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Designs for surveys of recreational pāua fisheries

New Zealand Fisheries Assessment Report 2023/04

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EXECUTIVE SUMMARY

Hartill, B.[1] (2023). Designs for surveys of recreational pāua fisheries.

***New Zealand Fisheries Assessment Report 2023/04.* 19 p.**

This report reviews available information on recreational harvesting from pāua (*Haliotis iris*, PAU) stocks in New Zealand, to determine which fisheries are likely to be of most interest to fisheries managers and inform the design of surveys to estimate recreational harvests taken from these stocks. The only informative recreational pāua harvest estimates currently available are those provided by the 2011–12 and 2017–18 national panel surveys and a roving creel survey of the recreational pāua fishery along the Kaikōura coast during a three-month open season in 2021–22 that followed a survey design based on an early draft of this report. Many of the national panel survey estimates may be unreliable as they are based on a limited number of pāua gathering events reported by a small number of panellists. These estimates suggest, however, that other survey methods could be used to estimate the recreational harvest taken from a small number of pāua stocks. These stocks are: PAU 2 and PAU 3; and perhaps PAU 5D and PAU 7.

The fishery that is currently of greatest concern is in PAU 3, where the vast majority of the recreational harvest is taken along a 55-km stretch of coast adjacent to the Kaikōura coastal highway. A roving-roving survey design is proposed, to provide a pāua harvest estimate that should be more accurate and defensible than any estimate provided by a less targeted national panel survey. This onsite survey method is considered to be the most viable onsite method available, because gathering effort is dispersed along the coast. The two components to this method are: an initial progressive instantaneous count of pāua gatherers made during a single pass along a surveyed stretch of coast; followed by interviews with gatherers during the return trip, to collect catch per trip data. Randomly timed replicate surveys would be required for all combinations of seasonal, day-type (weekend days vs. midweek days), and tidal (low and high tide) strata to provide estimates of the average harvest occurring within each stratum.

The other fishery where levels of recreational harvesting are of potential concern is in PAU 2, although much of this stock is closed to commercial harvesting. The main area of overlap between the commercial and recreational fisheries occurs on the south-east coast of the North Island, between Turakirae Head on the south coast and Cape Turnagain on the Wairarapa coast. A roving-roving survey design, such as that proposed for the Kaikōura coast could be used here too, given the experience gained from the PAU 3 survey. Access to this stretch of coast is far more discontinuous than at Kaikōura, and it would therefore be necessary to break up the survey area into a greater number of spatial strata, requiring a larger and more expensive survey.

The two remaining pāua stocks where there is a potentially substantive need to estimate recreational harvests are in PAU 5D and PAU 7. Although the harvest estimate from the 2017–18 national panel survey suggests that an appreciable tonnage of pāua is taken from the PAU 5D stock, much of this would have been taken from areas which are closed to commercial fishing. Conversations with commercial pāua fishers and Ministry for Primary Industries fisheries officers suggest that the likely level of recreational harvesting in commercially fished areas is not currently of great concern, in part because the sea state and water clarity on this exposed coast precludes harvesting on most days. A roving-roving survey in this area is therefore unlikely to be cost-effective, because it would be necessary to survey a very high proportion of days in a survey year, to ensure that a harvest estimate is reasonably precise given the unpredictability of weather on this coast.

No survey method is proposed for the PAU 7 fishery because the majority of the recreational harvest from this stock is taken from boats, and a complete census of all access points is not possible given the

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geography of this area. The only onsite survey method that has been used to date, to provide estimates of the recreational harvests taken from boats in Fishery Management Area 7 is the aerial-access approach, but shellfish gathering effort is too cryptic to be reliably counted from the air and the panel survey method probably offers the most viable means of estimating recreational pāua harvests in this area.

1. INTRODUCTION

This report was originally written in 2016, to inform the design a survey of the Kaikōura pāua (*Haliotis iris*, PAU) fishery that was planned for 2017. An earthquake in Kaikōura on the 14th of November 2016, and a subsequent three-year closure of the road along that coast, and the closure of the pāua fishery prevented that survey taking place as scheduled. The Kaikoura pāua fishery was reopened for a three-month period from 1 December 2021 to 28 February 2022, and the recreational pāua harvest for that season was estimated by a roving count survey based on a survey design recommended by a previously unpublished version of this report (Holdsworth 2022). This report is therefore a revised version, to provide updated data summaries derived from the more recent 2017–18 national panel survey (NPS), for all the pāua fisheries except PAU 3, because recreational harvesting from the Kaikōura area was prohibited in 2017–18. The data summary for the PAU 3 fishery (which was divided into the PAU 3A and PAU 3B fishery in 2021) is therefore based on data provided by the pre-quake 2011–12 NPS.

The only recreational pāua harvest estimates that are currently available are those provided by national and regional telephone diary surveys conducted between 1991 and 2001 (Tierney et al.1997, Bradford 1998, Boyd et al. 2004, Boyd & Reilly 2004), by the 2011–12 and 2017–18 national panel surveys (Wynne-Jones et al. 2014, Wynne-Jones et al. 2019), and a roving creel survey of the recreational pāua fishery along the Kaikōura coast during a three-month open season in 2021–22 (Holdsworth 2022). The telephone diary estimates from the early to mid-1990s are now out of date and of unknown reliability, and the estimates provided by the 1999–00 and 2000–01 surveys are thought to be significantly biased.

Although the more recent national panel surveys appear to provide reasonably accurate and precise recreational harvest estimates for most of New Zealand's key recreational fisheries, offsite methods such as the NPS do not usually provide defensible estimates for niche fisheries with low participation rates, for example those for pāua and red rock lobster (*Jasus edwardsii*, CRA). Also, a significant proportion of the harvest taken from shellfish stocks is often accessed from the shore, where the resource is available to transient seasonal workers and visiting tourists whose activity and harvest is not in scope for an offsite survey design. Onsite survey methods potentially offer a more targeted and cost-effective means of surveying all shellfish harvesting effort, given the direct observational survey methods used.

The focus of this study is to design a survey method that could be used to provide robust estimates of the recreational harvest of pāua taken along a stretch of the PAU 3 coast that extends from the Clarence River (35 km north of Kaikōura) to the Conway River (20 km to the south). Pāua harvests taken along this stretch of coast account for the majority of the recreational harvest taken from the PAU 3, with most of the remaining effort occurring further south at Gore Bay, Motunau, and around Banks Peninsula.

The scope of this study has also been broadened by an initial assessment of data and harvest estimates provided by the NPS data and harvest estimates. This has been done to determine and prioritise which recreational pāua fisheries could be potentially surveyed using onsite survey methods, such as those proposed here for PAU 3.

The objectives of this programme were

1. To design a survey tool to robustly estimate the recreational fisheries harvest of part of, or, all of PAU 3.
2. To provide cost estimates for delivery of the survey design developed under specific objective one.

2. REVIEW OF EXISTING DATA ON RECREATIONAL PĀUA FISHERIES

The pāua harvest estimates provided by the 2011–12 NPS for PAU 3, and the 2017–18 survey for all other pāua stocks, are given in Figure 1 and Table 1. Recreational harvest estimates from national panel surveys are available for all pāua stocks except for PAU 4 (as the screening survey used to recruit panellists did not cover the population on the Chatham Islands). Another harvest estimate is available for PAU 4, however, from a census of Chatham Islanders and associated surveys of fishers visiting these islands during the 2008–09 fishing year (Davey et al. 2011). The total recreational harvest estimate for PAU 4 produced by this survey was 3.7 t.

