Marine Mammal Monitoring on California Cooperative Oceanic Fisheries Investigation (CalCOFI) Cruises: Summary of Results 2016-2019

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Northern right whale dolphins and short-beaked common dolphin. Photo by Katherine Whitaker

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Executive Summary

Cetacean distribution, density, and abundance in the Southern California Bight were assessed through visual and acoustic surveys during thirteen California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruises from July 2016 – July 2019. Visual monitoring incorporated standard line-transect protocol during all daylight transits, while daytime acoustic monitoring employed a towed hydrophone array during transits and sonobuoys deployed at oceanographic sampling stations. Visual effort included 1,010 observation hours covering 19,295 kilometers. A total of 913 sightings were made, which included 13 different cetacean species. Acoustic effort included 682 sonobuoy deployments and 329 towed array deployments.

Blue whales, fin whales, and humpback whales were the most frequently sighted mysticetes. Blue whales were primarily observed during summer, while fin whales and humpback whales were observed year-round. Gray whale sightings only occurred during winter and spring, and minke whales were only sighted in summer.

Short-beaked and long-beaked common dolphins were the most frequently encountered odontocetes, while Risso's dolphins, Pacific white-sided dolphins, and bottlenose dolphins were also observed somewhat regularly. Seasonally, short-beaked common dolphins were most abundant in winter and spring, whereas long-beaked common dolphins were most abundant in summer and fall. Sightings of Pacific white-sided dolphins peaked in the spring, whereas Risso's dolphins were never encountered during spring cruises.

Beaked whale echolocation clicks were only detected on one occasion in towed array recordings collected between 2008 and 2019. The low acoustic encounter rate of beaked whales in this dataset may be linked to the continuous use of shipboard echosounders during CalCOFI cruises.

The CalCOFI marine mammal monitoring program examines seasonal and inter-annual patterns in density, abundance, and distribution on a longer continuous time scale and with a higher rate of sampling than previous cetacean surveys off the California coast, particularly for the winter and spring periods, for which there are currently few data available.

Project Background

Long-term assessments of abundance, density, and distribution are central to evaluating potential effects of anthropogenic activities and ecosystem variability on cetacean populations (Carretta *et al.*, 2016). The California Current Ecosystem (CCE) is a productive and dynamic habitat (Hayward and Venrick, 1998; Chhak and Di Lorenzo, 2007) that supports a diverse community of cetacean species as well as an array of human activities including commercial fishing, shipping, and naval exercises. The intersection between cetacean and human use of the CCE has resulted in entanglements in fishing gear (Carretta *et al.*, 2013), ship strikes (Berman-Kowalewski *et al.*, 2010), and disturbances from anthropogenic sound (McDonald *et al.*, 2006; Hildebrand, 2009; Goldbogen *et al.*, 2013).

California Cooperative Oceanic Fisheries Investigation (CalCOFI) cruises, conducted in the Southern California Bight (SCB) four times per year, provide a unique and valuable platform to document spatial and temporal variations in cetacean abundance, density, distribution, and habitat use patterns. Cetacean surveys have been integrated into (CalCOFI) quarterly cruises off southern California since 2004 using both visual and acoustic detection methods (Soldevilla *et al.*, 2006). The objectives of the cetacean monitoring program are to make seasonal, annual, and long-term estimates of cetacean density and abundance within the study area, to determine the temporal and spatial patterns of cetacean distribution, and for future habitat-based density modeling efforts.

Methodology

Marine mammal surveys were initiated as part of the California Cooperative Oceanic Fisheries Investigation (CalCOFI) cruises beginning in 2004, and consisted of both visual observations and passive acoustic effort. Visual monitoring incorporated standard line-transect survey protocol (Buckland *et al.*, 1993; Barlow, 1995; Barlow and Forney, 2007) that includes two experienced observers scanning for marine mammals during transits between CalCOFI stations. Information on all cetacean sightings was logged systematically, including species, group size, reticle of cetacean position relative to the horizon, relative angle from the bow, latitude, longitude, ship's heading, behavior, environmental data, and comments. The following report summarizes the marine mammal visual sightings, towed array recording effort and sonobuoy deployment effort associated with CalCOFI surveys conducted from 2016-2019.

Acoustic monitoring for cetaceans during 2-4 hour transits between stations was conducted using a 6-element 300 m towed hydrophone array. Each pre-amplified element was band-pass filtered from 1.5 kHz to 200 kHz to decrease flow noise at low frequencies and to protect from signal aliasing at high frequencies. The multi-channel array data were sampled using both a Steinberg UR44 sampling at 192 kHz and a National Instruments NI-9223 sampling at 300 kHz. Acoustic monitoring at CalCOFI oceanographic sampling stations was also conducted with passive SSQ-53F DIFAR sonobuoys that sampled at 48 kHz. Sonobuoys were deployed one nautical mile before each daylight station and typically recorded for approximately 2 hours while oceanographic sampling was underway. After leaving a station, sonobuoy signal reception was generally lost after 5 miles.

