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Cover: Opakapaka as viewed from the underwater camera (left) and caught during research fishing operations (right). Photo courtesy of [NOAA photos]

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Executive Summary

To improve the data used in stock assessments, the Pacific Islands Fisheries Science Center has developed a multi-gear, Bottomfish Fishery-Independent Survey in Hawaii (BFISH). BFISH was designed to provide species-specific, size structured abundance and biomass for the main Hawaiian Islands "Deep7" bottomfish complex. This study evaluated the impact of sampling season and survey gear on abundance estimates.

The survey employs two gears: (1) hook and line, the standard gear in the commercial fishery and, (2) stereo cameras. In 2016 and 2017, surveys were conducted using the two gears in two seasons (spring, fall). However, there were significant disparities in the spatial distribution and intensity of sampling effort with respect to season and gear. Despite these limitations, data were sufficient for a preliminary analysis of season and gear effects.

Domain and habitat strata estimates of CPUE and proportion occurrence showed similar patterns between the two gears for most species. These findings were consistent with pilot studies. Species abundance estimates were generally higher for the camera gear; however, there were some differences in gear size selectivity for ehu, opakapaka, onaga, and kalekale. It is unclear whether these differences arise from size selectivity or spatial disparities in sampling or stock distribution.

CPUE estimates were significantly lower in spring compared to fall for onaga and kalekale. There were also some differences in seasonal length frequencies for opakapaka. The differences in CPUE estimates may be due to reduced sampling effort and limited spatial coverage in the spring. A large number of observations with no length information likely further influenced differences in size frequency distributions.

This study highlighted an imbalance in spatial coverage and sampling intensity of the two gears. Ideally, future surveys would ensure comparable spatial sampling coverage for all gears and that lengths are obtained for each individual fish. Further gear calibration experiments throughout the sampling domain would benefit the accurate conversion of gear-specific CPUE to a uniform nominal unit. Sampling and data issues notwithstanding, this study did not detect a strong seasonal signal; hence, future seasonal surveys appear to be a lower priority.

Introduction

Commercial and recreational fishing are extremely important to the economy and culture of Hawaii (Haight et al. 1993). The Hawaiian deep-slope (75–400 m) “Deep7” bottomfish fishery consists of seven species, six snappers and one grouper, and serves as the primary insular commercial fishery (Langseth et al. 2018; Table 1). Under the Magnuson–Stevens Fishery Conservation and Management Act (MSA), the Pacific Islands Fisheries Science Center of the National Oceanic and Atmospheric Administration (PIFSC) is mandated to conduct formal assessments of the Deep7 stock. Until recently, Deep7 assessments relied solely on fishery-dependent estimates (i.e., catch per unit effort, CPUE) as the principal index of relative abundance and biomass (Brodziak et al. 2014, Langseth et al. 2018).

To improve the data used in stock assessments, the PIFSC has developed a multi-gear, Bottomfish Fishery-Independent Survey in Hawaii (BFISH) (Richards et al. 2016, Ault et al. 2018). Pilot studies to quantitatively evaluate effective sampling methods, mapped habitat covariates (e.g., benthic substrate, slope, and depth), and survey gears were conducted from 2011–2015 in the waters between the islands of Maui, Molokai, and Lanai (“Maui Nui complex”). Results from these pilot studies were used to design the operational BFISH survey that was first fully implemented throughout the eight main Hawaiian Islands in 2016 (Ault et al. 2018). The BFISH survey follows a probabilistic sampling design that provides robust, cost-effective estimation of population-level metrics (Ault et al. 1999, Smith et al. 2011).

Table 1. The Hawaiian Islands Deep7 bottomfish complex.

Common name	Scientific name	Species code
Ehu	*Etelis carbunculus*	ETCA
Gindai	*Pristipomoides zonatus*	PRZO
Hapu'upu'u	*Hyporthodus quernus*	HYQU
Kalekale	*Pristipomoides sieboldii*	PRSI
Lehi	*Aphareus rutilans*	APRU
Onaga	*Etelis coruscans*	ECTO
Opakapaka	*Pristipomoides filamentosus*	PRFI

This study evaluated two elements of BFISH: (1) appropriate sampling season and (2) survey gear efficiency. Assumptions of the BFISH design include no differences between seasons or gears in estimation of size-structured abundance for Deep7 species. Little information has been published on seasonal differences in stock distribution. In 2016 and 2017, spring and fall surveys were conducted to test the seasonality assumption. These BFISH surveys employed two gears: (1) hook and line, the standard gear in the commercial fishery, and (2) stereo cameras. These gears have been standardized to a single nominal effort unit (Richards et al. 2016), but this assumes both gears are sampling proportional to the stock.

Methods

Survey design

The BFISH survey domain encompasses the full extent of mapped bottomfish habitats from 75 to 400 m depths, extending from the Big Island of Hawaii 600 km northwest to the island of Niihau (Figure 1). The survey frame was comprised of 500×500m primary sample units (PSU) stratified according to three depth categories (75 to <200 m, ≥200 to <300 m, ≥300 to 400 m), and three substrate composition-complexity categories (softbottom-all slopes, hardbottom-low slope, hardbottom-high slope) (Table 2; Ault et al. 2018). Samples were allocated among strata following a Neyman scheme (Cochran 1977), and sample units within strata were randomly selected without replacement from a discrete uniform probability distribution to ensure equal probability of selection (Law and Kelton 2000).

Survey gears

Within each stratum-specific, randomly selected PSU, individual species number and length composition were obtained from one or both of the two survey gears. Hook-and-line effort was standardized to 30 minutes of active fishing by one vessel using two lines, each with four standard size hooks and two types of bait (Richards et al. 2016). Each fish caught by the gear was identified to species and measured to the nearest cm fork length (FL). Cameras (Richards et al. 2016) were deployed in two randomized replicate 15-minute drops. Video footage was analyzed to generate species level counts using the MaxN method (Cappo et al. 2016) with FL measurements to the nearest mm. Camera counts were averaged by PSU. Both gears were necessary to sample the BFISH domain due to depth limitation of the camera (250 m) and areas that excluded fishing.

Domain and strata estimation

Species-level strata and domain abundance metrics (CPUE, proportion occurrence, length frequency, and average length) were estimated following standard stratified random sampling procedures (Cochran 1977, Lohr 2010, Ault et al. 2018). All metrics were estimated for two life history phases: pre-exploited combined with exploited; and exploited only. Exploited phase was defined as fish ≥ 29 cm FL, the length of a one pound opakapaka that can be sold in Hawaii.

Gear evaluation

Domain and strata estimates of CPUE, proportion occurrence, and length frequency for the two life phases were compared between gears. Due to the depth limitation of the camera gear, deep strata were excluded. Domain-level exploited phase average length estimates were compared using a pairwise t-test at 95% confidence ($\alpha = 0.05$).

Seasonal evaluation

Domain and strata estimates of mean CPUE and length frequency for the two life phases were compared between spring and fall. Survey years were evaluated both independently and combined. Seasonal domain-level CPUE and average length estimates were compared using a pairwise t-test at 95% confidence ($\alpha = 0.05$).

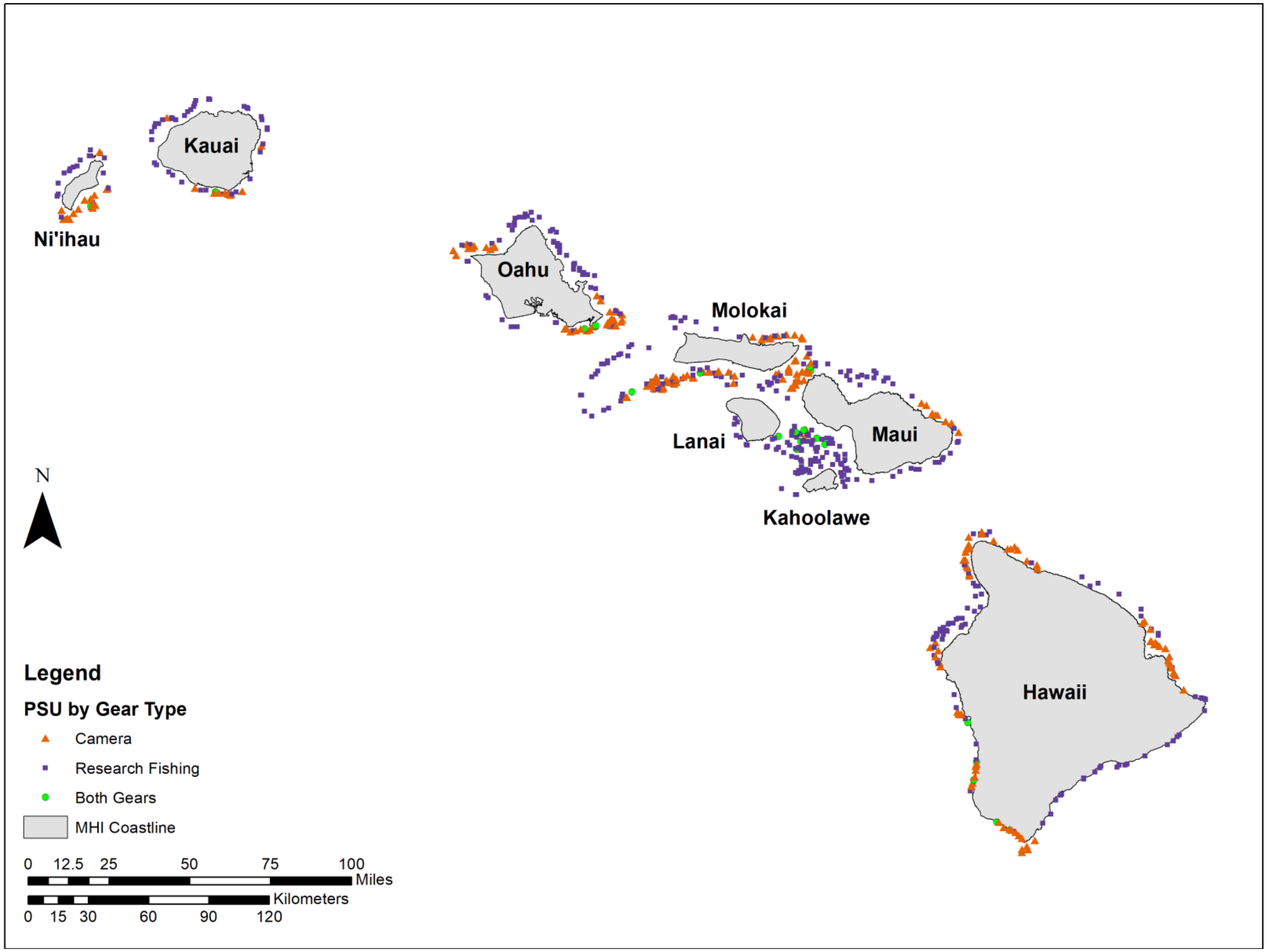

Figure 1. Spatial distribution of PSUs sampled during the fall surveys (2016 and 2017 combined). The camera surveys are denoted by orange triangles, research fishing surveys by purple squares, and green circles denote PSUs surveyed by both gears.

Table 2. Number of 500 × 500 m grid cells (PSUs) by substrate-slope-depth strata for the main Hawaiian Islands.

Substrate	Slope	Depth	Strata code	PSUs
SB (Softbottom)	A (all, high and low slope)	S (Shallow, 75 to <200m)	SB_A_S	1863
HB (Hardbottom)	L (low slope)	S	HB_L_S	4562
HB	H (high slope)	S	HB_H_S	4777
SB	A	M(Medium, ≥200 to <300m)	SB_A_M	1449
HB	L	M	HB_L_M	2688
HB	H	M	HB_H_M	2412
SB	A	D (Deep, ≥300 to 400m)	SB_A_D	1591
HB	L	D	HB_L_D	3801
HB	H	D	HB_H_D	2749
			Total	25,892

Results

Sampling effort by season and gear

Sampling effort by year, strata, season, and gear is shown in Table 3. Spring surveys only used one gear type: research fishing in 2016 and cameras in 2017. The spatial distribution of gears for the fall 2016–2017 surveys combined is shown in Figure 1. The sampling effort for cameras was more restricted compared to research fishing (Table 3, Figure 1). The spatial distribution of sampling effort was more restricted in spring (Figure 2), particularly in the Maui Nui region. A large number of observations lacked length information (Table 4), which was corrected for research fishing after spring 2016. Observations lacking lengths were excluded from exploited phase CPUE and length frequency analyses. The four most abundant species (ehu, opakapaka, onaga, and kalekale) in the commercial catch and the survey were the focus of gear and season analyses.

Table 3. Number of PSUs sampled each survey year, strata, season, and gear type. See Table 2 for strata code descriptions.

		2016				**2017**			
		Spring		**Fall**		**Spring**		**Fall**	
Strata code	PSUs	Camera	Fishing	Camera	Fishing	Camera	Fishing	Camera	Fishing
SB_A_S	1863	0	10	1	5	2	0	6	6
HB_L_S	4562	0	34	10	29	5	0	25	18
HB_H_S	4777	0	49	50	67	25	0	69	127
SB_A_M	1449	0	11	1	5	2	0	2	4
HB_L_M	2688	0	16	4	27	6	0	14	22
HB_H_M	2412	0	18	32	61	16	0	34	77
SB_A_D	1591	0	16	0	5	0	0	0	6
HB_L_D	3801	0	35	0	19	0	0	0	25
HB_H_D	2749	0	29	0	33	0	0	0	38
Total	**25892**	**0**	**218**	**98**	**251**	**56**	**0**	**150**	**323**

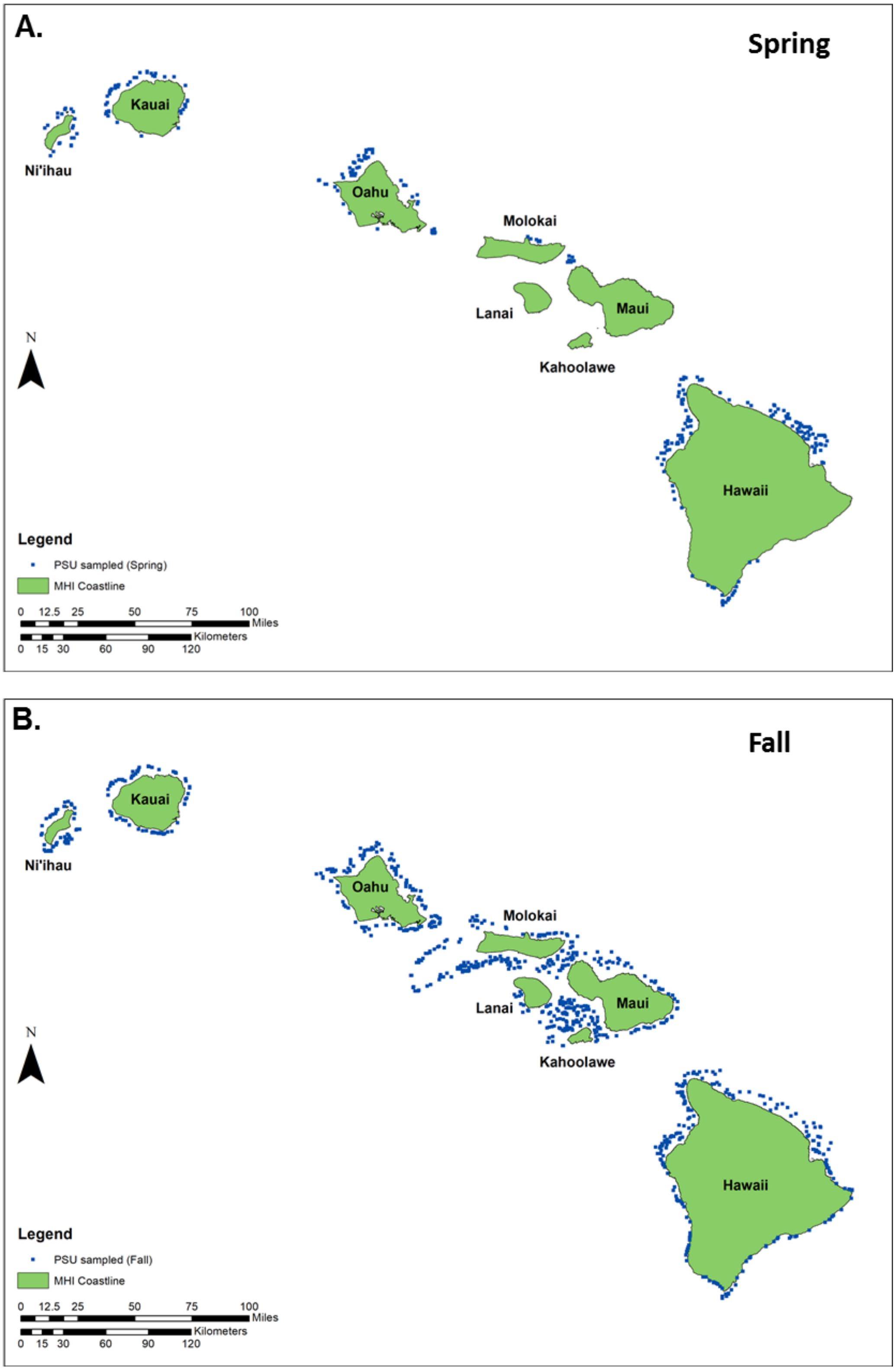

Figure 2. The spatial distribution of primary sampling units (PSUs) sampled during 2016 and 2017 combined: (A) spring and (B) fall.

