Center for Independent Experts independent peer review of "Shore-based and boat-based fishing surveys in Guam, CNMI, and American Samoa: Survey design, expansion algorithm, and a case study"

By

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Executive Summary

The shore-based and boat-based recreational fishing surveys in Guam, CNMI, and American Samoa generally follow a stratified two-stage cluster sampling design, where primary sampling units are days stratified by weekdays and weekend days. Fishers and trips in each region are secondary sampling units, clustered within days and shifts. This complex survey design could be more clearly described in the background documentation. However, I commend the agencies for designing and conducting these surveys with much statistical rigor given the staffing, transport, and other logistical and cost-constraints. Nevertheless, the many constraints in the complex random scheduling of sampling days and shifts, and the non-probabilistic targeting of fishers to interview based on gear type, compromises the tracking of selection and inclusion probabilities, and may cause bias. Also, some of the surveys have scheduled the sampling within selected days with shifts that have gaps or overlaps, which complicates analysis and can cause bias. It is recommended that alternative, simpler survey designs with even stricter probabilistic sampling be considered. Ideally, shifts are defined by non-overlapping time-intervals within days. For some of the shore-based and boat-based surveys under review multiple shifts are completed within randomly selected days. It is likely that fishing effort, which clearly is affected by weather conditions, be relatively more homogeneous on short time scales such as within days, and more variable between days over the year. In this case, it could be more efficient to increase the number of field days for the same cost by only sampling one random shift each day, or by sampling shifts randomly within weekday and weekend strata. It is recommended that the efficiency of alternative survey designs be explored through simulations, based on historic data. The sampling during night is generally problematic, and it is recommended that the main survey effort be allocated to cover the day-time fishing. Night-time fishing could be monitored with low sampling frequency to check assumptions of low effort.

Point-estimators for catch rate, fishing effort, and expanded catch estimates based on estimation domains seems reasonable, but respective variance estimators are likely to result in bias because they do not fully account for the multi-stage cluster sampling designs. It is recommended that analysis be conducted to assess if the strong assumptions about simple random sampling within domains are reasonable. The boat-based expansion script (in R) for Guam accurately implements the estimators as provided in the PIFSC Tech memo, and the methods for imputations and sensitivity analysis are well documented and reasonable given the assumptions. These methods would need modifications if estimators for stratified multi-stage cluster sampling are deemed necessary.

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1. Background

This review was commissioned through Center of Independent Experts (CIE) to provide an independent review to evaluate the survey design and expansion algorithm of shore-based and boat-based fishing surveys in American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands (CNMI). The shore-based effort and catch surveys each utilize a roving survey design, where data are collected on fishing effort, and catch per unit effort (CPUE) for incomplete trips. The boat-based surveys are mainly an access point survey by design, where data are collected on effort, and CPUE for complete trips. Boat-based catch and effort surveys to estimate CPUE are conducted at major ports, and additional data on boat-effort are also obtained along travel routes between ports trough trailer counts. For both shore-based and boat-based surveys, expanded catch is estimated as the product of catch rate (from catch survey) and fishing effort (from effort survey).

Local departments in each territory conduct boat-based and shore-based creel surveys: the Guam Department of Agriculture, Division of Aquatic and Wildlife Resources (DAWR); the CNMI Department of Lands and Natural Resources, Division of Fish and Wildlife (DFW); and the American Samoa Government Department of Marine and Wildlife Resources (DMWR). Data management and programming support for the creel surveys are provided by NOAA's Western Pacific Fishery Information Network (WPacFIN). The creel survey data have been used to estimate and report total catch, catch-per-unit-effort (CPUE), and fishing effort, mostly at annual levels across island areas. The statistical method used to compute these estimates is referred to as the expansion algorithm.

Expanded catch and effort estimates (and other estimates such as CPUE) are used by the territorial agencies in their fiscal year reports, and in calendar year reports to the various plan teams and committees under the Western Pacific Regional Fishery Management Council ("the Council"). The goals and objectives specific to this review of the Pacific Islands territorial fishing surveys are to:

1. Evaluate the survey design for the shore-based and boat-based surveys to estimate catch rate and fishing effort estimates.

2. Evaluate survey expansion algorithm for catch rate, fishing effort, and expanded catch estimates (point estimators and variance estimators included in the document and the expansion script in R)

3. Suggest future research priorities to improve the existing survey design and expansion algorithm.

The review started with a webinar on August 23rd, 2021. A team of scientists from NOAA PIFSC, consisting of Hongguang Ma, Ph.D. Statistician NOAA PIFSC, Toby Matthews, Programmer & analyst; Ph.D. candidate. University of Hawaii & NOAA PIFSC, Marc Nadon, Ph.D. Stock Assessment Scientist NOAA PIFSC, and Felipe Carvalho, Ph.D., Research Mathematical Statistician (Stock Assessment Program leader), provided an overview of the review objectives, and brief overview of background material.

NOAA PIFSC distributed background materials and the main the NOAA Technical Memorandum NMFS-PIFSC Report (PIFSC tech memo) to the review panel via a folder on Google Drive, that also included a Google sheet to facilitate communication between the

panel and report authors, the terms of reference, background readings, and a folder containing all the files (R code and survey data) necessary to reproduce the Guam boat-based expansion results presented in the report. In addition, an R package expalg.cie was also developed to assist the review by easily reproducing the case study presented in the report.

The Google sheet was meant to track questions/requests from the panel and corresponding responses from the authors in an effort to avoid numerous email threads. During the review PIFSC staff responded quickly to questions/requests. PIFSC were very responsive to our requests for clarifications and more information to better understand the survey designs and logistical constraints.

Upon reviewers' requests several follow-up webinars were held where PIFSC staff provided more detailed information on the survey designs, logistical constraints, and staffing resources for the shore-based and boat-based surveys. In the webinars held on September 9 (20:00 to 22:00 Norway time) and September 16 (20:00-22:00 Norway time) Honguang Ma and Toby Matthews provided additional information for shore-based surveys in Guam, CNMI, and Sonoma, with ample time for questions. During webinars on September 22 (20:30 to 22:30 Norway time), and September 30 (20.30 to 22:30, Norway time) they gave detailed presentation of survey design, sample selection, and staffing for boat-based surveys in Guam, CNMI, and Somoa. Hongguang Ma and Toby Matthews provided summary notes by email following these webinars that were extremely helpful and necessary for our understanding of the complex survey designs, and the logistical challenges.