Passive acoustic recordings collected from all cruises between 2008 and spring 2019 were analyzed for presence of beaked whale echolocation clicks. An automated detector was used to identify candidate signals (Soldevilla et al., 2008; Roch et al., 2011), and an unsupervised clustering algorithm (Frasier et al., 2017) was used to separate possible beaked whale echolocation clicks from false positives including vessel noise, echosounders, and dolphin echolocation clicks. An analyst scanned remaining encounters using DetEdit (Solsona-Berga *et al.*, 2020) to assess whether the detected signals were consistent with beaked whales.

Results

Thirteen CalCOFI cruises were conducted from July 2016 to July 2019. This included 215 days at sea and 1,010 marine mammal visual observation hours on effort. Total effort included over 19,000 kilometers of distance surveyed, yielding 913 sightings of 17 identified cetacean species (Table 1).

Table 1. Summary data from CalCOFI cruises between July 2016 and July 2019. Spring cruises in 2017 and 2018 (1704SH and 1804SH) were extended surveys that also sampled further north up to San Francisco. Winter cruises in 2018 and 2019 (1802SH and 1902RL) were shortened surveys due to government shutdowns that impacted ship time.

Cruise	Cruise Dates	Survey Effort [hours]	Distance Surveyed [km]	# of sightings (on effort)	# Species
1607OS	07/10/16 – 07/27/16	103.80	1,594.45	66	11
1611SR	11/06/16 – 11/22/16	64.91	1,282.33	68	13
1701RL	01/05/17 – 01/20/17	76.52	1,456.98	60	11
1704SH	03/28/17 – 04/20/17	121.12	2,549.91	108	11
1708SR	08/01/17 – 08/16/17	82.61	1,690.25	108	12
1711SR	11/09/17 – 11/24/17	74.39	1,479.30	56	11
1802SH	02/01/18 – 02/11/18	34.65	774.09	60	13
1804SH	04/05/18 – 04/27/18	105.72	2,093.77	84	13
1806SR	06/09/18 – 06/24/18	85.62	1,533.82	65	10
1810SR	10/14/18 – 10/29/18	72.42	1,343.91	57	10
1902RL	02/06/19 – 02/13/19	27.76	675.80	36	11
1904RL	04/02/19 – 04/18/19	62.54	1,326.71	62	10
1907BH	07/11/19 – 07/26/19	98.75	2,186.00	83	11
Total		**1,010.80**	**19,295.65**	**913**	**Max: 13**

Mysticete sightings

Five different species of mysticetes were identified on summer 2016 through summer 2019 cruises: minke (*Balaenoptera acutorostrata*), blue (*B. musculus*), fin (*B. physalus*), gray (*Eschrichtius robustus*), and humpback (*Megaptera novaeangliae*) whales. Large whales that could not be identified to species were logged as unidentified large whale (ULW).

Total numbers of on-effort groups and individuals sighted for each mysticete species are shown in Table 2. On-effort visual detections of mysticetes for 2016 through 2019 are shown in Figure 1. Spatial and temporal trends were apparent for several species. Blue whales, fin whales, and humpback whales were the most frequently sighted mysticetes. During winter and spring cruises, most mysticete sightings primarily occurred within ~350 km of the shoreline. During summer and fall cruises, mysticetes were frequently sighted along the continental slope and in offshore waters. All minke whale and gray whale sightings occurred along the continental shelf. Blue whales were primarily observed during summer, while fin and humpback whales were observed year-round. Gray whale sightings only occurred during winter and spring, and minke whales were only encountered in summer.