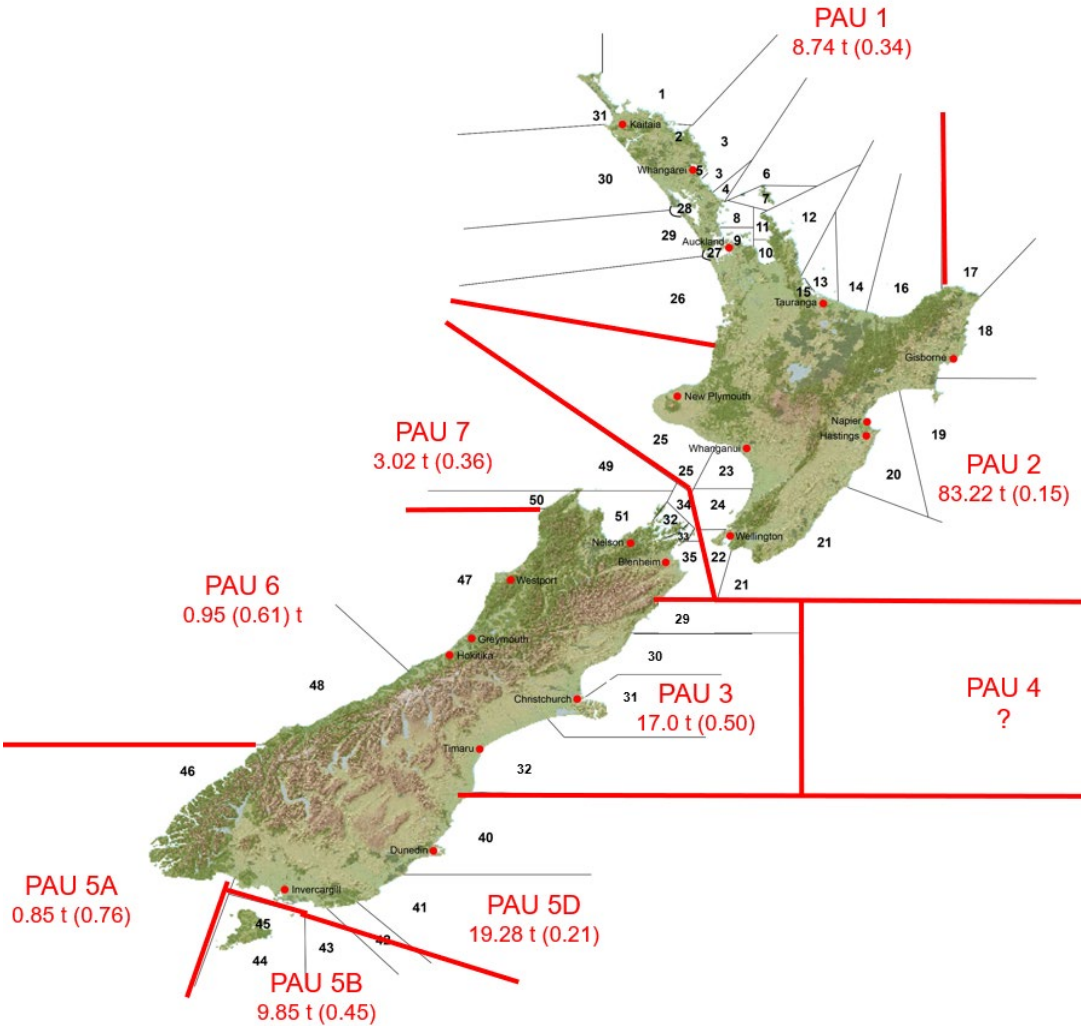

Figure 1: National panel survey estimates of the recreational harvest (tonnes) from each pāua stock, based on the 2011–12 NPS for PAU 3, and the 2017–18 NPS for all other pāua stocks. Coefficients of variation are given for each estimate in parentheses. Red lines delineate the boundaries of each pāua stock and grey lines and numbers denote trip reporting areas used by panellists.

The harvest estimate for PAU 5B will also be an underestimate, because residents on Stewart Island were also excluded from the screening survey sample frame and their harvest was therefore not estimated. The panel survey harvest estimates for PAU 5A and PAU 6 are also considered to be uninformative, because of the low number of panellists reporting pāua harvests taken from these two west coast Quota Management Areas (QMAs) (Table 1). Previous analyses conducted by the National Research Bureau (who conducted the national panel surveys) suggest that harvest data from at least 250 panellists would be required to provide a robust recreational harvest estimate for a given fish stock (Andy Heinemann, National Research Bureau, pers. comm.). The recreational harvest of pāua from these two south-west coast stocks is likely to be negligible relative to the commercial harvest given the low population density along this coast.

Table 1: Summary of survey data and harvest estimates provided by the 2011–12 NPS for (Wynne-Jones et al. 2014) PAU 3, and the 2017–18 NPS (Wynne-Jones et al. 2019) for all other pāua stocks, relative to the Total Allowable Commercial Catch (TACC) and recreational allowances where they were applied in 2020–21.

Fish stock	Panellists (taking pāua)	Fishing events (pāua)	Harvest (t)	CV	Informative estimate	TACC (t)	Recreational allowance (t)
PAU 1	27	41	8.74	0.34	N	2	–
PAU 2	179	384	83.22	0.15	Y	121	–
PAU 3*	35	67	16.98	0.31	N	46	–
PAU 4	–	–	–	–	–	326	–
PAU 5A	3	4	0.85	0.76	N	150	–
PAU 5B	10	21	9.85	0.45	N	90	6
PAU 5D	50	90	19.28	0.21	?	89	22
PAU 6	3	7	0.95	0.61	N	1	–
PAU 7	14	22	3.02	0.36	N	94	15

* The TACC for PAU 3 is for the fishery operating south of the Conway River (PAU 3B, which was gazetted on 1 October 2021). The northern Kaikōura coast PAU 3A commercial fishery was still closed in 2020–21.

Of the five remaining fish stocks, only the recreational harvest estimate for PAU 2 could be considered adequate for management purposes, given the relatively large number of panellists (179) reporting pāua harvests from this area and the high level of precision associated with this estimate (15% CV). The spatial extent of the PAU 2 stock is broad, however, extending from Tirua Point on west coast of the North Island, around the southern coast to Cape Runaway north of East Cape on the east coast of the North Island. Only part of the recreational harvest in PAU 2 will be taken from areas where commercially harvesting takes place (between Castlepoint and Wellington), and a more focused recreational harvest estimate is required for this stretch of coast so that a direct comparison can be made with commercial harvesting levels.

This study therefore focuses on the four stocks for which there were enough panellist data available, to at least inform a characterisation of the fishery (the southern and Wairarapa coast of PAU 2, PAU 3, PAU 5D, and PAU 7). These characterisations are based on two summaries of diarist data; estimates of the harvest and number of panellists reporting activity in sub regions of each QMA (panellist reporting areas delineated as grey lines in Figure 1), and a summary of the harvest taken by shore-based and boat-based methods in each QMA (Table 2).