The PIFSC tech memo, which is the focus of this review, use the boat-based access-point survey in Guam as a case study to describe in more detail how effort and catch rate estimates for different fishing methods at different ports are combined to estimate total catch. The shore-based roving creel surveys are generally more complex sampling, with CPUE collected from incomplete trips. These evaluations of surveys were therefore dependent on the additional information provide in the background material, and through the webinars and notes.

2. Description of the Individual Reviewer's Role in the Review Activities

This CIE desk review was conducted independently by Dr. John Hoenig and me. We have collective expertise in statistical survey sampling methods, including survey design and estimation of catch/effort for fishery-dependent surveys. We have comprehensive knowledge of both theoretical and applied sampling survey methods applied to marine fisheries, and a strong understanding of population modeling and stock assessment. Dr. Hoenig is a world renown expert on the use of statistical theory, mathematical modeling, and computer simulation to interpret survey data on catch and effort in recreational fisheries and has published numerous peer reviewed papers on methods related to roving creel surveys. In this review, Dr. Hoenig provided very useful diagrams that summarized the survey-designs for shore-based surveys, based on the detailed discussions during webinars and additional notes provided by PIFSC staff.

I bring international research and management experience in quantitative fisheries biology and ecological statistics, specializing in statistical survey sampling methods. I have broad

hands-on experience in the development and optimization of fisheries-dependent and fisheries- independent surveys and monitoring programs to support stock assessments and ecosystem-based fisheries management. My theoretical training in survey sampling statistics, and extensive experience with the design and analysis of artisanal and recreational fisheries surveys, including access-point surveys, aerial surveys and roving creel surveys of recreational fisheries, are particularly relevant for this review. In this review I have focused especially on aspects related to the survey design and estimation methods of the shore-based and boat-based surveys and provide some thoughts on possible future improvements. My skills in R-programming are admittedly rusty, but I have sufficient understanding and experience to assess if the R-scripts used for the estimation of CPUE, effort, and catch are consistent with the estimators provided in the PIFSC expansion report. I defer to Dr. Hoenig for more detailed evaluation of the R-programming.

3. Summary of Findings for each ToR in which the weaknesses and strengths are described

3.1. Evaluate the shore-based and boat-based fishing survey designs and determine if the survey designs are appropriate.

In general, the surveys are described with sufficient details in the PIFSC tech memo and background material, and in follow-up webinars, and notes provided by PIFSC to assess if the designs are appropriate, and to assess sources of bias.

These surveys under review employ survey designs where the spatial sampling frames are clearly defined, and the scheduling of sampling in time and space is randomized, but with several logistical and staffing constraints that are well documented. The surveys generally follow a stratified multi-stage cluster sampling design (e.g., Jessen 1978; Lehtonen and Pahkinen 2004; see also ICES 2014), with days (or shifts for shore-based surveys in CNMI) typically being primary sampling units. For a stratified sample of days, recreational fishers (by gear type) or trips are counted, and fishers are intercepted and interviewed to obtain data on catch and effort during shifts within selected areas. This complex survey design (by default) is appropriate for collecting representative data from recreational fishers in the field since no sampling frames for selecting individual fishers and boat-trips exists in advance. The surveys are generally conducted with much attention to minimizing bias by spreading out the sampling in time and space, and by randomizing survey routes. I commend the agencies for designing and conducting these large-scale surveys with much statistical rigor given the staffing, transport, and other logistical constraints. It should be noted, however, that the many constraints in the complex scheduling of sampling days and shifts, as well as the non-probabilistic targeting of fishers to interview based on gear type, compromises the tracking of selection and inclusion probabilities, and may cause bias. Also, the overlap of shifts, or gaps between shifts within selected days, complicates the analysis and may cause bias, but I recognize that this departure from best practice mainly is driven by logistical constraints related to transportation.

One critique I have with respect to the PIFSC tech memo and background material provided on the Google Drive is the lack of clear definitions of sampling units for each stage in the sampling process. In particular, the temporal sampling frames for the multi-stage cluster sampling could be more clearly defined, especially for American Samoa, where sub-sampling of days is conducted on shifts that are overlapping.

3.1.1. Shore-based surveys

Guam

Monthly effort and catch per unit effort (CPUE) surveys are conducted separately and assumed to be independent. The land-based effort surveys are conducted by motor vehicle, with a spatial sampling frame consisting of three regions that are accessible by road. These survey follows a stratified two-stage cluster sampling design, with a (temporal) sampling frame of days (primary sampling units, PSUs) that are stratified into weekdays (WD) and weekend days (Saturdays)/Holidays (WE). Effort on Sundays is assumed to be zero, and hence Sundays are excluded from the sampling frame. The surveys are conducted monthly with a stratified random sample of two PSUs in each of the weekday and weekend day strata. For each selected day, the surveys are conducted in morning and afternoon shifts (06:30-12:00; and 19:00 – 24:00), each covering all 3 regions. Notice that shifts are nested within days, and thus cannot be selected by simple random sampling from all possible morning and afternoon shifts each month. Also, the shifts that are defined for each sampling day (PSU) cannot be considered unique strata since the shifts have gaps. Fishing effort data are recorded by gear type, reef zone, and time/type of day. Effort units are recorded in hours fished per gear-type. It is not clearly defined what window of time within each day that these shifts represent.

Additional aerial effort surveys are conducted monthly (by airplane) to cover a larger portion of total effort on the island than the three regions covered by the roving creels surveys. These data are used for bias-correction of effort estimates from the land-based surveys. For obvious reasons flights are only conducted during daytime. The survey design is stratified cluster sampling where PSUs are days, which are stratified into weekdays and weekend days. Aerial surveys are conducted on one WD and one WE day scheduled each month on the same days as the first "weekday" and "weekend/holiday" in the land-based effort survey. Each selected PSU is sub-sampled, by scheduling 2-hour flights starting at a randomly selected hour between 8 am and 12 pm, which from my understanding is assumed to represent the portion of the daytime shift from 06:00 to 18:00. The flights cover 72 (out of 92) defined inshore fishing areas along the coastline, where approximately 85% of the effort occur. Fishing effort data are recorded by gear type, reef zone, and time/type of day.