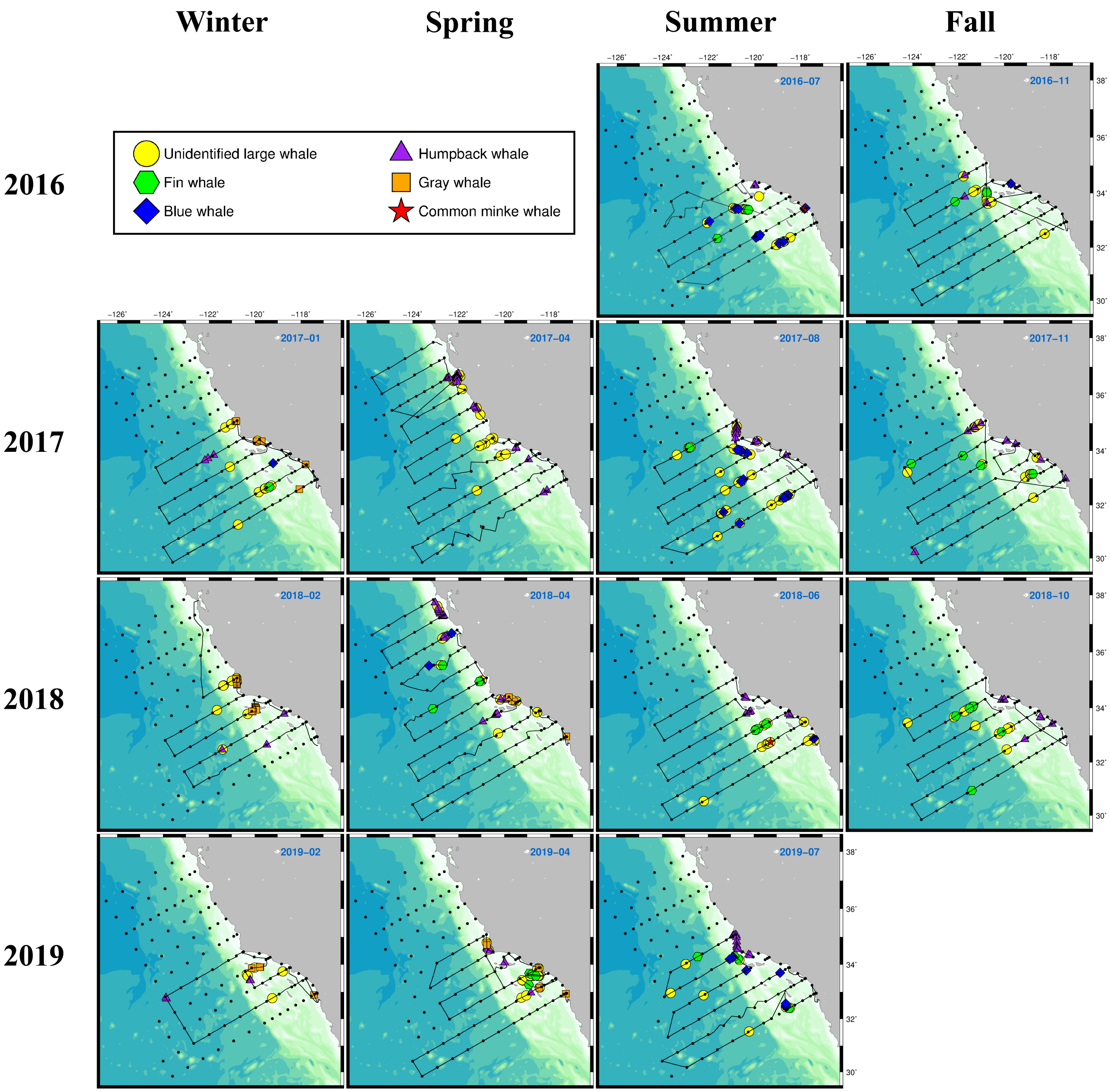


Figure 1. On-effort mysticete sightings during CalCOFI cruises summer 2016 – summer 2019. CalCOFI stations are represented by black dots and the ship's track line is represented as a solid black line between stations. Spring cruises in 2017 and 2018 were extended surveys up to San Francisco, while winter cruises in 2018 and 2019 were shortened due to government shutdowns.

Table 2. On-effort mysticete sightings summer 2016 - summer 2019.

		Species	Minke	Blue	Fin	Gray	Humpback	ULW
2016	Summer	# Groups	1	11	4	0	3	13
		# Ind	1	15	32	0	4	18
	Fall	# Groups	0	1	3	0	4	13
		# Ind	0	1	3	0	4	71
2017	Winter	# Groups	0	1	1	6	4	11
		# Ind	0	2	2	19	5	19
	Spring	# Groups	0	0	0	0	26	30
		# Ind	0	0	0	0	47	40
	Summer	# Groups	0	14	4	0	12	34
		# Ind	0	30	4	0	21	42
	Fall	# Groups	0	0	4	0	9	12
		# Ind	0	0	8	0	16	20
2018	Winter	# Groups	0	0	0	15	4	9
		# Ind	0	0	0	26	5	11
	Spring	# Groups	0	2	3	3	35	12
		# Ind	0	2	4	5	66	13
	Summer	# Groups	1	1	4	0	8	13
		# Ind	1	1	34	0	11	19
	Fall	# Groups	0	0	5	0	10	13
		# Ind	0	0	14	0	370	20
2019	Winter	# Groups	0	0	0	4	5	5
		# Ind	0	0	0	6	43	8
	Spring	# Groups	0	0	4	5	7	15
		# Ind	0	0	5	23	46	23
	Summer	# Groups	0	9	5	0	12	7
		# Ind	0	10	6	0	35	10
Total # Groups			**2**	**39**	**37**	**33**	**139**	**187**
Total # Individuals			**2**	**61**	**112**	**79**	**673**	**314**

Odontocete sightings

Twelve different species of odontocetes were identified on summer 2016 through summer 2019 cruises: long-beaked (*Delphinus capensis*) and short-beaked (*D. delphis*) common dolphins, Risso's dolphins (*Grampus griseus*), short-finned pilot whales (*Globicephala macrorhynchus*), northern right whale dolphins (*Lissodelphis borealis*), Pacific white-side dolphins (*Lagenorhynchus obliquidens*), killer whales (*Orcinus orca*), Dall's porpoises (*Phocoenoides dalli*), sperm whales (*Physeter macrocephalus*), striped dolphins (*Stenella coeruleoalba*), bottlenose dolphins (*Tursiops truncatus*), and Cuvier's beaked whales (*Ziphius cavirostris*). Common dolphins that could not be identified to species were logged as *Delphinus* species (Dsp). Any other dolphin that could not be identified to species was logged as unidentified dolphin (UD).