Table 2: Estimates of the proportion of the pāua harvest reported by panellists in each fish stock, by harvesting method and fishing platform provided by the 2017–18 National Panel Survey (2011–12 National Panel Survey for PAU 3) (Wynne-Jones et al. 2014, 2019).

	QMA						
	1	2	3	5A	5B	5D	7
Diving or snorkelling/ from boat	0.25	0.02	0.20	–	0.41	0.01	–
Diving or snorkelling/ from shore	0.50	0.70	0.68	0.41	0.27	0.50	0.53
Hand gathering/ from boat	0.17	0.11	–	0.24	0.32	0.28	0.47
Hand gathering/ from shore	0.08	0.17	0.11	0.36	0.01	0.21	–
Diving or snorkelling	0.75	0.72	0.88	0.41	0.68	0.51	0.53
Hand gathering	0.25	0.28	0.11	0.59	0.32	0.49	0.47
Boat-based methods	0.42	0.13	0.20	0.24	0.72	0.29	0.47
Shore-based methods	0.58	0.87	0.80	0.76	0.28	0.71	0.53

3. ONSITE SURVEY DESIGN FOR THE CORE RECREATIONAL PAU 3 FISHERY

3.1 Characterisation of the recreational fishery in PAU 3

In 2011–12 the PAU 3 fishery extended from the Clarence River to the Waitaki River, although most of the recreational pāua taken from this area was harvested along a 60-km stretch of coastal highway between the Clarence River (35 km north of Kaikōura) and Oaro (25 km to the south of Kaikōura and 12 km north of the Conway River). The only other areas in PAU 3 where recreational pāua harvesting commonly takes place are where there is public road access to the rocky coast, at Gore Bay and at Motunau, and around Banks Peninsula.

The PAU 3 QMA was split into two separate QMAs on 1 October 2021, with PAU 3A covering the area north of the Conway River, and PAU 3B covering the area south of the Conway River. Most of the recreational harvest from these two areas is therefore taken from PAU 3A.

Most of the concern about the level of recreational harvesting is along the Kaikōura coast (PAU 3A), where commercial fishers have suggested that amateur pāua gatherers may take as much as 100 t annually (Jeremy Cooper, CEO, Pāua Industry Council, pers comm.). The coastal highway provides easy access to relatively high densities of pāua.

There are several reasons why the 16.98 t recreational harvest estimate provided by the 2011–12 NPS for PAU 3 is likely to be a significant underestimate. The pāua harvest taken by local residents will be significantly underestimated because no meshblocks (spatially defined clusters of up to 100 dwellings which were the primary sampling unit used in the screening survey) were selected from the Kaikōura District (Wynne-Jones et al. 2014). Some local pāua fishers would have been recruited from adjoining Territorial Local Authorities (11 meshblocks sampled from the Marlborough District to the northwest and 4 from the Hurunui District to the south), but residents from the Kaikōura District would probably account for most of the pāua taken by locals along this coast. Another limitation with the NPS estimate is that harvests by non-New Zealand residents were not assessed, because they were not in scope for the initial screening survey. Much of the harvest in this area is taken by freedom campers and other tourists from overseas, and by seasonal orchard workers who are recruited from the Pacific Islands for the fruit harvest season every summer (Mark Green, Ministry for Primary Industries (MPI) Fisheries Officer, pers. comm.).

Offsite survey methods such as panel surveys do not, therefore, provide an appropriate means of estimating the recreational pāua harvest in this area. This is because the initial screening survey is unlikely to encounter transient fishers harvesting pāua from this stock in the coming year. The incidence of pāua fishers in the surveyable population is also likely to be relatively low for this and other pāua stocks, and prohibitively large-scale and expensive screening and panel surveys would therefore be required to obtain reasonably accurate harvest estimates.

Regardless of these limitations, some valuable information can be inferred from the data provided by the 2011–12 NPS for the PAU 3 fishery. Over half of the PAU 3 harvest estimate was taken by panellists from area 29, between the Clarence and Conway rivers (Figure 1, Table 3). This estimate suggests the pāua harvest taken along the Kaikōura coastal highway is appreciable, and that it may potentially approach the guestimate of 100 t suggested by commercial fishers, when harvests by local and transient fishers are taken into account.

Table 3: Summary of survey data and harvest estimates for each of the reporting areas in PAU 3 used by panellists participating in the 2011–12 NPS (harvesting from area 29 was closed to fishing during the 2017–18 NPS, following the 2016 earthquake). Refer to Figure 1 to see spatial extent of each reporting area.

Reporting area	Panellists (taking pāua)	Fishing events (pāua)	Harvest (t)	CV
29 Clarence River to Conway River	21	38	10.3	0.31
30 Conway River to Sumner Beach	4	13	1.6	0.92
31 Sumner Beach to Rakaia River	13	21	5.0	0.68
32 Rakaia River to Waitaki River	0	0	0.0	–
Areas 29–32 total	35	67	17.0	0.15

Almost all of the harvest from panellist reporting area 30 would have been landed at Gore Bay and at the boat ramp at Motunau. Fisheries Officers working in this area suggest that the combined catch landed at these two access points would be less than 5% of that taken along the Kaikōura coast (area 29), where pāua are far more accessible (Mark Green, Fisheries Officer, Kaikōura and Steve James, Honorary Fisheries Officer Coordinator, Christchurch).

The pāua harvest reported by panellists fishing in area 31 would have been taken from Banks Peninsula, which is bracketed by long stretches of beach to the north and south, that do not provide a suitable habitat for pāua. Most of the pāua taken on the northern coast of Banks Peninsula by recreational fishers are undersized, as pāua growth in this area is stunted, but legal size pāua are more common on the southern coast, where access is more restricted (Steve James, MPI Fisheries Officer, pers comm.). The rocks around Timaru provide the only pāua habitat in reporting area 32, where the water is usually murky and the pāua are mostly below the minimum legal size limit (Reyn Naylor, retired NIWA Fisheries Scientist, pers comm.). No panellists reported pāua harvests taken from area 32.

The 2011–12 panellist data also suggest that 80% of the harvest from PAU 3 was taken from the shore (Table 2) and a closer examination of the data available from reporting area 29 alone suggests that approximately 95% of the pāua harvest in this area in 2011–12 was taken from the shore. A local fisheries officer (Mark Green) has also suggested that around 95% of the harvest from the Kaikōura area is taken from the shore, in part because boat-based fishing parties cannot take pāua when they have scuba gear onboard their boat, which is a common occurrence in that area. The limited amount of diarist data available suggest that the relative incidence of boat-based pāua harvesting is higher in reporting area 30, and most of this is probably landed at the boat ramp at Motunau.

All available information therefore suggests that most of the pāua harvest taken from the Kaikōura area (PAU 3) is taken from the shore, with onsite methods offering the most viable means of providing harvest estimates along this short stretch of coast, where much of the effort is transient. Almost all onsite surveys of recreational fishers in New Zealand to date have been based around creel surveys conducted at fixed access points that fishers funnel through (Hartill et al. 2012), but different methods are required here given the dispersed and unpredictable distribution of fishing effort along the Kaikōura coast.

