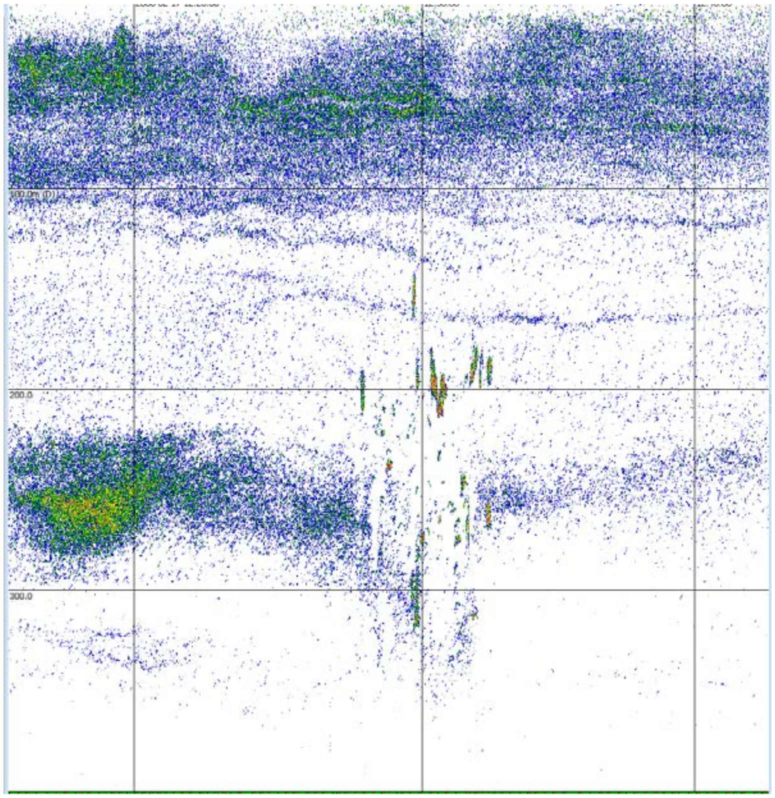
Recommendations for the Use of Active Acoustics at the Pacific Islands Region



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Cover: Active acoustic echogram showing large fish presumably feeding on micronekton. Image courtesy of Réka Domokos.

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Preface

Active acoustics work at the Pacific Islands Fisheries Science Center (PIFSC) commenced in 2004 as a small-scale, ancillary operation to assess the forage-base of economically important fish and protected species in regions of interest, then to develop a fishery-independent method to estimate biomass of a Hawaiian bottomfish stock consisting of six species of lutjanid snappers and a single grouper (the Deep-7 complex), for stock assessment purposes. This document was prepared in the spring of 2018 to provide a summary of knowledge gained and difficulties encountered through the intervening 14 years, and to assess what is needed to produce results that would effectively contribute to the objectives of the Science Center. Focus was placed on bottomfish since the merits of active acoustics were evaluated based on stock assessment, and at the time fisheries independent methodologies for stock assessments were not being considered at the Center. This document was presented to the PIFSC Science Council for review, followed by a brief presentation summarizing its core points. Based on its review focusing on the merits and investments needed to achieve substantial results for Deep-7 stock assessment, the Science Council voted to suspend active acoustic work at the Center on June 26, 2018.

Executive Summary

The Pacific Islands Fisheries Science Center (PIFSC) conducts research in support of ecosystem-based management and conservation of fisheries and living marine resources in the Pacific Islands Region (PIR), encompassing Hawaii, Guam, American Samoa, the Commonwealth of the Northern Mariana Islands, Palau, Micronesia, and the Marshall Islands. The vastness of the region makes it prohibitive to monitor effectively using only traditional methods such as ship-based sampling. Currently, observational data for economically important fisheries target species, as well as for their forage, are obtained via traditional methods, such as fisheries-dependent data, trawling, and visual observations, with the recent addition of optical surveys to improve stock assessment of the main Hawaiian Islands (MHI) Deep-7 bottomfish complex. Active fisheries acoustics, which involves the interpretation of emitted sound reverberated off objects, are not used routinely as a survey tool at PIFSC, although numerous advantages are well documented and routinely used worldwide, including at other Science Centers. Active acoustics efficiently provide fisheries-independent data that are continuous along transects in space and time throughout the water column, independent of light or avoidance/attraction (see appendix). Active acoustics can be used to study behavior, including predator-prey interactions, as well as the distribution, abundance, and composition of key forage species.

While active acoustics methodologies are not routinely used at PIFSC, preliminary observations have been conducted to assess the feasibility of active acoustics to support Deep-7 stock assessment in the Main Hawaiian Islands, with encouraging results. Infrequent active acoustics surveys were previously completed to assess the distribution and relative biomass of micronekton, forage for economically important fisheries and protected species.

The use of active acoustics in the PIR carries unique challenges due to consistently rough sea conditions, lack of protected waters, and the enormous area of the region. Under prevailing sea conditions, the NOAA Ship *Oscar Elton Sette* is inadequate to provide quality data on required spatiotemporal resolutions. Hull-mounted transducers, such as those on the *Sette*, are positioned at insufficient depth to avoid bubbles that degrade data. While utilization of a vessel with a retractable centerboard would significantly improve data quality (e.g., the NOAA Ship *Reuben Lasker*), a single platform is not sufficient to obtain required spatiotemporal resolutions.

Utilization of acoustics-equipped autonomous platforms could enable collection of high- quality data on suitable spatiotemporal scales with the fraction of financial and temporal resources needed for ship-based surveys. A number of autonomous surface platforms equipped with active acoustics and environmental sensors could collect simultaneous data across large areas over periods of months and provide concurrent information on marine resources and their environment on spatiotemporal scales necessary for ecosystem-based fisheries management. Initial investment in autonomous platforms and their instrumentation would be returned within a few years of operation by reducing the need for expensive ship-time and by significantly reducing the number of staff required for operations. Acoustic data obtained by autonomous platforms not affected and degraded by inclement weather noise would allow for the development of automated processing and analyses that would be required due to the significantly increased data volume. With some initial investment and provision of resources, active acoustics could significantly contribute to improving our understanding of ecosystem

functions and interactions and provide fishery-independent time series of biomass and size-structure of economically important stocks to improve stock-assessment models.

Introduction

The Pacific Islands Fisheries Science Center (PIFSC) is in charge of administering and conducting research in support of the conservation and management of living marine resources in the western and central Pacific. The pelagic tropical and subtropical waters of the Pacific Islands region (PIR) provide habitat for numerous economically important pelagic fisheries (e.g., tunas, billfishes) and many protected resources (e.g., turtles, cetaceans). Insular areas of the PIR provide habitat to other targeted species, such as the Deep-7 bottomfish complex at the main Hawaiian Islands (MHI), bigeye tuna aggregations at Cross Seamount, and Hawaiian monk seals at the Northwestern Hawaiian Islands (NWHI). The insular habitats across the different archipelagoes of the PIR are also home for numerous coral species whose future in the changing climate is uncertain and are in need of close monitoring.

As we prioritize efforts toward ecosystem-based fisheries management (EBFM), we need to broaden our understanding of ecosystem components and processes. Increasing our knowledge requires, in part, the collection, processing, and analyses of physical, biological, chemical, socio-cultural, and economic observations to improve our understanding of the underlying processes, drivers, threats, status, and trends across the ecosystems that the managed resources are an integral part of. Development of advanced technologies and methodologies can be used to provide more cost-effectively the needed information on appropriate spatiotemporal scales.

Globally, advanced technologies are providing increased access, new perspectives, and more accurate observational data to improve understanding of our marine ecosystems (Robison 2004). One of these technologies that made significant strides in our understanding of the distribution, abundance, and behavior of our protected or economically important marine organisms is the use of active acoustics. Active acoustics uses characteristics of reflected sound to obtain information on the properties of the reflecting object that is in fisheries applications are organisms in the water column. This methodology provides significant advantages over traditional sampling methods, such as trawling, fishing, or visual observations as active acoustics is not limited by light conditions and it is continuous along transects in space and time effectively providing large amount of data on a variety of spatiotemporal scales with no avoidance/attraction bias at about ≥50 m ranges (Gerlotto and Fréon 1992; Gerlotto et al. 1999; Hjellvik et al. 2008; De Robertis and Handegard 2013). In addition, active acoustic surveys provide information on undisturbed behavior, inter- and intra-species interactions and other ecosystem components on scales relevant to a variety of ecosystem processes and the effects of climate (Koslow 2009; Trenkel et al. 2011; Benoit-Bird and Lawson 2016). For a more in-depth description of the use of active acoustics in fisheries applications see the Appendix.

Five of the six NMFS Centers have established routine active acoustic surveys as an integral part of their data collection to provide information on the status and trends of economically important fisheries and protected resources. The only center that has not incorporated active acoustics routinely into its observational methodologies is the PIFSC. Four of the other five centers/regions, being continental, afford inherent similarities with each other’s ecosystems and, consequently, to their approaches of stewardship. The remaining science center, the Southwest Fisheries Science Center (SWFSC), surveys subtropical resources in the Gulf of Mexico. In contrast to these mostly temperate, continental shelf or near-shore regions or closed seas, the PIR is responsible for tropical or subtropical pelagic or archipelagic regions away from continents that often necessitate different approaches.