The catch per unit effort (CPUE) survey covers three regions accessible by road. PSUs are site-days. Regional interviews of fishers within a stratified random sample of days are used to estimate catch-per-unit-effort data (CPUE; "interview survey"). These surveys are conducted 2 WDs and 2 WE (Saturdays only due to logistics, assumed to represent WE and Holidays) per month, with two shifts within each day (06:30-12:00; 19:00-24:00) that have gaps. Each selected random day is assigned to one region. The large region 3 is covered for weekdays and weekend days every month, while regions 1 and 2 are alternated. Starting location for survey routes are randomiced in each day and region, with alternating clockwise and counterclockwise directions.

Reasonable procedures are in place to reduce bias in the selection of fishers to interview by gear and to secure adequate number of interviews for estimating CPUE. The aim is to select fishers that have fished at least 30 mins, which is consistent with recommendations in Hoenig

et al. (1997) and Pollock et al. (1997). Gears that are rarely used, and gears with highly variable catch are prioritized in order to achieve adequate number of interviews. Some fishing methods like spear-fishing are challenging to spot, and are given priority when interviews can be achieved at end of trip. Surveyors generally select fishers to interview based on gear, and stage of fishing (beginning, middle, end). Average shore-based CPUE is estimated from multiple interviews, as the average weight caught per hour divided by the number of hours fished per gear type. Effort is estimated as the number of gears-per-hour seen fishing in a given survey area.

Given the expected differences in species composition of catches from different gears, I understand the desire to depart from random sampling of fishers to secure data on CPUE for gears that are used rarely. However, this is a form of non-random sampling which is like quota sampling (Moser 1952; Rada and Martin 2014). There are known issues with bias in samples of people based on quotas since the actual inclusion probabilities of fishers in the sample of people (and gears) will be unknown. Clearly, the targeting of fishers that uses certain gears for interviewing within a PSU or shift, will not be representative of the whole population of active fishers for that PSUs or shift. This would cause serious bias concerns if data were collected for parameters on for example demographics of the population of fishers, but I have much less concerns when the data only are used to estimate CPUE. I believe that this departure from random sampling is reasonable for these CPUE surveys and find it reasonable to assume simple random sampling for estimating mean CPUE.

CNMI (Mariana Islands)

The effort and CPUE surveys cover a spatial sampling frame consisting of 27 non-overlapping spatial segments (numbers 4-30 on the Western side of the Island) that are accessible by road, out of a total of 38 non-overlapping segments that cover the whole coastline of Saipan. Surveys are scheduled quarterly according to a very complex survey design. The temporal survey frame consists of days within each year that are stratified into weekdays and weekend/holidays, where weekends include Saturdays. Each day is then stratified into 4 non-overlapping 6-hour shifts (00-06; 06-12; 12-18; 19-24). This results in 1460 possible unique shifts per year. In my understanding, this survey design can best be described as a stratified random cluster-sampling design, where day/shift combinations (1460) form the sampling frame, and where shifts can be considered primary sampling units (PSUs). A complicated system of randomization is used to schedule a stratified random sample of 16 shifts within each of the WD and WE strata by quarter. PSUs (6-hour shifts) are selected randomly without replacement subject to several constraints (for example, selections of adjacent shifts are avoided, and shifts cannot be scheduled the day after a boat survey). Within each selected shift, alternating 2-hour effort surveys (participation counts) and 2-hour CPUE surveys (interviews) are conducted, with a random start of order. It is my understanding that the order will depend on the alternations in the previous month, to secure alternating effort end CPUE surveys over the year. The start of the spatial travel routes is randomized for each 6-hour shift.

For estimating effort, it seems reasonable to follow the stratified design with WD and WE and then assume simple random sampling of PSUs within each stratum. For estimating CPUE, it seems reasonable to collapse the WD and WE strata and assume simple random sampling of PSUs throughout the year to secure adequate number of interviews for selected gears. Overall, the low sampling fractions of PSUs annually ($f_1 = {}^{n}/_{N}$ ~ 10%) suggest that

the variance estimation could be based on the PSUs only (Williams 2000), ignoring the variance in the second stage sampling due to sub-sampling of times (2-hour periods) (and sub-sample of fishers within 2-hour periods). However, for effort, the weekend stratum will have larger f_1 and it would be beneficial to include the finite population corrections and the second-stage variance to achieve a more accurate variance estimate (see Hansen et al. 1953).

American Samoa

The spatial sampling frame covers three regions, while the temporal survey frame for a year consists of days (PSUs) that are stratified into weekdays (WD) and weekend/holidays (excluding Sundays) (WE). The surveys are approximately following a stratified two-stage cluster sampling design, where days are primary sampling units, and shifts (06:30-13:00; 10:30-19:00; 16:30 – 24:00) & regions are selected in the second stage. Notice that the shifts are overlapping, which complicates the analysis. For each selected shift, one region is selected for surveying, with the restricts that the two teams cannot be assigned to the same regions if they have been assigned in identical shifts. The travel route for each selected region is randomized. By post-stratifying the surveys by region, the design will approximate stratified two-stage cluster sampling with days as primary sampling units and shifts as secondary sampling units. In actuality, the shifts (secondary sampling units, SSUs) are also sub-sampled by alternating effort and CPUE surveys within 2-hour intervals. Because of the high sampling intensity these alternating surveys are assumed to cover the whole shift. In the CPUE surveys, gears and fishers are subsampled (tertial sampling units) within each shift.

Shifts are scheduled by week for WD, with 4-5 sampling days/shifts per week for each team, and monthly for WE with two days/shifts for each team per month. The shifts are selected with a complex restricted random assignment of shifts for weekdays and weekends among two survey teams. Unlike for CMNI, the shifts cannot be considered primary sampling units since they are nested within selected days. Also, the shifts that are defined for each sampling day (PSU) cannot be considered unique secondary sampling units in a proper two-stage sampling design. The reason is that shifts overlaps. The estimation domain for CPUE in American Samoa is day or night (encompassing six 2-hour time intervals), while the effort is estimated for individual 2-hour time intervals. The complexity of this survey design makes it challenging to specify appropriate variance estimators for effort and CPUE. With very high sampling fraction of days, the first-stage variance component nearly disappears, and days can approximately be considered strata. The issue then is that the variance within days due to sub-sampling of shifts cannot be easily estimated since for the most part only one shift is surveyed per day. This suggest that the survey design can be assumed to follow a stratified random cluster design, with shifts as PSUs within WD and WE strata. The issue is still to define the sampling frame to be used in the expansion to estimate total catch and effort, since shifts are overlapping.