3.2 Roving-roving survey design for the shore-based Kaikōura fishery

The most suitable onsite means of estimating the pāua harvest taken by shore-based fishers along the Kaikōura coastal highway is a roving-roving survey design (Pollock et al. 1994). There are two components to a suitable roving-roving survey design: a progressive/semi-instantaneous count of pāua gatherers made during a single transit of the coast, to provide a point-in-time estimate of total effort within a given spatio-temporal stratum; and a roving creel survey of pāua gatherers to provide harvest per trip and average trip length data for the same stratum. As with all onsite surveys, the spatio-temporal sample frame used should be informed by the local context and dynamics of the fishery, and the methods proposed here are partially informed by a site visit with guidance provided a local MPI Fisheries Officer (Mark Green).

Spatial stratification

The potential extent of a spatial survey stratum is primarily determined by the time required to complete a progressive count of gatherers along the shoreline, as time is still be required to collect catch effort data from gatherers. Ideally a progressive count should take no longer than one hour to complete, which restricts the surveyable length of coastline to less than 30 kilometres, as gathering effort may be intensive at times. The Kaikōura coast could therefore be divided into three spatial strata: a Northern stratum from Waipapa Bay to the Hāpuku River, north of Kaikōura Peninsula (approximately 30 km by road); a Middle stratum comprising the Kaikōura Peninsula to the mouth of the Kahutara River just south of Kaikōura; and a neighbouring Southern stratum extending south to Oaro (approximately 20 km by road, Figure 2). Up to 100 gathering parties may be observed in any of these spatial strata during the summer when the tide is low (Mark Green, pers comm.).

In 2016 Mark Green suggested that about 30% of the pāua gathered along the Kaikōura coast was taken in the Northern stratum. Almost no recreational harvesting occurs along the coast north of Waipapa Point, where the road turns inland before passing over the Clarence River. There is also a 3-km stretch of gravel beach centred on Mangamaumu, which does not provide a suitable habitat for pāua. This leaves two stretches of coast in the Northern stratum where pāua harvesting occurs; a 2-km stretch of boulder bank north of the Hāpuku River and 14 km of rocky coastline running north from Vic Rock (at the Te Ikawataroa Rocks) to Waipapa Point. Gatherers and their cars should be visible from most of the neighbouring coastal highway, but there are some areas where the interviewer would have to walk away from the road to observe pāua gathering.

Almost all of the pāua taken from the Middle stratum will be from the Kaikōura Peninsula, as there is a gravel beach extending north from Lyle Creek (in Kaikōura) to the Hāpuku River, and a further stretch of beach to the south, running from the Racecourse Rocks to the Kahutara River. Much of the suitable pāua habitat occurs along a 5-km stretch of coast on the south-eastern side of the Kaikōura Peninsula, which is only accessible at low tide. Mark Green has suggested that almost all harvesting in this stratum occurs during the low tide and that there is probably little point in surveying the high tide in this area. He estimates that only about 10% of the Kaikōura coastal pāua harvest is taken from this stratum; mostly by spear fishers targeting finfish and rock lobster, who also take their limit of pāua. Progressive counts of pāua gatherers throughout this stratum could be made from a series of cliff top observation points, with separate and concurrent counts made by two interviewers; one covering the northern half of the peninsula and another covering the southern area. Gatherers could be interviewed when they returned to their cars after harvesting pāua. An alternative fixed-point census approach could be used to estimate the pāua harvest from this stratum, instead of a roving-roving survey design, but this approach is not recommended. Although a full census of all those returning to car parks at either end of the roads north and south of the peninsula is feasible, gathering effort along the coast to the west of these car parks would be missed, resulting in an underestimate of the harvest taken from this stratum.

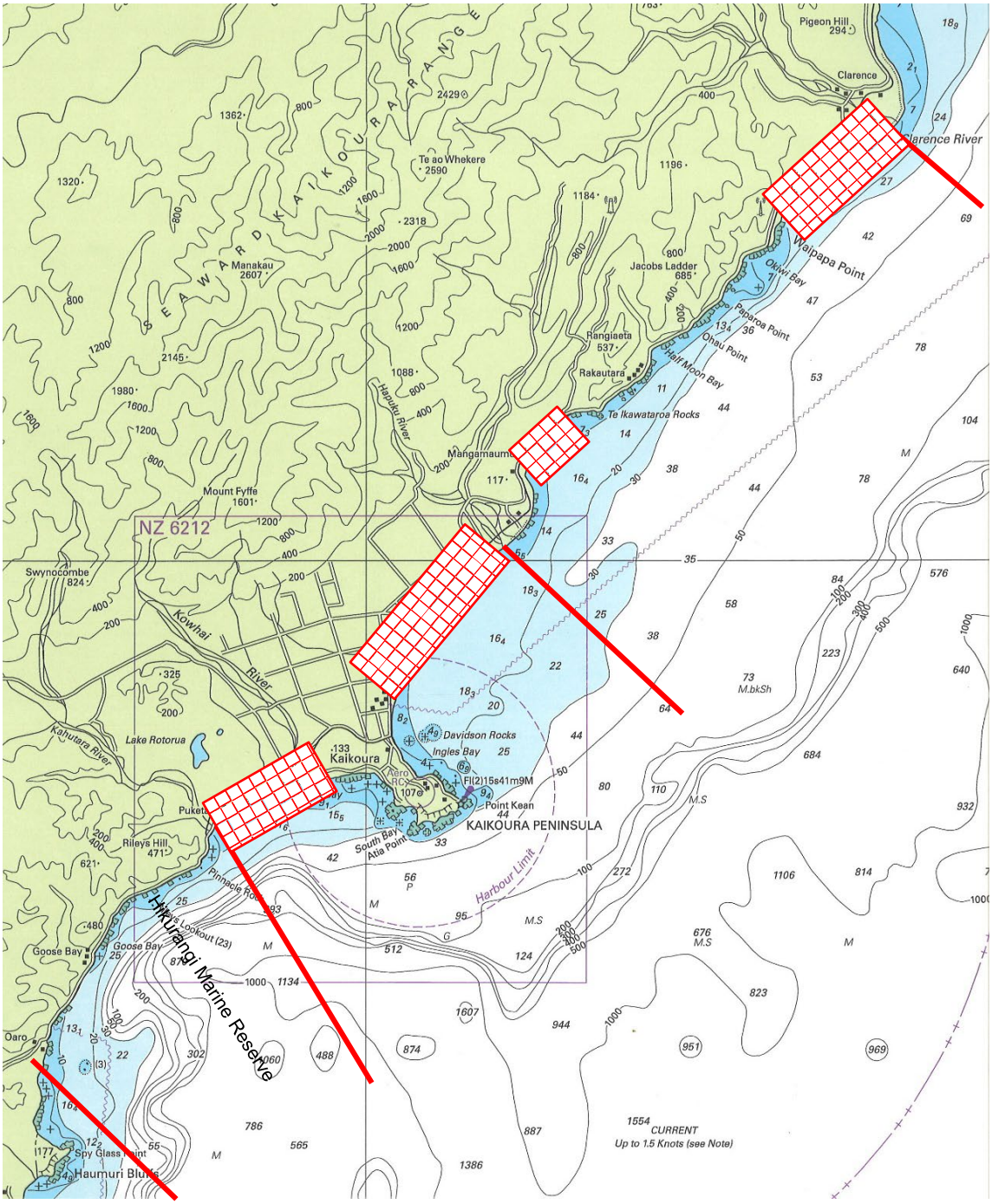

Figure 2: Spatial stratification of the Kaikōura coast. Red lines delineate the boundaries between three spatial strata: Northern, Middle, and Southern. Hashed rectangles denote stretches of coast which can be ignored as they do not support suitable pāua habitat. Pāua harvesting is also prohibited in the Hikurangi Marine Reserve in the Southern stratum, which has a 2-km coastal boundary running south from Rileys Lookout.