Total numbers of on-effort groups and individuals sighted for each odontocete species are shown in Table 3. Odontocete detections for summer 2016 through summer 2019 revealed spatial and temporal trends (Figure 2). Short-beaked and long-beaked common dolphins were the most frequently encountered odontocetes, while Risso's dolphins, Pacific white-sided dolphins, and bottlenose dolphins were also observed somewhat regularly. Short-beaked common dolphins were detected offshore more frequently than inshore; in contrast, long-beaked common dolphins were more frequently detected in inshore waters. Seasonally, short-beaked common dolphins were most abundant in winter and spring, whereas long-beaked common dolphins were most abundant in summer and fall. Sightings of Pacific white-sided dolphins peaked in the spring, whereas Risso's dolphins were never encountered during spring cruises.

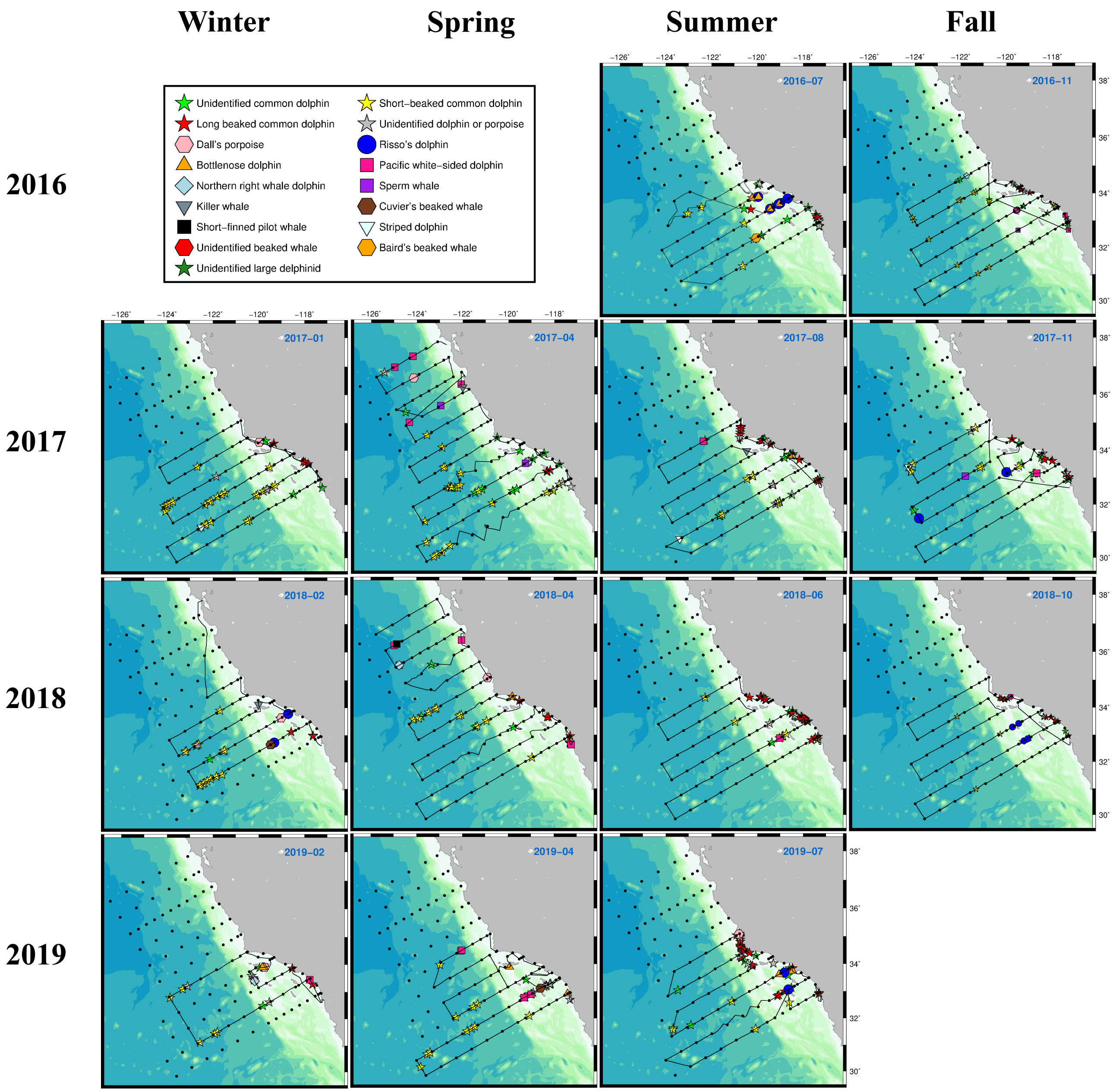


Figure 2. On-effort odontocete sightings during CalCOFI cruises summer 2016 – summer 2019. CalCOFI stations are represented by black dots and the ship's track line is represented as a solid black line between stations. Spring cruises in 2017 and 2018 were extended surveys up to San Francisco, while winter cruises in 2018 and 2019 were shortened due to government shutdowns.