Table 4. Percent of individual species records with missing length information by survey and gear type. NA denotes no records.

	Spring		Fall 2016		Fall 2017	
Species	Camera (2017)	Fishing (2016)	Camera	Fishing	Camera	Fishing
Focal species	-	-	-	-	-	-
Ehu	60.0 %	4.2 %	47.4 %	0.7 %	15.8 %	0.0 %
Kalekale	100.0 %	0.0 %	27.5 %	0.0 %	7.6 %	0.0 %
Onaga	0.0 %	100.0 %	33.3 %	0.0 %	66.7 %	0.0 %
Opakapaka	20.0 %	0.0 %	20.4 %	0.0 %	9.2 %	0.0 %
Non-focal species	-	-	-	-	-	-
Gindai	100.0 %	0.0 %	60.0 %	0.0 %	83.3 %	0.0 %
Hapu'upu'u	50.0 %	0.0 %	100.0 %	0.0 %	66.7 %	0.0 %
Lehi	50.0 %	0.0 %	18.2 %	NA	44.4 %	NA

Gear comparison

Relative abundance (CPUE and proportion occurrence)

Estimates of CPUE for species, life phase, domain and strata were evaluated for potential gear-specific differences. Relative abundance and occurrence were generally higher for camera gears compared to fishing for each species, following the results of pilot studies (Figure 3). The exception was ehu (ETCA), where both CPUE and occurrence were higher for fishing gear. In general, species estimates of proportion occurrence tracked CPUE patterns for life phases. Subsequent results presented in this report focus on CPUE.

The pattern of CPUE estimates across habitat strata and life phases were similar between gears for ehu (Figure 4), opakapaka (Figure 5), onaga (Figure 6), and kalekale (Figure 7). The exceptions were strata where no fish were observed by either of the gears, which were perhaps related to differences in the intensity and spatial distribution of sampling effort.

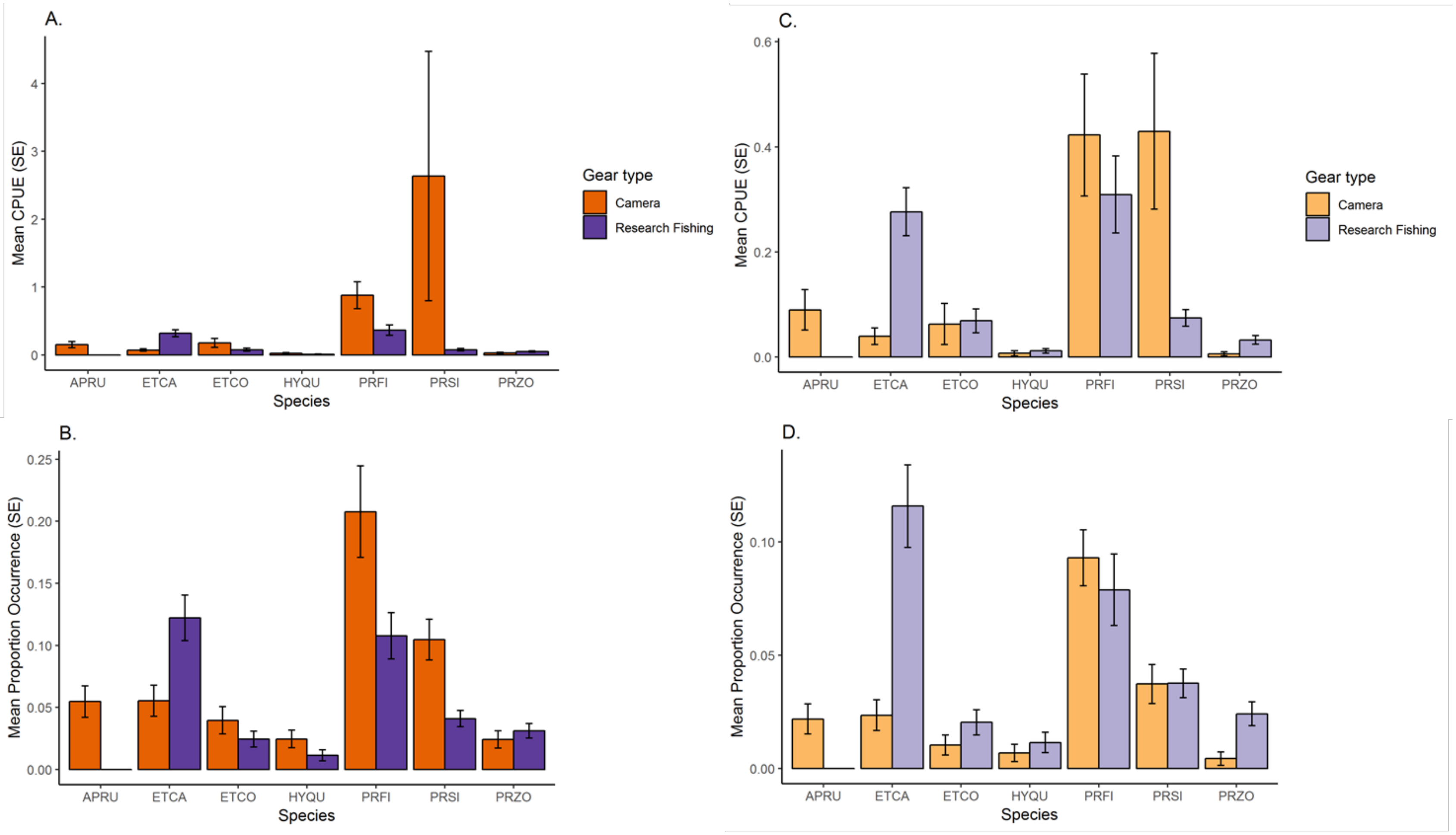

Figure 3. Gear comparison of CPUE and proportion occurrence with +/- 1 standard error displayed as vertical lines, by species for both phases (A, B) and exploited phase (C, D), respectively, during fall 2016–2017 combined. See Table 1 for species code descriptions

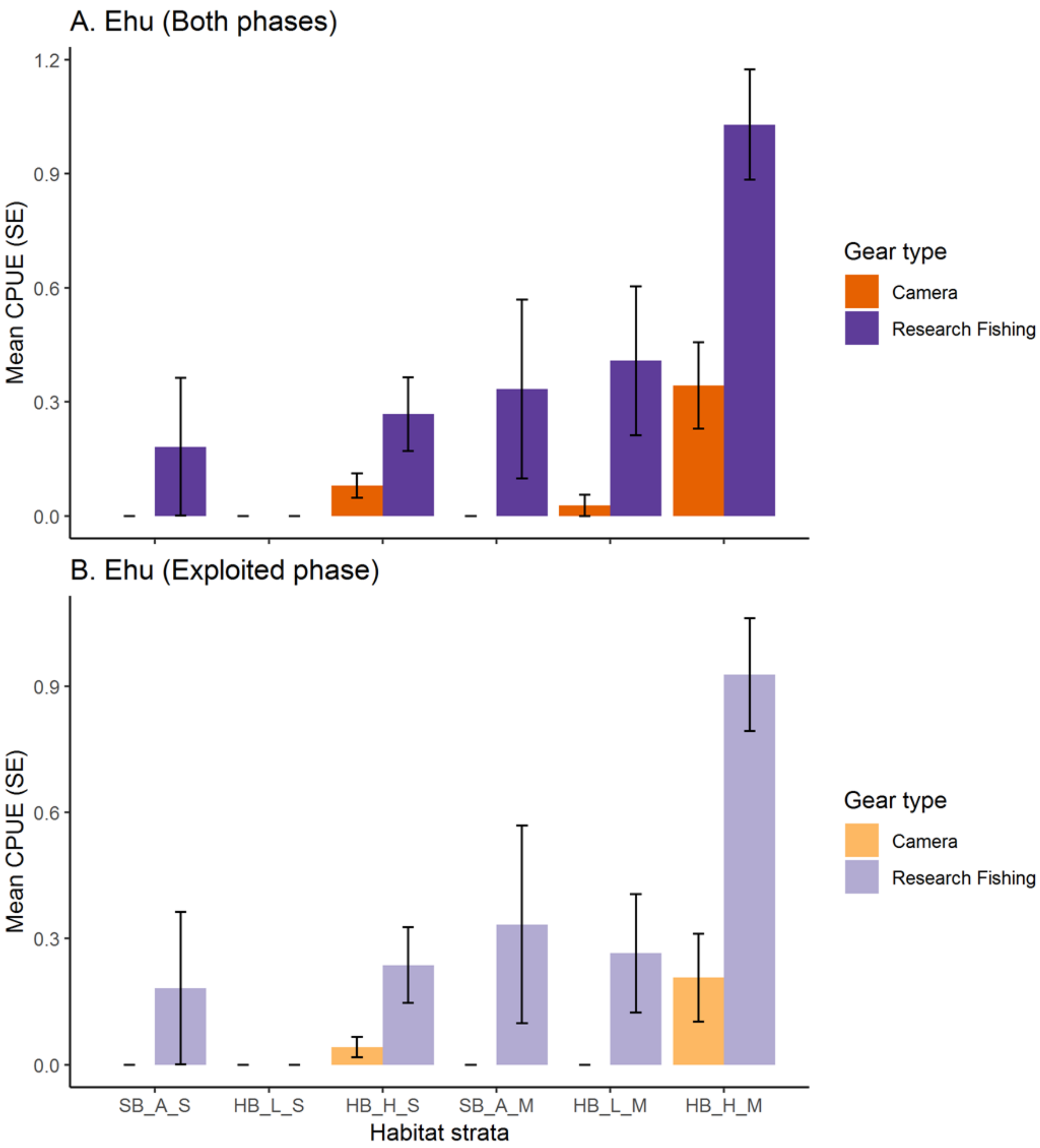

Figure 4. Gear comparison of CPUE and associated standard error (vertical lines) for ehu using 2016–2017 fall data combined by strata for both phases (A) and exploited phase (B). See Table 2 for strata code descriptions.

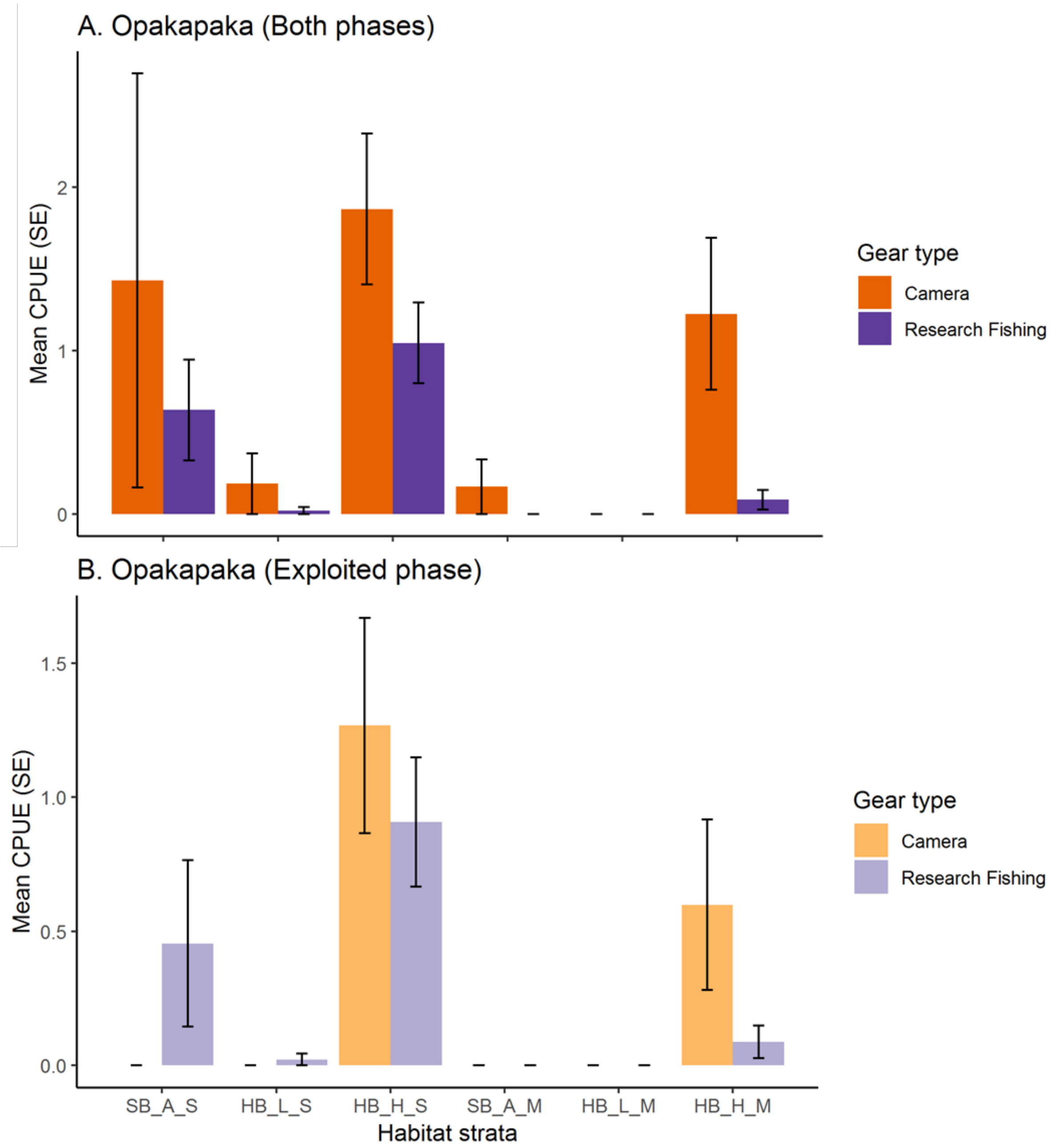

Figure 5. Gear comparison of CPUE and associated standard error (vertical lines) for opakapaka using 2016–2017 fall data combined by strata for both phases (A) and exploited phase (B). See Table 2 for strata code descriptions.

