

Application of deep learning to estimate blue and fin whale call density in the southern California Current Ecosystem

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ABSTRACT

See main manuscript.

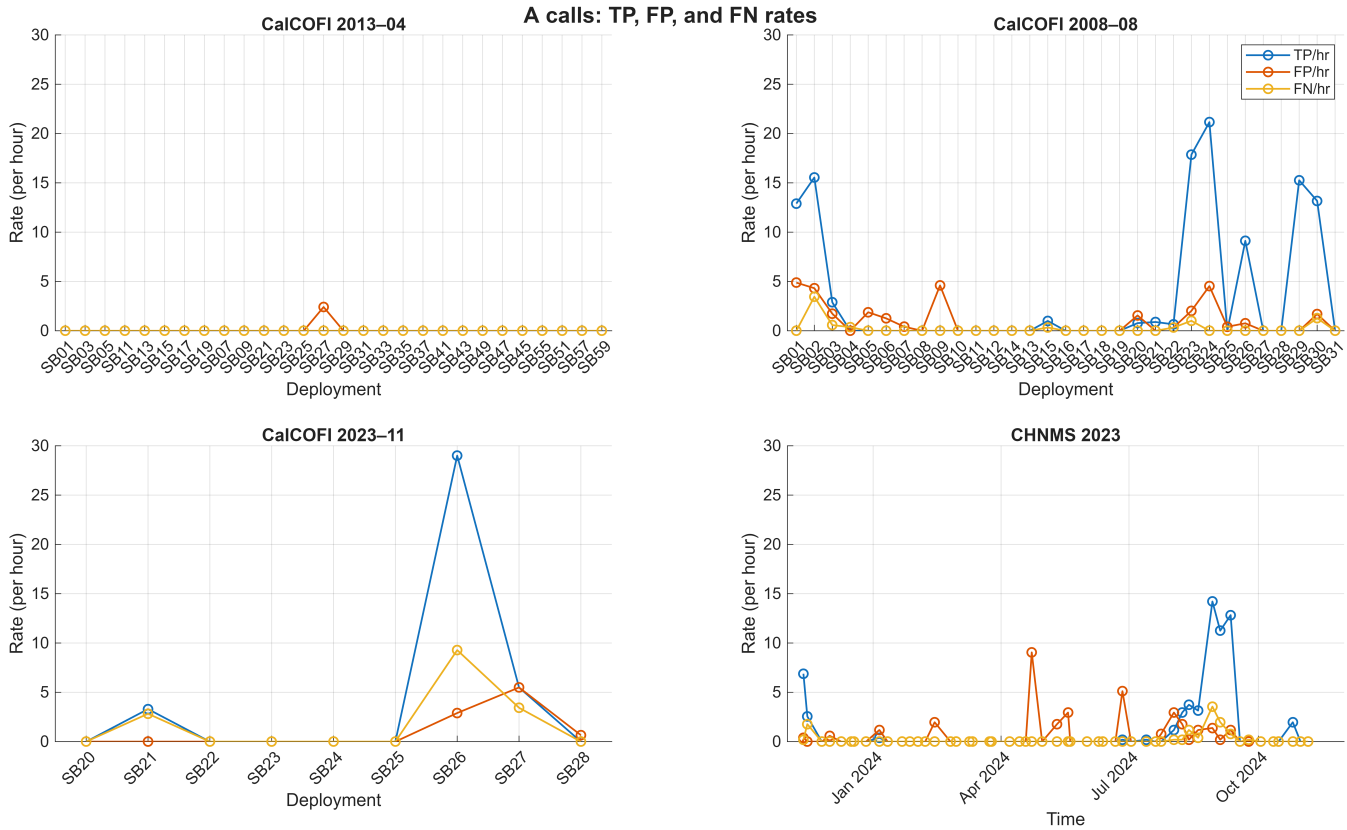
Supplementary Table S 1. Summary of CalCOFI sonobuoy survey cruises included in analysis. Recording hours reflect the total duration of sonobuoy deployments within each cruise.