Table 3. On-effort odontocete sightings summer 2016 - summer 2019.

		Species	Dc	Dd	Dsp	Gg	Gm	Lb	Lo	Oo	Pd	Pm	Sc	Tt	UD	Zc
2016	Summer	# Groups	4	8	10	5	0	0	0	0	0	0	0	4	3	0
		# Ind	435	285	1236	168	0	0	0	0	0	0	0	125	208	0
	Fall	# Groups	5	13	12	2	0	1	3	0	0	1	0	1	9	0
		# Ind	3059	1007	359	96	0	54	25	0	0	1	0	145	231	0
2017	Winter	# Groups	4	26	3	0	0	0	0	0	1	0	1	0	2	0
		# Ind	1369	1640	246	0	0	0	0	0	5	0	4	0	84	0
	Spring	# Groups	3	23	12	0	0	1	4	1	2	2	0	0	4	0
		# Ind	356	1297	795	0	0	118	461	6	7	8	0	0	45	0
	Summer	# Groups	8	7	20	0	0	0	1	1	0	0	1	1	5	0
		# Ind	2970	425	2760	0	0	0	15	2	0	0	160	15	171	0
	Fall	# Groups	5	8	9	2	0	0	1	0	0	1	1	0	4	0
		# Ind	1029	2041	1227	59	0	0	10	0	0	2	4	0	260	0
2018	Winter	# Groups	2	18	4	2	0	0	1	1	1	0	0	1	1	1
		# Ind	712	1829	504	11	0	0	5	6	3	0	0	34	3	3
	Spring	# Groups	7	10	4	0	1	1	4	0	1	0	0	1	0	0
		# Ind	1478	183	79	0	75	80	202	0	3	0	0	120	0	0
	Summer	# Groups	17	6	12	0	0	0	1	0	0	0	0	0	2	0
		# Ind	4588	626	1047	0	0	0	30	0	0	0	0	0	47	0
	Fall	# Groups	11	3	5	4	0	0	1	0	0	0	0	1	4	0
		# Ind	4790	73	1386	46	0	0	13	0	0	0	0	9	464	0
2019	Winter	# Groups	3	6	2	0	0	1	2	0	1	0	0	2	5	0
		# Ind	482	1244	495	0	0	8	21	0	15	0	0	127	119	0
	Spring	# Groups	0	17	2	0	0	0	4	0	0	0	0	2	5	1
		# Ind	0	2195	125	0	0	0	55	0	0	0	0	43	113	5
	Summer	# Groups	19	4	15	2	0	0	0	0	1	0	0	2	7	0
		# Ind	5899	333	2547	51	0	0	0	0	3	0	0	18	337	0
Total # Groups			**88**	**149**	**110**	**17**	**1**	**4**	**22**	**3**	**7**	**4**	**3**	**15**	**51**	**2**
Total # Individuals			**27167**	**13178**	**12806**	**431**	**75**	**260**	**837**	**14**	**36**	**11**	**168**	**636**	**2082**	**8**