The method of active acoustics has been used tentatively by PIFSC to fill some data gaps in support of its mandates. In pelagic regions, active acoustics were used to obtain information on factors that play a crucial role in the distribution and biomass of most species in the PIR (e.g., the biomass, distribution, and composition of their forage base, micronekton). Regions studied thus far are the American Samoa and CNMI, and the subtropical gyre and its northern boundary north of the MHI. In nearshore regions, active acoustics have been used to study the distribution and biomass of some economically important species such as bigeye tuna and of its forage, micronekton, at Cross Seamount, to study the West Hawaii ecosystem, and to investigate the possibility of employing active acoustics to derive abundance and biomass estimates of the MHI Deep-7 complex.

Implementing active acoustics as a routine survey tool at PIFSC would provide a broad range of benefits for the advancement of priority PIFSC research. Our marine resources in archipelagic regions within PIFSC stewardship are highly rugose areas with steep slopes and outcrops, prohibitive of trawling. Active acoustics, in combination with traditional fisheries research methods and other advanced technologies, such as stereo-camera observations would provide fisheries-independent abundance and size-distribution data to enhance and improve stock assessments. The immense volume (approximately 22 million km^3) of the pelagic regions occupied by our marine resources are prohibitive to effective monitoring using only traditional methods. Active acoustics, in combination with trawling and camera observations, could provide a more efficient means to collect information on the abundance and distribution of fisheries and protected resources in this vast region. Active acoustic instruments, whether in pelagic or near-shore environments, can be mounted on autonomous or remotely-operated platforms that are the most significant advanced technology for pelagic research since the introduction of active acoustics into fisheries research (Robison 2004). Simultaneously operated multiple autonomous platforms would provide data on scales appropriate to ecosystem-based processes over large areas, especially beneficial for the PIRs (Figure 1). Significantly expanded use of autonomous platforms could greatly increase spatial and temporal coverage, efficiency, and cost-effectiveness by reducing necessary ship-time and staff-time involved in data collection.

In the following two sections, the use of active acoustics in support of two high-priority PIFSC mandates (1) improvements in stock assessments for the Deep-7 bottomfish complex, and (2) the implementation of EBFM, will be discussed in detail.

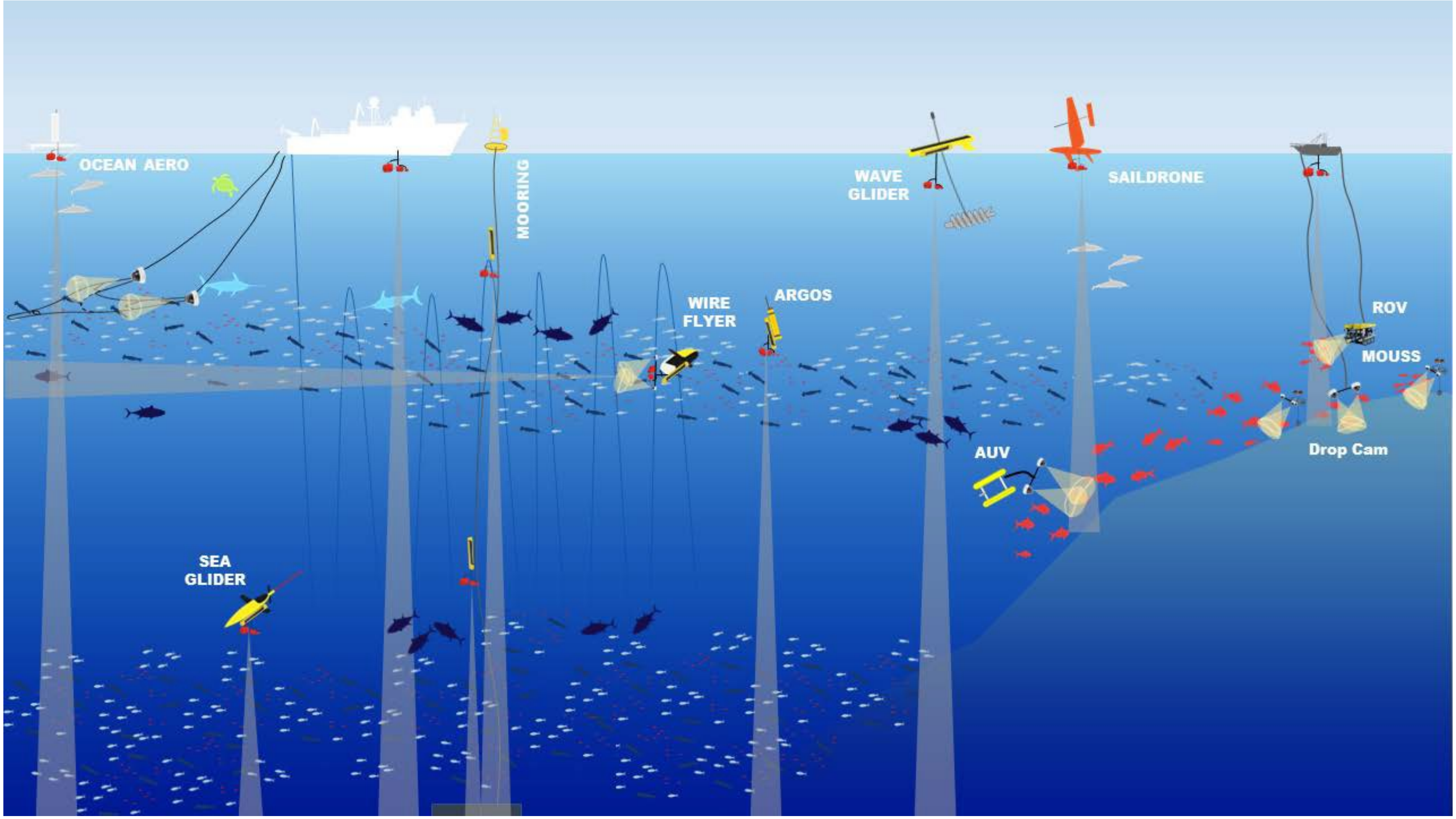


Figure 1. Visual presentations of various platforms for active acoustics and oceanographic sensors and/or cameras in pelagic and insular environments.

Part 1. Active acoustics in direct support of stock assessment

Present State and Data Gaps of Assessment of Deep-7 Stock

Under the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act, one of the current PIFSC benchmark priorities is to advance the science used to inform management of the federally managed insular Deep-7 bottomfish stocks in the main Hawaiian Islands. The Deep-7 represent an economically and culturally important stock complex comprising six species of semi-demersal snapper, and one grouper (Table 1). Effective stock assessment requires estimates of abundance, catch, and biological information over time and area of the stock. Current stock assessments for the Deep-7 stocks rely on fishery-dependent data with availability of fisheries-independent data only from 2016. Accuracy of fishery-dependent data are known to be affected by numerous factors, such as market and fuel pricing, weather, misreported and unreported catch, size-specific targeting in the fishery, and availability and density of prey. Fishery-dependent data also have the potential to be biased by fishing pattern of the fleet, catchability, gear type, and fishing depths, introducing some potential information gaps in current assessments. As part of its efforts to continually improve the data used to inform stock assessments, PIFSC commenced the development of fisheries-independent surveys in 2012 that became operational using a stationary baited stereo-video camera systems (bottomfish cameras “BotCam” and later modular optical underwater survey system “MOUSS”) from NOAA shipsand small commercial boats, and standardized hook-and-line sampling from cooperative research fishing vessels (Richards et al. 2016). The Bottomfish Fishery Independent Survey for Hawaii (BFISH) has completed two surveys thus far and is slated to be conducted annually each fall. These surveys are planned to cover approximately 425 variance-weighted stratified-random 500 m × 500 m primary sampling units (PSU). Approximately 325 of these PSU are sampled using research fishing while the remaining 100 are sampled using the camera gear. Resulting data allow for estimation of size-structured abundance and absolute biomass of Deep-7 species with a coefficient of variation (CV) of approximately 20% (Richards et al. 2016).

Augmenting fisheries-dependent data with estimates from fishery-independent observations can be used to improve stock estimates (Langseth et al. 2018). Stereo-camera observations and research fishing provide an excellent way to obtain accurate species identification and size estimates/measurements. However, significant data gaps still exist due to the limitations of the BFISH methods. Each methodology has several limitations, and while they are designed to be complementary to each other, some of the limitations cannot be mitigated. Research fishing has constraints similar to those of fishery-dependent data excluding market and fuel price, reporting, and location/time of fishing. Experimental fishing is designed to mitigate effects of weather and fishing patterns, depth, and gear type used by the fishery, although selectivity issues of the gear cannot be eliminated. Optical observations survey only the bottom layer down to the photic depth potentially missing significant portions of Deep-7 complex that occupy depths farther up in the water column and in subphotic depths. Further, the use of optical gear is limited to daylight hours with a field of view of about 82°, the representativeness of which is not well understood.

Table 1 List of Hawaiian and scientific names of Deep-7 species and non-Deep-7 species that as of yet could not be separated by acoustics alone.