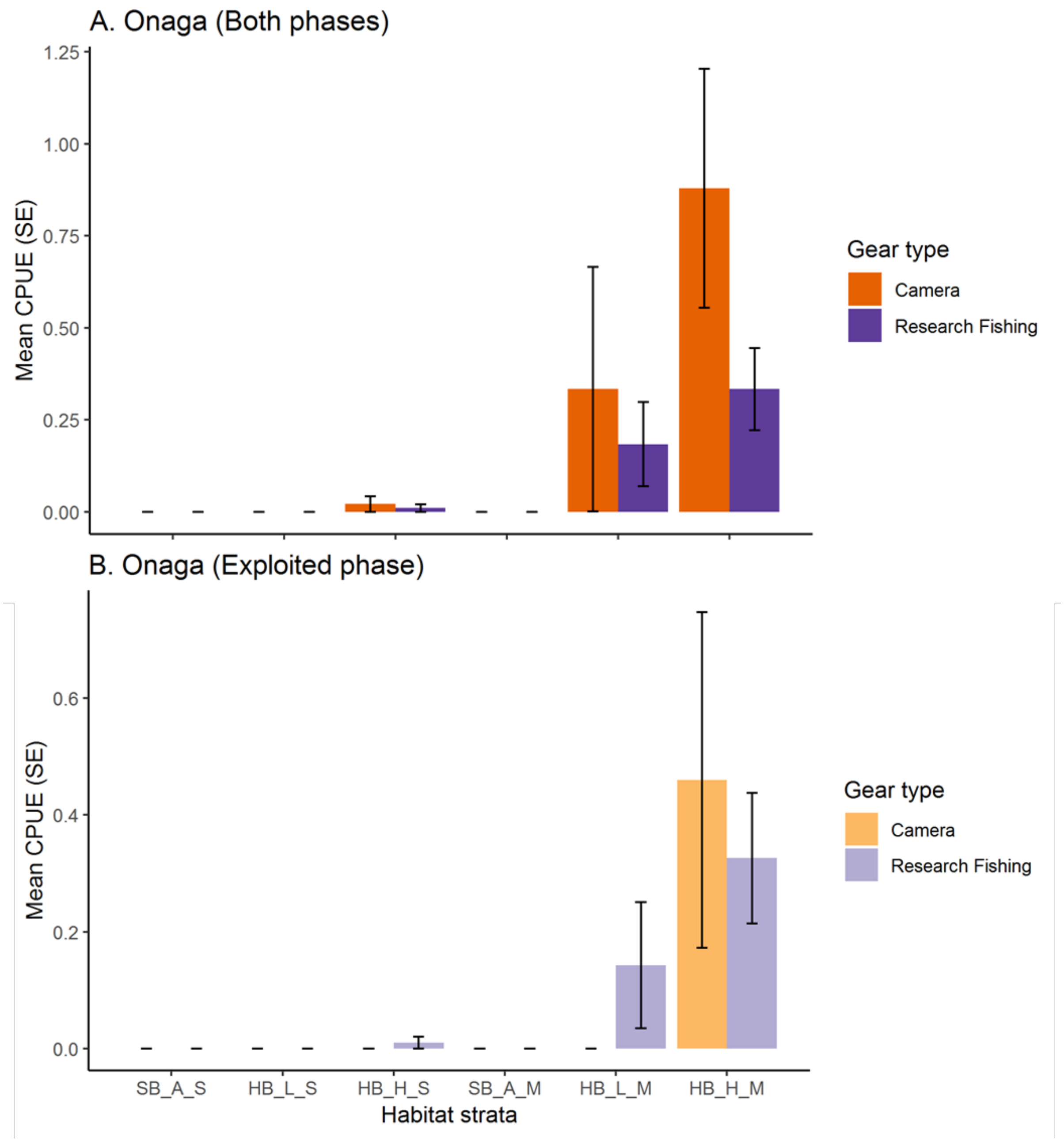

Figure 6. Gear comparison of CPUE and associated standard error (vertical lines) for onaga using 2016–2017 fall data combined by strata for both phases (A) and exploited phase (B). See Table 2 for strata code descriptions.

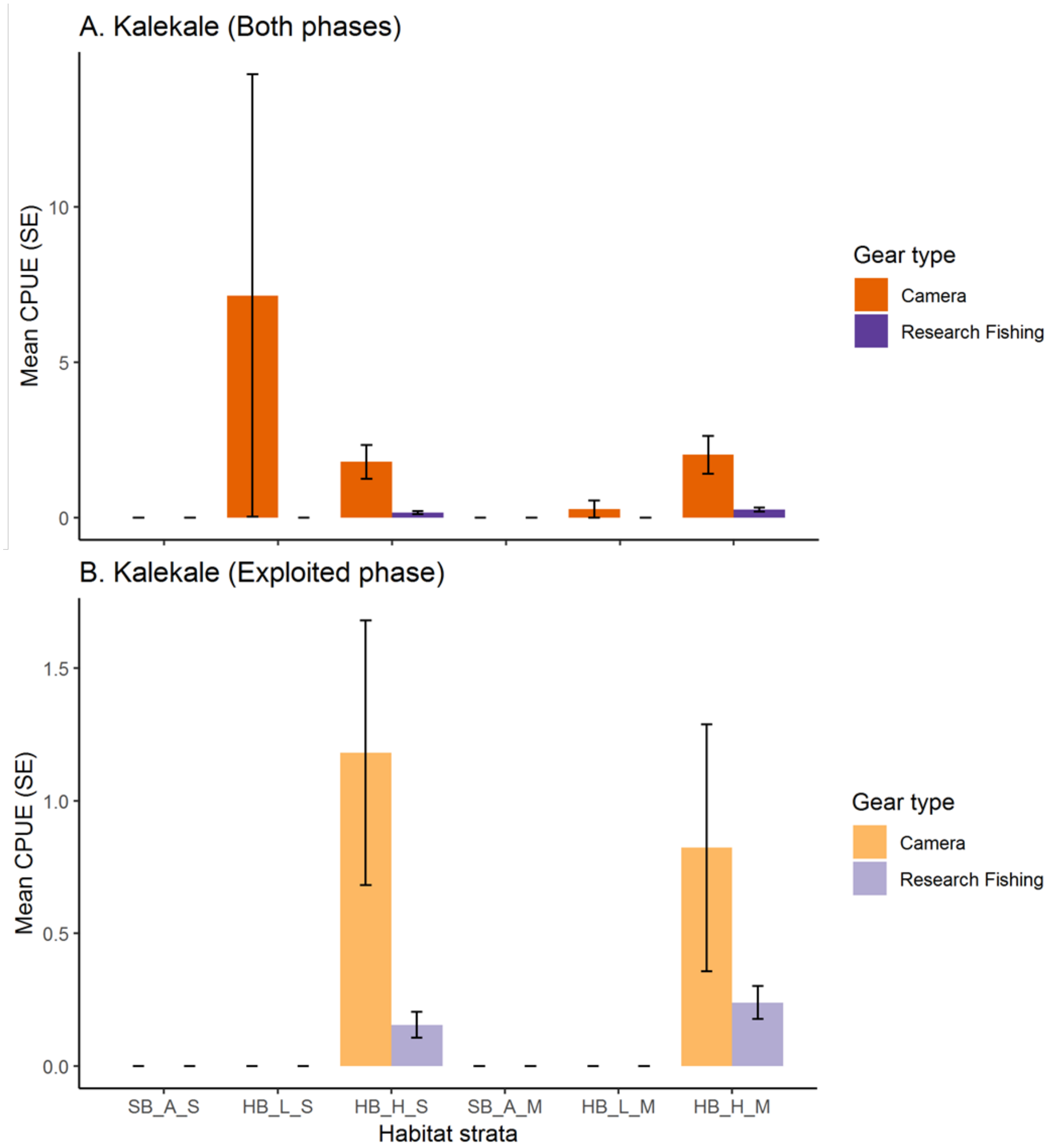

Figure 7. Gear comparison of CPUE and associated standard error (vertical lines) for kalekale using 2016–2017 fall data combined by strata for both phases (A) and exploited phase (B). See Table 2 for strata code descriptions.

Length frequency gear comparison

Length frequency distributions for the two gears varied among species at the domain and strata levels (Figures 8–16). In general, length frequencies for the two gears were similar for the species' exploited life phases. The main differences were small fish observed by one gear and not the other. The camera observed the smallest lengths for opakapaka (Figures 11–12) and kalekale (Figures 15–16), whereas research fishing sampled the smallest lengths for ehu (Figures 8–10) and onaga (Figures 13–14).

Some differences were observed in average length of the exploited stage between the gears (Figures 8B, 11B, 13B, and 15B). This may be a function of missing lengths for the camera gear (Table 4), as well as disparities in sampling effort.

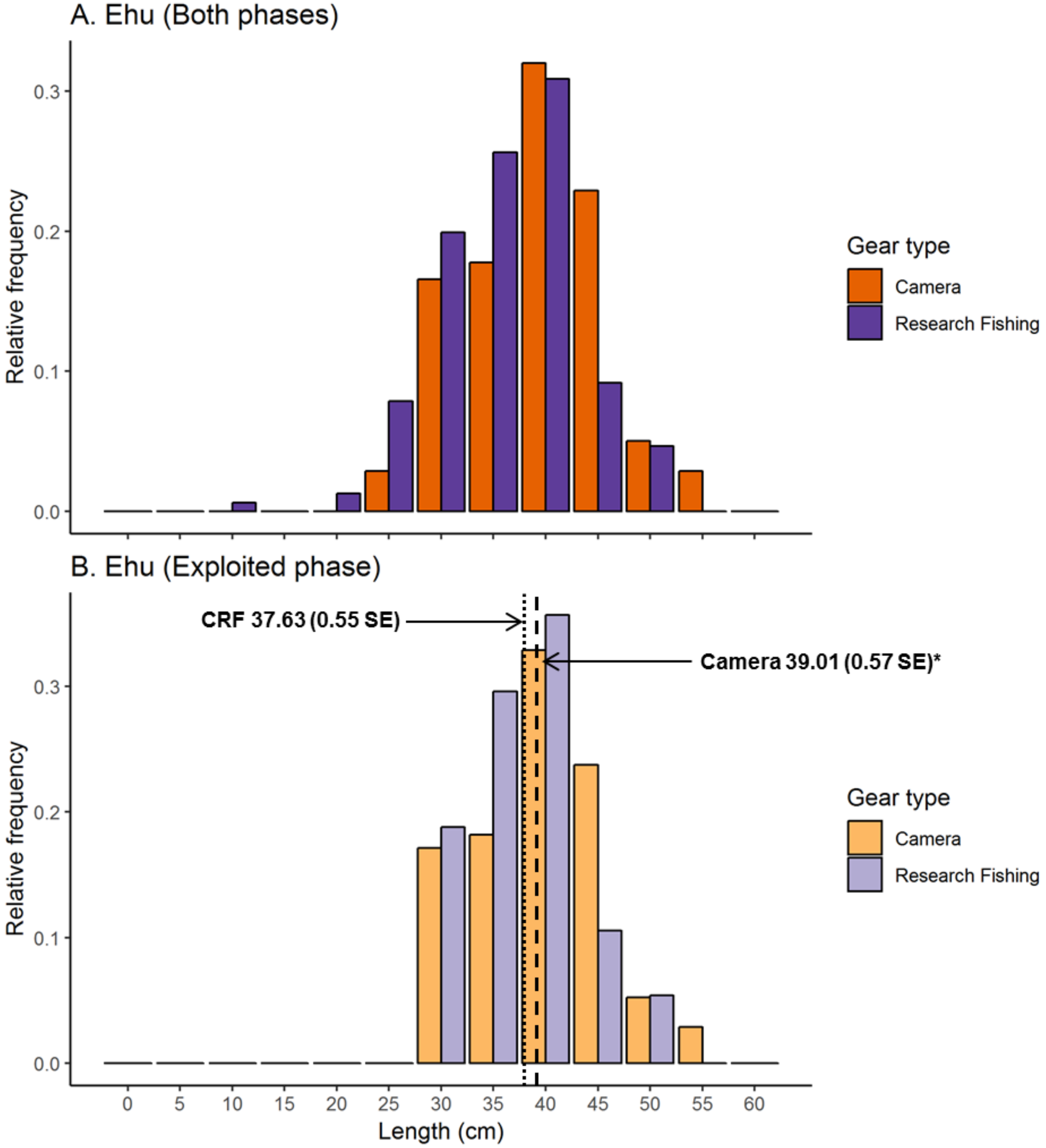

Figure 8. Gear comparison of length frequency (2016–2017 Fall) for ehu by life phase: (A) both phases and (B) exploited phase. Average length of the exploited phase denoted by dashed line (fall) and dotted line (spring). Significant difference in average length indicated by (*).

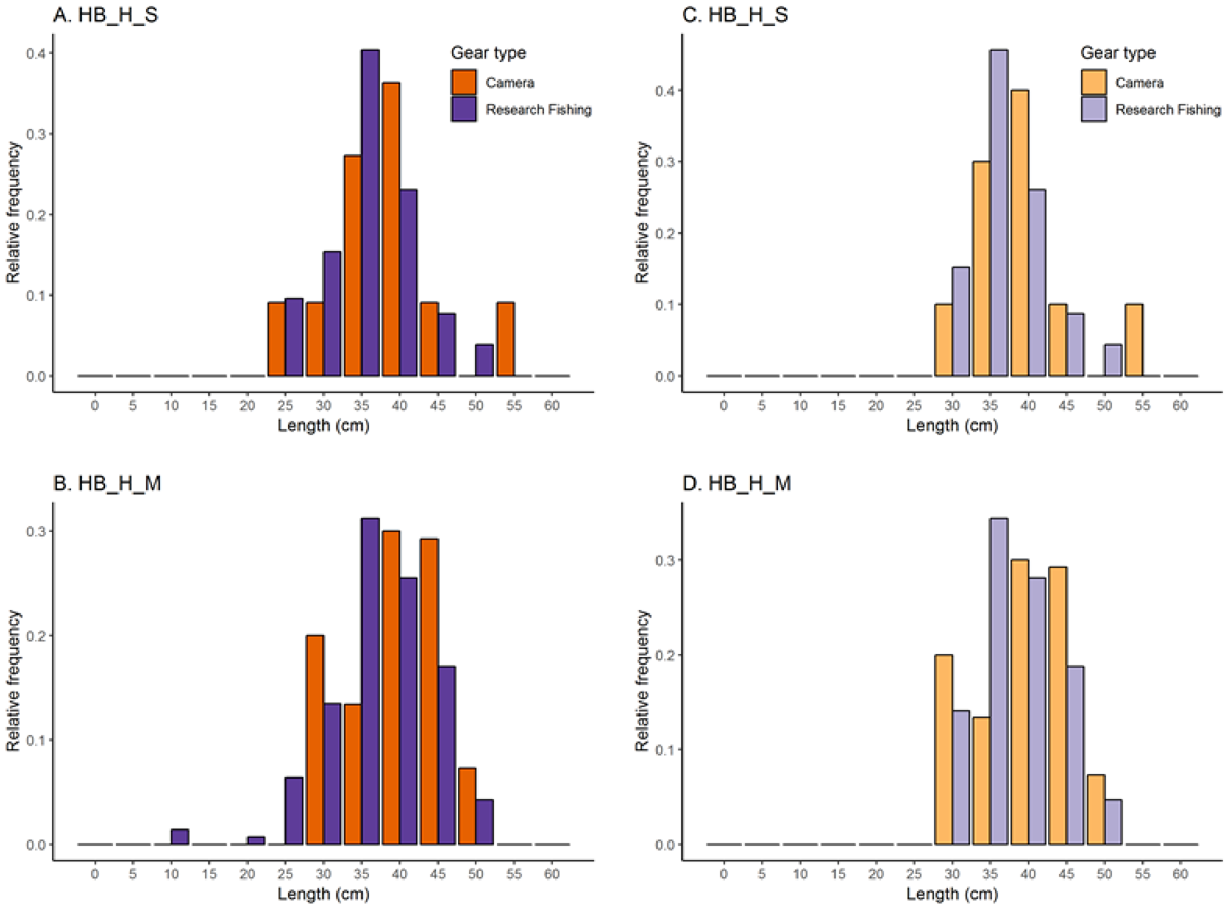

Figure 9. Gear comparison of length frequency (Fall 2016–2017) for ehu by strata and life phase: (A–B) both phases and (C–D) exploited phase. See Table 2 for strata code descriptions.

