound.

In 1987, twenty stations were added north of the standard survey sampling area to better assess abundance and distribution of walleye pollock (*Gadus chalcogrammus*) and snow crab (*Chionoecetes opilio*) populations. Data from these stations are included in the abundance estimates herein. From 2000 to 2004, and again from 2011 to 2012, several stations within the 0-30 m depth stratum were added to investigate the nearshore distribution of either juvenile yellowfin sole (*Limanda aspera*) or red king crab (*Paralithodes camtschaticus*). Some Pacific halibut were caught at these nearshore stations but the results were not incorporated into the NMFS abundance estimates because the stations were not part of the standard grid.

Since 1982, the EBS has been surveyed using a NMFS 83-112 Eastern trawl with a 25.3 m headrope and 34.1 m footrope. The trawl net was deployed with equipment that recorded data describing each tow. Through 2012, a Netmind[1] trawl mensuration system recorded net height and width, a Sea-Bird[2] data logger recorded temperature and depth, and a tilt sensor was used to detect when the footrope hit the bottom. In 2013, the Netmind system was replaced with the Marport[3] trawl mensuration system. A 30-minute tow was attempted at each station.

In 2017, the survey charter began on 31 May. Following several days of set-up and equipment testing, the *F/V Vesteraalen* conducted the first standard tow on 4 June. The northern extension was conducted at the end of the standard survey and the charter concluded in Dutch Harbor on 31 August.

Pacific halibut sampling in 2017

Pacific halibut were measured on all standard survey tows aboard both vessels. Pacific halibut from tows aboard the IPHC-staffed vessel were assigned randomly into one of two groups: one for biological sampling, and one for wire tagging; with the goal of assigning 50% of the fish to each group. This was achieved by laying out two fish at a time, rolling a set of dice, then assigning one fish to each group based on predetermined number designations. This step was repeated until all the fish were sorted. Fish in the tagging sample were kept briefly in a live tank while sorting was taking place, and then assessed for condition using NMFS observer criteria. Those fish with an assessment of Excellent and Poor category were outfitted with a wire tag through the operculum. Those fish assessed in the Dead category were measured and discarded. A fin clip was obtained from each tagged fish for genetic analyses. For a full description of the tagging project, see Forsberg et al. (2016).

Fish in the biological sample group were assessed for sex, maturity, and prior hooking injuries, and the otolith was removed for aging. An additional subsample was selected for the extraction of flesh samples as part of an energetics study and for fin clips which will be used for a genetics study. Northern extension stations were treated the same as standard stations for sampling. Pacific halibut caught in tows at corner crab stations, and during duplicate tows, were excluded from the regular sample.

[1] Northstar Technical Inc., 1 Duffy Place, St. John’s, NL, A1B 4M6.
[2] Sea-bird Electronics Inc., 13431 NE 20th Street, Bellevue, WA, 98005.
[3] Marport Deep Sea Technologies, AIRMAR Technology Corporation, 35 Meadowbrook Drive, Milford, NH 03055, USA

Pacific halibut from the non-staffed IPHC vessel were measured for fork length and randomly divided into two groups: tagging and no sample. Tagging criteria was the same as for the IPHC-staffed vessel. Those fish in the no sample group were released. Because of vessel mechanical issues, Pacific halibut tagging was not continuous throughout the entire survey, but did take place during all trips.

Sex and maturity determinations were made via macroscopic gonad examination for each biologically sampled Pacific halibut, which is described in detail in the survey manual (IPHC 2017). Female fish were assigned to one of four stages of maturity: immature, ripening, ripe/spawning, and spent/resting. Males were assigned to one of two maturity stages: immature and mature. Immature fish, regardless of sex, were those that would not be expected to participate in the upcoming spawning season. The other stages represented various phases of the reproductive process, and fish in those categories were considered mature enough that they could participate in the upcoming spawning season.

Information concerning injuries to the mouth, jaw, or eye caused from longline gear (i.e., PHI) has been collected in recent years as part of an IPHC special project. The objective was to assess the types of PHI a fish might sustain and still survive.

Once the raw data and samples are collected at sea, there are several aspects of processing that occur to make the information useable. Pacific halibut ages are determined by reading the otoliths from each fish, and this procedure is detailed in Forsberg (2001). By 2003, all commercial and setline survey otoliths were read using the break-and-bake technique, but this procedure works better for older fish, whereas surface reading is better for the youngest fish. Therefore, trawl otoliths continue to be read using a combination of the two techniques. All Pacific halibut caught during the surveys on all vessels are measured for fork length and weighed. Swept-area estimates of abundance and biomass are calculated using these lengths and weights, the procedure for which is outlined in Clark et al. (1997) and Stauffer (2004).

Results

A total of 2,211 Pacific halibut were encountered by the two vessels during the survey (Fig. 1). A total of 235 tows were performed by the *F/V Vesteraalen* during the standard grid bottom trawl survey. On average, between four and five tows were conducted daily. The *F/V Vesteraalen* standard sample consisted of 1,194 Pacific halibut (Fig. 2). Of those, 591 otoliths were collected and 476 Pacific halibut were released with wire tags after a fin clip was collected for genetic testing. NOAA staff on the non-IPHC vessel also tagged a subsample of Pacific halibut resulting in 208 releases. Fish in the tagging sample that were > 82 cm in length were released alive if possible. Of the sampled fish caught by the *F/V Vesteraalen*, the split was 50/50 between number of females and males. Ninety-six percent of the females and 19% of the males were assessed as immature (Table 1). PHIs were found on 5.5% of the sampled fish. A total of 199 tissue samples were collected for an energetics study.

Additionally, 94 tows were made by the *F/V Vesteraalen* in the northern Bering Sea extension area. A total of 65 Pacific halibut were caught and 35 were retained for a biological sample. Of those, 71% (25) were females and 29% (10) were males (Table 2). The small sample size in the north makes comparisons difficult, but overall, Pacific halibut in the north had a larger median length of 61 cm compared to the median length in the standard survey at 51 cm. In addition, all of the females in the northern area were assessed as immature, and all of the males were assessed as mature. A total of 27 fish were tagged and released from the *Vesteraalen* and 28 from the *F/V Alaska Knight*.

Length and age distribution

Total Pacific halibut abundance in the EBS as estimated using the trawl survey catches in 2017 was 53 million fish (Fig. 3), which was a notable decrease following a stable levels over the past four years of estimates in the 62-66 million fish range. Biomass estimates continued to indicate a decline with a total in 2017 of 293 million pounds, compared to 339 million pounds in 2016. Note that the size break-outs for abundance in Figure 4 have been modified from earlier versions to better coincide with how the IPHC uses data in the stock assessment.

The 2017 survey indicated a continued decline in the overall stock in the Bering Sea and failed to indicate any large year or size classes approaching the Pacific halibut commercial fishery (Fig. 4). Very small fish (< 20 cm) were represented more strongly than usual, but mortality of these fish is high and does not necessarily indicate increased recruitment into the commercial fishery at 81.3 cm fork length. However, they are worth noting as the survey continues into the future.

The age composition for Pacific halibut sampled in both 2016 and 2017 is shown in Table 3. Ages in the samples ranged from 2-18 years, and 1-23 years for 2016 and 2017, respectively. The 5-year-olds (2011 year class) in 2016 were most abundant and represented 31% of the sample, and were the same year class that were also most abundant in the 2015 sample (Table 3a). In 2017, the 4-year-olds (2013 year class) were the largest sampled cohort making up 21% of the sample (Table 3b). Also notable in 2017 was that 5% of the fish were 1-year-olds (2016 year class), which are fish that are generally too small to be vulnerable to the trawl and are thus not often seen in the survey. Fish from the older year classes including the 2004 and 2005 year classes that once showed high abundance, have grown to a size where they are largely capable of avoiding survey trawl gear. This likely negatively influences catches of these fish (Clark et al. 1997).

In the northern Bering Sea extension, abundance estimates for 40-100 cm Pacific halibut showed a decrease from 2010 estimates, but showed slight increases in both the smaller and larger size classes (Fig. 5). Ages ranged from 4-13 years in 2017 (Table 4) which is similar to the 4-12 year range collected during the last survey in that area in 2010. Average age in 2017 was 6.4 years compared to 5.7 years in the standard survey to the south.

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Table 1. Assigned maturity status of Pacific halibut that were retained for biological sampling during the NMFS Bering Sea trawl survey in 2017. Females were assigned to one of four states: 1=immature, 2=ripening, 3=ripe/spawning, 4=spent/resting. Males were assigned to one of two states: 1=immature and 2=mature. Fish assigned to "Sex Unknown" were primarily those selected for the tagging sample.