3.1.2. Boat-based Surveys

The boat-based CPUE surveys in Guam, CNMI, and American Samoa generally follow a stratified two-stage cluster sampling design, where primary sampling units are days stratified by weekdays and weekend days. For a stratified random sample of days each month, field surveys are conducted at selected ports (access-points) each selected day, in two or more shifts that aims to cover most of the fishing effort each day. In American Samoa, all four ports included in the sampling frame are covered on each day. Within each shift, the number

of boat-trips are estimated based on trailer counts, and counts of boats that are leaving or entering the port, and on-site interviews of fishing parties are obtained from returning boats in the selected ports (access-points). The aim is to collect complete trip data on catch and effort from all returning boats trips in each shift, but, when necessary, a subsample of trips is selected for interviews. If more than one fishing vessel returns at the same time, prioritization is based solely on the rarity of the fishing method used. This non-probabilistic targeting of fishers to interview based on gear type, compromises the tracking of selection and inclusion probabilities, and can cause bias.

In Guam and CNMI, additional roving creel surveys are conducted to estimate boat-effort island-wide as part of the shore-based surveys. During these surveys, boat-trailers are counted in all main ports, as well as from lesser boat-launch areas.

The boat-based effort and CPUE surveys are generally conducted with much attention to randomizing the sampling in each stage, and to spread out the sampling in time and space over the year. The spatial sampling frame, and the under-coverage due to logistics is well documented. I commend the agencies for designing and conducting these high effort surveys with much statistical rigor given the staffing, transport, and other logistical constraints. The one critique I have is that the hierarchy of the multi-stage sampling is not clearly defined by defining the sampling units for each stage. In particular, the shifts within days in some cases have gaps or overlaps, which complicates the design, and can cause bias.

Guam

The access-point surveys follow a stratified cluster sampling design, with ports as spatial strata, and days as primary sampling units (PSUs) stratified by WD and WE. Three main ports are surveyed for effort and CPUE, each on separate days. Effort and CPUE access-point (port) surveys are conducted on the same survey assignments, with "Bad weather days" assumed to have 0 effort. Clearly, the effort and CPUE surveys are not independent in this case.

Port-surveys are conducted on 4 random weekdays and 4 random weekend days (Saturdays only due to logistics, assumed to represent WE and Holidays) per month with two shifts each day. Interviews by boat party on return to harbor. The spatial sampling frame of access-points covers: (1) Agana Boat Basin; (2) Agat Marina, and (3) Merizo Pier, while the temporal survey frame for a year consists of days (PSUs) that are stratified into weekdays (WD) and weekend/holidays (excluding Sundays) (WE).

The three ports are surveyed on separate days, with a monthly sampling schedule of 2 random weekdays and 2 random weekend days for port 1, and 1 random weekday and 1 random weekend day for each of ports 2 and 3. Each survey day is covered with morning and evening shifts. In port 1, the surveys on a given day are conducted from 05:00-12:00 and from 16:00-24:00. In port 2, the surveys are conducted from 5:30-12:00 and from 16:00-24:00. In port 3, the surveys are conducted from 6:00-12:00 and from 16:00-24:00. A complication here is that the morning and evening shifts have a gap, but the assumption is that these shifts cover all but nighttime fishing in these three ports. The aim is to collected data on effort and catch based on interviews for all returning trips, and to maintain log of all trips departing and returning. Effort is measured as number of trips, and CPUE is catch per trip.

If more than one fishing vessel returns at the same time, prioritization is based solely on the rarity of the fishing method used. Complete trip data are collected on time spent fishing, # people onboard, gear, locations fished, catch in # by species/length kept and # released, and what kind of monetary costs/benefits were associated with the trip. Use length-weight relationships to estimate weights. CPUE by species is measured as kg/trip by gear.

Additional roving creel effort surveys (boat-trailer counts) are conducted as part of the shore-based surveys on 2 random weekdays and 2 random weekend days, with two 4–5-hour shifts starting 6:30 and 19:00 each day (morning and evening shifts). Counts of watercraft trailers attached to vehicles near ports and other watercraft launching points around Guam are used to estimate participation rates (by gear type) in offshore ("boat-based") fishing activity around Guam. Scheduling of survey days mirrors the inshore land-based effort survey schedule. It is conducted concurrently with the land-based effort survey, with recordings at 10 recognized watercraft launch ramps within the survey area. In addition, the number of empty watercraft trailers attached to vehicles near the shore along the route are recorded.

CNMI (Mariana Islands)

The boat-based roving creel effort surveys collects data on participation in recreational fishing from vessels in CNMI's waters from all ports in this region, including Sugar Dock, Fishing Base, Smiling Cove, Tanapag, and DFW Ramp.

The boat-based access-point surveys collets data on boat effort and CPUE. The access-point surveys follow a stratified two-stage cluster sampling design, with ports as spatial strata, and days as primary sampling units (PSUs) stratified by weekdays and weekend days. The spatial sampling frame of access-points covers: (1) Smiling Cove; (2) Sugar Dock, and (3) Fishing Base. The monthly scheduling process involves a stratified random sample of 3 weekdays and 3 weekend days with some logistical restrictions to avoid back-to-back sampling days. Since 2005, two shifts cover each sampling day (10:00-18:00; and 18:00-2:00). These shifts are well defined temporal strata within PSUs. On each day, ports are assigned sequentially on a rotating schedule throughout the year across weekdays and weekend days. Two types of charter boat activity occur in Saipan: (1) Large head boats, that take 20–40 people out to conduct shallow-water bottom-fishing, and (2) Regular sized "six-pack" boats that takes up to six paying passengers out. Each of these types of charter boats are considered as separate strata within PSUs and are expanded as separate domains in the expansion because their types of trips (target species) and the number of days spent fishing (effort) are different.