Deep-7 species	**Snappers**	*Etelis coruscans*	onaga
		Etelis carbunculus	ehu
		Pristipomoides sieboldii	kalekale
		Pristipomoides filamentosus	ōpakapaka
		Pristipomoides zonatus	gindai
		Aphareus rutilans	lehi
	Grouper	*Epinephelus quernus*	hapuʻupuʻu
Non Deep-7 species	**Aggregated**	*Lutjanus kasmira*	taape
		Decapterus sanctae-helenae	opelu
		Naso species	opleu kala
		Mulloidichthys pfluegeri	wekeula
	Loose	*Seriola rivoliana* or *S. dumerili*	kahala

While the limitations listed above can potentially be mitigated by the combination of the two methodologies, uncertainty and bias caused by the shared inabilities in both BFISH systems cannot be fully addressed. Both camera and fishing methods are limited in space and time with unknown or unverified effective sampling areas for the fishing and camera, respectively. Precision and sampling power are further reduced by the effect of bait in the systems. The baited systems can also introduce bias based on attraction/avoidance behavior of species, the function of which are not well understood. Stratification in abundance is not taken into account by either systems as they selectively sample specific targeted depths. All these inaccuracies and bias reduce the validity of densities estimated per sampling volume, thus, reducing the validity of total abundance estimates.

In addition to limitations of data, the cost-effectiveness of the BFISH methodologies are not optimal. Both fishing and camera observations provide data on a limited spatiotemporal scale for each survey grid. Fishing operations require approximately six chartered fishing vessels each with 3–4 personnel, operating over the course of 20–30 days. Optical observations presently require NOAA ship-time and typically employ two small boats for deployment and recovery of the camera equipment with several crew over the course of about 15 days. The total cost of a survey is presently about $750,000, excluding data processing and analysis.

Potential Use of Active Acoustics in support of Deep-7 Stock Assessment

The biggest advantage of the video-camera observations and research fishing methodologies is their ability to provide accurate size-estimates for individual species. However, this information is provided as “snap-shot” or small window of the spatiotemporally heterogeneous reality. In contrast, active acoustic surveys can provide spatiotemporally continuous data over large spatiotemporal regions along transect lines. Using active acoustics, data can be obtained vertically throughout the water-column. Observations from the surface are unbiased by avoidance/attraction behavior in ranges of Deep-7 habitats ranges (Gerlotto and Fréon 1992; De Robertis and Handegard 2013) and data can be collected during the day and at night, and to depths well below the depth-range of Deep-7. During acoustic surveys, the exact survey volume is known (a function of sound speed, beam geometry and pulse length), giving accurate density estimates of acoustic returns. Further, in absence of instrument packages and bait, behavior of fishes is not affected in Deep-7 depth; therefore, traits such as movement patterns and organizational structure can be observed. Biomass of organisms near ledges, in crevices, or behind steep slopes, unobservable by video-camera observations are also undetectable by active acoustics because fish echoes cannot be effectively separated from those of the sea-floor (the acoustic “deadzone”). However, since volume of the deadzone can be calculated from sound speed, beam geometry, pulse length, and the measured sea-floor and the shadow-zone depths, biomass in the deadzone can be estimated from observed densities immediately above the deadzone.

In addition to these advantages of active acoustics methodologies over those of BFISH, acoustic instruments can be mounted on autonomous platforms significantly reducing the need for expensive ship-time, chartered fishing vessels, small boats, and staff involved in deploying/recovering camera platforms and conducting research fishing, as these observations would be only needed to ground-truth the acoustics data. Active acoustic instruments on autonomous platforms have been shown to provide valuable data that are difficult or impossible to obtain by other means (Robison 2004; Guihen et al. 2014; Benoit-Bird et al. 2016; Benoit-Bird et al. 2017; Ludvigsen et al. 2018). The autonomous platforms would typically include surface platforms with instruments positioned about 10 m below to prevent inclement weather noise and to eliminate biases or inaccuracies in abundance estimates due to avoidance/attraction behavior of bottomfish and be able to obtain valuable information on other behavioral patterns. Autonomous platforms could be programmed to survey grids established as representative of the stock area by the BFISH (Richards et al. 2016). Use of multiple autonomous platforms would reduce survey time and increase accuracy of abundance estimates.

While autonomous platforms would increase cost-effectiveness and accuracy, use of traditional hull-mounted acoustic instruments on NOAA ships or side-mounted on a small boat in protected/exposed regions, is also a viable option. Using these traditional non-autonomous acoustic methods, surveys could be conducted more efficiently and cost-effectively as collection of acoustic data needs fewer personnel and can be done in a slightly shorter time per grid as the BFISH method (see section Present State of Active Acoustics in support of Deep-7 Stock Assessment on page 8). However, use of NOAA ships and other large vessels is a limiting factor and less cost-effective, especially due to the significant inclement weather noise of the *Sette* (Figure 2) and unknown noise of the proposed replacement vessel. Initial investments in stand-alone acoustic instruments and autonomous platforms could be returned in savings during the first few years of surveys with costs-effectiveness and efficiency significantly increased in the following years.

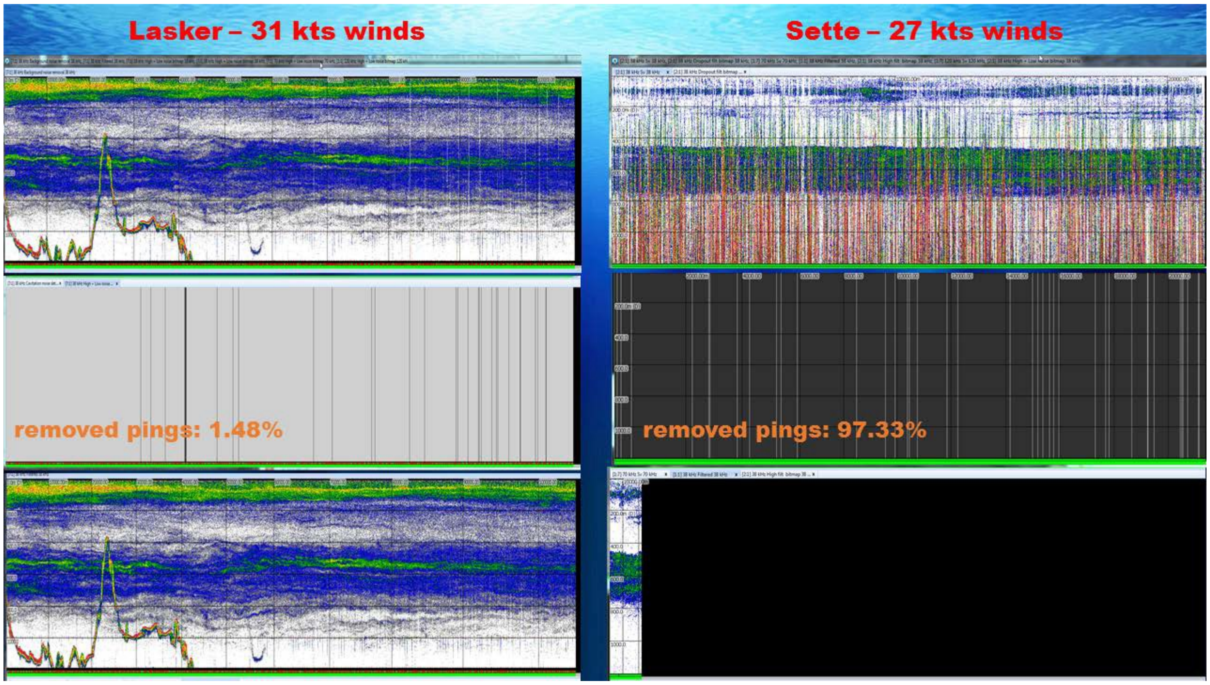


Figure 2. Example of data collected by transducers installed on a retractable centerboard (NOAA Ship *Reuben Lasker*, left) and on the hull (*Sette*, right) in windy conditions. Top panels show the original data (abscissa: time and distance, ordinate: depth), middle panels the retained (light grey) and lost (black) pings to noise, and bottom panels the retained data with pings consolidated.

A key challenge in using active acoustic methods for bottomfish is the correct species-level identification of organism. Identification of organisms in the water column to a well-defined level is required without which many of the benefits of the active acoustic method are less meaningful. This challenge is especially significant in tropical and subtropical regions, such as the Hawaiian Deep-7 habitat where species richness is high and species commonly intermix. Compounding this challenge is the similar morphology of the six lutjanid snappers of the Deep-7 complex, giving similar acoustic returns or “target strengths” (TS), which are a function of morphology, physiology, body type, size, shape, and orientation of the organism; therefore, in a highly diverse environment the same TS can be produced by a variety of types of organisms. In species-rich environments, the use of other acoustic descriptors is necessary to identify the echoes, such as frequency-dependence of TS, aggregation shape, size, density, number of individuals in a group, grouping and individual swimming pattern, distance from bottom, and bottom depth. Defining TS and other acoustic descriptors for Deep-7 and non-Deep-7 species in the same habitat will facilitate the identification of Deep-7 species to enable density and size distribution estimates for each predetermined grid in the stock area. While the ultimate goal is the species-level identification of Deep-7, present stock assessment requires abundance estimates for Deep-7 complex as a single aggregated stock (Langseth et al. 2018).