Cruise ID	Year	Season	Start	End	No. Buoys	Recording (hrs)
CC0403	2004	Spring	23-Mar	08-Apr	24	61.7
CC0407	2004	Summer	13-Jul	24-Jul	22	54.2
CC0411	2004	Fall	03-Nov	18-Nov	38	128.1
CC0501	2005	Winter	04-Jan	18-Jan	27	61.1
CC0504	2005	Spring	15-Apr	30-Apr	31	83.8
CC0507	2005	Summer	02-Jul	16-Jul	32	79.8
CC0511	2005	Fall	05-Nov	20-Nov	26	39.8
CC0604	2006	Spring	02-Apr	16-Apr	29	62.2
CC0607	2006	Summer	09-Jul	24-Jul	36	73.6
CC0610	2006	Fall	22-Oct	04-Nov	27	58.2
CC0701	2007	Winter	13-Jan	30-Jan	24	105.2
CC0703	2007	Spring	28-Mar	14-Apr	27	56.1
CC0706	2007	Summer	29-Jun	13-Jul	27	57.5
CC0711	2007	Fall	03-Nov	18-Nov	23	49.5
CC0803	2008	Spring	25-Mar	05-Apr	18	35.6
CC0808	2008	Summer	15-Aug	29-Aug	31	67.7
CC0810	2008	Fall	15-Oct	29-Oct	19	29.8
CC0901	2009	Winter	22-Jan	21-Jan	30	68.9
CC0903	2009	Spring	08-Mar	22-Mar	28	56.3
CC0907	2009	Summer	15-Jul	30-Jul	36	155.5
CC1001	2010	Winter	13-Jan	31-Jan	20	55.9
CC1004	2010	Spring	12-Apr	16-Apr	12	28.6
CC1007	2010	Summer	31-Jul	15-Aug	22	94.9
CC1010	2010	Fall	29-Oct	12-Nov	20	56.0
CC1101	2011	Winter	13-Jan	28-Jan	27	70.8
CC1104	2011	Spring	10-Apr	27-Apr	29	55.0
CC1107	2011	Summer	27-Jul	12-Aug	33	73.0
CC1110	2011	Fall	17-Oct	30-Oct	19	75.9

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Table 1 continued

Cruise ID	Year	Season	Start	End	No. Buoys	Recording (hrs)
CC1201	2012	Winter	28-Jan	12-Feb	23	119.5
CC1203	2012	Spring	25-Mar	06-Apr	25	47.8
CC1207	2012	Summer	10-Jul	26-Jul	29	136.9
CC1210	2012	Fall	20-Oct	03-Nov	26	63.0
CC1301	2013	Winter	11-Jan	25-Jan	21	89.9
CC1304	2013	Spring	07-Apr	22-Apr	21	79.3
CC1307	2013	Summer	07-Jul	21-Jul	31	73.4
CC1311	2013	Fall	10-Nov	24-Nov	25	82.3
CC1401	2014	Winter	29-Jan	04-Feb	12	44.3
CC1404	2014	Spring	02-Apr	16-Apr	26	121.6
CC1407	2014	Summer	07-Jul	21-Jul	26	72.6
CC1411	2014	Fall	09-Nov	22-Nov	27	89.2
CC1501	2015	Winter	16-Jan	29-Jan	28	95.3
CC1507	2015	Spring	30-Jul	30-Jul	29	77.8
CC1510	2015	Fall	29-Oct	13-Nov	28	86.7
CC1601	2016	Winter	08-Jan	21-Jan	26	86.8
CC1604	2016	Spring	01-Apr	14-Apr	22	78.1
CC1607	2016	Summer	10-Jul	26-Jul	28	82.0
CC1611	2016	Fall	07-Nov	21-Nov	26	92.0
CC1701	2017	Winter	06-Jan	20-Jan	30	103.2
CC1703	2017	Spring	29-Mar	12-Apr	29	62.0
CC1708	2017	Summer	02-Aug	15-Aug	31	88.4
CC1711	2017	Fall	09-Nov	23-Nov	25	57.0
CC1806	2018	Summer	09-Jun	24-Jun	30	126.8
CC1902	2019	Winter	07-Feb	12-Feb	12	46.3
CC1904	2019	Spring	03-Apr	16-Apr	23	73.6
CC1907	2019	Summer	12-Jul	26-Jul	30	114.7
CC2107	2021	Summer	19-Jul	01-Aug	33	115.2
CC2110	2021	Fall	31-Oct	14-Nov	28	100.0
CC2204	2022	Spring	07-Apr	16-Apr	17	57.7
CC2208	2022	Summer	16-Aug	29-Aug	25	42.9
CC2211	2022	Fall	06-Nov	19-Nov	17	53.2
CC2301	2023	Winter	07-Jan	25-Jan	36	89.7
CC2303	2023	Spring	26-Mar	15-Apr	27	83.7
CC2307	2023	Summer	03-Jul	17-Jul	28	62.7
CC2311	2023	Fall	04-Nov	18-Nov	27	53.0
CC2401	2024	Winter	11-Jan	31-Jan	22	63.1
CC2403	2024	Spring	29-Mar	07-Apr	4	17.9
CC2407	2024	Summer	28-Jul	11-Aug	40	150.5
CC2411	2024	Fall	16-Nov	23-Nov	13	29.4
Total (68 cruises)					1743	5104.3