	Females				Males				
Fork length (cm)	**1**	**2**	**4**	**Total**	**1**	**2**	**Total**	**Sex Unknown**	**Grand Total**
10-14	11			11	5		5	60	76
15-19	5			5				5	10
20-24	1			1	7		7	1	9
25-29	13			13	8		8	21	42
30-34	5			5	5	1	6	8	19
35-39	25			25	21	9	30	22	77
40-44	55			55	10	54	64	94	213
45-49	22			22		37	37	53	112
50-54	37			37	2	55	57	89	183
55-59	40			40		31	31	64	135
60-64	30			30		14	14	43	87
65-69	9	1		10		12	12	27	49
70-74	8			8		17	17	24	49
75-79	9			9		10	10	22	41
80-84	9			9		6	6	14	29
85-89	3			3		2	2	9	14
90-94	6	2	1	9		1	1	6	16
95-99	3	4		7		1	1	6	14
100-104	2			2				4	6
105-109	2	1	1	4				1	5
110-114		1		1					1
115-119								3	3
120-124			1	1				1	2
125-129								1	1
130-134								1	1
Grand Total	**295**	**9**	**3**	**307**	**58**	**250**	**308**	**579**	**1,194**

Table 2. Assigned maturity status of Pacific halibut that were retained for biological sampling during the NMFS Bering Sea trawl survey northern extension in 2017. Females were assigned to one of four states: 1=immature, 2=ripening, 3=ripe/spawning, 4=spent/resting. Males were assigned to one of two states: 1=immature and 2=mature. Fish assigned to "Sex Unknown" were those selected for the tagging sample.

	Females		Males		Sex	Grand
Fork length (cm)	1	Total	2	Total	unknown	Total
30-34			1	1		1
45-49					4	4
50-54	2	2			2	4
55-59	6	6	4	4	7	17
60-64	7	7			4	11
65-69	4	4	5	5	5	14
70-74	3	3			2	5
75-79	1	1			3	4
80-84	2	2				2
85-89					1	1
95-99					1	1
105-109					1	1
Grand Total	**25**	**25**	**10**	**10**	**30**	**65**

Table 3. Pacific halibut mean fork length (FL; cm) and age (years) composition from sampled fish for the a) 2016 and b) 2017 NMFS Bering Sea trawl survey standard grid.

a)

Age	Avg FL (cm)	Std dev FL (cm)	# fish aged	Year class
2	29.1	2.47	13	2014
3	33.4	6.10	60	2013
4	45.6	3.79	140	2012
5	49.2	3.93	161	2011
6	52.8	5.57	43	2010
7	64.0	5.29	14	2009
8	65.8	9.92	24	2008
9	68.5	7.23	11	2007
10	71.0	11.63	6	2006
11	76.6	15.67	11	2005
12	79.9	15.15	17	2004
13	89.0	10.93	11	2003
14	85.1	7.65	7	2002
15	86.7	5.03	3	2001
17	84.0	n/a	1	1999
18	89.0	n/a	1	1998
26	97.0	n/a	1	1990
Total	51.4	14.93	524	

b)

Age	Avg FL (cm)	Std dev FL (cm)	# fish aged	Year class
1	12.9	1.48	30	2016
2	24.5	3.00	12	2015
3	37.9	5.49	86	2014
4	42.3	4.64	122	2013
5	52.0	4.17	95	2012
6	55.6	4.48	82	2011
7	61.0	8.62	33	2010
8	66.1	8.97	14	2009
9	70.7	9.47	18	2008
10	68.0	10.04	20	2007
11	75.6	8.35	11	2006
12	83.0	10.07	20	2005
13	89.9	10.40	10	2004
14	84.5	14.73	8	2003
15	84.7	15.02	7	2002
16	95.3	10.60	3	2001
17	77.0	n/a	1	2000
23	91.0	n/a	1	1994
Total	51.1	18.06	573	

Table 4. Pacific halibut mean fork length (FL; cm) and age (years) composition from sampled fish for the northern Bering Sea extension in 2017.

Age	Avg FL (cm)	Std dev FL (cm)	# fish aged	Year class
4	55.0	7.07	2	2013
5	58.4	3.81	8	2012
6	64.6	4.50	8	2011
7	68.7	12.66	3	2010
8	60.5	6.36	2	2009
9	83.0	n/a	1	2008
12	68.0	n/a	1	2005
13	68.0	n/a	1	2004
Total	63.1	7.83	26	

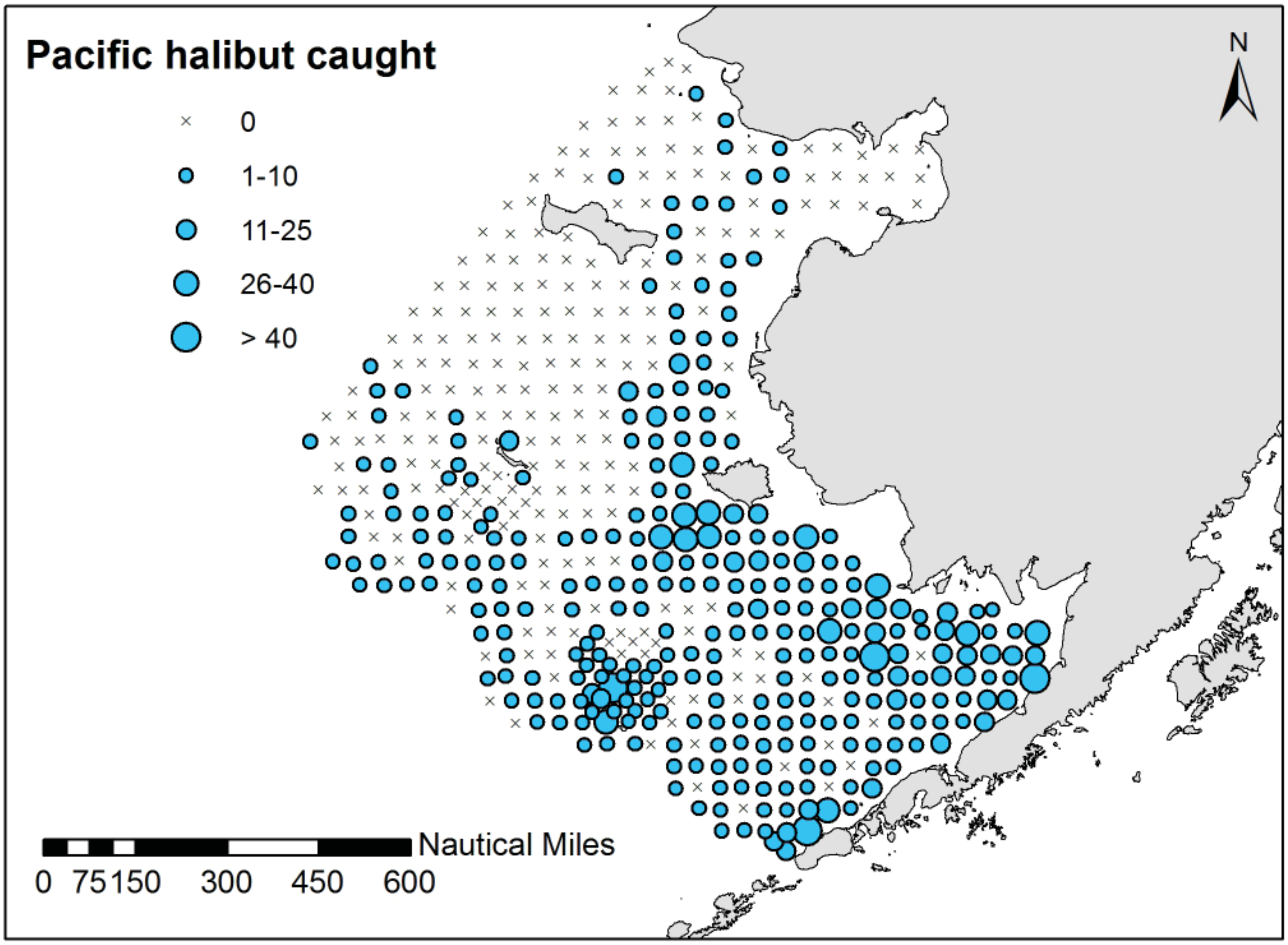

Figure 1. Number of Pacific halibut encountered at each survey station, by both vessels, during the 2017 NMFS Bering Sea trawl survey. Note that in 2017, additional stations were surveyed to the north of the standard grid (aka northern extension). Stations with an X indicate that no Pacific halibut were encountered.