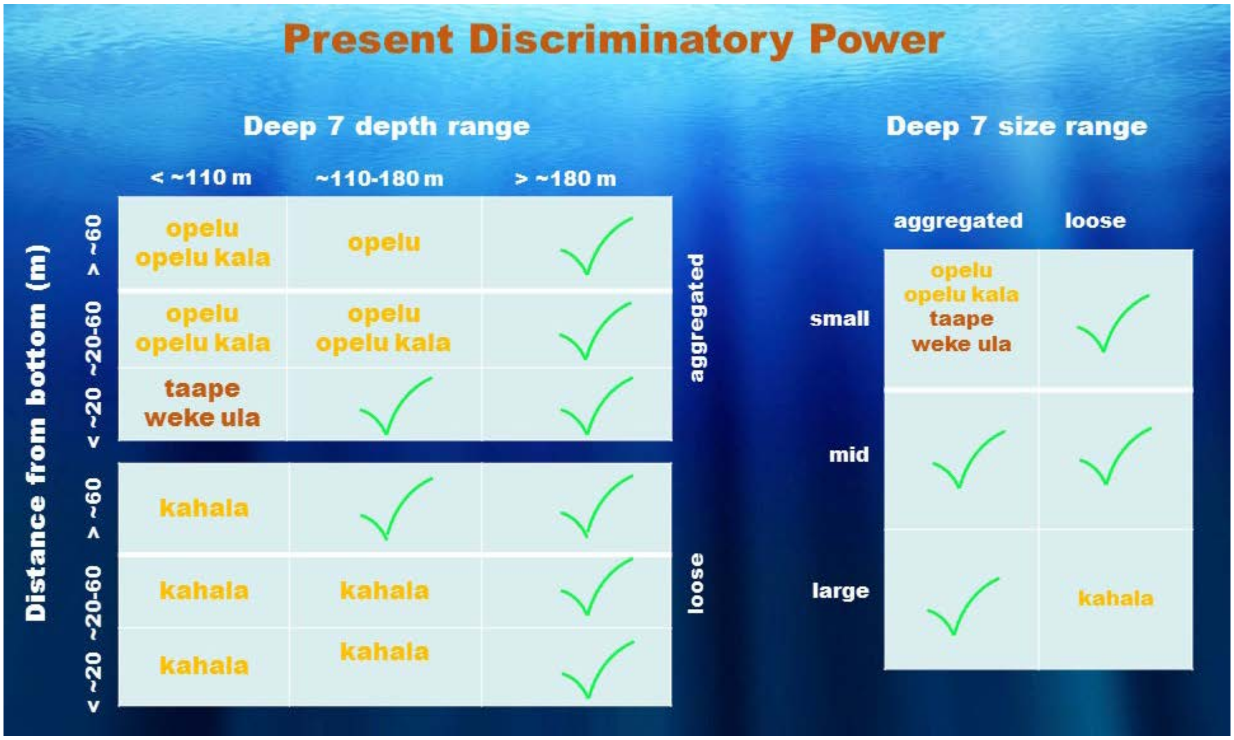
Preliminary acoustic work indicates that separation of echoes from Deep-7 bottomfish species from those of other organisms is likely achievable with further work (see section Present State of Active Acoustics in support of Deep-7 Stock Assessment on page 8). Identification of Deep-7 to species level was also shown as likely achievable in certain situations, but less promising in a few other circumstances. While the challenges of separating organisms to the species level using active acoustics alone might never be fully overcome, camera and/or research fishing could be used as needed to complement acoustics observations, still significantly improving efficiency and cost-effectiveness of data collection.

Present State of Active Acoustics in support of Deep-7 Stock Assessment

Snappers, including the six Deep-7 species, are ubiquitous in tropical and subtropical oceans and are economically important worldwide. In Hawaii, revenue from the Deep-7 complex comprises more than 70% of total bottomfish revenue (Minling Pan, Pacific Islands Fisheries Science Center, unpublished data), a fishery with significant cultural importance (Hospital and Beavers 2014) that PIFSC is mandated to manage by the Magnuson-Stevens Fisheries Conservation and Management Act (U.S. Department of Commerce 2007). Despite the importance of this fishery, there are critical data gaps preventing accurate abundance estimates, hampering management efforts. Development of an active acoustics method could fill many of these data gaps, significantly benefiting not only local stock assessment but also those of regions worldwide. While other NMFS centers have developed and routinely use active acoustic methodologies to survey their fisheries resources, these methods are not adaptable for the Deep-7 bottomfish surveys due to key differences in both fish distribution and behavior, environmental conditions, species diversity, and habitat type.

During approximately 6 days in 2010–2013, some preliminary active acoustic surveys were conducted by PIFSC to investigate the possibility of developing a methodology for deriving abundance and biomass estimates. Acoustic data collection was aimed to develop a TS vs. size (fork length, FL) relationship for Deep-7 species and other acoustic descriptors, and to investigate survey methodologies that would give CVs similar to those acquired using the BFISH methodology. TS vs. FL relationship and acoustic descriptors were collected either from fish of known species and size using hook and line or from simultaneous stereo-camera or research fishing. These experiments found that the TS vs. FL relationship developed from fish identified here as Deep-7 species corresponded well to that developed in the early 2000s using fish with known species and sizes (Kelly J. Benoit-Bird et al. 2003). TS vs. FL were similar to other common non-Deep-7 species with similar size, morphology, and physiology; however, paired optical and acoustics observations showed that sizes of all frequently observed non-Deep-7 species were exclusively at the small or large end of the Deep-7 size-range (Figure 3, right).

Acoustic descriptors developed allowed for further separation of Deep-7 echoes from those of non-Deep-7, although available data are very limited. At depths below approximately 180 m, separation of Deep-7 species was complete. Identification of Deep-7 species was also possible in mid- range (110–180 m depth) within approximately 20 m of the seafloor for tight aggregations and further than approximately 60 m from the seafloor for loosely grouped fishes (Figure 3, left). One loosely grouped species could not be separated from two Deep-7 species at the large end of size-range in mid-range depths; however, preliminary data indicated that there were likely significant differences in frequency response of this non-Deep-7 species from those of Deep-7 species allowing for identification. Using the available data, only four tightly-aggregated non-Deep-7 species—some of which likely intermix with Deep-7 species—at the small end of Deep-7 size-range and depths, less than approximately 180 m could not be separated: two species each for fish within and further than approximately 20 m of the seafloor. Available data indicated that species-specific acoustic descriptors, such as aggregation shape, size, distance from bottom and bottom depth can be identified by collecting more data to allow better separation of these four small-sized non-Deep-7 tightly aggregated species.



Present Discriminatory Power

Deep 7 depth range

Grouping	Distance from bottom (m)	< ~110 m	~110-180 m	> ~180 m
aggregated	> ~60	opelu opelu kala	opelu	✓
	~20-60	opelu opelu kala	opelu opelu kala	✓
	< ~20	taape weke ula	✓	✓
loose	> ~60	kahala	✓	✓
	~20-60	kahala	kahala	✓
	< ~20	kahala	kahala	✓

Deep 7 size range

	aggregated	loose
small	opelu opelu kala taape weke ula	✓
mid	✓	✓
large	✓	kahala

Figure 3. Present discriminatory power of acoustic descriptors for Deep-7, as determined by simultaneous active acoustics and optical or fishing operations and groundtruthed by application of developed descriptors to acoustic data of known fish. Green check-marks indicate separation is achieved in that category, with fish names indicating species that could not be separated by acoustics alone (see Table 1 for scientific names). Light and dark orange text colors indicate likelihood of separation based on present data with light most likely, dark less likely. Left panels show separation by grouping behavior per distance from bottom and depth, while right panels show separation by size-range per grouping.

During the preliminary active acoustic experiments, surveys were conducted to examine scales of spatiotemporal variability in the active acoustic data. These surveys found a significant diel difference in observed abundance with higher values during daytimes. Data were horizontally and vertically autocorrelated within distances of 50 m or less and 5 m or less, respectively, along surveys. Continuous surveying more than one contiguous grid resulted in unacceptable variability in estimates for each grid and no significant differences among grids with different habitat types (Deep-7 bottomfish typically prefer hard-bottom, high relief habitats). Surveying individual grids six consecutive times (~40–45 min) resulted in the smallest CV of approximately 15–20% in estimated abundance/biomass values for a grid. Estimates of undetectable biomass were less than 5% of total Deep-7 biomass in the deadzone.

Acoustically-derived Deep-7 abundance and biomass positively correlated with benthic relief as expected, strengthening the validity of the acoustics descriptors developed (hardness was not yet considered in this comparison). This correlation and validations of the derived TS vs. FS relationship and acoustic descriptors performed using data from the preliminary study, as well as indications for improvement with the availability of more data, provide justification for further work. Steps to be taken for successful acoustic identification of Deep-7 species with their associated costs and benefits, along with deliverables will be outlined in the next section.

Active Acoustics Plan for Deep-7 Stock Assessment

As stated in the previous sections, active acoustics could efficiently provide continuous data in space and time over the entire water column along transects, unlimited by the availability of light, unaffected by uncertainty in sampling volume or presence of intruding platforms. Active acoustics can provide simultaneous data on the Deep-7's micronekton/zooplankton forage, which consists primarily of small fish, crustaceans, and gelatinous organisms (salps) (Haight et al. 1993). While present stock assessment does not incorporate forage, future EBFM models will likely assimilate data on Deep-7 forage, further boosting the applicability of active acoustic methods. Abundance and size-distribution estimates per grid with CV values not exceeding those achieved by BFISH could be obtained in slightly shorter time but with significantly fewer personnel. Moving away from ship-based to autonomous survey platforms and automated processing would drastically decrease cost and survey times as well as increase efficiency of surveys with initial investments returned within a few years.