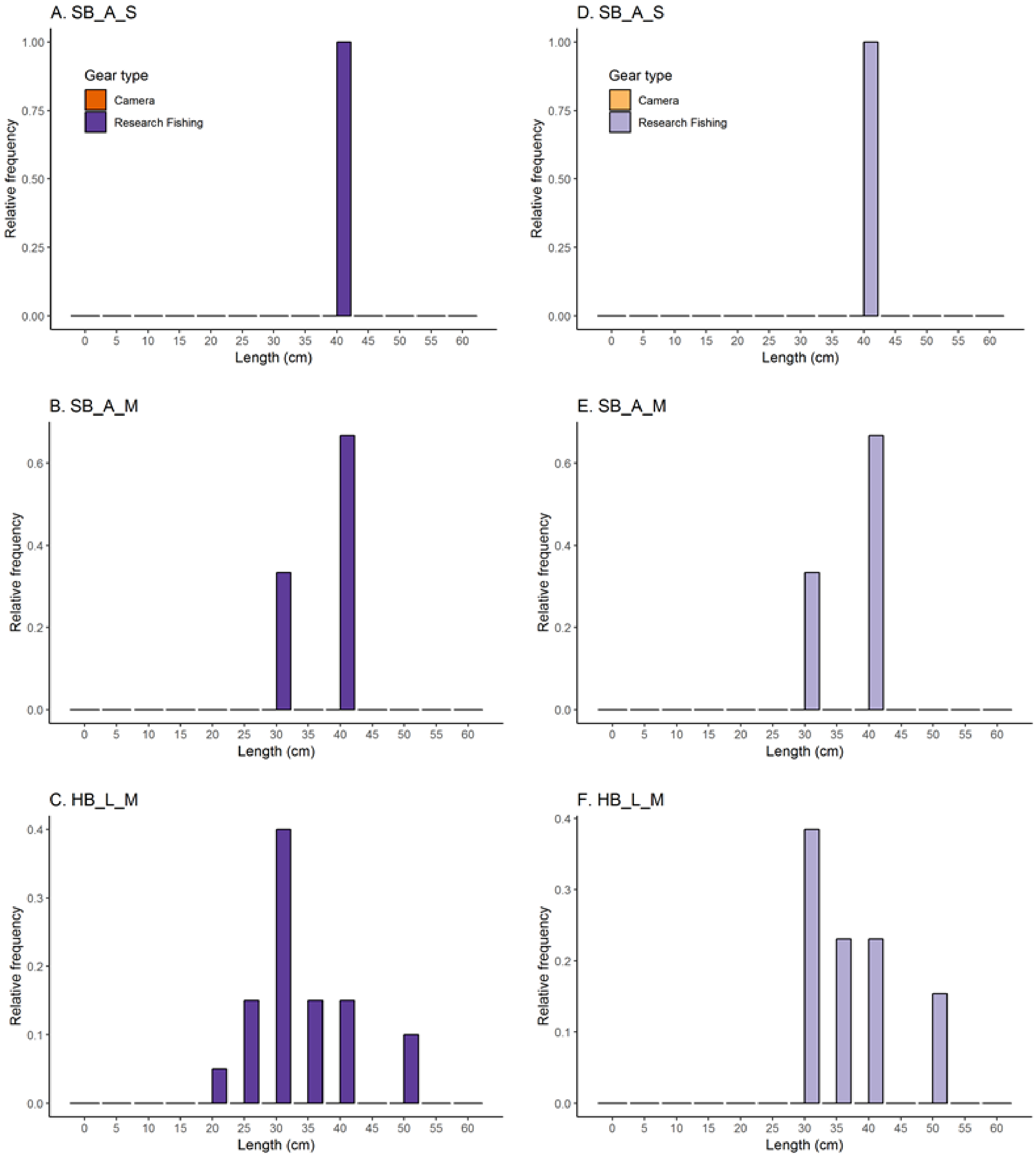

Figure 10. Gear comparison of length frequency (Fall 2016–2017) for ehu by strata and life phase: (A–C) both phases and (D–F) exploited phase. See Table 2 for strata code descriptions.

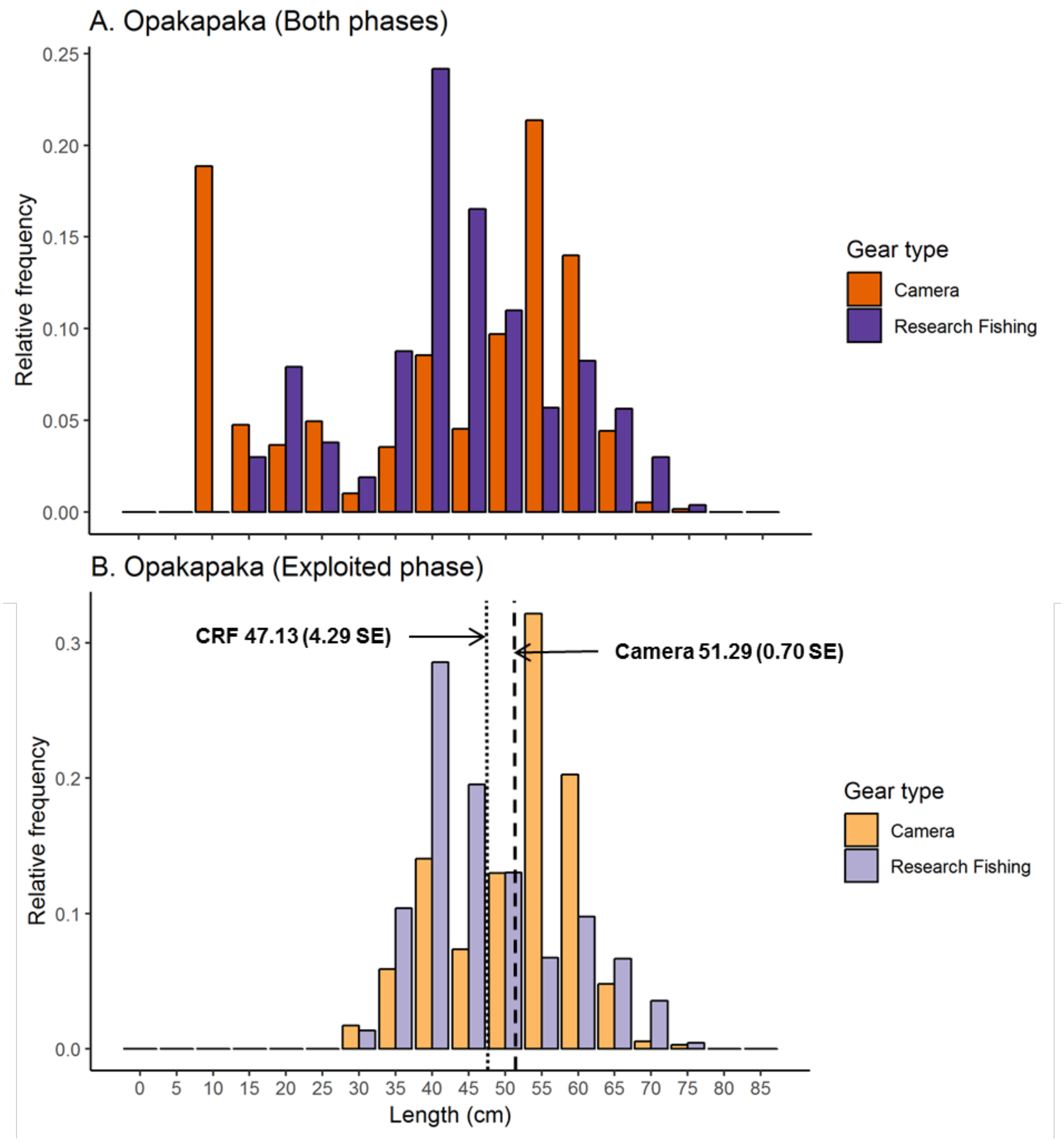

Figure 11. Gear comparison of length frequency (2016–2017 Fall) for opakapaka by life phase: (A) both phases and (B) exploited phase. Average length of the exploited phase denoted by dashed line (fall) and dotted line (spring).

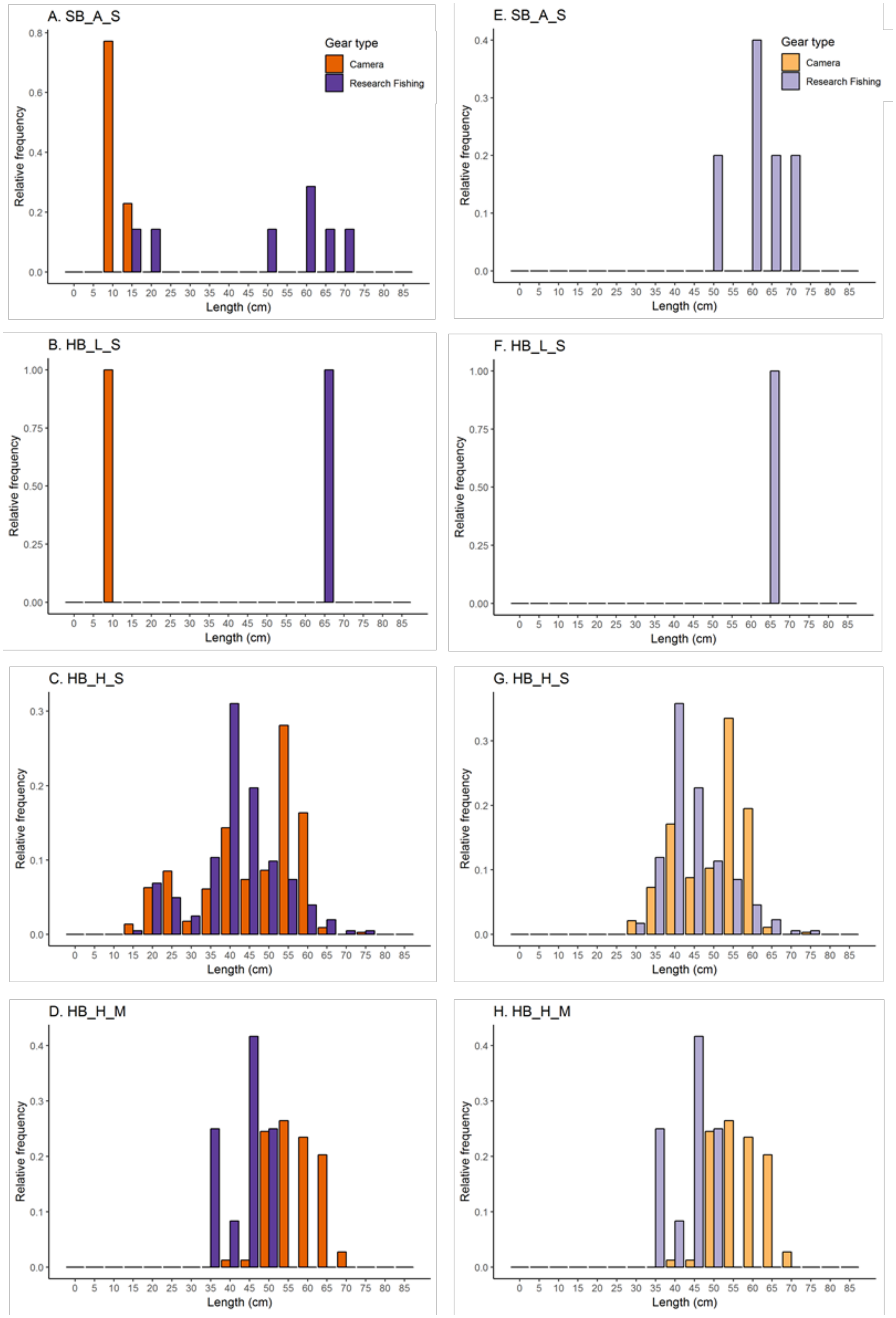

Figure 12. Gear comparisons of length frequency (Fall 2016–2017) for opakapaka by strata and life phase: (A–D) both phases and (E–H) exploited phase. See Table 2 for strata code descriptions.

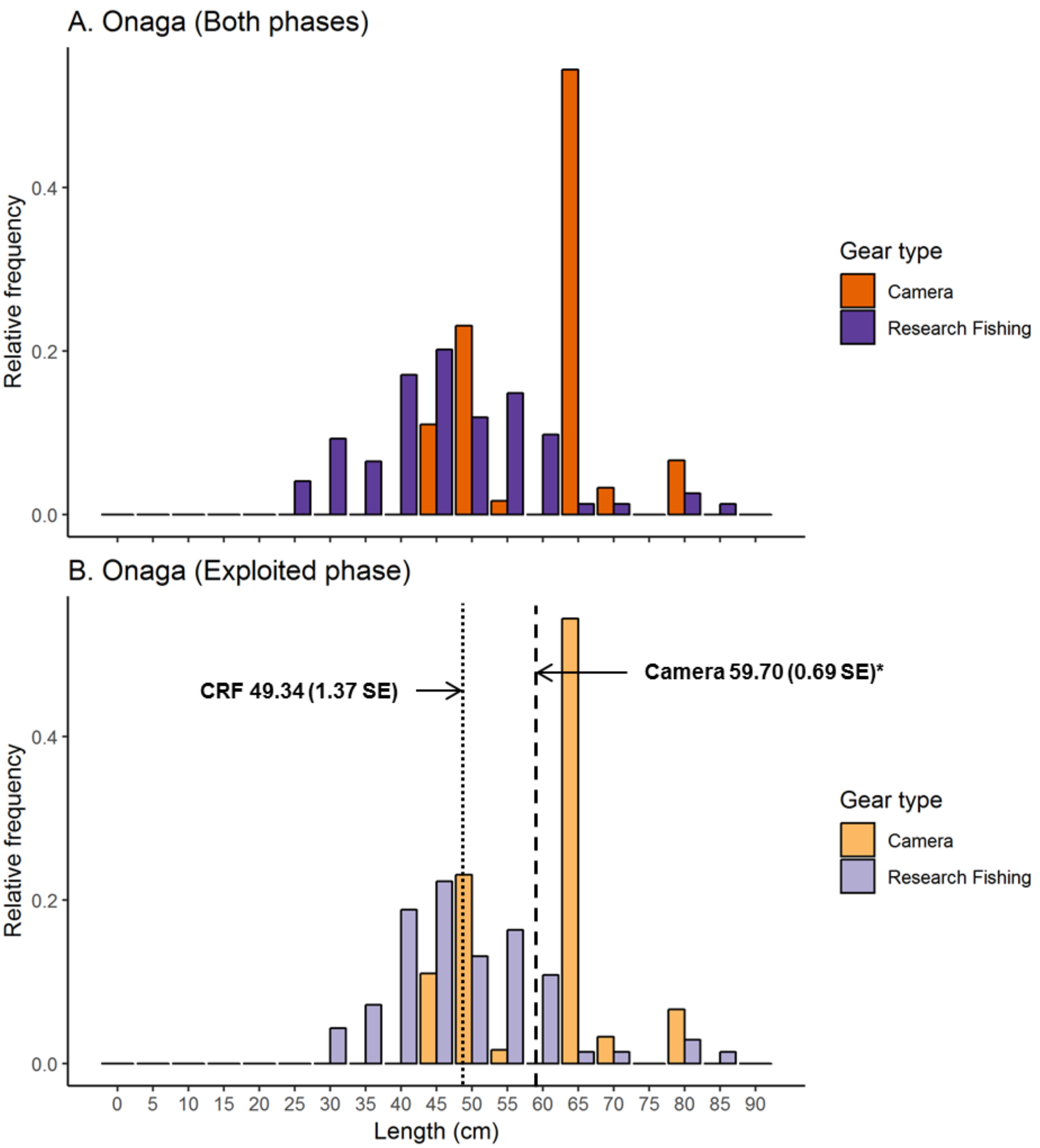

Figure 13. Gear comparison of length frequency (2016–2017 Fall) for onaga by life phase: (A) both phases and (B) exploited phase. Average length of the exploited phase denoted by dashed line (fall) and dotted line (spring). Significant difference in average length indicated by (*).