Effort is recorded at regular intervals during the two shifts each day (10:00, 14:00, 20:00, 22:00) while CPUE data from completed trips are collected trough interviews from 13:00 to 2:00. The assumption is that most trips that starts in the morning will return after 13:00. Each fishing trip may have multiple fishing methods conducted by a fisher, and data from each interview should be recorded by method (including catch information). The aim is to collect interview data from all retuning trips during a shift. However, when too many boats return at the same time, and cannot all be interviewed, staff prioritize interviews from boats fishing with the least-encountered methods for the past month. This non-probabilistic targeting of fishers to interview based on gear type, compromises the tracking of selection and inclusion probabilities, and can cause bias.

American Samoa

The boat-based surveys include an effort survey that record boat-counts coming and going from the main ports or sampling areas, and CPUE surveys that involves interviewing fishers at four access-points (ports) when they return to port to determine catch, method used, lengths and weights of fish, species composition, catch disposition, and if any fish were not kept (bycatch). The boat-based roving creel survey collects data to quantify fishing participation, effort, and catch conducted from vessels in American Samoa's waters. The boat effort survey record activity of boats coming and going from the four main ports or sampling areas (Pago Pago, Fagatogo, Utulei, and Faga`alu).

The temporal sampling frame is stratified by weekdays, and weekend days & holidays (only Saturdays er included in the frame. Sundays and Holidays are excluded since staff cannot work those days. Sundays are assumed to have zero effort. It seems reasonable to assume that Saturdays also represents effort during Holidays. Also, several weekdays are reserved for administrative work (including 2 payday Mondays per month and the 16th of each month for invoice collection day). These few exclusions are unlikely to cause much bias in effort and CPUE estimates.

The scheduling of sampling for effort and CPUE is quite complex, and difficult to follow. Staff drive along the main road that connects the four main ports on a stratified random sample of days, with a minimum of 12 weekdays and 2 weekend days per month. Participation counts are collected three times per shift during two separate daytime shifts (5:00-13:30); 13:00-21:30) most days. Night-time "graveyard" shifts are conducted on weekdays only at low frequency. The boat-based participation count is conducted during the same shift as the boat-based interview, using the same staff. So, if any fishers are encountered during or between participation runs, they are interviewed.

At access-points, boats are chosen for interviews on a first-come-first-served basis, with the priority being interviews first and participation counts second. Each boat can contain multiple interviews if they have fished multiple methods. Note that these interviews are nested within day, shift and boat-trip, and thus cannot be considered independent interviews within a day/shift/port combination.

From the remaining available working days (weekend or weekday), the scheduler will select 2 days to collect opportunistic interviews from other areas to provide more interview data on CPUE for the hard-to-obtain fishing methods. I believe that data from hard to obtain fishing methods, where sample sizes are low, and where non-probabilistic sampling methods are used, are most suitable for detecting presence-absence of species, and not for quantitative analysis to support catch allocation across gears.

3.2. Evaluate the shore-based and boat-based survey expansion algorithm and assess if the expansion methods are appropriate and consistent with the survey designs.

For the shore-based survey in Guam, which is used as a case in the PIFC Tech memo, fishing effort is computed based on mean effort (gear hours) across days scaled up to number of calendar days in a year for each combination of fishing method, day type, and survey shift.

This estimator for effort is appropriate since days are primary sampling units. The variance describes variation among sample days for gear counts from a region (for "hook and line") or from all regions combined. It hence is assumed that effort counts are independent between shifts. However, shifts are nested as time-strata withing randomly selected days (PSUs), and observations on effort for shifts within days are likely to be positively correlated. One reason is that effort is dependent on weather, which typically is more homogeneous within a day than between days.

The CPUE and respective variance *Var (CPUE_ghr)* (equation 8) is also estimated under the assumption that interviews are obtained from a simple random sample of fishers by gear type within strata/domains. This is not consistent with the survey design, because interviews and fish measurements are collected via multi-stage cluster sampling, with primary sampling units (PSUs) being days, and where fishers are intercepted within shifts that are strata within PSUs. Hence, the data on catch by species, lengths, and CPUE from individual fishers are not independent of each other, and therefore standard simple random sampling estimators employed may be biased, especially for variance estimation (see e.g., Nelson et al. 2014).

In general, the primary sampling units (PSUs) are days, stratified by weekdays and weekend days, that each are stratified by shifts. Fishers within PSUs are secondary sampling units (SSUs) stratified by shifts. Thus, fishers are interviewed in clusters within PSUs. I believe that the point estimates of CPUE are reasonable, but it would be more in accordance with the survey designs to estimate the variance in CPUE based on the variation in mean CPUE among days. Some suggested estimators are provided under recommendations for future research.

In the pdf file of the PIFSC tech memo posted on the Google drive there is a missing component in the estimator for variance of total catch, equation 10:

Var(w_tot) = var(ghr)·(CPUE_ghr)ˆ2+var(CPUE_ghr)ghrˆ2-var(ghr)·var(CPUE_ghr)

The term highlighted in yellow is missing. This is clearly a formatting error since the correct equation is implemented in the R-expansion script.

For boat-based surveys, estimates of mean CPUE (catch-peer trip) in each domain and its variance (equations 12 and 13) also assume that the interviews are obtained by simple random sampling in each domain.

3.3. Review the boat-based expansion script (in R) for Guam and assess if the expansion methods in the R script are consistent with the expansion algorithm described in the PIFSC tech memo.

I believe that the R-script provided in the PIFSC tech memo accurately implements the expansion estimators as described in the report. The script is well documented so that it is easy to follow.

3.4. Review the sensitivity analyses conducted for the boat-based survey in Guam regarding the impact of the interview pooling algorithm and selection of representative ports and provide suggestions if available.

The sensitivity analysis use criteria for pooling and imputation methods that are well documented in the PIFSC tech memo, and the methods seems appropriate given the assumptions and choice of estimators. The interview pooling with the criteria of minimum three interviews per estimation domain seems reasonable under the general assumption of simple random sampling of fishers within domains. Clearly, if all three interviews were obtained for a single day (PSU), or a single shift, the variance estimate could be quite biased. For variance estimators based on two-stage cluster-sampling (which is more in accordance with the survey design) were employed I would propose to set criteria for pooling based on number of PSUs with interviews.