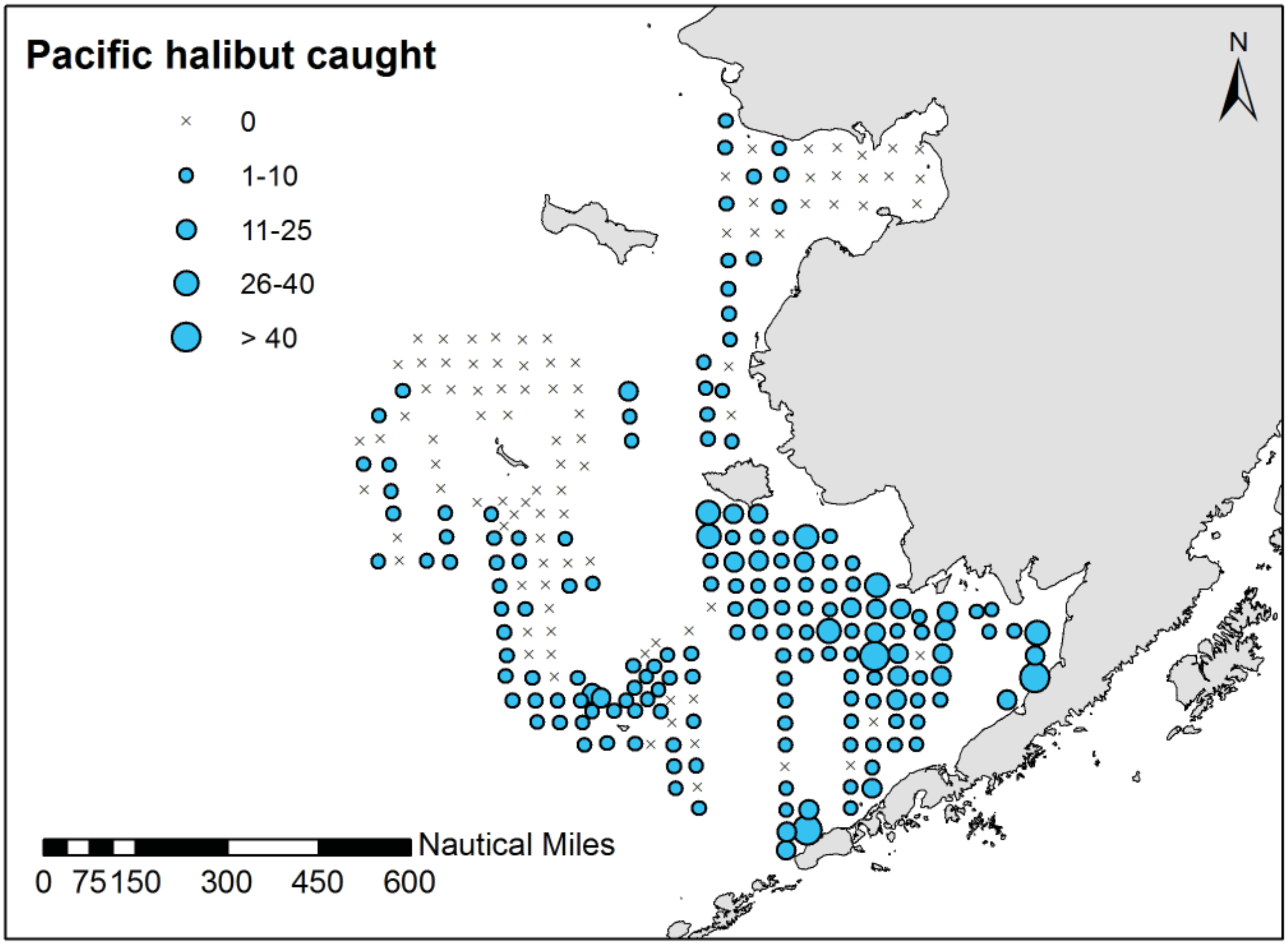

Figure 2. Number of Pacific halibut encountered by the *F/V Vesteraalen* during the 2017 NMFS Bering Sea trawl survey and subject to biological sampling or tagging. Stations with an X indicate that no Pacific halibut were encountered. Note that each station in the Bering Sea was occupied by only one vessel so while catches for each vessel were roughly representative of the area as a whole, sampling and tagging were not necessarily in proportion to abundance on a smaller spatial scale.

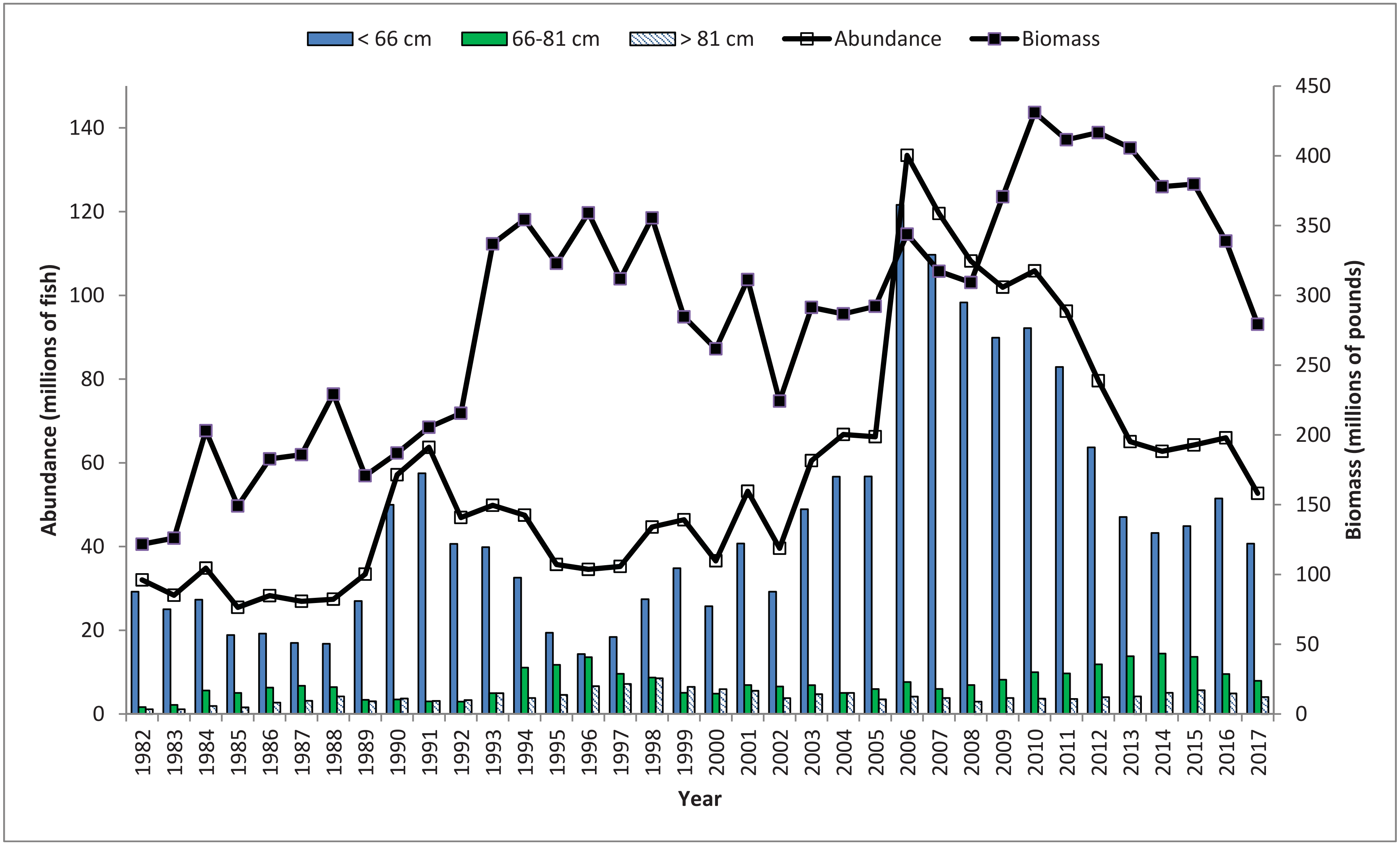

Figure 3. Abundance (numbers of fish) of Pacific halibut by length category and total biomass (pounds) as estimated by the NMFS Bering Sea standard trawl survey data from 1982-2017, using swept-area estimates.