Functional active acoustics methodology for Deep-7 stock assessment requires successful separation of Deep-7 species from those of other fish at the minimum, with the ultimate goal of identification of Deep-7 at the species level. While Deep-7 bottomfish are currently accessed as a single stock, call for species-specific management in the future is possible and likely preferred. Data collected thus far indicate that Deep-7 species-level identification will not be possible by TS alone but by first narrowing possible species using a variety of acoustic descriptors such as aggregation density, size, and shape, grouping pattern, number in group, swimming pattern, distance from bottom and bottom depth, then making final determination by differences in frequency response of species. It is likely that this final step is only achievable by obtaining continuous frequency spectra by wide-band acoustic signals. Previous studies using wide-band separation of Deep-7 species show promise (Au and Benoit-Bird 2003; Kelly J Benoit-Bird et al. 2003), although more data is needed to determine the effectiveness of this approach.

Observations

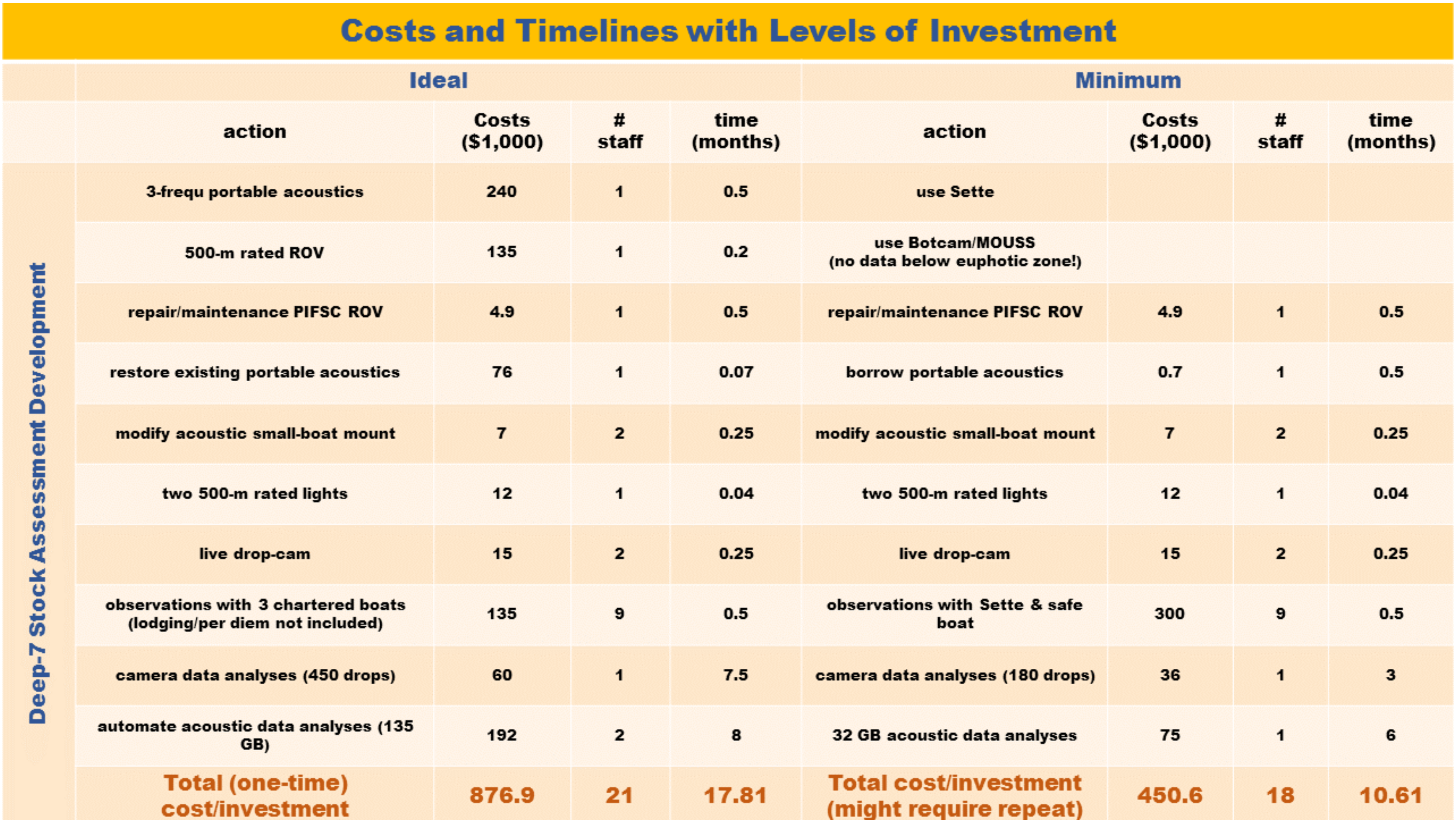
To develop functional acoustic descriptors for stock assessment, simultaneous active acoustics data with stereo-camera observations must be collected, possibly supplemented by research fishing. Acoustically locating bottomfish "hot-spots" would increase time-efficiency by maximizing data and allow for acoustic recordings while fish are in an undisturbed state. A 10–20-minute recording time would be sufficient in most circumstances. Acoustic recordings should be followed by simultaneous camera and/or fishing operations to identify species and sizes of observed fish.

Complementary camera and/or fishing operations could be used during operational surveys to ground-truth acoustic data as needed. Using complementary methodologies in addition to acoustics would likely increase accuracy of the acoustically-derived abundance and size-distribution estimates. Operational surveys should be conducted over grids defined by BFISH using the established sampling method during the preliminary observations.

Instrumentation

Ideally, acoustic transducers mounted on an autonomous surface platform operating at a minimum of three frequencies (38, 70, and 120 kHz) should be used (Table 2). Moving away from ship-based installations has many important advantages, including reduced costs, reduced time constraints, and mitigation of inclement weather noise. Some newer platforms are wind and/or solar powered, further reducing costs and significantly extending operational duration (e.g., Saildrone, designed for EK80 compatibility that is the NMFS standard for fisheries acoustics systems, and Submaran). These platforms typically cost approximately $250k and available for rent at approximately $2.5k per day. The purchase cost of a platform is roughly equivalent to approximately 8 days of operational costs of a NOAA ship.

Table 2. Example of costs/investments and benefits for the development of acoustic IDs of Deep-7 with investment (“ideal” scenario in left columns) and without investment (“minimum” columns to the right).



Costs and Timelines with Levels of Investment

	Ideal				Minimum			
	action	Costs ($1,000)	# staff	time (months)	action	Costs ($1,000)	# staff	time (months)
Deep-7 Stock Assessment Development	3-frequ portable acoustics	240	1	0.5	use Sette			
	500-m rated ROV	135	1	0.2	use Botcam/MOUSS (no data below euphotic zone!)			
	repair/maintenance PIFSC ROV	4.9	1	0.5	repair/maintenance PIFSC ROV	4.9	1	0.5
	restore existing portable acoustics	76	1	0.07	borrow portable acoustics	0.7	1	0.5
	modify acoustic small-boat mount	7	2	0.25	modify acoustic small-boat mount	7	2	0.25
	two 500-m rated lights	12	1	0.04	two 500-m rated lights	12	1	0.04
	live drop-cam	15	2	0.25	live drop-cam	15	2	0.25
	observations with 3 chartered boats (lodging/per diem not included)	135	9	0.5	observations with Sette & safe boat	300	9	0.5
	camera data analyses (450 drops)	60	1	7.5	camera data analyses (180 drops)	36	1	3
	automate acoustic data analyses (135 GB)	192	2	8	32 GB acoustic data analyses	75	1	6
	Total (one-time) cost/investment	**876.9**	**21**	**17.81**	**Total cost/investment (might require repeat)**	**450.6**	**18**	**10.61**

Moving away from ship-based active acoustic observations by PIFSC is likely a necessary move due to present issues experienced on the *Sette* with inclement weather noise and the unknown applicability of a replacement vessel (Figure 2). However, an approximate 6–7-day initial survey using the *Sette* as acoustic platform for the development of acoustic descriptors could be conducted at minimal initial cost. To improve effectiveness and data quality, chartered boats with side-mounted acoustic transducers, or *Sette* small boats launched from the *Sette* as an ancillary project during surveys with other primary goals, could be used for acoustic recordings. One of the *Sette* small-boats is equipped with a mount for horizontally looking transducers, requiring minimal adjustments for bottomfish work. Further, construction of another side-mount for other small boat(s) would not exceed approximately $5k. Side-mounts also could be constructed relatively inexpensively for chartered boats, such as fishing boats allowing for more flexibility but at an increased cost. Using *Sette* small boats would free the vessel to conduct other daytime operations but would limit acoustic operations in space and time. However, note that without dedicated time for the collection of adequate amount of data necessary for the development of acoustic descriptors, the duration of the development phase would extend significantly.