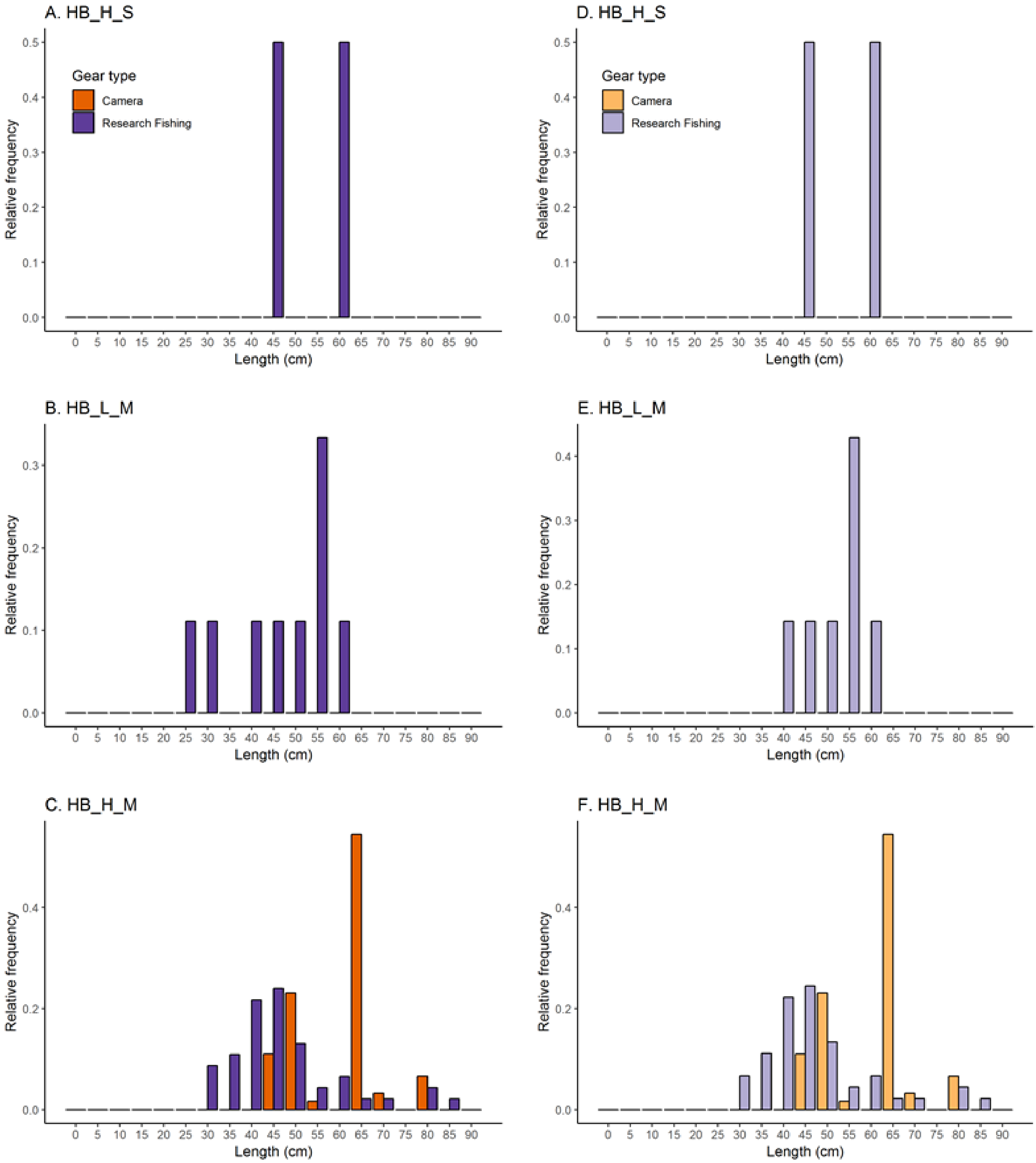

Figure 14. Gear comparisons of length frequency (Fall 2016–2017) for onaga by strata and life phase: (A–C) both phases and (D–F) exploited phase. See Table 2 for strata code descriptions.

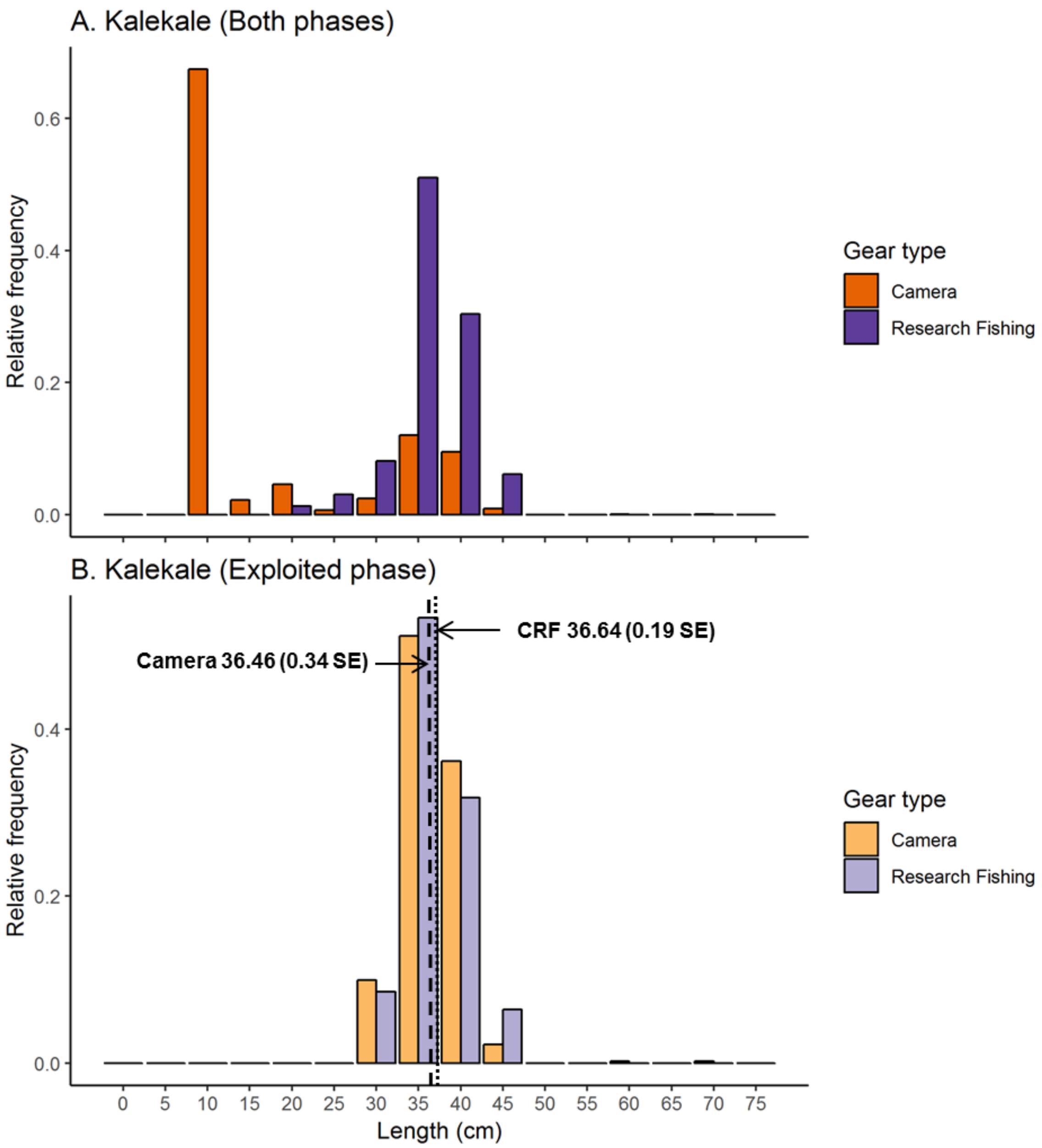

Figure 15. Gear comparison of length frequency (2016–2017 Fall) for kalekale by life phase: (A) both phases and (B) exploited phase. Average length of the exploited phase denoted by dashed line (fall) and dotted line (spring).

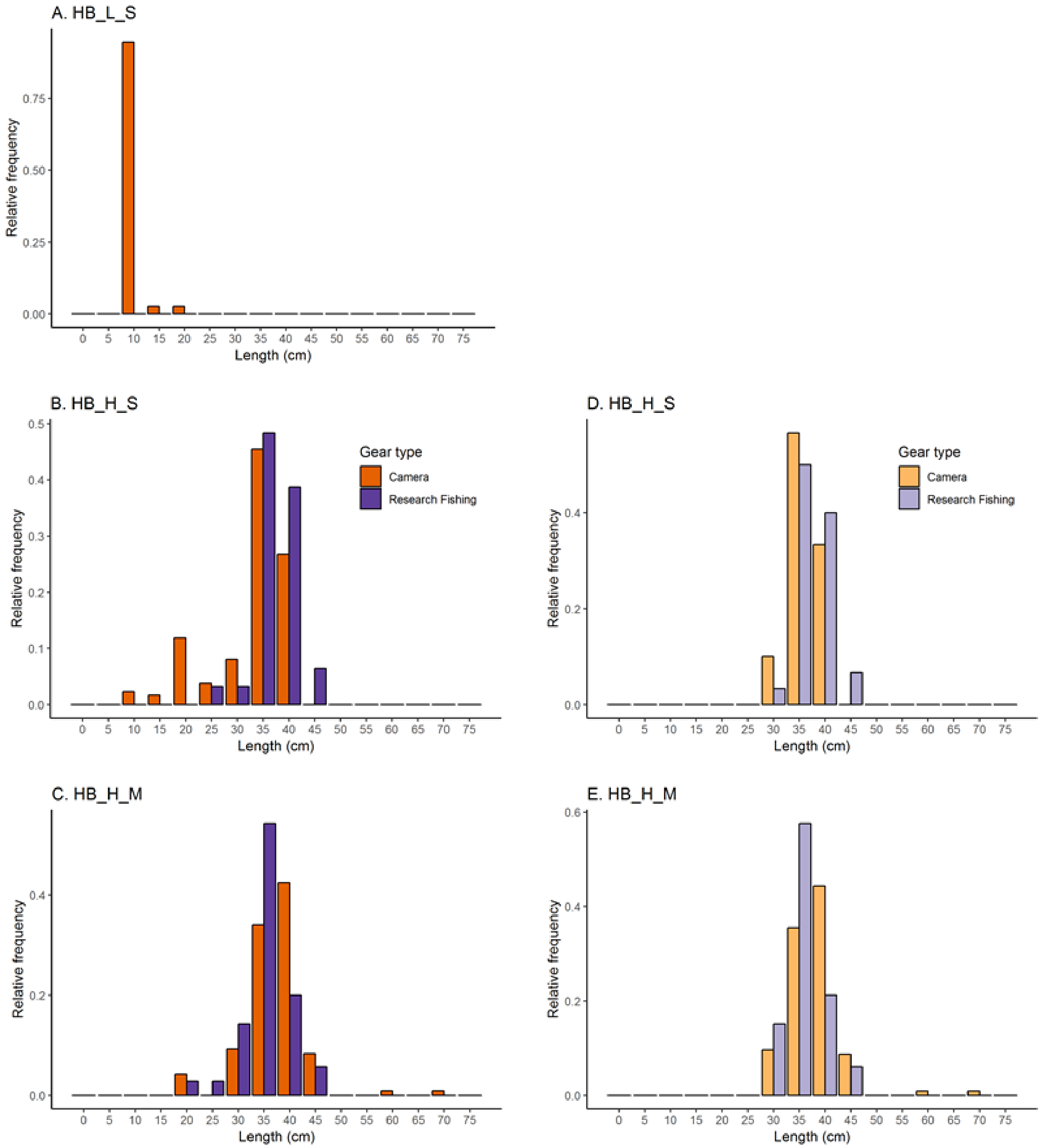

Figure 16. Gear comparison of length frequency (Fall 2016–2017) for kalekale by strata and life phase: (A–C) both phases and (D–F) exploited phase. See Table 2 for strata code descriptions.

Seasonal evaluation

Relative abundance (CPUE) seasonal comparison

Estimates of CPUE for species, life phase, domain, and strata were evaluated for potential season-specific differences (Figures 17–21). At the domain level, the only cases that showed significant seasonal difference in CPUE estimates were onaga (both life phases) during 2016 and 2016–2017, and kalekale (exploited phase) during 2017 (Figure 17, Table 5). In both cases, the spring estimates of CPUE were less than the fall estimates.

CPUE estimates by strata showed similar seasonal patterns by species and life phase. The only differences were strata where no fish were observed in one season or the other. These exceptions were perhaps related to differences in the intensity and spatial distribution of sampling effort between seasons (Table 3, Figure 2).

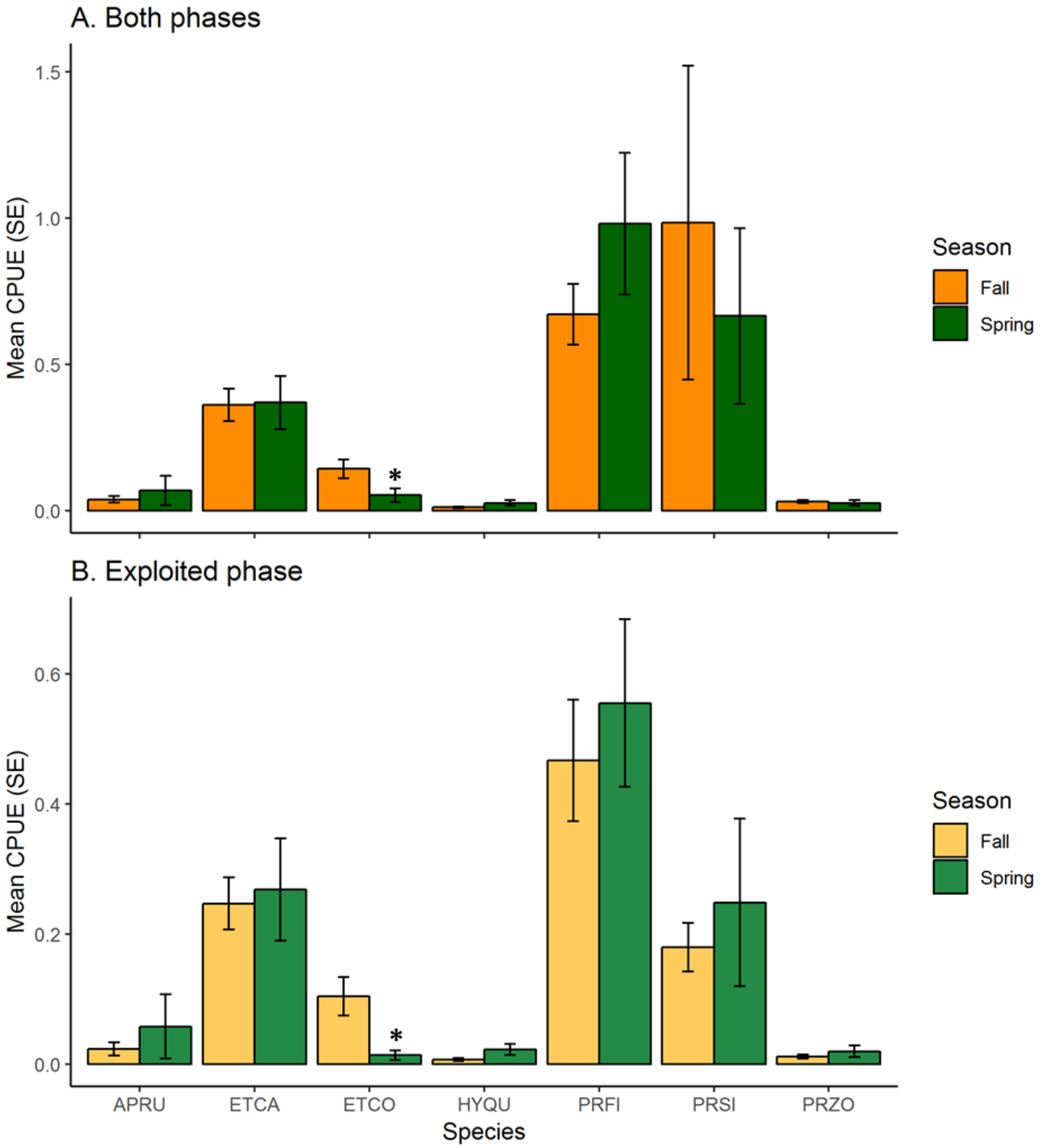

Figure 17. Seasonal comparison of mean CPUE and standard error for (A) both phases and (B) exploited phase for 2016–2017 combined, with +/- 1 standard error displayed as vertical lines. Significant differences (α = 0.05) are denoted with an asterisk (*). Species codes are listed in Table 1.