It has been suggested that 60% of the pāua harvest taken from the Kaikōura coast is gathered from the Southern stratum that runs south from the Kahutara River to Oaro. The majority of the harvest is taken from this area as the coast is partially sheltered from swells by the Kaikōura Peninsula, and it is the first pāua habitat encountered by those travelling from Christchurch. Pāua are found all along this 14-km stretch of coast, but gathering is prohibited in the Hikurangi Marine Reserve, which has a 2-km coastal boundary running south from Rileys Lookout. Most of the rocky shoreline is directly adjacent to the highway, and most of the harvesting occurs in areas where parking is available. The only areas where

the rocky shoreline is not visible from the highway are two campgrounds which are shielded by trees. These areas are usually accessible by car, but they are heavily congested during the holiday season and the interviewer would have to walk a few 100 metres along each campground's shore to count and interview gatherers during this time of year.

Temporal stratification

When this report was first written, pāua were harvested along the Kaikōura throughout the year, and a 12-month sampling design was proposed accordingly. Following the earthquake, the Kaikōura pāua fishery was only opened for a three-month season in 2021–22 and will be open for a two-month season in 2023. The 12-month sampling design described below should therefore only be considered if the fishery is no longer managed with seasonal closures. The methods described here provided the basis for a three-month open season survey of the Kaikōura pāua fishery running from 1 December 2021 to 28 February 2022 (Holdsworth 2022).

The proposed temporal sample frame should be based on a nested three-stage design. At the broadest level, the year could be divided into two seasonal strata; summer (1 December to 30 April) and winter (1 May to 30 November). Although recreational survey designs elsewhere categorise October and November as 'summer' months, the weather in Kaikōura during these months is not usually conducive to pāua harvesting and these months should therefore be included in the winter strata.

Two day-type strata should be nested within each seasonal stratum; a weekend/public holiday stratum and a midweek stratum. Fishing effort is usually higher during public holiday/weekends and all days falling between Christmas and the New Year will be treated as public holidays (between 24 December and 2 January during the 2016–17 year). Effort on Saturdays tends to be higher than on Sundays (Mark Green, MPI Fisheries Officer, pers. comm.). Effort during the public holiday/weekend stratum can therefore be highly variable but considerable, and it is likely that a high proportion of the sampling effort would be allocated to this stratum.

Harvesting effort within any given temporal stratum is likely to vary considerably from day-to-day, as the incidence of onshore swells is variable and unpredictable. This means that it will be necessary to conduct surveys on an appreciable number of randomly pre-selected days if the average daily harvest is to be estimated with reasonable precision and accuracy. There are no data available that could be used to gauge the level of sampling effort required to survey this fishery, and the level of sampling effort proposed in Table 4 is therefore nominal and based on experience elsewhere and discussions with local fisheries officers.

Alternative levels of sampling effort should also be costed if a survey is commissioned, so that some qualitative assessment could be made of the trade-off between survey cost and the risk of obtaining a biased or imprecise harvest estimate. The level of sampling effort proposed in Table 4 is considered to be the minimum for a survey of this nature, given experience elsewhere. Additional survey days could be allocated to the busier strata, especially in the Southern stratum, where around 60% of the pāua harvest could be taken.

Table 4: Proposed temporal sampling design based on the 2016–17 calendar. Surveys could be conducted of the same spatial strata during both the low tide and high tide on each surveyed day.

Season	Day-type	Days	Surveyed days	Sampling intensity
Summer	Weekend/holiday	69	20	29%
	Midweek	82	20	24%
Winter	Weekend/holiday	63	10	16%
	Midweek	151	10	7%
Total		365	60	

There would be some merit in installing a camera overlooking a coastal parking area commonly used by pāua gatherers, at least a year in advance of any survey, as daily effort counts provided by such a system could be used to inform survey design simulations. The relationship between daily effort counts and hindcast swell predictions could also be examined, so that some allowance could be made for interannual variability in levels of harvesting activity.

Relative levels of daily effort could also be monitored by a camera, during a surveyed year, to infer whether effort on surveyed days was broadly representative of that occurring throughout the temporally stratified year. This camera-based monitoring approach has previously been used to assess the representativeness of survey days flown during the aerial-access survey in QMA 1 in 2011–12 (Hartill & Edwards 2015). Effort monitoring such as this should ideally be based on observations of pāua gatherers rather than cars, but gatherers will be harder to detect unless the field of view is very narrow, especially during dawn and at dusk, and when it is raining.

Tidal height also has a marked influence on levels of pāua harvesting, and some form of within day tidal stratification will therefore be required within each seasonal/day-type stratum. Local knowledge consistently suggests that there is a higher level of harvesting within one and a half hours either side of low tide than at any other time during the tidal cycle. Less experienced gatherers and those who do not have a mask and snorkel available are more likely collect pāua when the tide is low. The length of the 'low tide' stratum will therefore be much shorter than the length of the 'high tide' stratum for each day, and two low tides falling within a surveyed day should be considered to be a single discontinuous stratum. Relative tidal stratum sizes will therefore vary by day (as day length changes throughout the year) and the length of these should be calculated for all days falling within a survey year. It has been suggested that legally compliant pāua harvesting only occurs during daylight hours (Mark Green, pers. comm.).

At least two survey clerks would be required to undertake the proposed survey design, given the sampling intensity of the summer weekend/public holiday stratum and the need to implement this temporal sampling design in three spatial strata. Although one clerk could conceivably survey 20 summer weekend/public holiday days in each of the three spatial strata, this would mean that they would be required to work 93% (3 × 31%) of all possible days, which is probably not tenable. One survey clerk could be assigned to the Northern stratum and another to the Southern stratum, and they could work together to survey the northern and southern halves of the Middle strata concurrently during low tides on a further 60 preselected days.

The estimation of the pāua harvest within each spatial/seasonal/day-type/tidal stratum on a survey day could be as follows. A spatially referenced progressive count of the number of gatherers could be made during a single uninterrupted transit along a stratum coastline. This count could be considered to be reasonably instantaneous given the speed of the observer relative to that of the fisher and the relatively short length of coastline associated with each spatial stratum (Pierce & Bindman 1994). The start time of the instantaneous count within each temporal stratum should be randomised to avoid any temporal/tidal cycle related sampling bias, although the need to survey the neighbouring spatial stratum during the same tidal cycle would be a consideration, especially during the relatively short 'low tide' tidal stratum. The order and direction in which the three spatial strata are surveyed during a single tidal stratum could be randomly determined in advance. Progress throughout this progressive count should be monitored on a GPS linked laptop which could be used to record the location of each gathering party, and the number of gatherers. All those below the water's edge will be considered to be gathering (unless this was obviously not the case). It has been suggested that 95% of those in the water will be targeting pāua, and the remainder will be taking pāua in a more opportunistic fashion regardless.