The use of platforms other than the *Sette* for acoustics data collection requires transducers and general purpose transceivers (GPT) – or their current version, wide-band transceivers (WBT) – that are not associated with the ship. Initial investment in an autonomous wideband Simrad system (WBAT with transducers, licenses, and controller unit) would roughly be $100–250k, depending on the number of narrow frequencies or wide frequency-bands to use simultaneously. In lieu of purchasing, we have the option to borrow EK60 and/or EK80 shared equipment owned by NMFS and are for the development of fishery-independent survey operations by all Centers (Shared Equipment), depending on availability. Borrowing an EK80 system would have the advantage of collecting wideband data to investigate the discriminatory power of species-specific frequency spectra without initial investment in a system. EK60 GPTs and transducers could also be borrowed from HIMB who owns a four- frequency system that we have borrowed in the past. However, borrowing systems would impose time restraints due to availability of instruments. To avoid possible time conflicts and resulting restraints in instrument use, the least expensive option would be to restore functionality of a partial portable EK60 system owned by PIFSC with the purchase of three transducers and one GPT for approximately $70k.

Cameras for stereo recordings should be mounted on ROVs as effective targeting of fish requires live feed and control. In addition to ROVs, an inexpensive minimalist frame with a fiber optic cable should be created for stereo viewing acoustic dead-zones (Figure 1, right). As a less optimal alternative, or in addition to the above-mentioned platforms, camera equipment could be mounted on borrowed MOUSS (Shared Equipment includes several MOUSS, two of which are currently residing at PIFSC) or on a borrowed AUV jointly owned by PIFSC and NEFSC. Regardless of the platform, optical equipment will need a vessel for deployment and recovery such as *Sette* small boats, chartered fishing boats, or the *Sette*. For a relatively insignificant cost, ROV and/or MOUSS may be modified to reduce weight to be able to launch them from a small boat equipped with a pole-mounted acoustic system to reduce the number of boats needed for the operations.

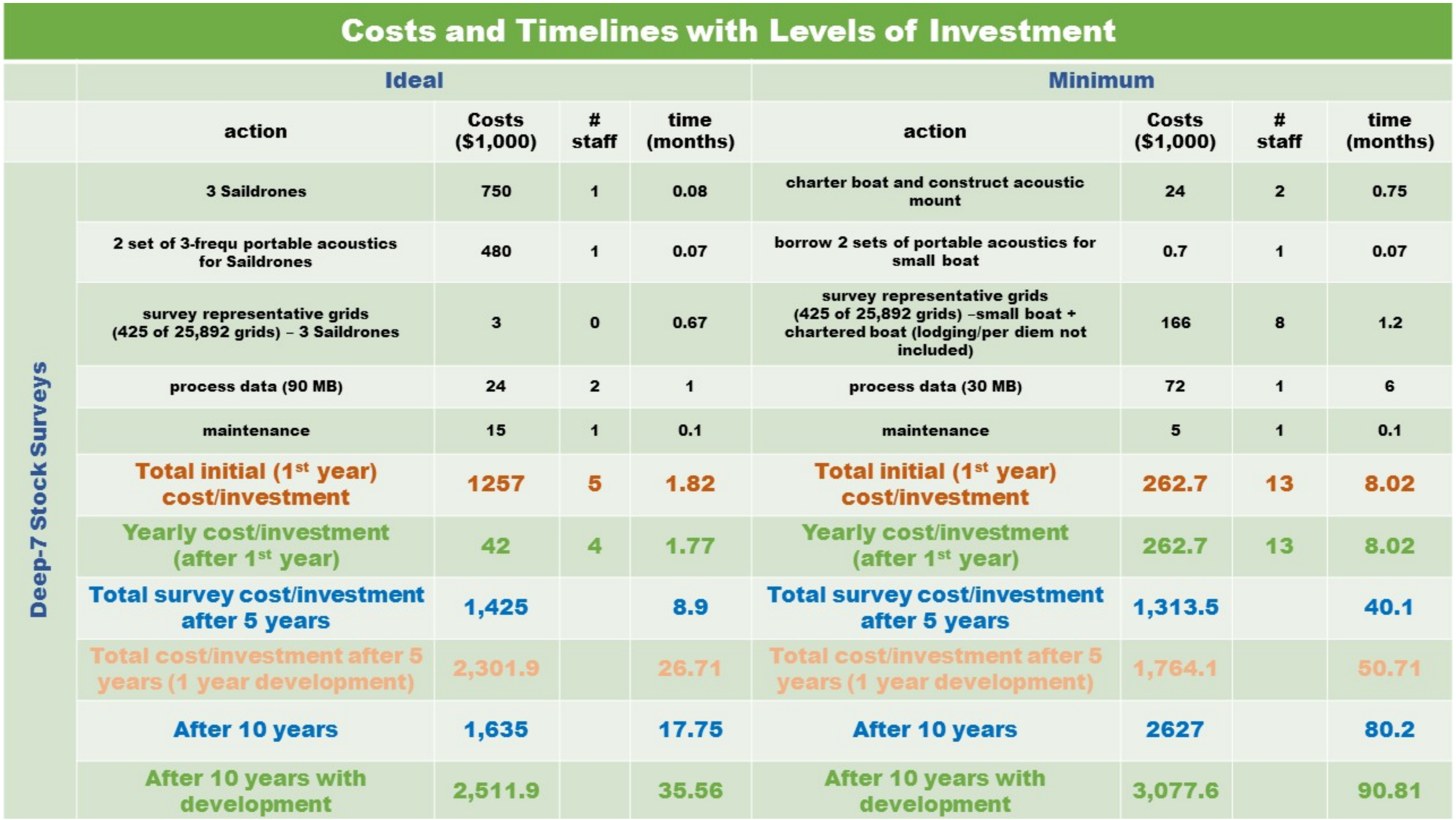
In addition to the above platforms, acoustics and camera systems could be moored at bottomfish hotspots with various bottom depths to obtain spatially stationary time series observations at various locations. The acoustic systems could be positioned ~approximately 10 m below the surface to avoid inclement weather noise, with cameras mounted at certain depth intervals. The two systems could be triggered by movement then stop recording during inactive periods. These observations could collect large amount of simultaneous data with minimal cost after initial investment: however, effects of the cameras on bottomfish would need to be evaluated before data within the volume of the camera's influence could be used for acoustic descriptor developments that involve behavior.

Data Processing, Personnel, and Timeframes

Acoustic data needs to be cleaned and processed, first to develop accurate acoustic descriptors for Deep-7 species and then the acoustic values converted to abundance/biomass and size. Stereo-video data needs to be observed framed by frame to determine species and sizes. Since manual execution of these processes are very time-consuming, investing in automation would bring significant long-term benefits. While developing algorithms to automate image processing of the video-camera data is underway at PIFSC, efforts to automate acoustic data processing has not been considered. Automation of acoustic data processing to develop Deep-7 descriptors to separate them from other species would likely require several months of an expert's time and adequate amount of data using image processing and machine learning techniques. However, once developed, significant savings in time and financial resources would be saved, especially as data quantity is likely to grow in the future.

With automation of processing and moving away from use of NOAA ships (the *Sette*), surveys could be conducted inexpensively and in a timely manner. Table 2 and Table 3 provide examples of developmental and survey scenarios with significant initial investment (left columns) to one with minimal investment (right columns). With investments in instrumentation and data processing, timeframe of acoustic descriptor development could be shortened as a 15-day survey could provide significantly higher amount of quality data in comparison to the case without investment. Further, as shown in the example in Table 3, yearly surveys could be conducted with significantly less financial resources ($42k vs. $263k) and in a significantly shorter time (1.77 months vs. 8.02 months). After 5 years, almost all survey-invested amounts could be recovered (~$1.425M vs. ~$1.314M) with significantly reduced total time spent (~9 months vs. ~40 months) on the operations.

Table 3. Example of costs/investments and benefits of active acoustics surveys in support of Deep-7 stock assessment with investment (“ideal” scenario in left columns) and without investment (“minimum” scenario in right columns)



Costs and Timelines with Levels of Investment								
	Ideal				Minimum			
	action	Costs ($1,000)	# staff	time (months)	action	Costs ($1,000)	# staff	time (months)
Deep-7 Stock Surveys	3 Saildrones	750	1	0.08	charter boat and construct acoustic mount	24	2	0.75
	2 set of 3-frequ portable acoustics for Saildrones	480	1	0.07	borrow 2 sets of portable acoustics for small boat	0.7	1	0.07
	survey representative grids (425 of 25,892 grids) – 3 Saildrones	3	0	0.67	survey representative grids (425 of 25,892 grids) –small boat + chartered boat (lodging/per diem not included)	166	8	1.2
	process data (90 MB)	24	2	1	process data (30 MB)	72	1	6
	maintenance	15	1	0.1	maintenance	5	1	0.1
	Total initial (1st year) cost/investment	1257	5	1.82	Total initial (1st year) cost/investment	262.7	13	8.02
	Yearly cost/investment (after 1st year)	42	4	1.77	Yearly cost/investment (after 1st year)	262.7	13	8.02
	Total survey cost/investment after 5 years	1,425		8.9	Total survey cost/investment after 5 years	1,313.5		40.1
	Total cost/investment after 5 years (1 year development)	2,301.9		26.71	Total cost/investment after 5 years (1 year development)	1,764.1		50.71
	After 10 years	1,635		17.75	After 10 years	2627		80.2
	After 10 years with development	2,511.9		35.56	After 10 years with development	3,077.6		90.81

Part II. Active acoustics in support of EBFM

During the last few decades, both public and private research institutions engaging in management and protection of economically important and protected marine resources have recognized the importance of ecosystem interconnectedness and are moving away from single species-based management to ecosystem-based management approaches worldwide. The National Marine Fisheries Service (NMFS) policy states that it “strongly supports the implementation of Ecosystem-Based Fisheries Management (EBFM)” in support of management of fisheries and protected species (NMFSPD 2016). Observational data needs for successful EBFM are those of entire ecosystems on all scales that ecosystem processes occur. In recent decades, active acoustics has been recognized as an important tool to support EBFM due to its capability to provide observational data across significant portions of marine ecosystems at spatial resolutions ranging from micro-, meso-, and basin-scales and temporal scales ranging from seconds to decades (Godø et al. 2014). Active acoustics data can be used to investigate issues ranging from the level of single species and physiological responses to the environment to ecosystem-level studies and the effects of climate in support of ecosystem-based management (Koslow 2009; Trenkel et al. 2011; Benoit-Bird and Lawson 2016).