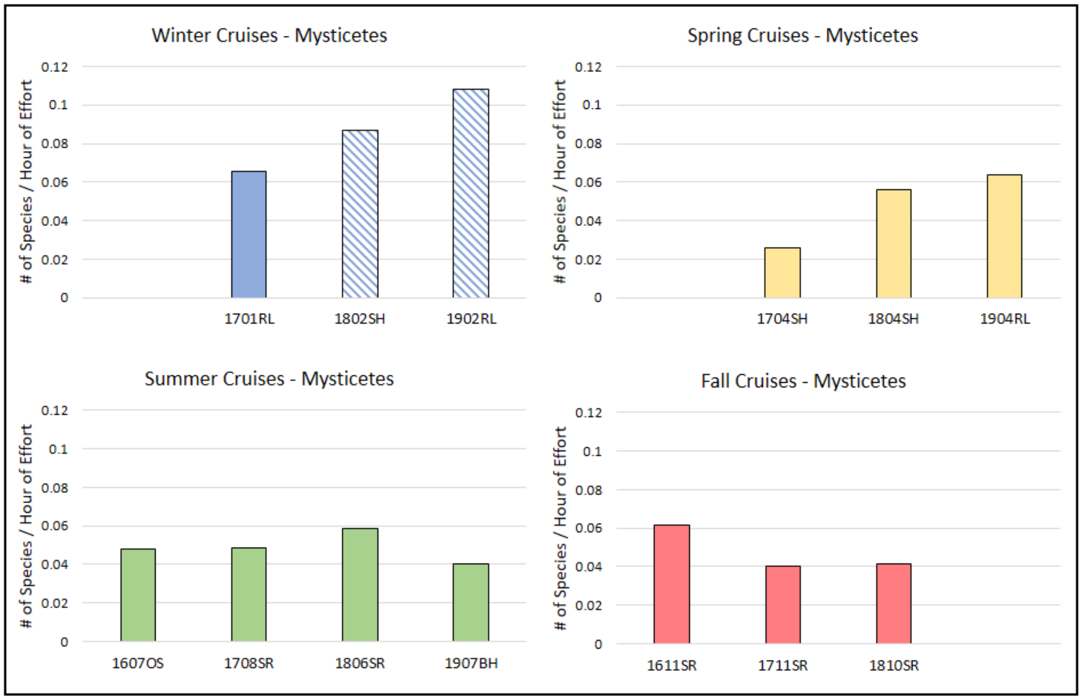
Species diversity

Marine mammal species diversity varied by season (Figure 3). Species diversity was calculated by dividing the number of species sighted by the total number of hours on visual effort. The spring 2017 (1704SH) and spring 2018 (1804SH) cruises were extended surveys that also conducted sampling between Pt. Conception and San Francisco, but only data from the southern 75 stations for all cruises were included in this analysis. The winter 2018 (1802SH) and winter 2019 (1902RL) cruises were abbreviated surveys due to government shutdowns that reduced the amount of ship time to 11 days and 8 days, respectively, and thus the species diversity values reported for these cruises are likely biased.

Mysticete species diversity was generally highest in the winter, has gradually increased across spring cruises, has remained roughly stable across summer cruises, and has declined across the fall cruises since 2016 (Figure 3a). The spring 2017 cruise (1704SH) had the lowest mysticete species diversity for all the cruises within the time period covered in this report.

Variations of odontocete species diversity were somewhat similar to that of the mysticetes (Figure 3b). Odontocete species diversity was generally lowest in the summer, has remained stable across spring cruises, and has declined across the fall cruises since 2016. The summer 2016 cruise (1607OS) had the lowest odontocete species diversity for all these cruises.

(a)



(b)

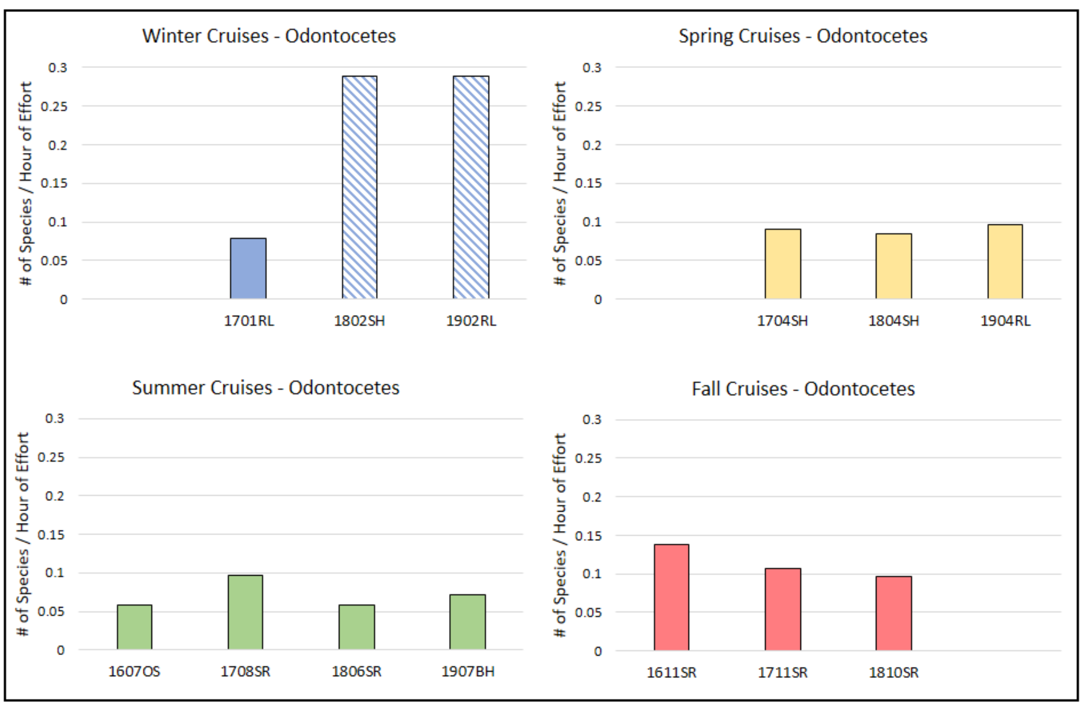


Figure 3. (a) Number of mysticete species visually detected per hour of effort during CalCOFI cruises 2016-2019. (b) Number of odontocete species visually detected per hour of effort during CalCOFI cruises 2016-2019. The diagonal striped pattern for the 1802SH and 1902RL data points denotes incomplete survey effort.

Acoustic effort

Acoustic effort on summer 2016 through summer 2019 cruises included 682 sonobuoy deployments and 329 towed array deployments (Figure 4, Table 4). Towed array effort ceased after the spring 2019 (1904RL) cruise, and thus there were no towed array deployments on the summer 2019 (1907BH) cruise.