Calculation of harvest estimates

Harvest estimates derived from a roving-roving access design are the product of an estimate of the total effort within a spatio-temporal stratum and an associated catch rate estimate.

An estimate of the total pāua gathering effort, $\hat{e}$, taking place within a spatial stratum within a tidal stratum *j* on a given survey day *i* is

$$\hat{e}_{ij} = I_{ij} \times T_j$$

where I_{ij} is the randomly timed 'instantaneous' count of gatherers made during the tidal stratum *j* on the survey day *i* and T_j the length of that tidal stratum expressed in hours.

These estimates can be combined and scaled up to provide an estimate of the total effort taking place during the tidal phase *j* across all days occurring within each seasonal/day-type stratum *k,* which is

$$\hat{E}_{kj} = \frac{\sum_i e_{ikj}}{\pi_k}$$

where π_k is the proportion of days surveyed within each seasonal/day-type stratum.

An estimate of the arithmetic average pāua catch rate $\hat{R}$ for a given seasonal/day-type/tidal stratum *kj* is estimated from data collected during interviews with gatherers when they have finished harvesting

$$\hat{R}_{kj} = \frac{\sum_{t=1}^{n} h_{kjt}}{\sum_{t=1}^{n} L_{kjt}}$$

where h_t is the harvest and L_t is the length of trip *t* expressed in hours and *n* is the number of trips investigated. Alternative estimates of average catch rates could also be calculated as geometric means, but these will probably produce estimates of a very similar magnitude, as most gatherers will take their daily bag limit of pāua.

An estimate of the harvest $\widehat{H}$ occurring during a seasonal/day-type/tidal stratum *kj* over the survey period is therefore

$$\widehat{H}_{kj} = \hat{E}_{kj} \times \hat{R}_{kj}.$$

The catch rate estimate used should be based solely on that reported by those gathering during the same tidal stratum (because gatherer proficiency is tidally related as discussed above). Data on catch rates and other aspects of gathering behaviour (such as the incidence of 'releasing' which may be a significant source of mortality for this haemophiliac species) should also be collected during interviews with fishers before, or after the progressive count is made on the return trip within a given spatial stratum. It is likely that it would be necessary to pool catch rate data across survey days (for each given temporal stratum) because few gatherers may be encountered on some surveyed days. Variance estimates could be calculated by a non-parametric bootstrapping approach similar to that used by Hartill & Cryer (2000). Two-stage bootstrapping should be used, where trips are bootstrapped within bootstrap days.

Harvest estimates should be expressed in terms of both numbers of pāua taken, and weight. Catch weights should be calculated from catch-at-length data by applying a length-weight relationship derived from pāua measured and weighed from the surveyed area. Interviews should therefore collect some paired length weight data during the course of the survey for this purpose.

It would also be necessary to conduct an independent assessment of trip durations reported by gatherers. The legal daily amateur limit for pāua in this area was reduced from 10 to 5 pāua for the three-month open season in 2021–22 (and may be reduced further for a two-month season in 2023), and this means that some gatherers will only require a short period of time to collect their limit (as short as 10 minutes). The potential for inaccurately reported gathering durations is therefore appreciable, as unintentional over- or under reporting of gathering effort by a few minutes could result in substantially biased catch rate and,

hence, total harvest estimates. Inaccurately reported trip durations are less of an issue for finfish fisheries when trip lengths are longer and the issue also is self-correcting when the maximum count aerial-access is used. The potential for inaccurate effort reporting should therefore be assessed by observing and recording the time that gatherers look for pāua (or at least spend below the water line) and then asking them at the end of their trip how long they spent gathering. The most cost-effective way of collecting this information would be for interviewers to focus much of their time on areas where multiple gathering parties can be seen at any one time. Video cameras could also be used to provide information on trip durations, but their effective field of view would be limited and corresponding fisher-based estimates of the time spent gathering would not be available. Any bias and uncertainty associated with reported trip durations should also be factored in when calculating the statistical uncertainty associated with harvest estimates.

It is unlikely that the data collected by the proposed roving-roving survey design could be used to provide recreational harvest estimates for any other species, as almost all of the shore-based effort is directed towards pāua. National panel survey estimates from 2011–12 suggest that only 18% of the harvest from CRA 5 was taken from the shore (Wynne-Jones et al. 2014) and different methods such as a bus route survey (e.g., Jones et al. 1990) would therefore be required to estimate the majority of the rock lobster harvest in the Kaikōura area, which would be taken from boats.

3.3 Estimation of the harvest taken from boats and from other areas of PAU 3

The methods proposed so far can be used to provide an estimate of the shore-based harvest from the Kaikōura coast, but boat-based gatherers will also take a small proportion of the harvest in this area, and pāua will be taken in other parts of PAU 3 which are less intensively fished.

There are at least 9 ramps or stretches of shingle beach along the Kaikōura coastal highway from where fishers sometimes launch their boats. Although this component of the fishery could be estimated directly by some form of bus route survey, the precision of any estimate of the boat-based harvest of pāua is likely to be low unless extensive and expensive sampling is undertaken. This is because only a small proportion of boats land pāua, as boat-based fishers prefer to primarily target blue cod (*Parapercis colias*) and rock lobster. For quantified evidence of this, see table 3 of Te Korowai o Te Tai o Marokura (2008) which suggests that less than 10% of boat trips involve targeting of pāua.

Alternatively, an approximate estimate of the boat-based harvest in this area could be assessed by comparing the relative magnitude of the boat-based pāua harvest reported by panellists with the reported shore-based harvest. Although the information provided by the 2011–12 NPS is partially compromised by the fact that households in the Kaikōura area were not surveyed during the first phase screening survey, these data can still provide sufficient resolution (from panellists living elsewhere). This approximate estimate would probably be an over-estimate, however, as transient fishers from overseas (who would not participate in a panel survey) are far less likely to be fishing from a boat than New Zealand residents.

A small-scale creel survey could be used to assess some, but not all of the remaining pāua harvest that is taken south of Oaro (the southern end of the Kaikōura highway). There is a 4-km stretch of coast immediately south of Oaro, which can only be accessed through a locked gate. Key holders could be asked to keep a diary, which would give some indication of the relatively low harvest taken from this area. Almost all of the pāua harvest taken between Oaro and Motunau passes through the southern car park at Gore Bay and across the boat ramp at Motunau (Steve James, MPI Fisheries Officer, pers. comm.) and a fixed-point creel survey could be used to assess the harvest landed at these access points if required. There is no cost-effective way of estimating the harvest taken from Banks Peninsula given the dispersed and low intensity of gathering effort in this area and the numerous access points which are relatively remote from each other. Government fisheries officers typically use checkpoints in this area to intercept fishers returning from multiple access points, but research providers do not have the necessary authority to direct traffic as required. The only other area of PAU 3 where recreational harvests of pāua could be taken off the rocks is at Timaru, and the harvest there is probably very modest.