The PIFSC has made extensive strides in recent years to provide science to support implementation of EBFM policies to better meet NMFS mandates to sustainably manage and conserve living marine resources across the PIR. However, monitoring forage that plays a foundational role in the distribution and biomass of their predatory fish species, has not been a regular part of assessment practices. Micronekton is the basic forage of most of pelagic predatory fishes that provide approximately 90% of total fisheries revenue in the PIR (Minling Pan, pers. comm.). Economically-important top predator catches, such as tunas that provide extensive revenues across the Pacific, are highly variable. This variability is poorly explained, although the role of their relationship to micronekton are thought to be a critical factor. For example, local and international pelagic fisheries target increased concentrations of tunas and billfishes at the Transition Zone Chlorophyll Front (TZCF) located between the subarctic and subtropical gyres of the North Pacific, and American Samoan longline fisheries target increased concentrations of albacore at eddy edges. Top predators are thought to be drawn to these regions due to increased availability of forage.

Observations of the link between predator-prey distribution and the effects of regional oceanography on micronekton are scarce with most evidence derived from model estimates (Menkes et al. 2015). Given the vast volume of this habitat and the traditional resource-intensive discrete methods, only about 1% of the oceans below the epipelagic layer have been sampled (Sutton et al. 2017). Applications of acoustics in combination of complementary methods, such as optical recordings or trawl sampling, have greatly advanced our knowledge of pelagic ecosystems in recent years (Sutton 2013). For example, one study conducted at PIFSC, using oceanographic in situ and satellite oceanographic data, active acoustics recordings, and fisheries log-book records in the American Samoa EEZ, showed the effects of oceanographic variables on seasonal and decadal scales (ENSO) on micronekton densities and biomass that significantly correlated with albacore tuna catch per effort (Domokos 2009).

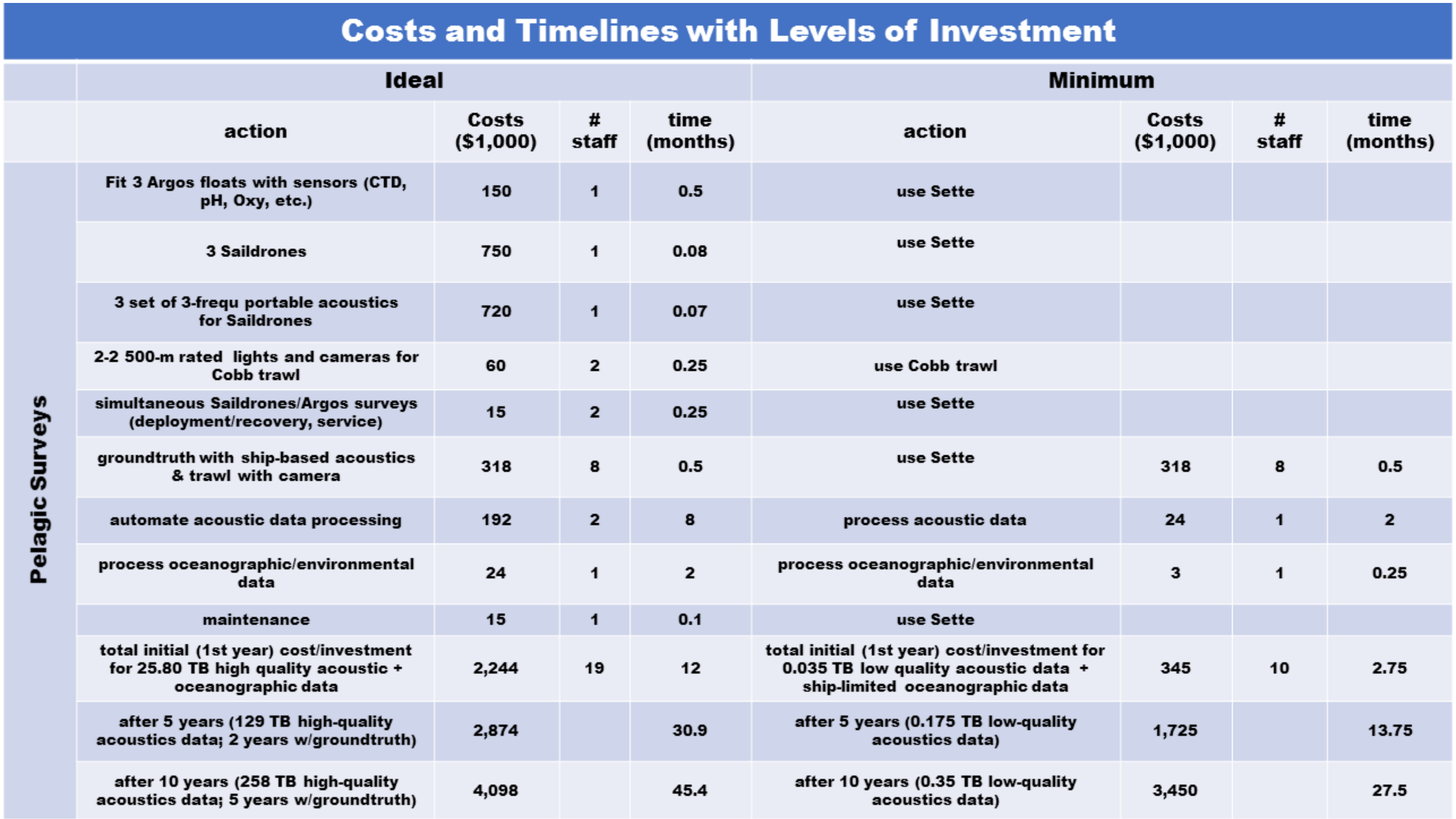
In spite of active acoustics’ demonstrated suitability to support ecosystem-based management approaches (Koslow 2009; Trenkel et al. 2011; Benoit-Bird and Lawson 2016), the use of active acoustics has not been implemented as part of routine surveys. PIFSC has typically conducted trawl surveys to sample scattering layers of micronekton in the immense volume of the PIR, methods that can provide only a “limited window of reality” (Merrett et al. 1991) that is biased by avoidance behavior and selectivity of the net. Further, a recent work showed that mesopelagic, as well as deeper organisms are heterogeneous at scales of 10–50 m both vertically and horizontally, scales smaller than previously believed and which trawling does not resolve (Benoit-Bird et al. 2016). Simple acoustic surveys, however, can provide large amounts of data at small scales along transects due to continuous sampling, data that easily can be converted into biomass estimates for primary groups of organisms, such as fish with and without swim-bladder, squids, crustaceans (“shrimp-like”), and gelatinous, the groups that make up the vast majority of micronektonic organisms. While identifying organisms to species level in scattering layers would require significant increase in investment in time and effort, in most cases it is not necessary for purposes of ecosystems research in support of fisheries. Separation of acoustic signals into major groups is made possible by unique frequency-dependence of groups of organisms and readily available models. For example, a simple model separating the scattering layers into three main groups (Korneliussen and Ona 2003) was successfully implemented in a recent work (Béhagle et al. 2017). Several multi-frequency models are available that separate organisms into larger number of groups (Fernandes et al. 2005; Trenkel and Berger 2013; Proud et al. 2015; Korneliussen et al. 2016; Peña 2018), and algorithms available to easily visualize composition patterns in the scattering layers (Wall et al. 2016).

Conducting regular active acoustic surveys with other in situ oceanographic data could provide time series of relative biomass to inform us how micronekton, the “missing link” between lower and higher trophic organisms, changes in response to changing environmental conditions. Ground-truthing the acoustics data with trawl samples and/or camera observations would enable improved estimates of absolute biomass by giving size estimates for major groups. These data would inform us how changes in temperature, salinity, and carbonate chemistry (i.e., acidification) affect micronekton biomass in the tropical and subtropical Pacific, factors that currently are not well understood. For example, while overall productivity and biomass of organisms is known to decrease with increasing stratification associated with warming surface temperatures by inhibiting mixing of nutrients into the euphotic zone, some research found higher micronekton biomass in warm waters with deeper mixed-layer depth than in cooler waters with more mixing (Domokos 2009; Béhagle et al. 2016). Knowledge of the status of micronekton could be used as an indicator of ecosystem status leading to changes in the availability of economically important resources.