Table 5. Summary of seasonal statistical comparisons of CPUE by species, year, and life phase. No significant difference noted by ns, S<F denoted spring CPUE is statistically significantly lower than fall CPUE.

	2016		2017		2016–2017	
Species	**both**	**exploited**	**both**	**exploited**	**both**	**exploited**
Ehu	ns	ns	ns	ns	ns	ns
Kalekale	ns	ns	ns	**S<F**	ns	ns
Onaga	**S<F**	**S<F**	ns	ns	**S<F**	**S<F**
Opakapaka	ns	ns	ns	ns	ns	ns

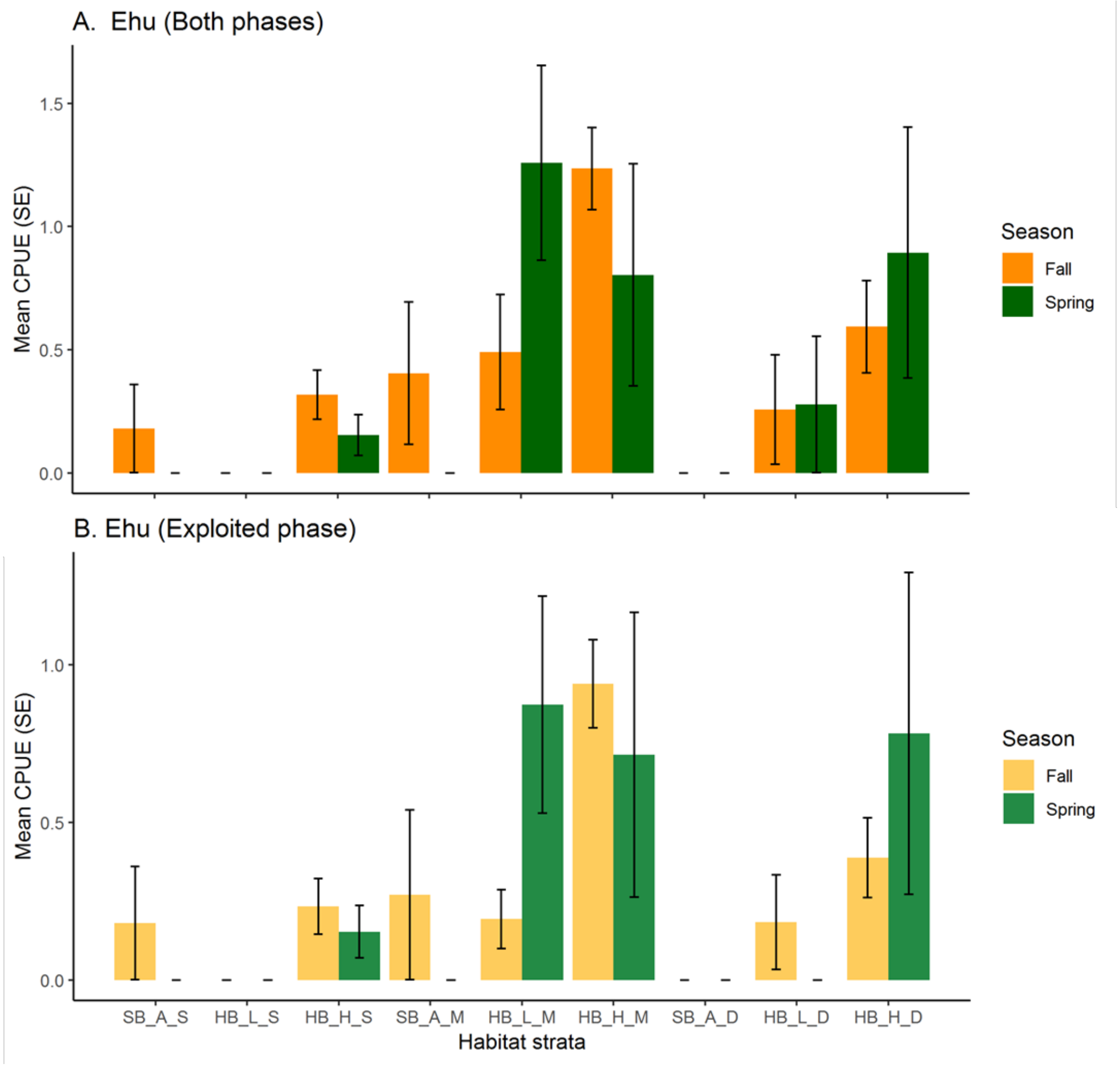

Figure 18. Seasonal comparison of mean CPUE and associated standard error (+/-1, displayed as vertical lines) for ehu using 2016–2017 combined by habitat strata for each life phase: (A) both phases, (B) exploited phase. See Table 2 for strata code descriptions.

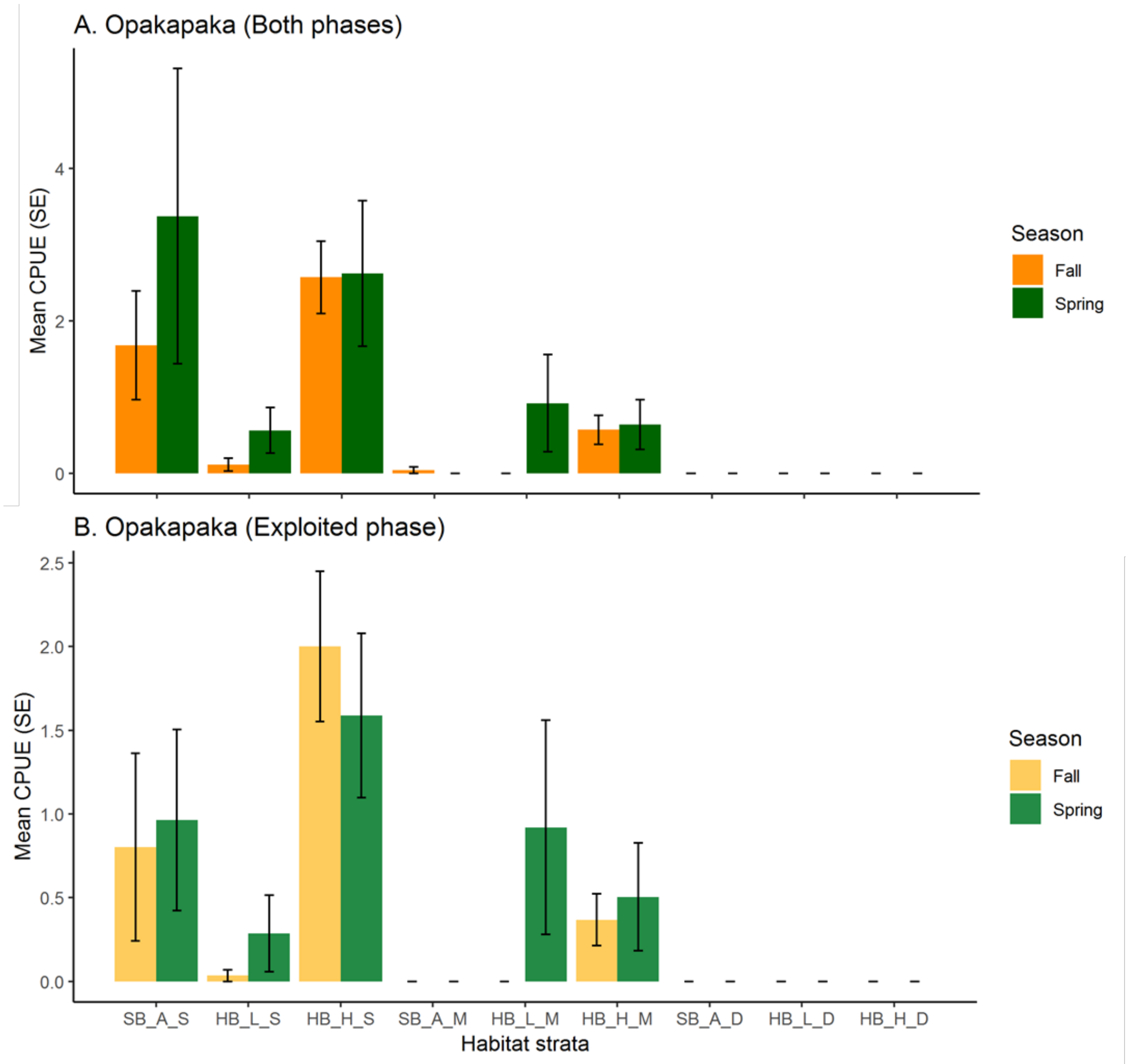

Figure 19. Seasonal comparison of mean CPUE and associated standard error (+/- 1, displayed as vertical lines) for opakapaka using 2016–2017 combined by habitat strata for each life phase: (A) both phases, (B) exploited phase. See Table 2 for strata code descriptions.

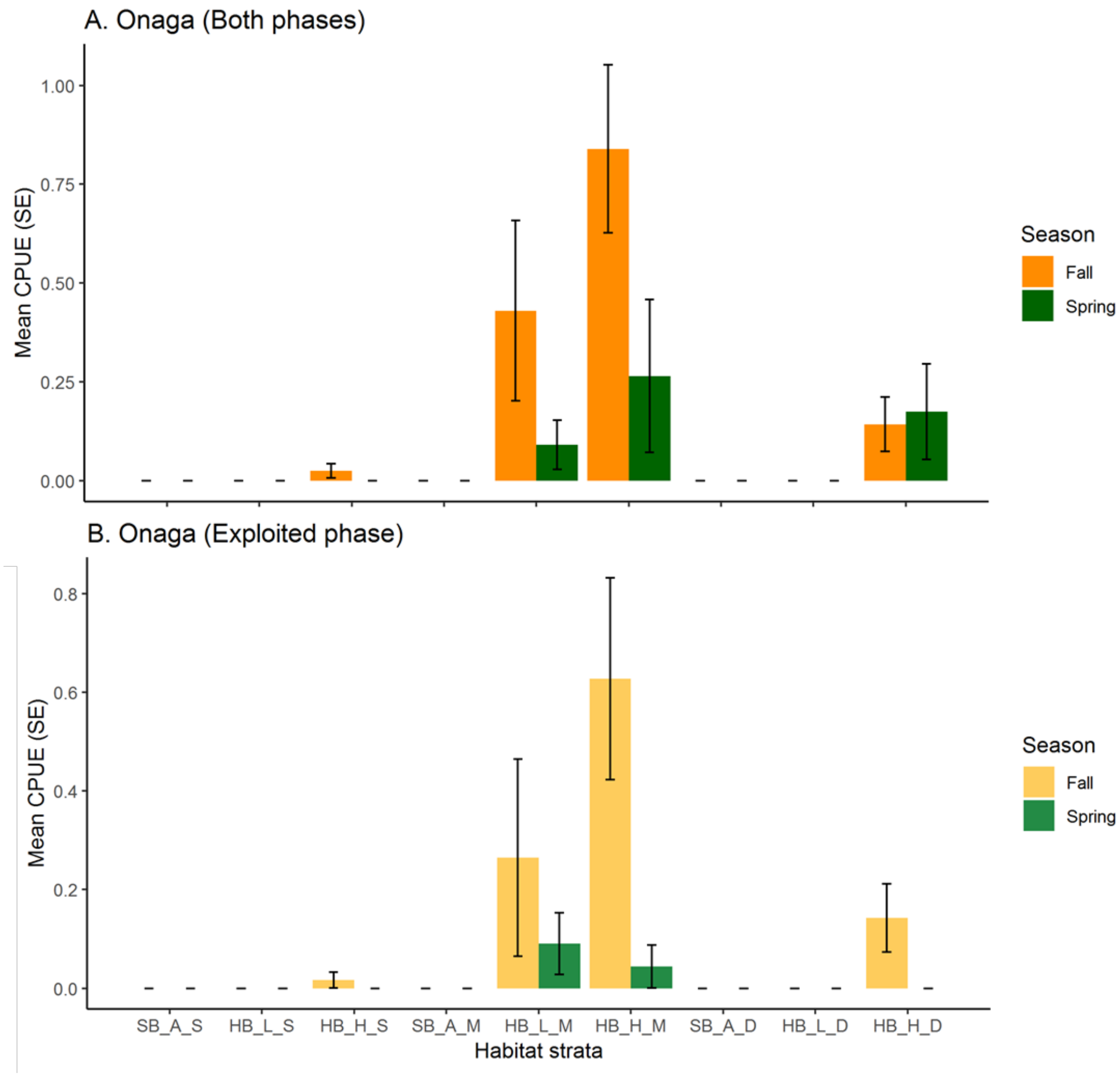

Figure 20. Seasonal comparison of mean CPUE and associated standard error (+/- 1, displayed as vertical lines) for onaga using 2016–2017 combined by habitat strata for each life phase: (A) both phases, (B) exploited phase. See Table 2 for strata code descriptions.

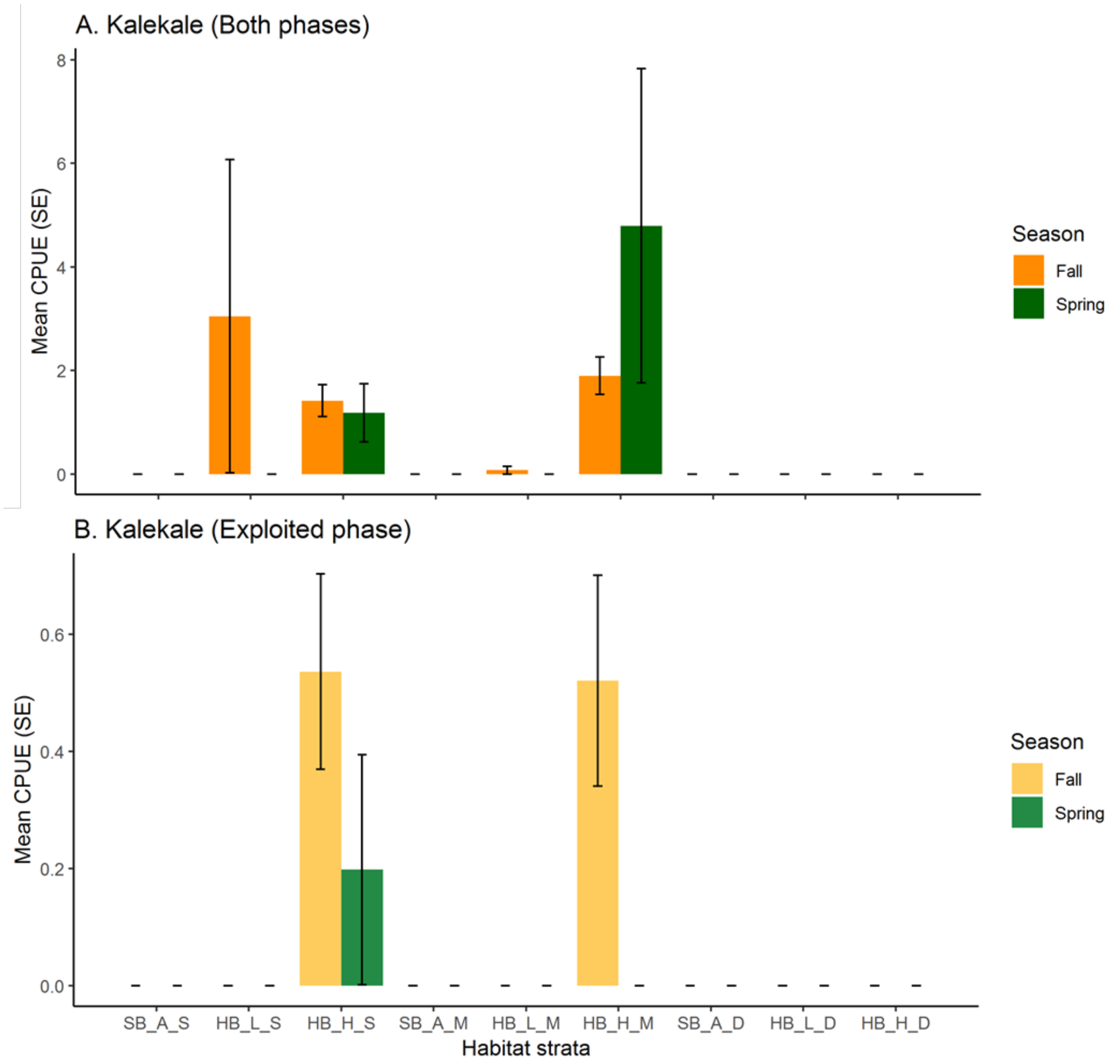

Figure 21. Seasonal comparison of mean CPUE and associated standard error (+/- 1, displayed as vertical lines) for kalekale using 2016–2017 combined by habitat strata for each life phase: (A) both phases and (B) exploited phase. See Table 2 for strata code descriptions.