Survey methods could therefore be used to estimate some but not all of the recreational harvest from PAU 3 south of Oaro, but the scale of this harvest probably does not warrant surveying, and the expedient of using panel survey data to provide an approximate estimate of the relative harvest from PAU 3 taken south of Oaro is recommended.

4. SURVEY OPTIONS FOR THE PAU 2 FISHERY

Harvest estimates provided by the 2017–18 NPS suggest that the majority of the recreational pāua harvest in New Zealand at that time occurred in PAU 2, where 58% of the estimated national pāua harvest was taken (Table 1). The spatial extent of the PAU 2 is extensive, as this QMA extends from Tirua Point on west coast of the North Island, around the southern coast, to Cape Runaway north of East Cape. Panellist data suggest that 87% of the recreational pāua harvest in this area is probably taken from the shore (Table 2).

Recreational fishers gather pāua from throughout PAU 2 (Table 5) but there is no onsite survey method currently available that can be used to cost-effectively estimate shore-based harvests over such a vast spatial scale. Aerial survey methods can be used to obtain semi-instantaneous counts of pāua gatherers along an extensive stretch of coast, but these counts are unlikely to be reliable given the low visibility of gatherers wearing wetsuits in the water.

The area of PAU 2 where there is the most concern about levels of recreational harvesting is along the stretch of coast between Cape Turnagain on the Wairarapa coast and Turakirae Head on the south Wellington coast (panellist reporting area 21 in Figure 1), as this is also the area where most of the commercial harvest is taken. Commercial fishers are prohibited from harvesting pāua to the west of Turakirae Head and the water north of Cape Turnagain is usually too murky for pāua harvesting.

Although pāua are found all along of coast between Turakirae Head and Cape Turnagain, most of this coast is only accessible from private land, and the majority of recreational gathering therefore takes place along the more accessible stretches of coast (Tony McKenna, MPI Fisheries Officer, pers. comm.). The main recreational harvesting areas are centred on Ngawi on the south coast, and between White Rock and Manurewa Point, to the east of Cape Palliser. There is a coastal road between these two stretches of coast, but it is only navigable by quad bike as it is in a very poor condition. The next most popular harvesting area is further to the north, between Castlepoint and Mataikona. Gathering along these three stretches of coast probably accounts for the majority but not all of the recreational pāua harvest that occurs within the commercially fished area in PAU 2. Recreational harvesting also sometimes occurs in other areas, such as around Turakirae Head, at Riversdale Beach, and at Ākitio, but the intensity of gathering in these areas is probably too low to justify the expense of a survey.

Table 5: Summary of survey data and harvest estimates for each of the reporting areas in PAU 2 used by panellists in 2017–18 when reporting their catch. Refer to Figure 1 to see spatial extent of each reporting area.

Reporting area	Panellists (taking pāua)	Fishing events (pāua)	Harvest (t)	CV
17 East Cape - Northern	5	8	0.60	0.57
18 East Cape - Southern	8	9	1.30	0.60
19 Hawke Bay - Northern	9	24	2.37	0.56
20 Hawke Bay - Southern	25	50	8.25	0.34
21 Cape Turnagain to Turakirae Head	56	115	29.43	0.30
22 Turakirae Head to Tītahi Bay	43	93	23.54	0.29
23 Waitōtara River to Manawatū River	0	0	0.00	–
24 Manawatū River to Tītahi Bay	10	19	2.40	0.40
25 Waitōtara River to Tirua Point	23	66	15.34	0.33
Total	179	384	83.22	0.15

The roving-roving survey design proposed for the Kaikōura fishery could be used to estimate recreational pāua harvests taken along the three main stretches of coast, especially given experience gained from an initial survey in PAU 3. The population density on the Wairarapa coast is low, however, and the availability of suitable and reliable interviewers may therefore be an issue.

5. SURVEY OPTIONS FOR THE PAU 5D FISHERY

According to the most recent national panel survey, the PAU 5D stock supports New Zealand's second largest recreational pāua fishery, from which an estimated 19.28 t was landed during the 2017–18 fishing year (Wynne-Jones et al. 2019, Table 1). Most of the reported harvest was taken from panellist reporting areas 40 and 43 which encompass Dunedin and Invercargill, respectively (Table 6) and 71% of the reported harvest was taken by shore-based gatherers (Table 2). The information provided by this survey should be regarded with some caution, however, given the limited number of diarists reporting pāua harvests and the limited number of associated gathering events (Table 6).

Table 6: Summary of survey data and harvest estimates for each of the reporting areas in PAU 5D used by panellists in 2017–18 when reporting their catch (Wynne-Jones et al. 2019). Refer to Figure 1 to see spatial extent of each reporting area.

Reporting area	Panellists (taking pāua)	Fishing events (pāua)	Harvest (t)	CV
40 Waitaki River to Tokomairaro River	14	34	6.56	0.38
41 Tokomairaro River to Long Point	13	19	2.84	0.37
42 Long Point to Slope Point	3	3	0.58	0.66
43 Slope Point to Te Waewae Inlet	20	34	9.31	0.31
Total	50	90	19.28	0.21

Although the available data suggest that recreational pāua fishing occurs all along the PAU 5D coast, commercial fishing is prohibited in some areas, which limits the spatial overlap between these two sectors. Almost all commercial harvesting occurs along three stretches of coast in PAU 5D which are relatively unpopulated: between Oamaru and Shag Point, north of Dunedin; between Nugget Point and Waipapa Point, in The Catlins; and between Riverton and the Waiau River, west of Invercargill (Ross Newton, commercial fisher, pers. comm.). Some of the recreational harvest taken from commercially fished areas will be taken by farmers from private land which is not accessible to the public and would be difficult to survey.

Pāua populations on the southern coast are in a reasonably healthy state, where commercial fishers have adopted a voluntary 132-mm minimum shell length limit, which is considerably larger than the 125-mm minimum legal size which recreational fishers generally comply with. Although commercial fishers would like to see minimum legal size limit in this area increased to 132 mm, because recreational fishers take fish before they reach the voluntary commercial size limit, there does not currently appear too much concern by commercial fishers about the annual pāua harvest taken by recreational fishers in this area (Ross Newton and Robby Wallace, commercial fishers, pers. comm.).

The weather along the exposed PAU 5D coast often precludes pāua gathering, and commercial harvesting is usually only possible on about 100 days per year in the northern and more sheltered areas and on about 50 days to the south (Ross Newton and Robby Wallace, commercial fishers, pers. comm.). The sea state visibility on many of these days is usually marginal for amateur fishers wishing to target pāua. Recreational pāua harvesting effort in this area is therefore likely to be spatially and temporally patchy and hard to predict and assess.

All available information therefore suggests that the recreational harvest of pāua in commercially fished areas will be relatively low relative to that taken by the commercial fishery (~85 t per annum) and any

survey of recreational pāua gatherers is unlikely to be cost-effective given the low and unpredictable level of harvesting that takes place. Although some form of onsite method could be used to estimate recreational pāua harvests from PAU 5D, it is unlikely that these surveys would produce estimates which are any better than those provided by the national panel survey approach used in 2011–12 (Wynne Jones et al. 2014) and 2017–18 (Wynne Jones et al. 2019).