While active acoustic methods are significantly more efficient than that of trawling, the enormous pelagic regions of the PIR renders acoustic transects conducted by a single ship still relatively ineffective, sampling only small regions at a time with the use of considerable amount of resources. For effective EBFM of pelagic resources, changes in micronekton abundance and composition over time in response to environmental variability and climate change must be monitored over vast regions of the Pacific Ocean along with oceanographic variables, both in situ and satellite-derived. To achieve adequate spatial and temporal coverage and reduce costs, several autonomous systems in tandem should be utilized. Autonomous acoustic transceivers (Simrad’s Wideband Autonomous Transceiver, WBAT) along with other oceanographic sensors could be mounted on a variety of platforms, such as moorings, wave- and seagliders, Saildrones, or Ocean Areo’s Submaran. Investing in only two sets of instruments per year, we could have 10 simultaneously operating platforms efficiently monitoring a large area (or areas) in 5 years, without need for high number of personnel, ship-time, and other expensive resources. With minimal initial investment, Argos floats could be outfitted with acoustic sensors, collecting large amounts of data in various parts of the Pacific. Increasing number of platforms would also allow biomass estimates of highly migratory top predators, such as tunas, that are typically spread over large areas, while ship-based acoustics would limit biomass estimates of such species in known “hotspots,” such as bigeye at Cross Seamount or albacore at the TZCF.

Moving away from ship-based surveys (see Figure 1) would not only eliminate limitations due to availability of ship-time, single surveys, and costs-limited spatial/temporal coverage, processing time would significantly be reduced due to the ability to automate processing of data not severely degraded by bubble-dropout and cavitation noise, a consistent problem with the *Sette*. Automation of processing will be necessary due to the significant increase in data volume from the autonomous systems. With time, the number of autonomous platforms could be increased, providing data on spatiotemporal scales necessary for understanding ecosystems-scale processes and vastly improving our ability to predict changes in the status of our economically important fishery or protected resources. For example, three Saildrones equipped with active acoustics operating in tandem with oceanographic sensors on Argos floats, could cover a 10 × 10 degree area (1,111,300 km^3 volume) in a 15-day period over transects spaced at every degree, in comparison to a 15-day single survey of 10 degrees length (~222 km^3 volume) using one platform. Costs/investments and timelines for these two scenarios are shown in Table 4 in the “ideal” (left) and “minimum” (right) column. Note that at 10 years in this scenario, total cost using the “status quo” operations approximates that of the “ideal” ($3.45M vs. $4.098M) but provides 3 orders of magnitude less acoustics data (0.035 TB vs. 25.8 TB). Assuming the use of the *Sette* as the single platform with no investment, the effective data volume would further be reduced from 35 GB to approximately 15 GB (calculated at 5 kn vessel speed).

Table 4. Example of costs/investments and benefits of active acoustics surveys in support of EBFM with initial investment in autonomous platforms and instruments (“ideal” scenario in left columns) and without investment (“minimum” scenario in the right columns).



Costs and Timelines with Levels of Investment

	Ideal				**Minimum**			
	action	**Costs ($1,000)**	**# staff**	**time (months)**	**action**	**Costs ($1,000)**	**# staff**	**time (months)**
Pelagic Surveys	Fit 3 Argos floats with sensors (CTD, pH, Oxy, etc.)	150	1	0.5	use Sette			
	3 Saildrones	750	1	0.08	use Sette			
	3 set of 3-frequ portable acoustics for Saildrones	720	1	0.07	use Sette			
	2-2 500-m rated lights and cameras for Cobb trawl	60	2	0.25	use Cobb trawl			
	simultaneous Saildrones/Argos surveys (deployment/recovery, service)	15	2	0.25	use Sette			
	groundtruth with ship-based acoustics & trawl with camera	318	8	0.5	use Sette	318	8	0.5
	automate acoustic data processing	192	2	8	process acoustic data	24	1	2
	process oceanographic/environmental data	24	1	2	process oceanographic/environmental data	3	1	0.25
	maintenance	15	1	0.1	use Sette			
	total initial (1st year) cost/investment for 25.80 TB high quality acoustic + oceanographic data	2,244	19	12	total initial (1st year) cost/investment for 0.035 TB low quality acoustic data + ship-limited oceanographic data	345	10	2.75
	after 5 years (129 TB high-quality acoustics data; 2 years w/groundtruth)	2,874		30.9	after 5 years (0.175 TB low-quality acoustics data)	1,725		13.75
	after 10 years (258 TB high-quality acoustics data; 5 years w/groundtruth)	4,098		45.4	after 10 years (0.35 TB low-quality acoustics data)	3,450		27.5

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Appendix: Active acoustics background for fisheries applications

Active acoustics, which involves the interpretation of emitted sound reverberated off objects is a well-established tool to study marine organisms worldwide. The use of active acoustics to study organisms started in the 1920-1930s and now is being applied through a wide trophic range of marine fauna from plankton to micronekton and to top predators (e.g., Zimmerman and Biggs 1999; Ressler et al. 2009; Irigoien et al. 2014; Gastauer et al. 2017) in a variety of habitats, such as benthic (e.g., Rooper et al. 2010; Ryan and Kloser 2013), continental shelf (e.g., Davison et al. 2015; La et al. 2016; De Robertis, Taylor, Wilson, et al. 2017), boundary layer (e.g., Benoit-Bird and Au 2001; Simão et al. 2014), archipelagic (e.g., Wilson and Boehlert 2004; Ariza et al. 2016; Cascão et al. 2017), and pelagic (e.g., Domokos et al. 2007; Trenkel and Berger 2013; Béhagle et al. 2016).

Active acoustics has significant advantages over the traditional sampling and visual methods, particularly in a marine environment due to its extensive spatial scales and the fact that most organisms reside under very limited light conditions. Contrary to traditional methods, acoustic data are not constrained to discrete, limited locations and times but can be collected continuously in time along transects at very fine spatiotemporal resolutions. Organisms can be acoustically monitored in the entire water column during day and night as well as below depths where light penetrates and can provide metrics such as biomass, abundance, spatiotemporal distribution, composition, and behavior in a cost-effective way. Bias inherent in trawl sampling due to selectivity of the net (Pakhomov et al. 2010; Suntsov et al. 2010; De Robertis, Taylor, Williams, et al. 2017) or inadequate sampling as a result of behavior and predator-prey dynamics (Marchal and Lebourges 1996) is eliminated, while avoidance-attraction bias is minimized to the near-surface layer in the vicinity of the vessel (Gerlotto and Fréon 1992; Gerlotto et al. 1999; Hjellvik et al. 2008; De Robertis and Handegard 2013).

Other advantages of active acoustics is that it is not limited to times, behavioral patterns or locations where organisms emit sound, such as passive acoustic observations do. Further, in contrast to acoustic tagging of organisms, active acoustics is ideal to observe aggregative or grouping behavior (e.g., Josse et al. 1999; Doray et al. 2006; Trygonis et al. 2016) and species interactions, such as those of predator and prey (e.g., Josse et al. 1998; Lebourges-Dhaussy et al. 2000; Ménard and Marchal 2003; Ménard et al. 2005). Combining with in situ or high-resolution satellite environmental data, acoustics can be used to study the interactions of organisms with their environment at a variety of scales (Josse et al. 1999; Wilson and Boehlert 2004; Doray et al. 2006; Domokos 2009; Cascão et al. 2017).

While active acoustics have exceptionally wide range of applicability and extensive capabilities, received acoustic signals need to be interpreted correctly to provide usable matrices of the reflective source, such as type of organism, species, size, or density. During the past few decades, impressive strides have been made to develop ways of identifying organisms based on specific characteristics such as their physiology, body type, shape, and composition. There is an ever-growing extensive database containing organism size and orientation vs. acoustic Target Strength (TS, the “reflectivity”) and other acoustic descriptors, such as behavior, of species or basic phylogenic groups of organisms, such as fish with or without swim bladder, shrimp-type, gelatinous organisms with or without gas inclusions, and cephalopods. Acoustically identifying such basic organism types enables us to obtain crucial information on biomass, distribution, and composition of the acoustic Scattering Layers (SL), composed of micronekton and zooplankton, that are ubiquitous in the world’s oceans and contain the largest percentage of the total faunal biomass on the Earth (Fernandes et al. 2005; Trenkel and Berger 2013; Jech et al. 2015; Proud et al. 2015; Ariza et al. 2016; Peña and Calise 2016; Wall et al. 2016).

Availability of active acoustic data on specific SL organisms or group of organisms is extensive (Miyashita et al. 1996; Benoit-Bird and Au 2001; Fernandes et al. 2005; Smith et al. 2013) and continues to grow at a steady rate. Active acoustic identification and echo categorization of nekton species or group of species has also been expanding rapidly (Bertrand et al. 1999; Kloser et al. 2002; Kelly J Benoit-Bird et al. 2003; Rooper et al. 2012; Ryan and Kloser 2013; Gastauer et al. 2016; Korneliussen et al. 2016), providing direct estimates of biomass, abundance, distribution, and behavior of economically important resources.

While acoustic identification of organisms to the species level can sometimes be challenging, active acoustic data can provide observations of entire ecosystems as opposed to those of single species with spatial resolution from micro- to meso- to basin-scales and temporal resolutions from seconds to hours to years and decades (Godø et al. 2014). Therefore, active acoustics is an ideal tool to investigate issues ranging from the level of organism and physiological responses to the environment to ecosystem-level studies and the effects of climate in support of ecosystem-based management (Koslow 2009; Trenkel et al. 2011; Benoit-Bird and Lawson 2016).