Length frequency seasonal comparison

The domain length frequency distribution for ehu showed minimal differences between seasons (2016–2017) for both life phases (Figure 22). The average length in spring was marginally larger than fall for the exploited phase. Length frequency distributions of both life phases were similar between seasons for ehu at the stratum level (Figure 23). Differences were found in strata with fish present in the fall but not spring (Figure 24).

For both phases of opakapaka, seasonal length frequencies were not consistent between 2016 and 2017 (Figure 25). A greater number of small fish were observed in spring 2016 compared to the fall 2016. In 2017, this pattern was reversed. Average length estimates of the exploited phase opakapaka differed by season in 2016, but not in 2017 (Figure 25 B, D). At the stratum level, seasonal differences in length frequencies for opakapaka were found in the soft bottom shallow and the hard bottom low slope strata (Figures 27–28).

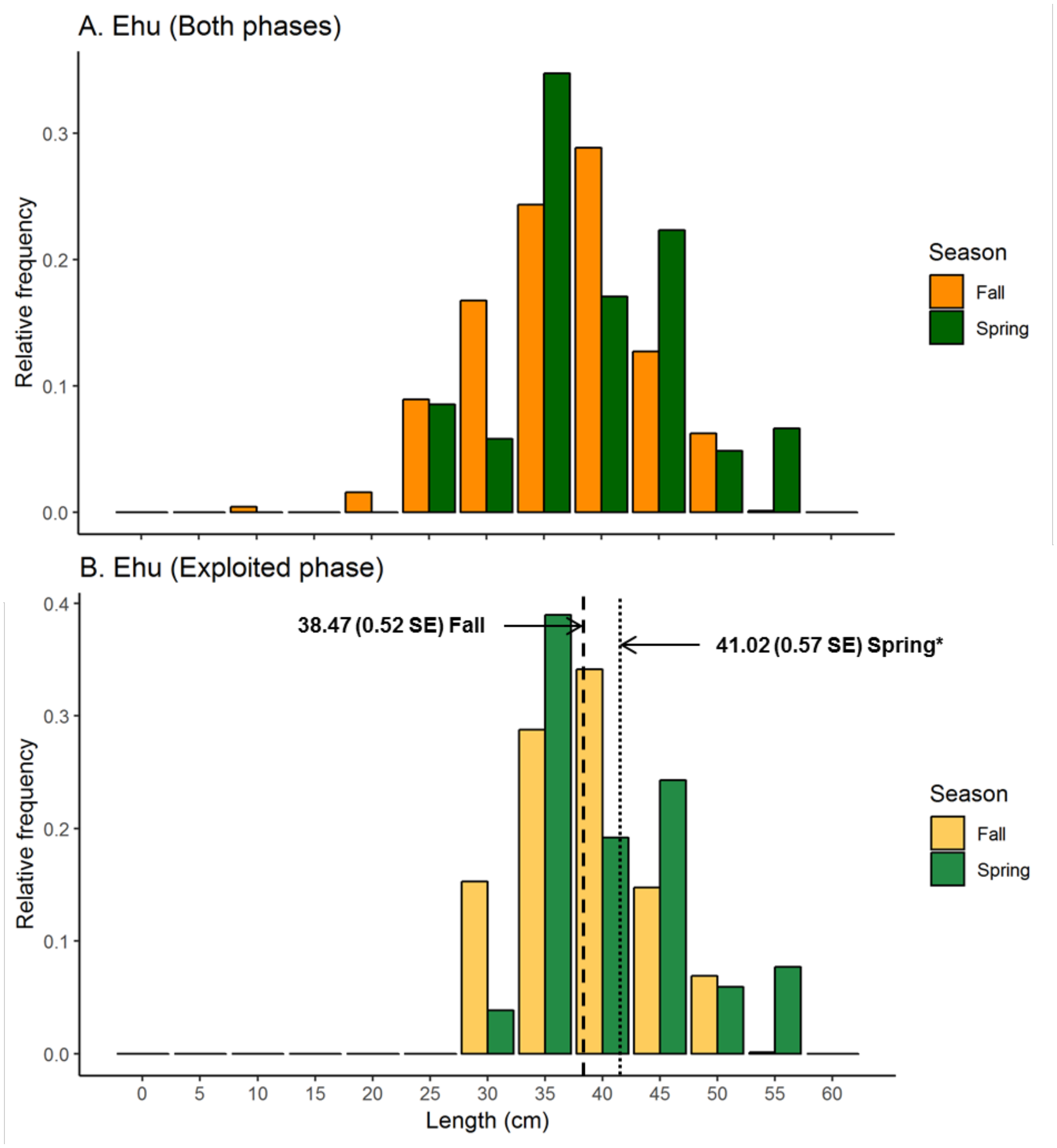

Figure 22. Seasonal comparison of length frequency (2016–2017) for ehu by life phase: (A) both phases and (B) exploited phase. Average length of the exploited phase denoted by dashed line (fall) and dotted line (spring). Significant difference in average length indicated by an asterisk (*).

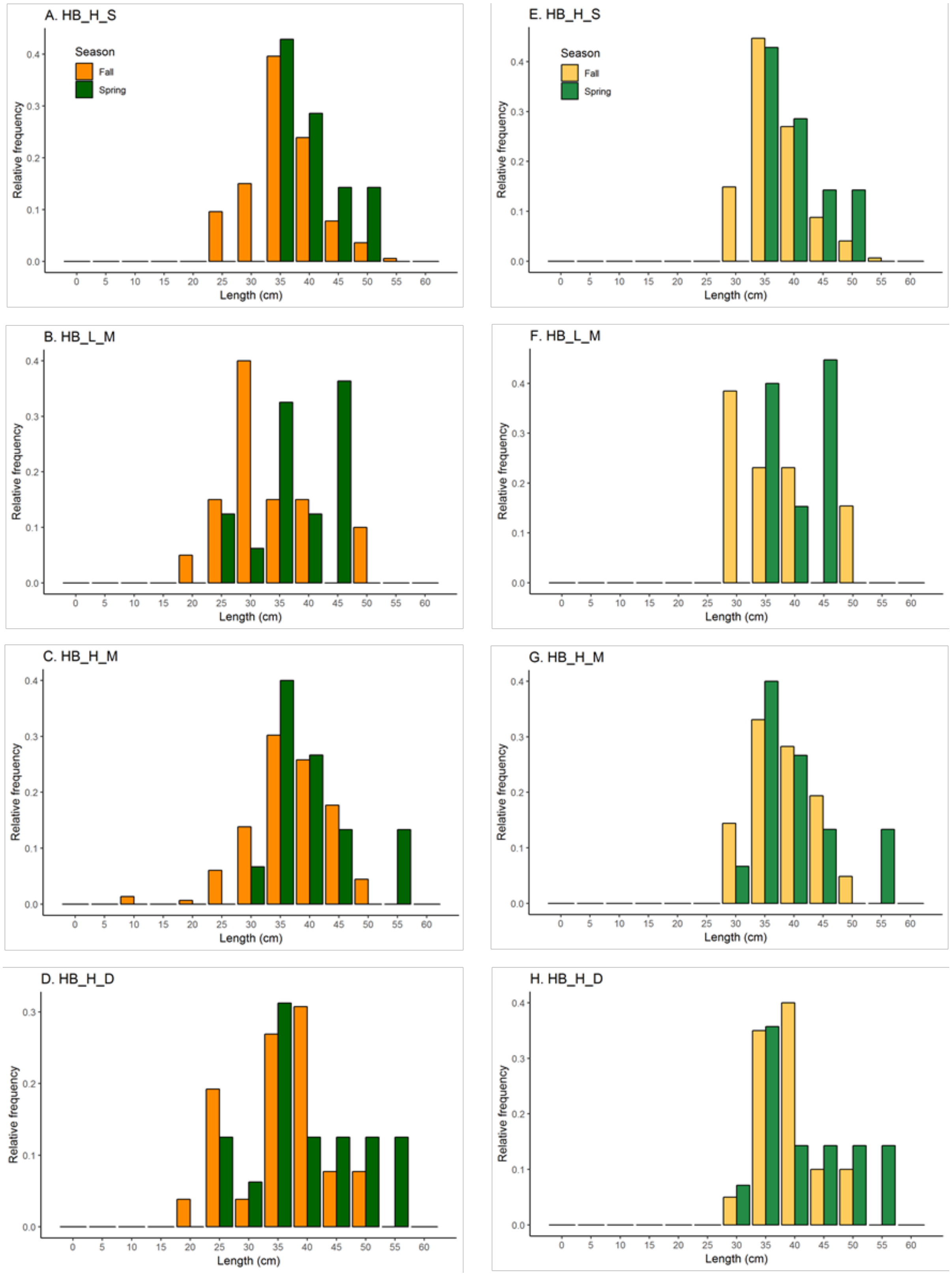

Figure 23. Seasonal comparison of length frequency (2016–2017) for ehu by strata and life phase: (A–D) both phases and (E–H) exploited phase. See Table 2 for strata code descriptions.

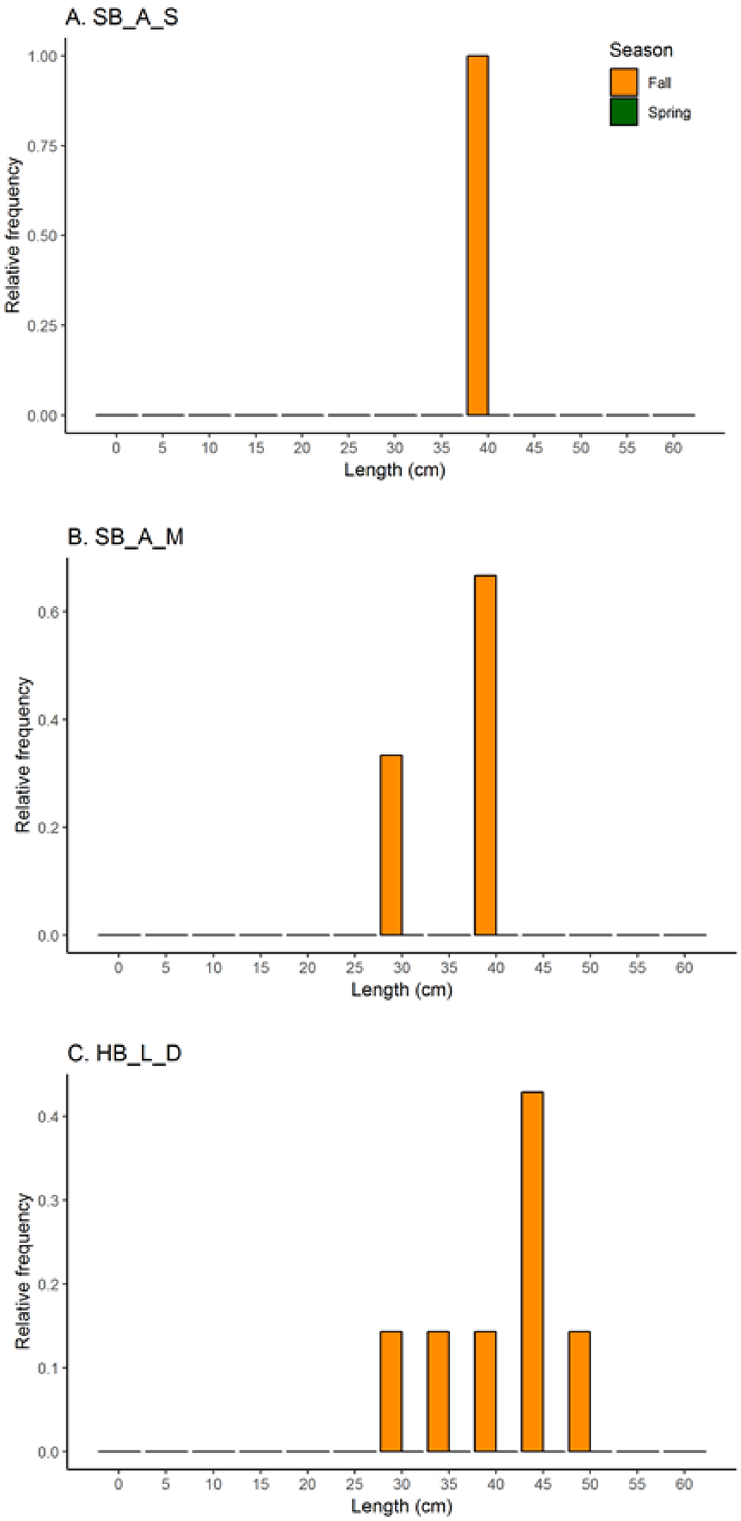

Figure 24. Seasonal comparison of length frequency (2016–2017) for ehu by strata (A–C) both phases and exploited phase because all lengths were 29 cm and above. See Table 2 for strata code descriptions.