6. SURVEY OPTIONS FOR THE PAU 7 FISHERY

Low levels of recreational pāua harvesting occur throughout PAU 7 (Table 7), which is New Zealand's third largest recreational pāua fishery (Table 1; Wynne Jones et al. 2019). Almost half of the estimated pāua harvest in this region is taken from boats (Table 2) which means that the shore-based roving-roving survey method proposed to assess shore-based harvests from the neighbouring PAU 2 and PAU 3 fisheries is not applicable here, as reliable counts of boat-based fishers cannot be made from the accessible shore.

Table 7: Summary of survey data and harvest estimates for each of the reporting areas in PAU 7 used by panellists in 2017–18 when reporting their catch. Refer to Figure 1 to see spatial extent of each reporting area.

Reporting area	Panellists (taking pāua)	Fishing events (pāua)	Harvest (t)	CV
32 Marlborough Sounds	3	5	0.45	0.70
33 Queen Charlotte Sound & Tory Channel	5	5	1.15	0.55
35 Tory Channel to Clarence River	2	3	0.61	0.77
49 North-west of the South Island	2	5	0.13	1.01
50 Cape Farewell to Kahurangi Point	1	1	0.20	1.00
Total	19	41	14.2	0.34

Over half of the estimated recreational harvest from PAU 7 in 2017–18 was taken by snorkelling or diving (Table 2), which are often not apparent from the air. The aerial-access method used to provide estimates of the recreational snapper (*Chrysophrys auratus*, SNA) and blue cod harvest in this Fishery Management Area 7 in 2015–16 (Hartill et al. 2017) cannot therefore be used to provide pāua harvest estimates in a direct manner. The boat-based pāua harvest in this area could be estimated in a relative sense, however, given the observed catch of pāua landed at boat ramps surveyed in 2015–16 relative to the landed catch of snapper and blue cod, as the number of boats fishing for finfish species is determined from the air with far more certainty. A similar approach was used to provide an estimate of the rock lobster harvest in QMA 1 in 2004–05, relative to the snapper harvest, which was estimated by an aerial access survey of the SNA 1 fishery at that time (Hartill 2008), but a PAU 7 harvest estimate based on this approach is unlikely to be any more reliable than that provided by the 2017–18 NPS.

7. ALTERNATIVE SURVEY APPROACHES

There are other methods that could be used to estimate the recreational harvest from key pāua stocks, but none of these are currently considered viable.

Although the panel surveys in 2011–12 and 2017–18 provided harvest estimates for most of New Zealand's substantive recreational fisheries, those available for most shellfish stocks are considered to be unreliable, as relatively few panellists reported shellfish harvesting (Wynne-Jones et al. 2014, Wynne-Jones et al. 2019). This is because only a minority of the recreational fishing population goes shellfish gathering, and it would therefore be necessary to recruit a far larger panel of fishers to ensure that pāua harvest estimates were based on an adequate number of gatherers per pāua stock (ideally at least 250; Andy Heinemann, National Research Bureau, pers. comm.). A panel survey method could be used to estimate the recreational harvest from pāua stocks in a cost-effective manner if a sample frame

was used that was more targeted than the New Zealand-wide meshblock sample frame used in the 2011–12 and 2017–18 panel surveys. Recreational fishers in some Australian states such as Tasmania and Western Australia are required to hold a licence to harvest abalone, and state licence databases are commonly used as cost-effective sample frames by offsite surveys designed specifically to estimate recreational abalone harvests. Although a licence frame offers a cost-effective and robust means of estimating stock-wide harvests of pāua, there has been widespread resistance to the introduction of marine recreational fishing licences for any species in New Zealand, even in the form of a free registry. Another limitation with this approach is that it is unlikely that freedom campers and other tourists would purchase a licence before gathering pāua opportunistically, and their harvest would therefore not be included in the assessed fishery. Māori would also probably be exempt from holding a licence given the second article of the Treaty of Waitangi, which guarantees undisturbed access to their fisheries. Available offsite survey methods do not, therefore, offer a complete or cost-effective means of estimating recreational pāua harvests in New Zealand.

Alternatively, some form of aerial-access survey method could be used to estimate the recreational pāua harvest, with randomly scheduled survey flights providing instantaneous counts of gatherers in a similar manner to the vehicle-based surveys proposed as part of the roving-roving survey suggested above for the PAU 3 fishery. One advantage with using planes as survey platforms is that they can be used to rapidly and cost-effectively survey a series of discontinuous stretches of coastline, instead of having to conduct multiple vehicle-based surveys. Fixed wing aircraft can only fly at speeds greater than about 70 km per hour, however, and the visibility of pāua gatherers would be limited at that speed at any altitude, especially when they are wearing wetsuits or were under water. Helicopters can cover similar distances and can hover when required, but cost at least twice as much as fixed wing aircraft to operate, and are not so readily available in some parts of the country. Alternatively, drones/UAVs (Unmanned Aerial Vehicles) could be used to conduct localised aerial surveys, but their range is usually limited to a few kilometres and they can only be stably operated when the wind speed is relatively low. Some form of aerial survey platform was considered when designing a survey for the PAU 3 fishery, but flying conditions off the Kaikōura coast are often unsafe because of severe turbulence caused by strong offshore winds (Ted Howard, Te Korowai o Te Tai o Marokura and local amateur pilot, pers. comm.). Counts of gatherers could be made from a boat, but sea conditions limit the speed at which a stretch of coast can be surveyed and the number of days on which it would be safe to survey an area.

Harvest estimates provided by most other onsite survey methods are usually based solely on data collected at a limited number of fixed access points such as public boat ramps. Boat ramps act as choke points which fishers funnel through when they return to land after fishing, and creel surveys conducted at these points usually provide the best means of collecting data from the wider fishery. A bus route method can be used to survey a string of access points, and this approach has been used to estimate recreational rock lobster harvests (Holdsworth 2014), but even this cost-effective method is only really applicable when fishers are funnelled through a limited number of defined locations. Most of the harvest taken from pāua fisheries is taken from the shore in a dispersed manner, however, and some form of roving-roving survey method is therefore the only viable approach for fisheries of this nature.

8. CONCLUSIONS

- The level of recreational harvesting from New Zealand's pāua stocks is poorly understood, but there are only a small number of stocks where this may be currently of concern: for PAU 2, PAU 3; and perhaps PAU 5D and PAU 7.
- The area where levels of recreational harvesting is most likely to equal or even exceed the commercial harvest is that adjacent to the Kaikōura coastal highway, which will account for the vast majority of the non-commercial harvest from PAU 3.
- The most viable means of estimating the recreational harvest from the Kaikōura coast is a roving-roving survey design, such as that proposed here.

- A similar approach could be used to estimate the level of recreational harvesting on the Wairarapa coast, which is the main area of the PAU 2 fishery where commercial harvesting takes place. Any such survey should be based on experience gained from implementing the survey design proposed for the Kaikōura coastal fishery.
- The likely level of recreational pāua harvesting in PAU 5D does not appear to be of significant concern.
- The accuracy of the 2017–18 national panel survey estimate for PAU 7 is hard to assess given the low number of panellists that reported landings from this stock, but estimates provided by this survey approach are likely to be the most reliable available. Onsite methods are unlikely to be viable given the diverse nature of the fishery and geography in this area.

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