In the selection of representative ports for imputing CPUE for non-sampled ports it seems most appropriate to use data from all sampled ports since this is more likely to represent the population variability in CPUE as compared to a single port.

3.5. Provide recommendations for future research/improvements for the survey design and expansion methods.

The expansion methods for estimating CPUE assumes simple random sampling of fishers or trips for interviews within estimation domains. For shore-based surveys, estimation domains used for CPUE and effort estimations in the PIFSC tech memo are fishing method, day type, shift, and region/route combinations. For boat-based surveys, estimation domains are combinations of fishing method, day type, and charter status in American Samoa while in Guam and the CNMI, ports also contribute to estimation domains. Strictly, the fishers and trips are collected in clusters, according to a complex multi-stage stratified cluster sampling design, since intercepts and observations of fishers generally are obtained for randomly selected days/shifts. If observations are more similar within days/shifts than for the general sample of fishers/trips, then the variance estimates under the assumption of independence may be biased downwards (see examples in Nelson 2014). Although some preliminary analysis for Guam, based on pilot studies (provided by Hongguang Ma by email on October 8, 2021) suggests little if any bias in variance estimates of CPUE based on the current expansion methods, I recommend that analysis be done to check if this holds for all the surveys. Hansen et al. (1953; pp 316-317) provide an estimator for the variance of a ratio for stratified two-stage cluster sampling, that also applies for finite populations by incorporating sampling fractions in each stage. The "Survey" package[2] in the R-CRAN library (developed by Lumley) provides suitable methods for analyzing data from the complex survey samples (see also Lumley 2010) from the stratified cluster sampling designs in all surveys. The R-scripts in the Survey Package even supports analysis of data for surveys that employ sampling without replacement and where sampling fractions are high.

It is possible that the cost-efficiency of the surveys could be improved by eliminating multiple shifts within sampling days, and instead increase the sample size of days, with random subsampling of single shifts within each day. Ideally, shifts are defined by non-overlapping time-intervals within days. This would support stringent cluster-sampling designs, where primary units (days) can be randomly selected in the first stage, and secondary sampling units (shifts) can be censused or randomly sampled in the second stage. Such more stringent definition of sampling units in each stage would also support alternative

[2] https://cran.r-project.org/web/packages/survey/survey.pdf

designs, where shifts are PSUs that can be randomly selected monthly or quarterly. It seems more reasonable to assume simple random sampling of fishers/trips within dayshifts, than across days/shifts.

For some of the shore-based and boat-based surveys under review multiple shifts are completed within randomly selected days. It is possible that this design, with high level of clustering, is inefficient compared to simpler designs. For example, it is likely that measurements of effort can be highly variable between days over the year but be relatively more homogeneous on a short time scales such as within days. If so, it may be inefficient to sample more than one shift in a day, compared to more days with single shifts selected at random. By keeping days as PSUs, and then subsample one random daytime shift per day (see Vølstad et al. 2006 for an example), or by sampling from all possible shifts monthly or annually directly with shifts as PSUs, the number of PSUs may be increased for the same cost. This could possibly increase the precision at no extra cost. In general, it seems most effective to design non-overlapping days shifts that covers most of the effort while being practical to survey. Night-fishing, which are difficult and more expensive to survey could be covered with much lower frequency to check assumptions that effort and catch is limited during night.

One way to evaluate the effects of local homogeneity on the efficiency of various survey designs for estimating effort, CPUE, is as follows:

Suppose that effort or CPUE surveys are conducted for an area on m non-overlapping shifts of equal length within each of n_m random selected days in a weekday or weekend stratum. For fixed survey cost, the number of days that can be sampled depends on the number of shifts sampled on a given day. Let y_{ij} denote the number of trips recorded on shift $j$for day i. An estimator for the average of the $y_{ij}\acute{}s$ is

$$(1)\ \bar{y}_{..} = {\sum\sum y_{ij}}/{n_m m}$$

and the variance is estimated by

$$(2)\ V(\bar{y}_{..}) = \left({S^2}/{n_m m}\right)[1 + (m-1)\rho],$$

where ρ, the intra-class correlation coefficient, is a measure of within day homogeneity for y_{ij} (see, e.g., Cochran 1977; Jessen 1978; Særndal et al. 1992). An estimator for ρ is

$$\rho = 1 - \left({S_w^2}/{S^2}\right)$$

where S_w^2 is the average of the within-day variances of y_{ij} and $S^2$is the overall variance across days (see Særndal et al. 1992, p 130). A positive ρ means that observations from multiple shifts within sampling days are more similar than observations from shifts further apart in time. Especially for effort, a positive ρ would be expected since weather conditions typically are more variable across days than within days. It follows from equation (2) that the mean effort estimated from n_1 single shift days would be more precise than the mean estimated from n_m days with m shifts each if

(3) $n_1 \geq {}^{n_m m}/_{[1+(m-1)\rho]}$.

As an example, for a moderate intra-class correlation of 0.3, a sample of 35 days with single shifts would be expected to achieve the same precision in the estimated mean effort as 24 days with double shifts. For a higher ρ of 0.5, a sample of 31 days with single shifts would be expected to achieve the same precision as 24 days with double shifts. For surveys with multiple shifts per day, historic data could be used to estimate ρ and assess if surveys could be optimized by increasing the number of sample days, and subsample single shifts randomly within days. For the same transport cost, and staff-hours, the sample sizes of PSUs could be substantially increased by shifting to single shifts as PSUs. Sukhatme, P.V. and B.V. Sukhatme (1970) provide an alternative similar method to assess the gains of stratification of PSUs in multi-stage cluster-sampling

For the shore-based and boat-based surveys in Guam it is possible that precision on effort estimates could be increased for a fixed cost by increasing the number of sampling days and selecting only one shift randomly per day.

For the shore-based surveys in CNMI, 6-hour shifts are approximately randomly sampled each quarter, with approximately even distributions of samples for each shift-period (00:00 to 2:00; 6:00-12:00; 12:00-18:00; 18:00-00:00) annually. Here, historic data could be used to estimate the distribution of effort by shift-period. Since night-time sampling is problematic, it could be effective to identify daytime shifts that covers the majority of daily effort. The survey design could then be adjusted to reduce sampling effort during night-time and focus effort on periods of the day where most of the effort occurs.