Beaked whale acoustic encounters

Analysis was conducted on towed array recordings collected between the winter 2008 and spring 2019 cruises (Table 5) to evaluate the potential presence of beaked whale echolocation clicks. Of the 46 cruises conducted during that time period, 38 had towed array data for this analysis. A beaked whale echolocation click detector used to identify echolocation click-like signals in the towed array recordings. An unsupervised learning algorithm was then used to identify distinct classes within the signals identified by the detector (Frasier et al. 2017). These signal classes included echosounders, banded echolocation clicks, un-banded echolocation clicks and ship noise. A deep neural network was then used to classify each detected signal to one of these four categories. Classification accuracy was estimated at 95.4% on an independent evaluation dataset. Signals classified as banded or un-banded echolocation clicks were manually reviewed to evaluate whether they were attributable to beaked whales using an interactive viewer (Figure 5; Solsona-Berga et al. 2020).

One confirmed Cuvier's beaked whale encounter was identified in towed array recordings from October 20th, 2012 from 21:50 to 22:10 UTC. No other confirmed beaked whale encounters were identified. Cholewiak et al. (2017) found that the use of shipboard echosounders was highly correlated with low beaked whale acoustic detection rates. The low acoustic encounter rate of beaked whales in this dataset may be linked to the continuous use of active acoustics during CalCOFI cruises.

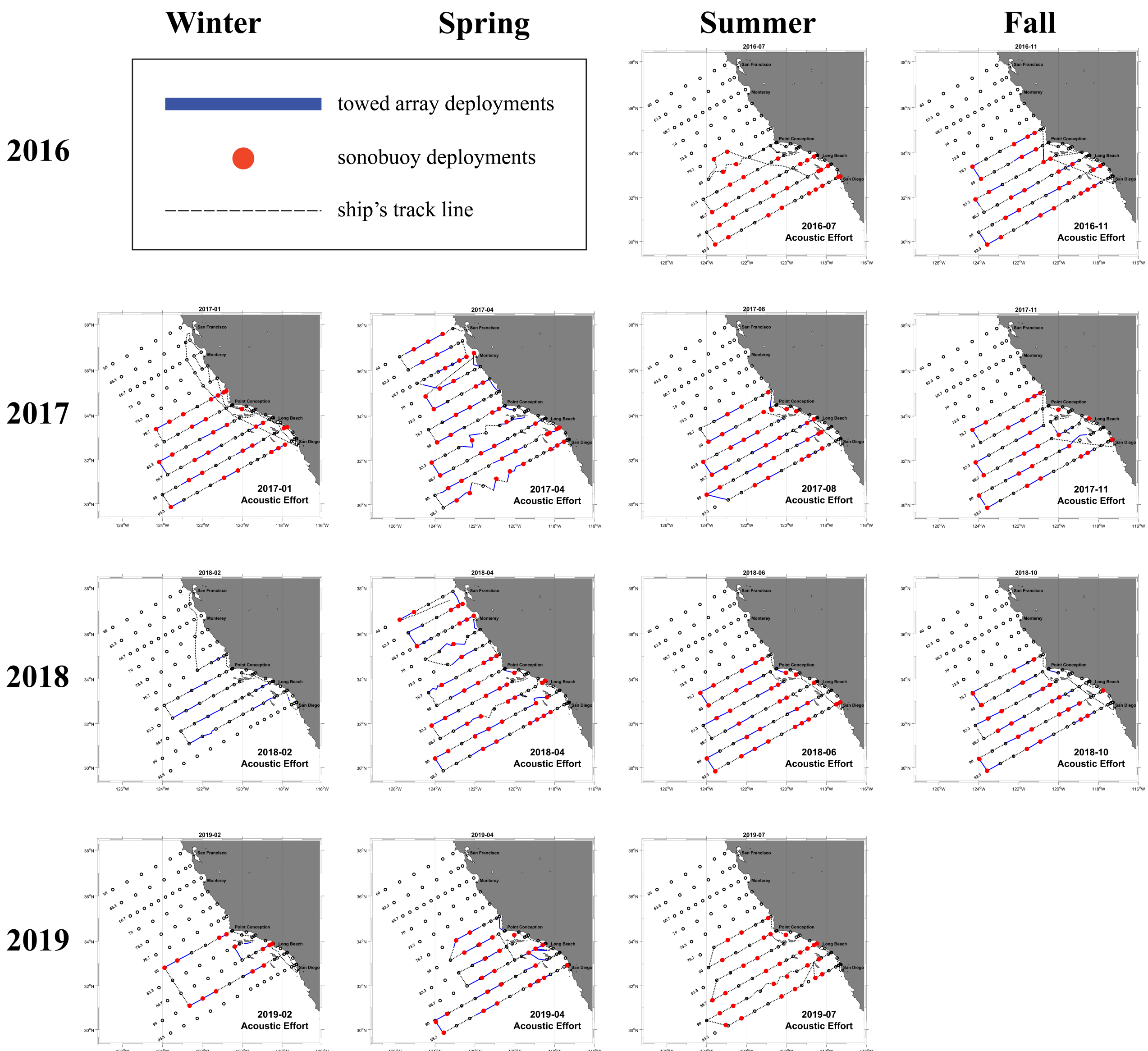


Figure 4. Acoustic effort summer 2016 – summer 2019. Solid blue lines represent towed array deployments and red circles represent sonobuoy deployments. Dotted black line represents the ship's trackline. Sonobuoys were not deployed on the winter 2018 cruise, and there were no towed array deployments during the summer 2019 cruise.