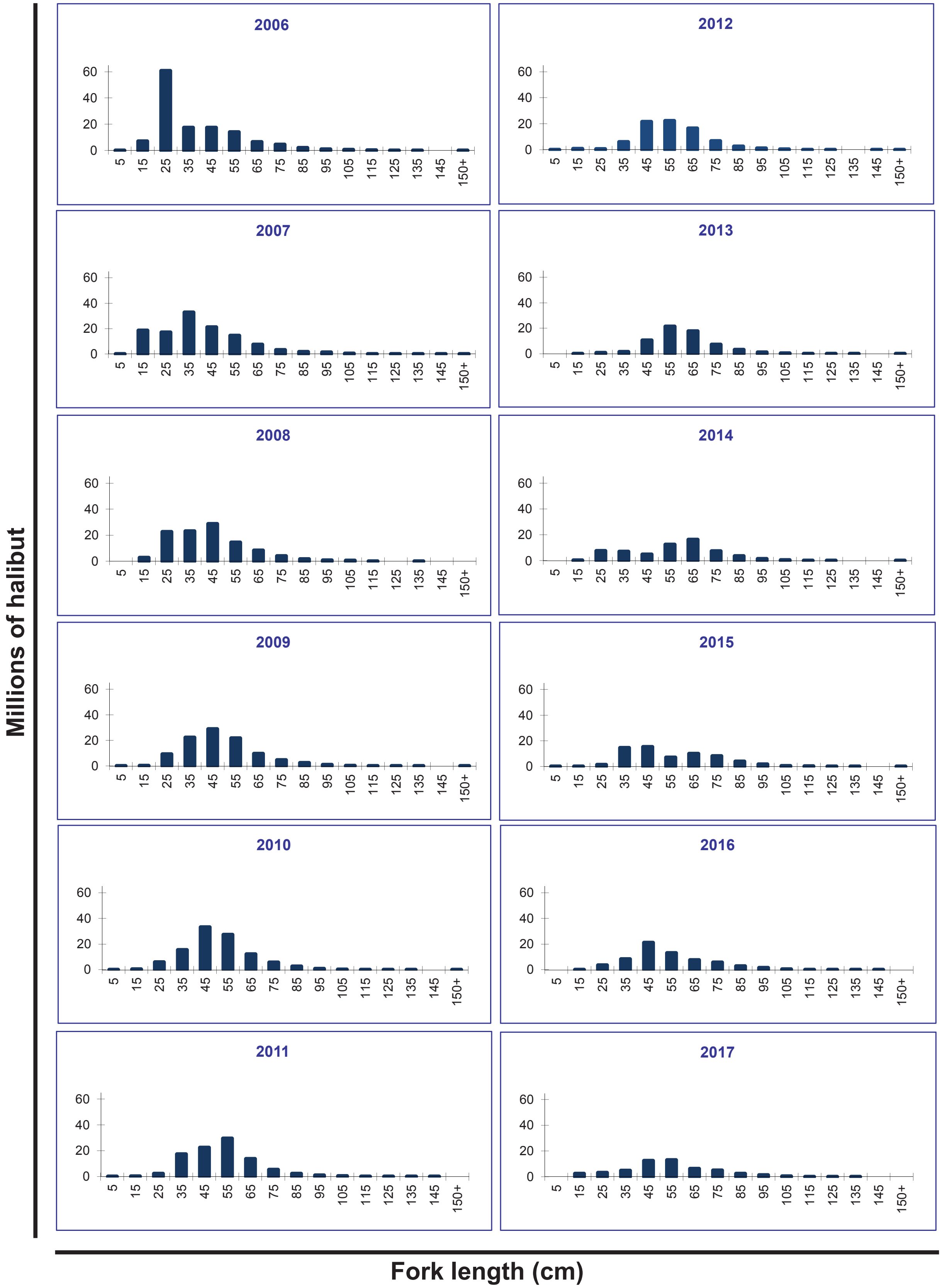

Figure 4. Pacific halibut abundance by 10-cm size bin in the Bering Sea as estimated by the NMFS Bering Sea standard trawl survey for the years 2005-2017. Note: Horizontal axis is fork length (cm) and the values showing on the graph represent the mid-point of each bin; vertical axis is millions of Pacific halibut.

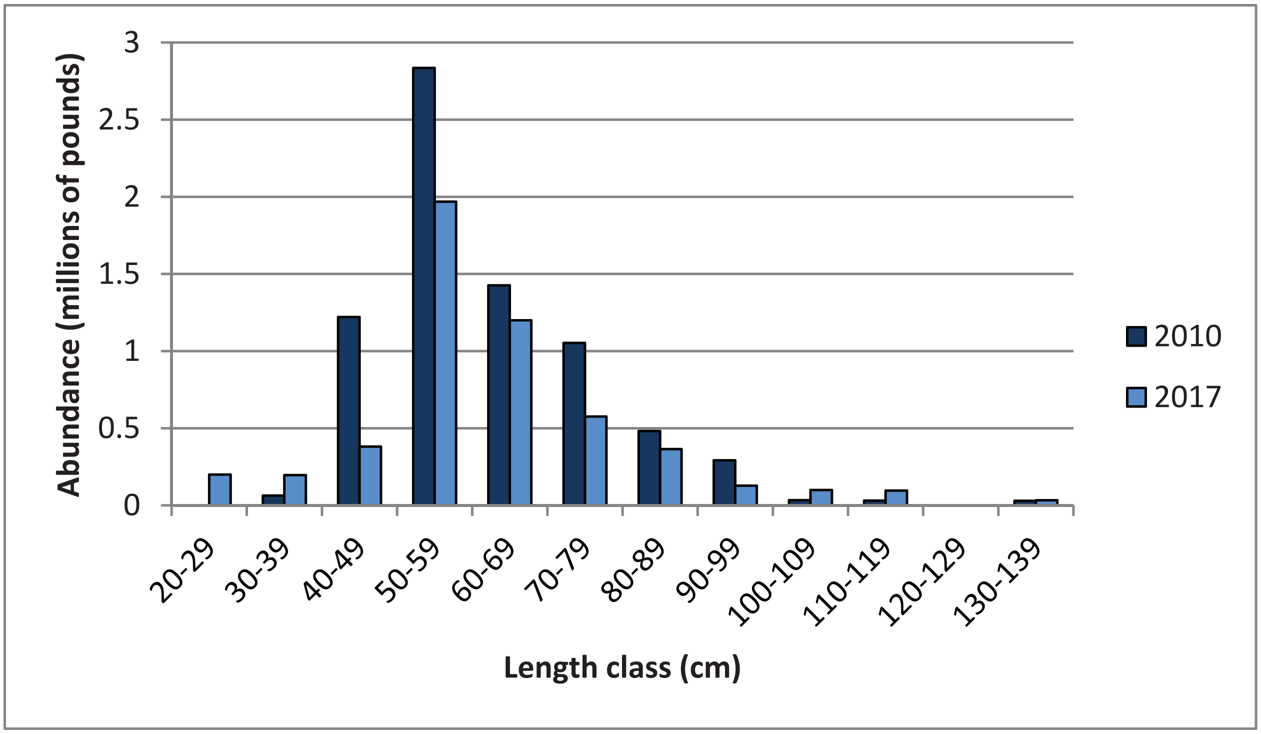

Figure 5. Estimated Pacific halibut abundance (number of fish) in the northern Bering Sea extension area surveyed in 2010 and 2017.

3.4.2 Results from the 2017 NOAA Fisheries Service Gulf of Alaska trawl survey

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Abstract

The NOAA Fisheries Service, Alaska Fisheries Science Center, conducted a bottom trawl survey of Gulf of Alaska groundfish and invertebrate resources in 2017 as a continuation of a series started in 1984. This survey is the tenth since changing the series from triennial to biennial in 1999. An International Pacific Halibut Commission biologist was deployed on one vessel for the duration of the survey to sample Pacific halibut for length, sex, maturity, otoliths, and prior hooking injuries. A total of 1,685 Pacific halibut were caught by the *F/V Ocean Explorer* and of those, 886 were sampled for length, otoliths, sex, maturity, and prior hooking injuries. The remaining 799 were measured and, if in suitable condition and < 82 cm fork length, were tagged and released, resulting in 713 total tag releases. Both abundance and biomass estimates declined slightly from 2016 values to 114 million Pacific halibut and 658 million pounds, respectively.

Introduction

The NOAA Fisheries Service (NFS) conducts bottom trawl surveys in the Gulf of Alaska (GOA) from the Islands of Four Mountains in the western GOA to Dixon Entrance in southeast Alaska. NFS scientists routinely collect catch and length data for Pacific halibut (*Hippoglossus stenolepis*), but since 1996 an International Pacific Halibut Commission (IPHC) biologist has been aboard these surveys to collect additional information. Survey trawl gear is size selective, making the data collected difficult to include directly in the stock assessment generated by the IPHC. Pacific halibut are vulnerable to the trawl from about 20-100 cm fork length (FL) (Clark et al. 1997), but a substantial portion of the commercial-sized population (O32 or ≥ 81.3 cm FL) exceeds 100 cm in FL. However, the trawl survey results provide a valuable comparison tool for the stock assessment, help identify trends in size-at-age, and are a useful index for assessing the relative abundance of cohorts approaching the commercial fishery.

The main objective of the survey as a whole was to gather data to extend this time series for monitoring trends in distribution, abundance, and biological condition of various groundfish stocks in the northeast Pacific Ocean. In 2017, two fishing vessels were chartered to carry out the survey. Each vessel was staffed with a crew of six scientists and a professional fishing crew and captain.