More advanced designs where selection probability of days/shifts is proportional to expected effort (based on historic data) could also be considered. For such designs, the Hansen Hurwitz estimator (Hansen and Hurwitz 1943) or similar estimators (Berger 2004) would be a good alternative. Different designs could be assessed through simulations with resampling from synthetic populations of catch and effort within days and shifts, based on historic data.

One of the challenges with roving creel surveys is that the estimates of CPUE are based on incomplete trips, and thus can be of highly variable accuracy especially when they are based on data from short portions of many trips. One possible method to improve estimates is to recruit intercepted fishers to provide post-trip data on catches (catches after the interview was conducted) either through web-surveys, by phone, or for example trough catch diary forms on small cards labeled with return address and with prepaid postage. Also, the use of tablets and apps could make the data collections in the field more accurate and quicker.

4. Conclusions and recommendations

The shore-based and boat-based recreational fishing surveys in Guam, CNMI, and American Samoa are generally well designed, and the agencies have taken great care to spread out the sampling in time and space. Although not explicitly described, the surveys generally follow a stratified multi-stage cluster-sampling design, with days as primary sampling units. The spatial sampling frame is well defined, and reasons for under-coverage are well documented. Given the logistical constraints, rigorous methods are employed to randomize sampling of

days. The subsampling of trips or fishers within shifts involve some targeting to ensure samples from gears that are rarely used, but in general it seems reasonable to assume simple random sampling. If possible, it is recommended that the survey designs be modified by defining shifts as non-overlapping time-periods and without gaps. Shifts would then clearly define secondary sampling units, or strata, within days. Also, this would support survey designs where shifts are primary sampling units, which would reduce the level of clustering. It is recommended that re-sampling simulations based on historic data be used to optimize allocation of sampling effort with respect to number of days versus number of shifts per day for a fixed cost.

The estimators for catch rate, fishing effort, and catch provided in the PIFSC Tech memo are reasonable, but the respective variance estimators do not fully account for the multi-stage cluster sampling designs, which may cause bias (likely in the direction of too low variance estimates). The interview pooling used to fill data-gaps, with the criteria of minimum three interviews per estimation domain, seems reasonable under the general assumption of simple random sampling of fishers within domains. It is recommended that analysis be conducted using estimators that accounts for the stratified cluster-sampling to assess if variance estimators under the strong assumptions about simple random sampling within domains are reasonable. If estimators for multi-stage cluster sampling are deemed necessary, then the interview pooling methods would also need to be based on criteria with minimum sample sizes of primary sampling units to support variance estimates.

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Appendix 1: Bibliography of materials provided for review

Hongguang Ma, Toby Matthews, Marc Nadon, and Felipe Carvalho. 2021. Shore-based and boat-based fishing surveys in Guam, the CNMI, and American Samoa: survey design, expansion algorithm, and a case study. Tech memo. U.S. Dept. of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-PIFSC-##, 115 p. doi:10.7289/V5/TM-PIFSC-##.

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Appendix 2: A copy of the CIE Performance Work Statement

Performance Work Statement

National Oceanic and Atmospheric Administration (NOAA)
National Marine Fisheries Service (NMFS)
Center for Independent Experts (CIE) Program
External Independent Peer Review

Shore-based and boat-based fishing surveys in Guam, CNMI, and American Samoa: Survey design, expansion algorithm, and a case study

Background

The National Marine Fisheries Service (NMFS) is mandated by the Magnuson-Stevens Fishery Conservation and Management Act, Endangered Species Act, and Marine Mammal Protection Act to conserve, protect, and manage our nation's marine living resources based upon the best scientific information available (BSIA). NMFS science products, including scientific advice, are often controversial and may require timely scientific peer reviews that are strictly independent of all outside influences. A formal external process for independent expert reviews of the agency's scientific products and programs ensures their credibility. Therefore, external scientific peer reviews have been and continue to be essential to strengthening scientific quality assurance for fishery conservation and management actions.

Scientific peer review is defined as the organized review process where one or more qualified experts review scientific information to ensure quality and credibility. These expert(s) must conduct their peer review impartially, objectively, and without conflicts of interest. Each reviewer must also be independent from the development of the science, without influence from any position that the agency or constituent groups may have. Furthermore, the Office of Management and Budget (OMB), authorized by the Information Quality Act, requires all federal agencies to conduct peer reviews of highly influential and controversial science before dissemination, and that peer reviewers must be deemed qualified based on the OMB Peer Review Bulletin standards[3]. Further information on the Center for Independent Experts (CIE) program may be obtained from www.ciereviews.org.

Scope

The National Marine Fisheries Service is seeking a desk review to evaluate the survey design and expansion algorithm of shore-based and boat-based fishing surveys in American Samoa, Guam, and the Commonwealth of the Northern Marina Islands (CNMI).

The shore-based effort and catch surveys each utilize a roving survey design. During the roving catch survey, encountered fishers are interviewed to gather data on fishing methods, hours fished, and fish caught (or released). In the roving effort survey, accessible shoreline is visited to record active fishing methods and gear counts. The shore-based survey is stratified by day type (weekday vs weekend) and shift (different periods in a day) in all three

[3]https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/memoranda/2005/m05-03.pdf

territories. The boat-based survey is mainly an access point survey by design. Catch and effort surveys are conducted at major ports and the surveys are stratified by day type and port (except for American Samoa). For both shore-based and boat-based surveys, expanded catch is estimated as the product of catch rate (from catch survey) and fishing effort (from effort survey).

Local departments in each territory conduct boat-based and shore-based creel surveys: the Guam Department of Agriculture, Division of Aquatic and Wildlife Resources (DAWR); the CNMI Department of Lands and Natural Resources, Division of Fish and Wildlife (DFW); and the American Samoa Government Department of Marine and Wildlife Resources (DMWR). Data management and programming support for the creel surveys are provided by NOAA's Western Pacific Fishery Information Network (WPacFIN). The creel survey data have been used to estimate and report total catch, catch-per-unit-effort (CPUE), and fishing effort, mostly at annual levels across island areas. The statistical method used to compute these estimates is referred to as the expansion algorithm.