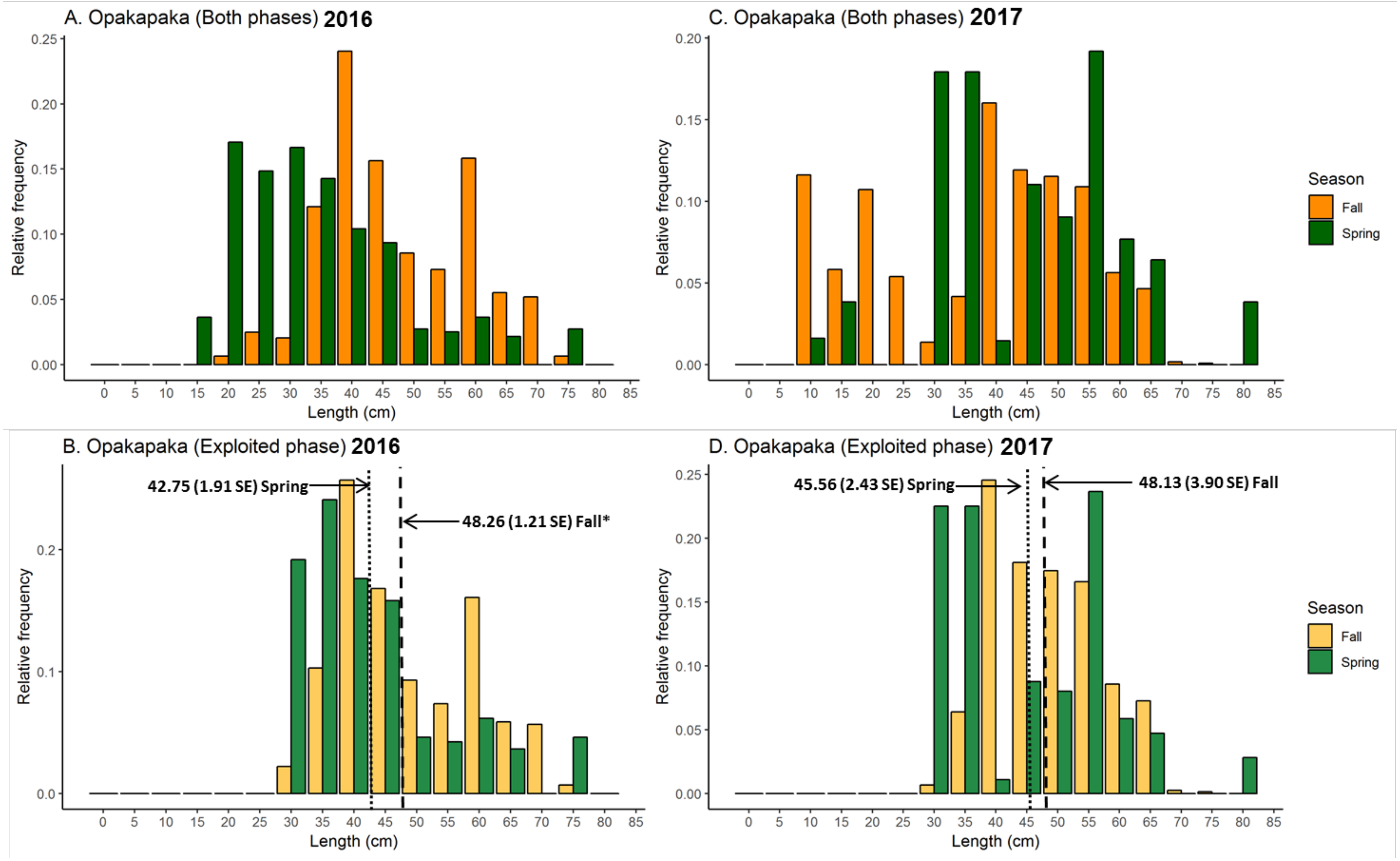

Figure 25. Seasonal comparison of opakapaka population length frequency by survey year and life phase: (A) 2016 both phases, (B) 2016 exploited phase, (C) 2017 both phases, (D) 2017 exploited phase. Average length of the exploited phase denoted by dashed line (fall) and dotted line (spring). Significant difference in average length indicated by an asterisk (*).

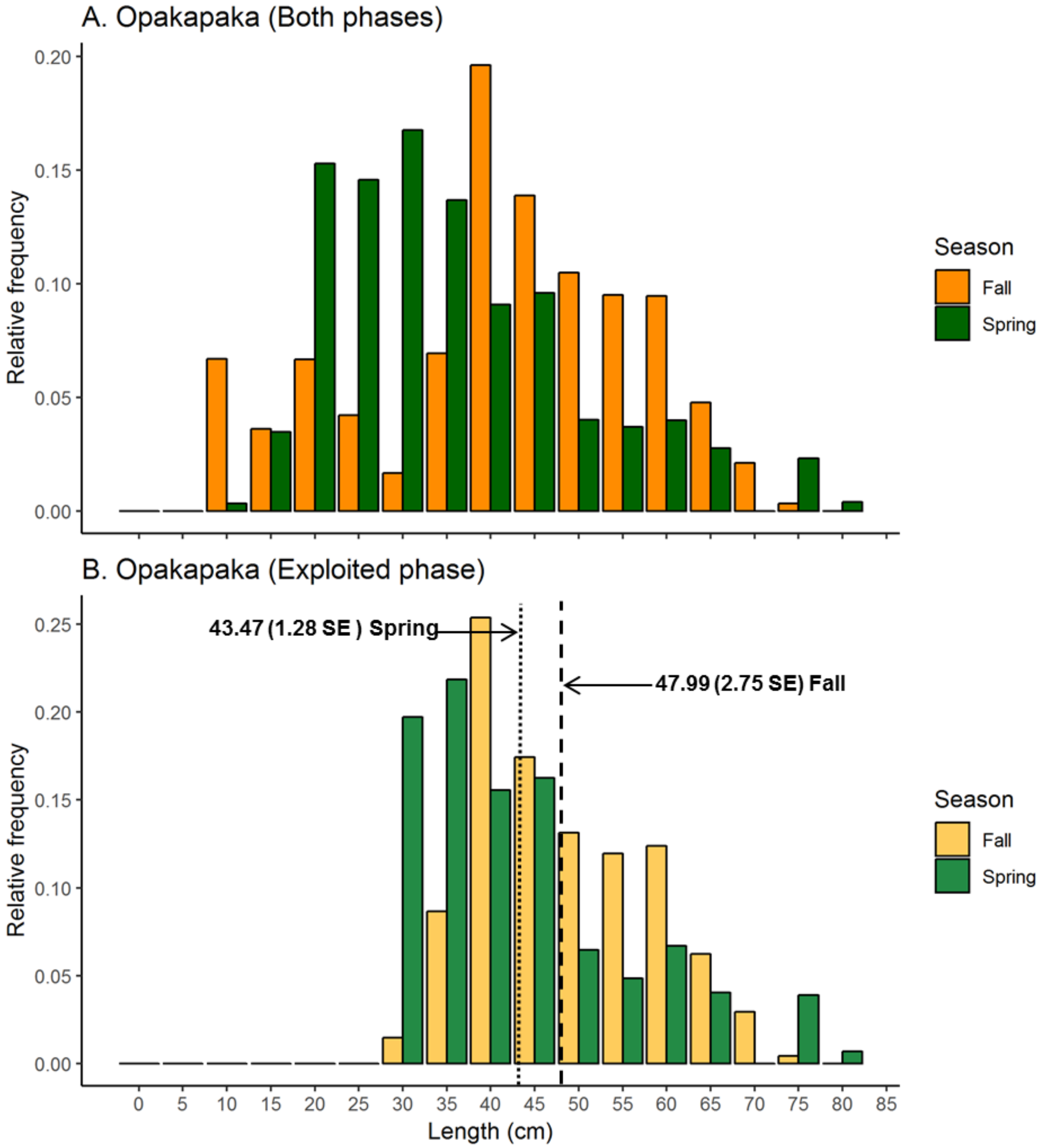

Figure 26. Seasonal comparison of length frequency (2016–2017) for opakapaka by life phase: (A) both phases and (B) exploited phase. Average length of the exploited phase denoted by dashed line (fall) and dotted line (spring). Average length was not significantly different between seasons.

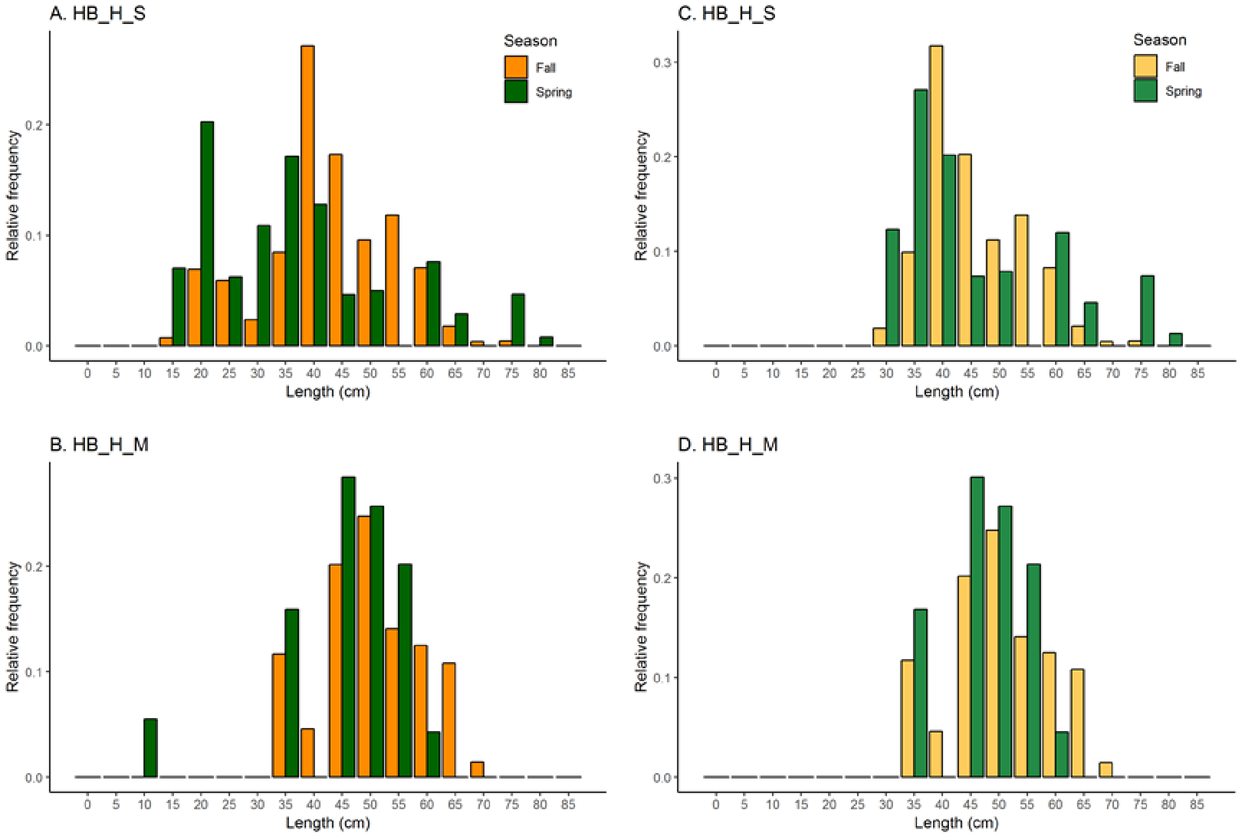

Figure 27. Seasonal comparison of length frequency (2016–2017) for opakapaka by strata and life phase: (A–B) both phases and (C–D) exploited phase. See Table 2 for strata code descriptions.

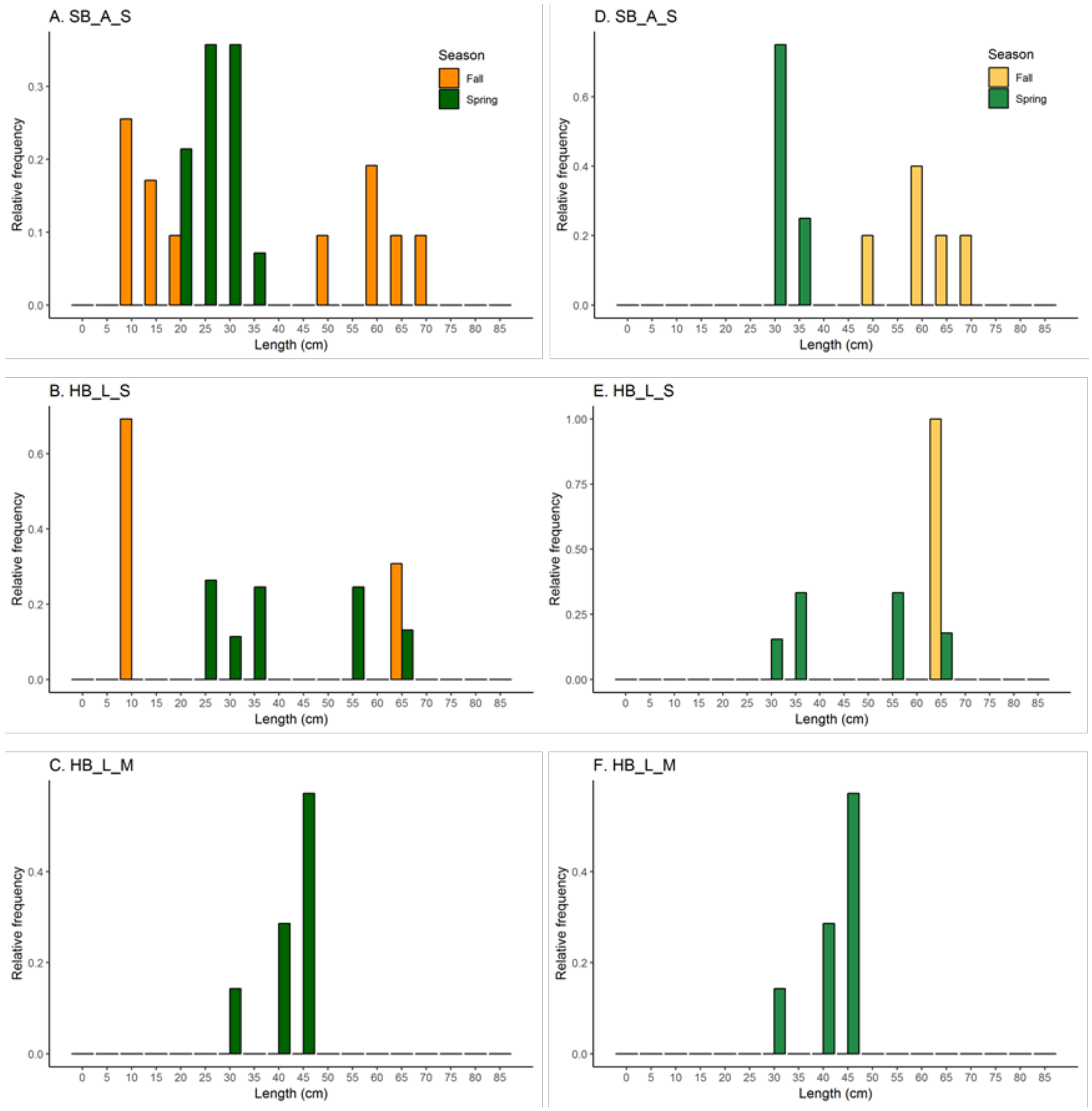

Figure 28. Seasonal comparison of length frequency (2016–2017) for opakapaka by strata and life phase: (A–C) both phases and (D–F) exploited phase. See Table 2 for strata code descriptions.

Discussion

This study used a suite of abundance metrics to evaluate the influence of season and gear on population estimates derived from the BFISH survey. In 2016 and 2017, surveys were conducted using two gears in two seasons. However, there were significant disparities in the spatial distribution and intensity of sampling effort with respect to season and gear. Despite these limitations, data were sufficient for a preliminary analysis of season and gear effects.

Gear comparison

Two survey gears are employed in the BFISH survey: research fishing and underwater stereo cameras (Richards et al. 2016). The camera gear is limited by light attenuation at depth and search area. The fishing gear is limited by catchability and selectivity. Comparisons of the two gears were restricted to shallow and medium depths where both gears were effective. Detection of differences was limited by disparity in sampling effort between gears. Camera surveys accounted for 36% of total PSUs for fall 2016–2017 combined.

Domain and habitat strata estimates of CPUE and proportion occurrence by life phase showed similar patterns between the two gears for most species. These findings were consistent with the pilot study (Richards et al. 2016). With the exception of ehu, abundance estimates were higher for the camera gear.

There were some differences in gear size selectivity for some species. Camera gear had smaller lengths for opakapaka and kalekale, while research fishing had smaller lengths for ehu and onaga. It is unclear whether these differences arise from size selectivity or spatial disparities in sampling or stock distribution or differences in behavior.

Seasonal evaluation

In general, there were few differences in life phase CPUE estimates for spring and fall surveys at the domain and stratum levels. CPUE estimates were significantly lower in spring compared to fall for onaga and kalekale. There were also some differences observed in seasonal length frequencies for opakapaka. The differences in CPUE may be due to the reduced sampling effort and limited spatial coverage in the spring. The large number of missing lengths likely further influenced differences in size frequency distributions. While these results point to the lack of a seasonal signal, that signal could be masked by insufficient information to detect seasonal differences if they were to have occurred.

Conclusions

These analyses highlighted an imbalance in spatial coverage and sampling intensity of the two gears. With respect to the survey, a principal product is size structured abundance. Future surveys should ensure comparable spatial sampling coverage for all gears and that lengths are obtained for each individual fish.

Discrepancies between the results of this research and those from the pilot studies (Richards et al. 2016) suggest that further gear calibration experiments are warranted throughout the sampling domain to accurately convert gear-specific CPUE to a uniform nominal unit.

Sampling and data issues notwithstanding, these analyses did not detect a strong seasonal signal. Despite some uncertainty, future seasonal surveys appear to be a lower priority.

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