An IPHC sampler was aboard one of the vessels to collect detailed Pacific halibut data and to assist the NFS scientific crew in attaining their survey goals. The main objectives for the IPHC biologist in 2017 were:

- record the FL on 100% of the halibut caught on all standard groundfish tows;
- collect sex, maturity, and prior hooking injury (PHI) data as well as otoliths on 50% of the catch;

- assess viability using NFS observer criteria on the other 50% of the catch, and subsequently tag and release all those individuals that were < 82 cm in FL and determined to be suitable for tagging.

This report describes the results of the 2017 GOA trawl survey and also updates trawl-survey-based abundance and biomass estimates for the area.

Survey area, vessels, and itinerary

The NFS has conducted a triennial GOA continental shelf survey since 1984, and beginning in 1999 this area has been surveyed biennially. The survey region extends from the Islands of Four Mountains (170° W longitude x 53° 30’ N latitude) to Dixon Entrance (132° W longitude x 54° N latitude). The primary NFS objective for the survey is to define the distribution and relative abundance of various groundfish and invertebrate species (von Szalay et al. 2016). Due to budget and manpower issues, the 2001 survey was truncated to include only the area from the Islands of Four Mountains to Montague Island (147° 30’ W longitude x 60° N latitude) at the entrance of Prince William Sound. The full range survey was restored in 2003.

The 1993, 1996, and 2001 surveys placed stations at depths ranging between approximately 20 and 500 m. The 1999 and later surveys were extended into deeper waters of the GOA continental slope, to as deep as 1000 m, subject to budget and time constraints. The survey is conducted in the summer months (May to August) and given the fact that trawl gear catches smaller halibut relative to other methods such as longline, and smaller halibut are generally found on more shallow grounds than their larger counterparts, the variation in maximum depth has not appeared to affect Pacific halibut data collection.

A total of 536 stations were successfully completed during the 2017 survey. Two chartered vessels participated: *F/V Sea Storm and F/V Ocean Explorer*. The IPHC sampler was aboard the *F/V Ocean Explorer* for the duration of its survey operations.

The scientific crew boarded the *F/V Ocean Explorer* on May 24th in Dutch Harbor, AK and spent several days setting up and calibrating equipment. The first survey tow was conducted on May 30th. Four legs were conducted with ports of call in Sand Point, Kodiak, and Seward, AK. The final tow was made on August 5th and the vessel arrived in the final port of Ketchikan, AK that same day.

Survey design

The survey area was divided into 59 strata based on depth, major geographic features, and International North Pacific Fisheries Commission (INPFC) statistical areas (Fig. 1). The survey design was a stratified random sampling scheme based on a Neyman optimum allocation strategy utilizing data from previous surveys (Stauffer 2004; Clark et al. 1997). The number of samples to be taken within each stratum was based primarily on distribution and abundance estimates of groundfish from prior surveys and the relative commercial value of the major groundfish species. At least two samples were required from each stratum. The entire survey area was overlaid with a 5x5 km (25 km^2) grid. The station locations within each stratum, larger than 5 km^2, were randomly selected without replacement from all grid cells, or portions of grid cells. Grid cells that had been deemed not suitable for trawling in previous surveys were also excluded from the selection. The stations allocated to each stratum were then assigned to the survey vessels. Beginning with the

1996 survey, a 15-minute tow at a speed of 3 nmi/hr was attempted at each designated station. Prior to that year, a 30-minute tow conducted at the same speed was attempted. Both vessels started sampling at the western end of the survey area and proceeded eastward.

The bottom trawl used for all survey sampling was NMFS's standard Poly Nor'Eastern trawl equipped with rubber bobbin roller gear (Stauffer 2004). This trawl has a 27.2 m headrope and a 36.7 m footrope consisting of a 24.9 m center section with adjacent 5.9 m "flying wing" extensions. Accessory gear for the trawl includes 54.9 m triple dandylines and 1.8 x 2.7 m steel V-doors weighing 850 kg each.

Electronic sensors were attached to the trawl net to record data about each tow: acoustic sensors recorded net height and width while fishing; a bathythermograph[1] recorded temperature and depth; and a bottom contact sensor detected when the footrope was in contact with the bottom.

All tows were given a success rating based on whether the following operational guidelines for successfully completing a standard survey tow were met:

- Each tow's duration was at least 10 minutes (distance fished approximately 0.74 nmi (1.4 km) at a speed of approximately 3 knots) unless an extremely large catch altered the fishing configuration of the net. An appropriate length of trawl warp (towing wire) was deployed as specified in the standard survey scope table (Stauffer 2004).
- The goal of each tow was to not exceed 20 m of depth change over the 15-minute towing period. In areas where this was not possible, trawl warp was adjusted prior to the tow to reflect the change in depth.
- Net mensuration indicated fishing gear was operating within acceptable limits, taking into account that the net width tends to increase and net height decreases with increased warp lengths.
- Survey gear maintained continuous contact with the bottom.
- There were no significant hang-ups, gear damage, or gear conflicts.

Halibut sampling

All Pacific halibut caught on the surveys aboard all vessels were measured for fork length. All fish caught by the IPHC-staffed vessel, *F/V Ocean Explorer*, were assigned randomly into one of two groups: one for biological sampling, and one for wire tagging, with the goal of assigning 50% to each group. This was achieved by laying out two fish at a time, rolling a set of dice, and assigning one fish to each group based on predetermined number designations. Pacific halibut in the tagging sample were measured and if fork length was < 82 cm, they were then assessed for fitness using NMFS observer viability criteria. All those in the "excellent" and "poor" categories were tagged and released. Those assessed in the "dead" category were measured and discarded. Pacific halibut $\geq$ 82 cm FL and in the tagging sample were released. For a full description of the tagging project, see Forsberg et al. (2016). Fish in the biological-sample group were assessed for sex, maturity, PHI, and the otolith was removed for aging. The sex and maturity stage of each sampled fish was determined by macroscopic examination of the gonads. Female fish were classified into four stages of maturity: immature, ripening, ripe/spawning, and spent/resting. Males were classified into two maturity stages: immature and mature. Immature for both sexes meant that the fish was not expected to participate in upcoming winter spawning. The other stages represented

[1] Sea-bird Electronics Inc., 13431 NE 20th Street, Bellevue, WA, 98005.

various phases of the reproductive process and fish in those categories were considered mature enough that they could participate in the upcoming spawning season.

A PHI is an injury to the mouth, jaw, or eye caused from longline gear. PHI assessments have been collected for several years as part of an IPHC special project designed to look at types of hooking injuries a fish might sustain and still survive as well as to obtain injury rates in relation to geography and proximity to other fisheries. Each fish is given an injury rating (which includes none, minor, moderate, and severe) based on pre-determined criteria.

Relative biomass and abundance estimates were derived by calculating a mean population density of Pacific halibut for each stratum, multiplying the mean density by the stratum area, and then summing across strata (Clark et al. 1997). Estimates are not adjusted for size-specific selectivity, so the reader should exercise caution when drawing conclusions regarding fish that are underrepresented in the trawl survey, i.e., Pacific halibut less than about 20 cm and greater than about 90-100 cm in length. The results are reported by INPFC regions (Fig. 1), which are the area designations that are used by NFS to present their survey results. For comparison, INPFC regions correspond with IPHC regulatory areas as follows: *Shumagin* encompasses the eastern portion of IPHC Regulatory Area 4A and western Area 3B; *Chirikof* is almost completely contained within Area 3B, with the exception of a very small portion of Shelikof Strait; *Kodiak* and *Yakutat* are primarily in Area 3A; and *Southeast* corresponds to the eastern portion of Area 3A and the outside waters of Area 2C.

Pacific halibut ages are determined by reading the otoliths from each fish and this procedure is detailed in Forsberg (2001). By 2003, all commercial and setline survey otoliths were read using the break-and-bake technique but this procedure works better for older fish, whereas surface reading is better for the youngest fish. Therefore, trawl otoliths continue to be read using a combination of the two techniques. Aging of Pacific halibut in the 2017 sample has not been completed as of the writing of this report, so age composition information in this report includes through the previous survey.

2017 survey results

The *F/V Ocean Explorer* conducted 268 groundfish tows and 243 of these were successful. On average, four to six tows were attempted daily. A total of 4,645 Pacific halibut were caught and measured. Of those, 1,685 were caught by the *F/V Ocean Explorer* (Fig. 2) and were retained for either biological sampling or tagging.

Of the 886 Pacific halibut in the biological sample, 40% were female and 60% were male (Table 1). Of the females sampled, 20% were coded as mature, which is well above the ~10% observed in the past several trawl surveys. A total of 96% of the male Pacific halibut were coded as mature. All Pacific halibut in the biological sample were examined for PHI. A total of 95 fish (5.8%) showed some form of previous injury: 77 fish (4.7%) showed minor damage and 18 fish (1.1%) showed evidence of moderate damage. This is slightly higher than the ~3% PHI observed in recent GOA trawl surveys.