Table 4. Acoustic deployments summer 2016 - summer 2019.

Year	Season	# sonobuoys deployed	# towed array deployments
2016	Summer	60	31
	Fall	56	25
2017	Winter	60	22
	Spring	76	53
	Summer	64	27
	Fall	50	25
2018	Winter	0	16
	Spring	72	40
	Summer	64	27
	Fall	51	27
2019	Winter	26	11
	Spring	50	25
	Summer	53	0
Totals		**682**	**329**

Table 5. Towed array recordings reviewed for beaked whale analysis.

Cruise		# Towed Array Deployments	# Hours Recorded
2008	Winter	25	68.6
	Spring	20	60.1
2009	Winter	29	67.5
	Spring	31	76.0
	Summer	26	61.5
	Fall	26	59.6
2011	Winter	32	90.2
	Spring	29	66.7
	Summer	32	76.5
	Fall	23	57.0
2012	Winter	22	55.0
	Spring	20	52.7
	Summer	29	94.2
	Fall	24	83.2
2013	Winter	25	75.9
	Spring	29	100.8
2014	Winter	13	39.9
	Spring	25	70.5
	Summer	34	86.3
	Fall	16	29.6
2015	Winter	35	81.6
	Spring	23	57.7
	Summer	34	71.4
	Fall	28	90.9
2016	Winter	29	73.2
	Spring	39	81.2
	Summer	31	82.1
	Fall	25	57.3
2017	Winter	22	55.8
	Spring	53	124.2
	Summer	27	75.1
	Fall	25	60.6
2018	Winter	0	33.2
	Spring	72	102.6
	Summer	64	77.6
	Fall	49	76.5
2019	Winter	26	29.4
	Spring	50	69.4
Total		**881**	**2671.5**

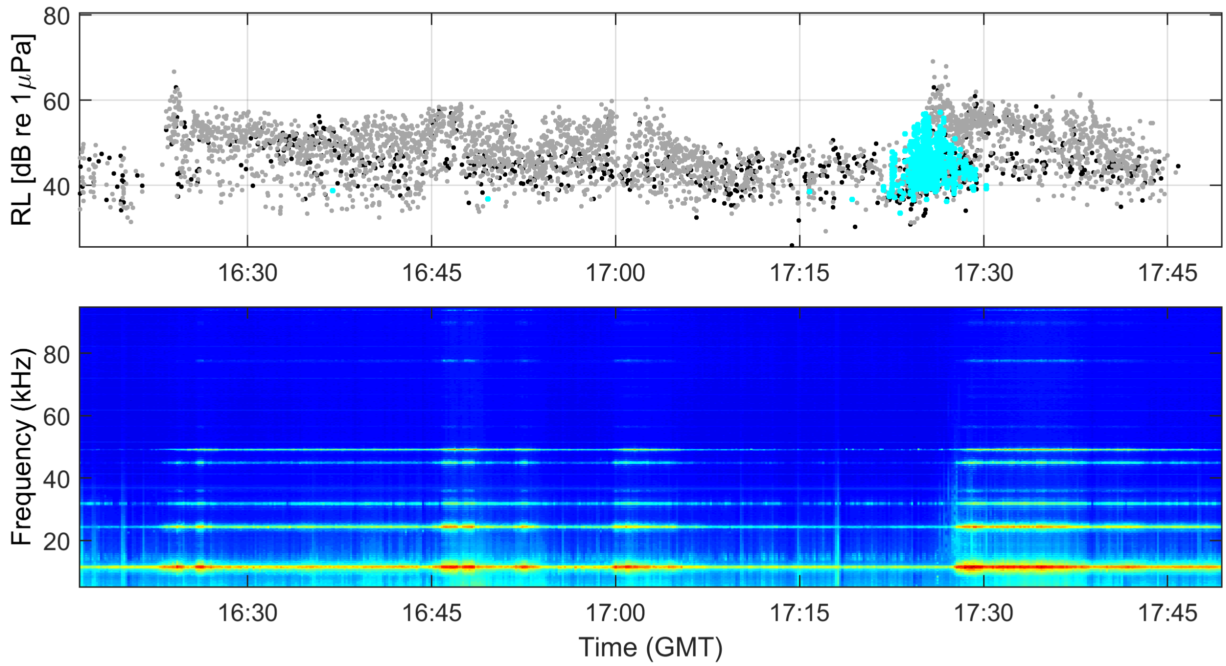


Figure 5. Example of interactive viewer used to verify potential beaked whale echolocation clicks in towed array recordings. A two hour mixed-signal event is shown. In the upper panel, blue points represent detections automatically classified by the neural network as un-banded odontocete echolocation clicks. Gray points represent detections automatically classified as false positives, and black points are those left unclassified due to low classifier certainty. The lower panel shows a long term spectral average of the event, dominated by echosounder, vessel and flow noise. This tool facilitates rapid review and manual editing of automatically-classified detections in complex datasets.

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