Expanded catch and effort estimates (and other estimates such as CPUE) are used by the territorial agencies in their fiscal year reports, and in calendar year reports to the various plan teams and committees under the Western Pacific Regional Fisheries Management Council ("the Council"). The Council and NOAA Fisheries evaluate estimated landings with respect to Annual Catch Limits established under the Revised Magnuson-Stevens Fisheries Management Act for the US Pacific Islands Region (PIR). Both raw and expanded data are for various uses, including for annual reports on US PIR fisheries such as *Fisheries of the US* and *Annual Stock Assessment and Fishery Evaluation (SAFE) Reports*.

The goals and objectives specific to the review of the Pacific Islands territorial fishing surveys are to:

1) Evaluate the survey design for the shore-based and boat-based surveys to estimate catch rate and fishing effort estimates.
2) Evaluate survey expansion algorithm for catch rate, fishing effort, and expanded catch estimates (point estimators and variance estimators included in the document and the expansion script in R)
3) Suggest future research priorities to improve the existing survey design and expansion algorithm.

The specified format and contents of the individual peer review reports are found in **Annex 1**. The Terms of Reference (ToRs) for the review of the surveys are listed in **Annex 2**.

Requirements

NMFS requires two reviewers to conduct an impartial and independent peer review in accordance with the PWS, OMB Guidelines, and the ToRs below. The reviewers shall have working knowledge and recent experience in survey design and catch/effort expansion for fishery-dependent surveys. The reviewers should be a survey statistician with comprehensive knowledge of both theoretical and applied sampling design and analysis. Furthermore, the reviewers should have a proficient understanding of the R programming language, familiarity with the R package "dplyr", and experience with data manipulation using the R function "array". Experience in marine fisheries is beneficial. Each CIE reviewer's

duties shall not exceed a maximum of 10 days to complete all work tasks of the peer review described herein.

Tasks for reviewers
Each CIE reviewer shall complete the following tasks in accordance with the PWS and Schedule of Milestones and Deliverables herein.

Pre-review Background Documents: Review the following background materials and reports prior to the review:

a) Guam creel survey manual (Jasper et al.)
b) Guam boat-based creel survey (Oram et al., packaged as PIFSC administrative report but not officially released)
c) Saipan boat-based creel survey (Oram et al., not officially released)
d) American Samoa boat-bases creel survey (Oram et al., not officially released)
e) Pacific Insular Fisheries Monitoring, Assessment & Planning Summit (PIFMAPS) (Final Report)

Webinar: Additionally, approximately two weeks prior to the peer review, the CIE reviewers will participate in a webinar with the NMFS Project Contact and other staff to address any clarifications that the reviewers may have regarding the ToRs or the review process. The NMFS Project Contact will provide the information for the arrangements for this webinar.

Desk Review: Each CIE reviewer shall conduct the independent peer review in accordance with the PWS and ToRs, and shall not serve in any other role unless specified herein. Modifications to the PWS and ToRs cannot be made during the peer review, and any PWS or ToRs modifications prior to the peer review shall be approved by the Contracting Officer's Representative (COR) and the CIE contractor.

a) PIFSC tech memo "Shore-based and boat-based fishing surveys in Guam, CNMI, and American Samoa: Survey design, expansion algorithm, and a case study"
b) R script for boat-based survey expansion in Guam

Contract Deliverables - Independent CIE Peer Review Reports: Each CIE reviewer shall complete an independent peer review report in accordance with the PWS. Each CIE reviewer shall complete the independent peer review according to required format and content as described in Annex 1. Each CIE reviewer shall complete the independent peer review addressing each ToR as described in Annex 2.

Place of Performance
Each CIE reviewer shall conduct an independent peer review as a desk review; therefore, no travel is required.

Period of Performance
The period of performance shall be from the time of award through October 2021. Each reviewer's duties shall not exceed 10 days to complete all required tasks.

Schedule of Milestones and Deliverables: The contractor shall complete the tasks and deliverables in accordance with the following schedule.

Within two weeks of award	Contractor selects and confirms (2) reviewers
Within four weeks of award	Contractor provides the pre-review documents to the reviewers
August 2021	Each reviewer conducts an independent peer review as a desk review
Within two weeks after review	Contractor receives draft reports
Within two weeks of receiving draft reports	Contractor submits final reports to the Government

Applicable Performance Standards
The acceptance of the contract deliverables shall be based on three performance standards: (1) The reports shall be completed in accordance with the required formatting and content (2) The reports shall address each ToR as specified (3) The reports shall be delivered as specified in the schedule of milestones and deliverables.

Travel
Since this is a desk review travel is neither required nor authorized for this contract.

Restricted or Limited Use of Data

The contractors may be required to sign and adhere to a non-disclosure agreement.

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Annex 1: Peer Review Report Requirements

1. The report must be prefaced with an Executive Summary providing a concise summary of the findings and recommendations, and specify whether or not the science reviewed is the best scientific information available.

2. The main body of the reviewer report shall consist of a Background, Description of the Individual Reviewer's Role in the Review Activities, Summary of Findings for each ToR in which the weaknesses and strengths are described, and Conclusions and Recommendations in accordance with the ToRs.

3. The reviewer report shall include the following appendices:
    a. Appendix 1: Bibliography of materials provided for review
    b. Appendix 2: A copy of the CIE Performance Work Statement

Annex 2: Terms of Reference for the Peer Review

Shore-based and boat-based fishing surveys in Guam, CNMI, and American Samoa: Survey design, expansion algorithm, and a case study

1. Evaluate the shore-based and boat-based fishing survey designs and determine if the survey designs are appropriate.
2. Evaluate the shore-based and boat-based survey expansion algorithm and assess if the expansion methods are appropriate and consistent with the survey designs.
3. Review the boat-based expansion script (in R) for Guam and assess if the expansion methods in the R script are consistent with the expansion algorithm described the PIFSC tech memo.
4. Review the sensitivity analyses conducted for the boat-based survey in Guam regarding the impact of the interview pooling algorithm and selection of representative ports and provide suggestions if available.
5. Provide recommendations for future research/improvements for the survey design and expansion methods.