Within the tagging sample of 799 Pacific halibut, those assessed as being in either "excellent" or "poor" condition, and that were < 82 cm FL, were tagged and released. This resulted in 713 wire tag releases. Those determined to be "dead" or were ≥ 82 cm FL, were measured and discarded without tags (Forsberg et al. 2016).

Spatial distribution of all Pacific halibut caught on the survey by both vessels is shown in Figure 2.

Age composition, abundance, biomass, and distribution

Both the abundance and biomass estimates exhibited a fairly consistent decline beginning in 2003 with the exception of an abrupt, but short-lived increase in 2009. In 2013, the estimates began leveling off and this continued into 2017 with a slight decline from 2015 values (Fig. 3). The 2017 estimates were 114 million fish and 658 million pounds of biomass. Individual size class categories representing fish < 82 cm all exhibited the same trend as the overall, but there was a slight increase in the abundance of ≥ 82 cm fish. Recruitment at the smallest sizes which represent year classes from about 2014 to present, appears low compared to other recent survey years (Fig. 4).

The age composition for halibut sampled in 2015 is shown in Table 2. Ages in the sample ranged from 1 to 29 years. The 2005 year class continued to show strongly (9% of aged fish in the sample) despite those fish attaining larger sizes which make them less vulnerable to the trawl gear. The largest percentage of aged samples came from the 2012 and 2011 year classes which together were 38% of the sample. Mean ages and lengths of Pacific halibut by sex for the years during which Pacific halibut have been sampled (1999-present) are summarized in Table 3. In all years except 2017, females averaged slightly larger than their male counterparts. However, in all years, male average age was higher than for females. Minimum age was comparable, but maximum age of males was greater than for females in all years.

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Table 1. Maturity of Pacific halibut sampled during the NFS Gulf of Alaska trawl survey in 2017, aboard the *F/V Ocean Explorer*, as assessed by the IPHC sea sampler. For females: 1 =immature, 2=ripening, 3=ripe/spawning, and 4=spent/resting. For males: 1=immature, 2=mature, and U=unknown/could not be determined.

	Females					Males				Tagging sample	
Length (cm)	1	2	4	U	Total	1	2	U	Total	Sex unknown	Grand Total
10-14				2	2						2
15-19										1	1
20-24	1				1	1			1		2
25-29	1				1		1		1	6	8
30-34	7				7	6	2		8	7	22
35-39	7				7	4	16		20	21	48
40-44	31				31	6	51		57	71	159
45-49	60			3	63	3	76		79	136	278
50-54	50			1	51	2	85	1	88	120	259
55-59	28			1	29	1	50	2	53	77	159
60-64	16				16		49		49	64	129
65-69	12				12		51		51	52	115
70-74	14	1		1	16		48		48	70	134
75-79	14	8			22		54		54	60	136
80-84	15	18	2		35		12		12	44	91
85-89	7	13	4		24		7	1	8	38	70
90-94	6	4	2		12		2		2	12	26
95-99	2	8			10					7	17
100-104	1	3	1	1	6					3	9
105-109	3	4			7					6	13
110-114				1	1						1
120-124		1		1	2					3	5
160-164										1	1
Total	275	60	9	11	355	23	504	4	531	799	1,685

Table 2. Distribution of age (years) and average fork length (FL; cm) of Pacific halibut sampled in the 2015 NFS Gulf of Alaska bottom trawl survey.

Age (years)	Avg FL (cm)	Std Dev FL (cm)	# aged fish	Year class
1	17.4	1.82	16	2014
2	27.5	9.01	72	2013
3	35.7	4.85	381	2012
4	41.8	6.49	231	2011
5	49.6	7.34	88	2010
6	55.5	8.33	54	2009
7	59.9	6.73	93	2008
8	63.1	7.09	90	2007
9	65.0	8.12	100	2006
10	68.1	8.79	147	2005
11	69.9	8.51	99	2004
12	72.5	9.76	70	2003
13	73.6	12.90	53	2002
14	77.2	9.18	45	2001
15	77.7	7.95	23	2000
16	90.0	17.09	12	1999
17+	85.7	10.88	27	1998 and earlier
Average	53.2	18.18	1,601	

Table 3. Summary of Pacific halibut fork length (FL; cm) and age (years) observed during the Gulf of Alaska NFS trawl surveys 1999-2015. Note that mean length in this table was derived from only those fish that were also aged.

	Females					
Year	Mean FL (cm)	Std Dev FL (cm)	Mean age	Std Dev of age	Min age	Max age
1999	60.3	27.93	6.4	3.82	2	21
2001	53.8	26.37	5.7	3.92	1	21
2003	58.0	23.57	6.1	3.76	2	24
2005	62.4	21.35	6.6	3.64	2	22
2007	58.7	21.86	6.4	3.55	2	25
2009	58.1	19.09	6.6	2.82	2	23
2011	59.8	16.76	7.2	2.90	2	22
2013	60.5	18.34	8.1	3.86	2	19
2015	52.8	20.48	5.9	3.50	1	18

	Males					
Year	Mean FL (cm)	Std Dev FL (cm)	Mean age	Std Dev of age	Min age	Max age
1999	55.9	19.31	7.1	4.39	2	25
2001	52.0	21.27	6.5	4.69	2	28
2003	57.3	18.46	7.6	4.94	1	26
2005	60.7	16.46	8.2	4.92	2	30
2007	56.7	16.74	7.3	4.30	1	27
2009	55.5	14.83	7.1	3.37	2	27
2011	55.6	12.75	7.6	3.61	2	30
2013	55.3	13.26	8.3	4.06	2	33
2015	53.5	16.52	7.5	4.32	1	29

	All halibut					
Year	Mean FL	Std Dev FL	Mean age	Std Dev of age	Min age	Max age
1999	58.0	23.96	6.8	4.14	2	25
2001	52.8	23.73	6.1	4.38	1	28
2003	57.6	20.68	7.0	4.56	1	26
2005	61.4	18.71	7.5	4.48	2	30
2007	57.5	19.01	6.9	4.03	1	27
2009	56.6	16.78	6.9	3.17	2	27
2011	57.3	14.71	7.4	3.34	2	30
2013	57.4	15.75	8.2	3.98	2	33
2015	53.2	18.18	6.9	4.09	1	29

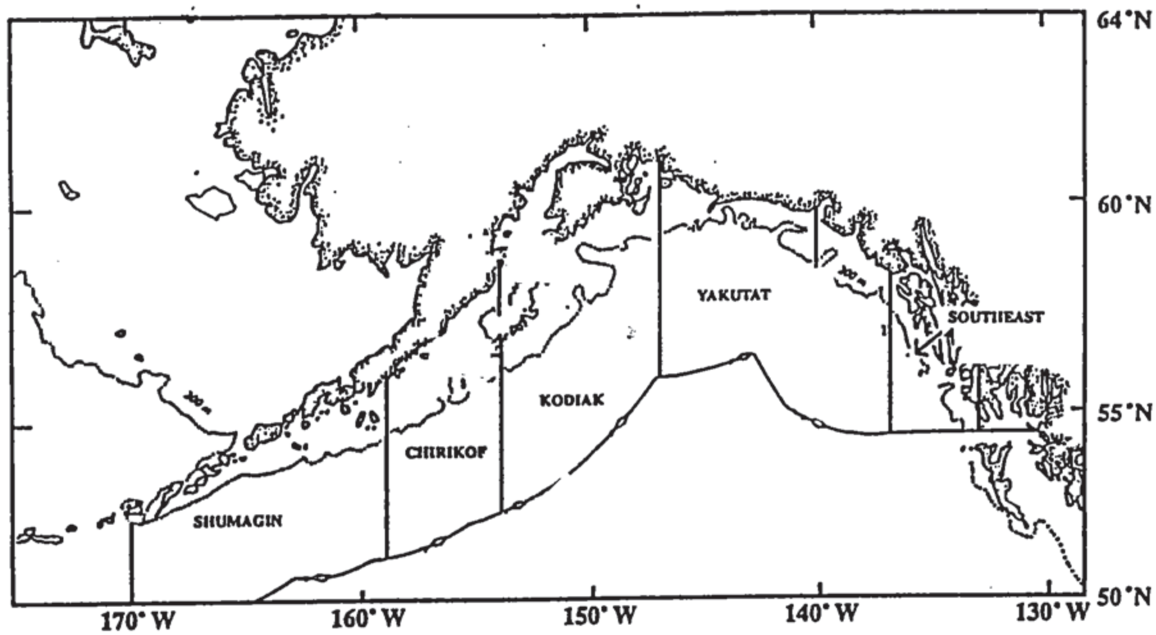

Figure 1. INPFC-defined regions in the Gulf of Alaska.

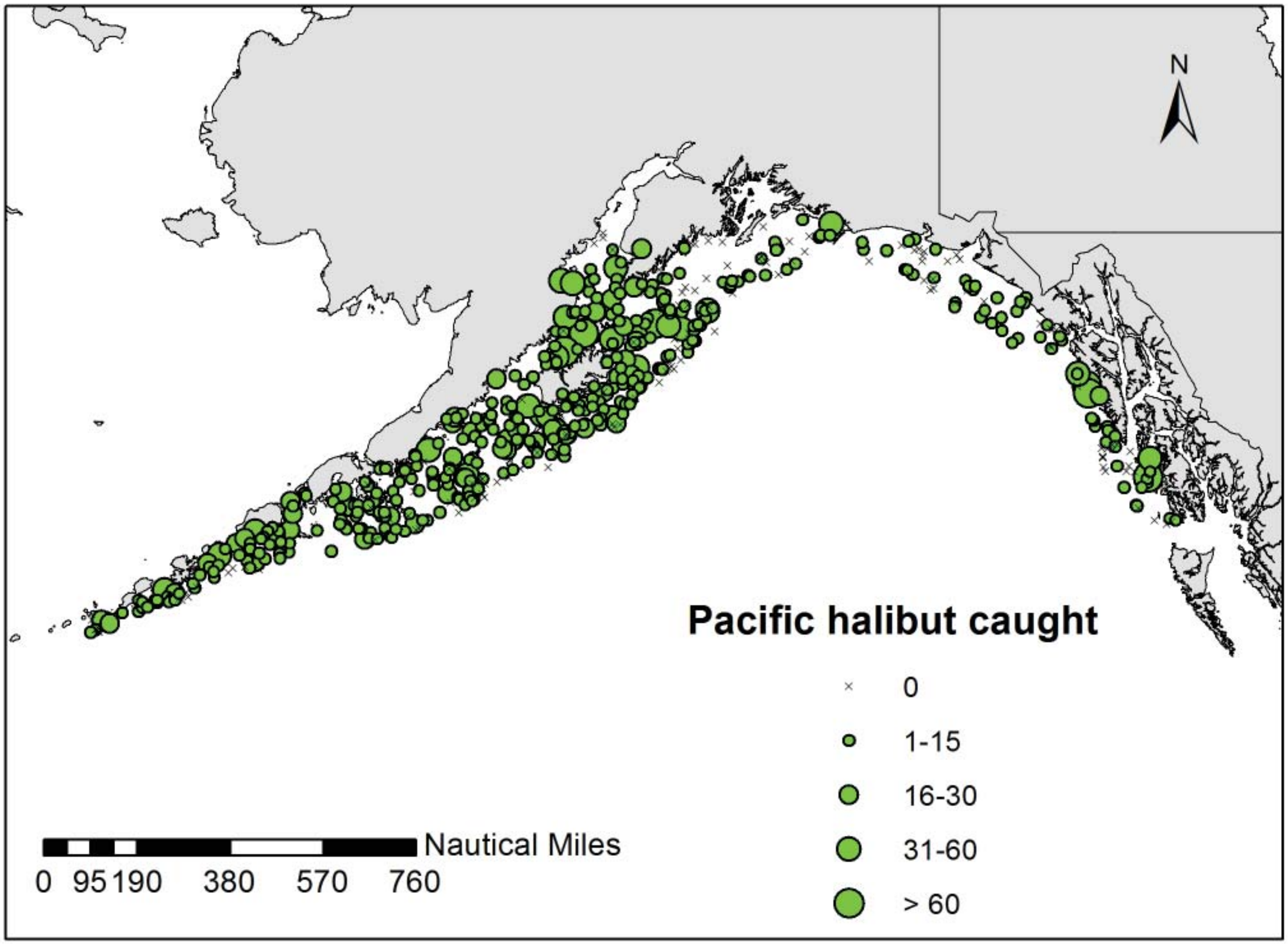

Figure 2. Spatial distribution, by location, of Pacific halibut caught by the *F/V Ocean Explorer* during the 2017 GOA bottom trawl survey.

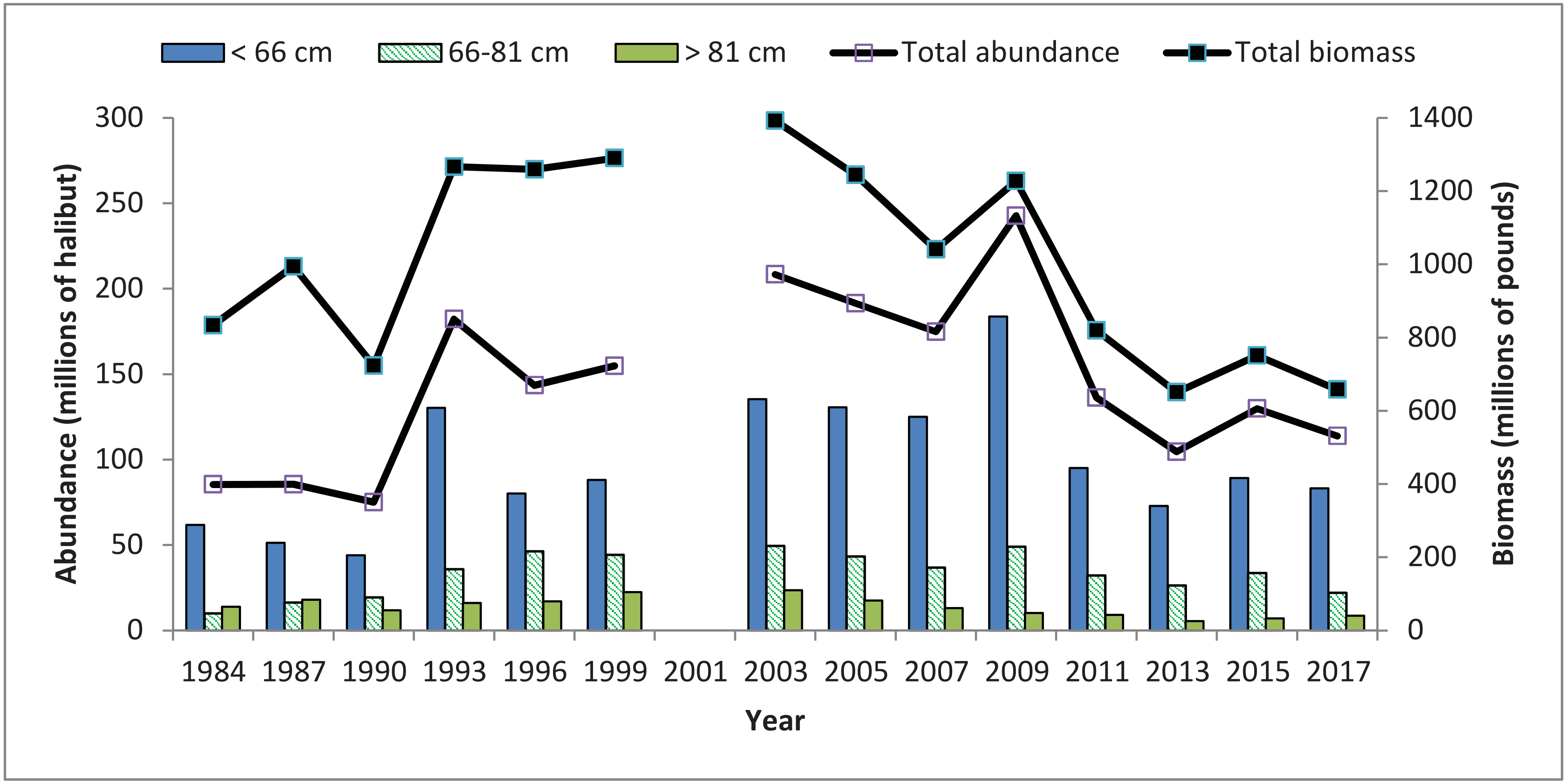

Figure 3. Estimated total abundance (millions of Pacific halibut; line with closed symbols) and abundance by size category (bars) along with total biomass (pounds; line with open symbols) for the survey years 1984-2017 as estimated using NFS Gulf of Alaska bottom trawl survey data. Note that the 2001 estimate is absent in this figure because the survey did not include all INPFC regions that year.

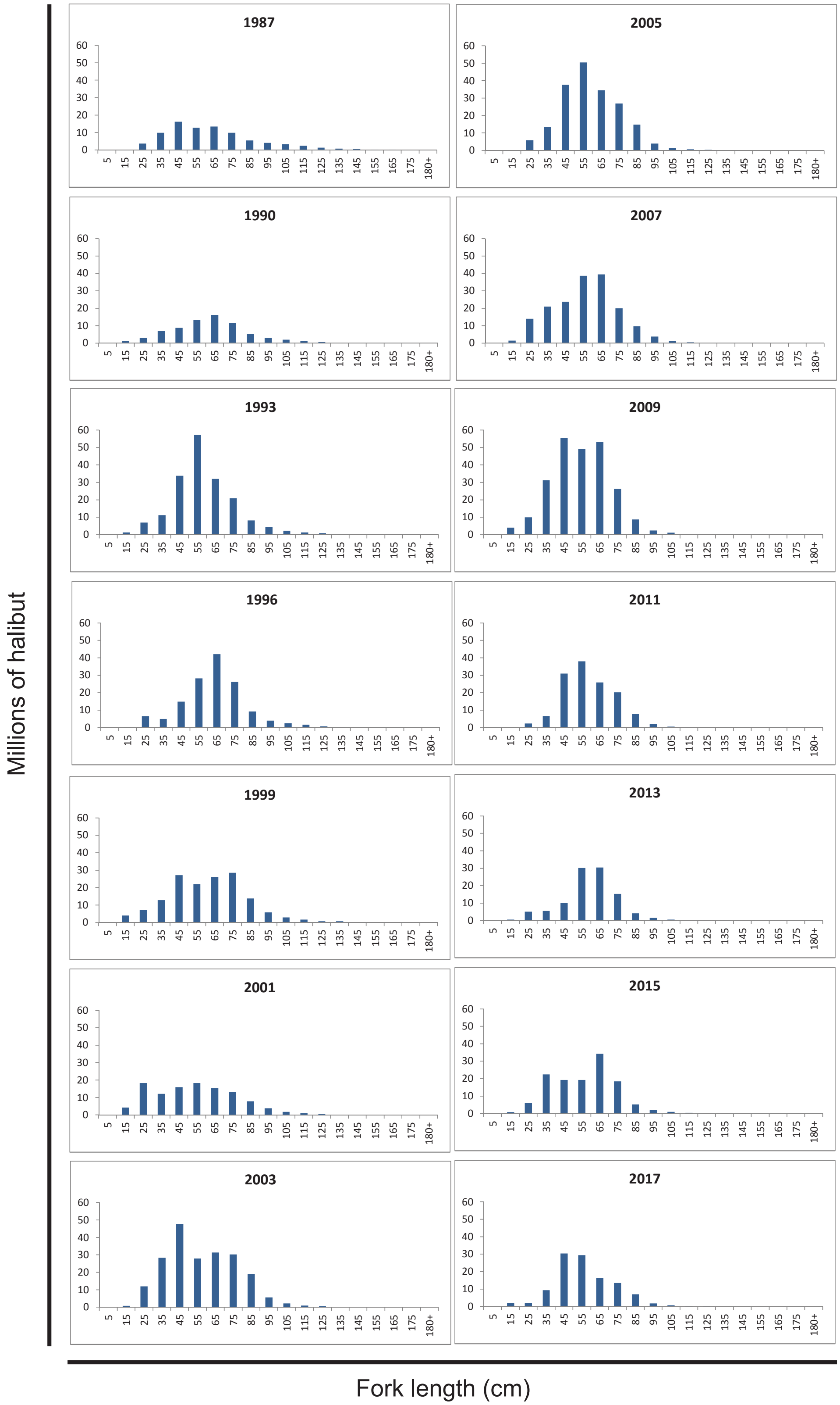

Figure 4. Pacific halibut abundance by 10- cm size bin in the Gulf of Alaska as estimated by the NFS GOA trawl survey for the years 1987-2017. Horizontal axis is fork length (cm) and the values showing on the graph represent the mid-point of each bin; vertical axis is millions of halibut. Note: The 2001 abundance estimates include only the Shumagin, Chirikof, and Kodiak regions; the Yakutat and Southeast regions were not surveyed. All other years include all areas.

To ensure that the most up to date information is available to Commissioners and stakeholders, the suite of stock assessment documents listed here are available on the IPHC website Annual Meeting page.

4.1 Summary of the data, stock assessment, and harvest decision table for Pacific halibut (*Hippoglossus stenolepis*) at the end of 2017 (IPHC-2018-AM094-08)

Ian Stewart, Allan Hicks, Raymond Webster, and David Wilson

4.2 Overview of data sources (IPHC-2018-AM094-09)

Ian Stewart and Raymond Webster

4.3 Stock assessment of the Pacific halbut stock at the end of 2017 (IPHC-2018-AM094-10)

Ian Stewart and Allan Hicks

4.4 Pacific halibut catch tables (IPHC-2018-AM094-11)

Ian Stewart

5.1 Executive Summary

Allan C. Hicks

The International Pacific Halibut Commission (IPHC) approved the formation of the Management Strategy Advisory Board (MSAB) in 2013 to oversee the Management Strategy Evaluation (MSE) process and to advise the Commission and Secretariat on the development and evaluation of candidate objectives and strategies for managing the fishery. The MSAB met twice in 2017. The first meeting (MSAB09) was held from 9-11 May and discussed the MSAB goals and objectives, the framework and design for simulations to evaluate fishing intensity, and management procedures to address distributing the TCEY. The second meeting (MSAB10), held from 23–26 October, reviewed the goals and objectives, discussed the results of the simulations examining fishing intensity, further discussed methods to distribute the TCEY, and prepared a program of work for 2018–2022. Reports from both meetings are available at the IPHC website (www.iphc.int).

Chapter 5.2 (IPHC-2018-AM094-12) provides an update of the MSE process for 2017. It is divided into six sections: goals and objectives, the framework for the simulations, scenarios and uncertainty, simulation results, ideas on distributing the TCEY, and a five-year program of work. This paper is a summary of the major progress made in 2017. For specfic details, see meeting documents from MSAB09 and MSAB10.

There are six goals defined by the MSAB: 1) biological sustainability, 2) fishery sustainability, access, and stability, 3) minimize discard mortality, 4) minimize bycatch and bycatch mortality, 5) serve consumer needs, and 6) preserve biocomplexity. The first four goals have one or more objectives associated with them, as well as corresponding performance metrics against which to evaluate each objective.

The simulation framework is composed of an operating model and a management procedure. The operating model is a representation of the population and fishery, and consists of things that we cannot, or choose not, to control. The management procedure consists of things that we can control and includes monitoring (i.e., data collection), an estimation model (i.e., the stock assessment), and a harvest rule (e.g., the fishing intensity). The results presented in 2017 assumed that the necessary observations for the harvest rule were known exactly. In other words, the management procedure had perfect information.

Uncertainty in the operating model came from many sources, including uncertainty in some parameters (e.g., natural mortality), simulated random recruitment, regime shifts that modify average recruitment, and variable size-at-age. Varaible recruitment and size-at-age were the two largest components to the overall variability.

The closed-loop simulations were used to investigate the fishing intensity in the scale component of the harvest strategy policy. Various values for the spawning potential ratio (SPR) and two values of the threshold (trigger) point in the harvest control rule (30% and 40%) were evaluated. The trigger point protects the spawning biomass when fishing intensity is high, and a higher trigger point results in more protection of the spawning biomass (e.g., maintains a higher stock status, on average). The trigger point causes similar yields at lower SPR values (high fishing intensity) because the overall fishing intensity from the harvest control rule is being reduced. However, this also results in higher annual variability of the TCEY. SPR values between 20% and 55% are likely to meet the goals and objectives defined by the MSAB.

Ideas on estimating the stock distribution and distributing the TCEY were discussed at both MSAB meetings in 2017. Stock distribution is the method used to determine how the population is distributed across different areas, is a scientific component, is best done using the IPHC fishery-independent setline survey (FISS), and is a useful tool to preseve biocomplexity. A biologically-based method to determine the distribution of the stock should use biologically define regions that can be further split into IPHC Regulatory Areas. Further distributing the TCEY can be done using distribution procedures such as different relative harvest rates in some areas or incorporating fishery-dependent data. These distribution procedures can operate on regions and IPHC Regulatory Areas.

A five-year program of work was developed that defines general tasks. A more specific three-year plan is to continue evaluating the scale component of the harvest strategy policy and present those results at the 2019 Annual Meeting (AM095). After that, work will continue on procedures to distribute the TCEY and results from evaluating procedures related to the scale and distribution components of the harvest strategy policy will be presented at the Annual Meeting in 2021 (AM097).

5.2 An update on the IPHC Management Strategy Evaluation (MSE) (IPHC-2018-AM094-12)

Allan C. Hicks and Ian Stewart

This paper was prepared for the 2018 International Pacific Halibut Commission (IPHC) Annual Meeting (IPHC-2018-AM094-12), and can be found on the IPHC website Annual Meeting page.