Supplementary Figure S 1. True positive, false positive, and false negative rates for A calls across evaluation datasets. Four panels show the rate of true positives (TP/hr), false positives (FP/hr), and false negatives (FN/hr) for A-call detections, standardized by recording effort (counts divided by effort duration in hours) at the deployment/encounter level. CalCOFI datasets (2013–04, 2008–08, 2023–11) are summarized by individual sonobuoy deployment (x-axis labeled by deployment ID), while CHNMS 2023 is summarized over verified encounter windows (5-hrs) through time. Rates are shown as lines with markers to highlight variability in detection outcomes among deployments/encounters and differences in error structure across datasets.

Supplementary Table S 2. CalCOFI sonobuoy cruises used for model training and testing. For training, recording hours reflect the total duration of 60-s spectrograms sampled from each cruise (not full deployment durations). For testing, recording hours reflect the full duration of all annotated sonobuoy deployments.

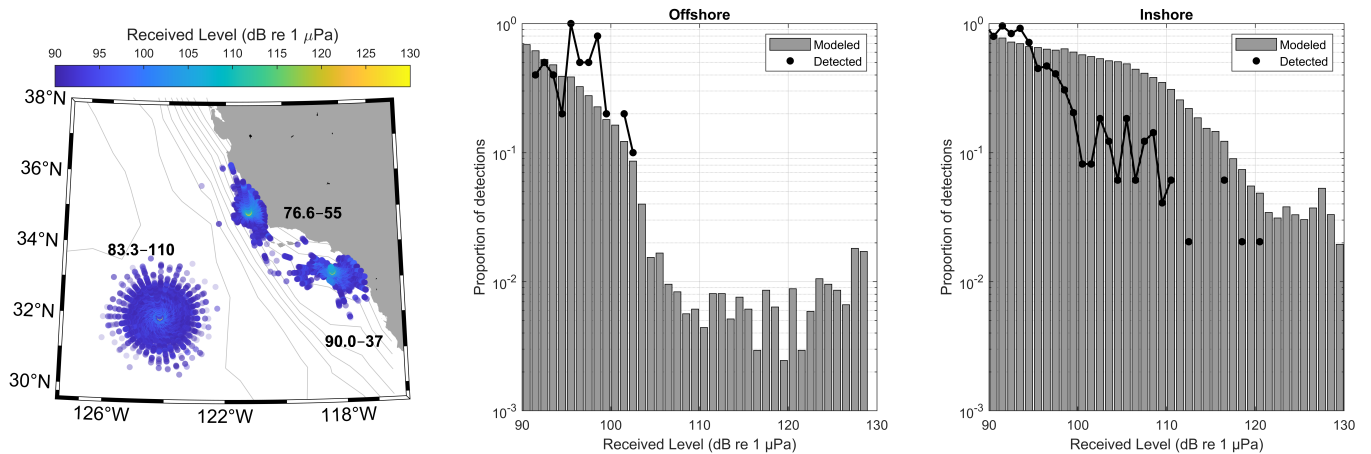
Cruise ID	Year	Season	Sonobuoys	Recording (hrs)
<i>Training</i>				
CC0603	2006	Winter	1	2.00
CC0706	2007	Summer	12	5.37
CC1107	2011	Summer	1	0.32
CC1110	2011	Fall	1	4.43
CC1301	2013	Winter	1	0.03
CC1307	2013	Summer	9	0.80
CC1311	2013	Fall	5	0.48
CC1407	2014	Summer	9	6.13
CC1501	2015	Winter	6	14.93
CC1507	2015	Summer	8	3.22
CC1601	2016	Winter	3	4.28
CC1604	2016	Spring	1	1.07
CC1611	2016	Fall	1	0.02
CC1701	2017	Winter	2	0.13
CC1806	2018	Summer	5	0.15
CC1907	2019	Summer	3	9.97
CC2411	2024	Fall	1	4.40
Train total				57.73
<i>Testing</i>				
CC0808	2008	Summer	32	69.50
CC1304	2013	Spring	28	115.68
CC2311	2023	Fall	9	16.11
Test total				201.29

Supplementary Table S 3. HARP deployments used for model training, validation, and testing. Recording hours reflect the total duration of 60-s spectrograms sampled from each deployment for training and validation, and the full annotated deployment duration for the CHNMS test dataset.

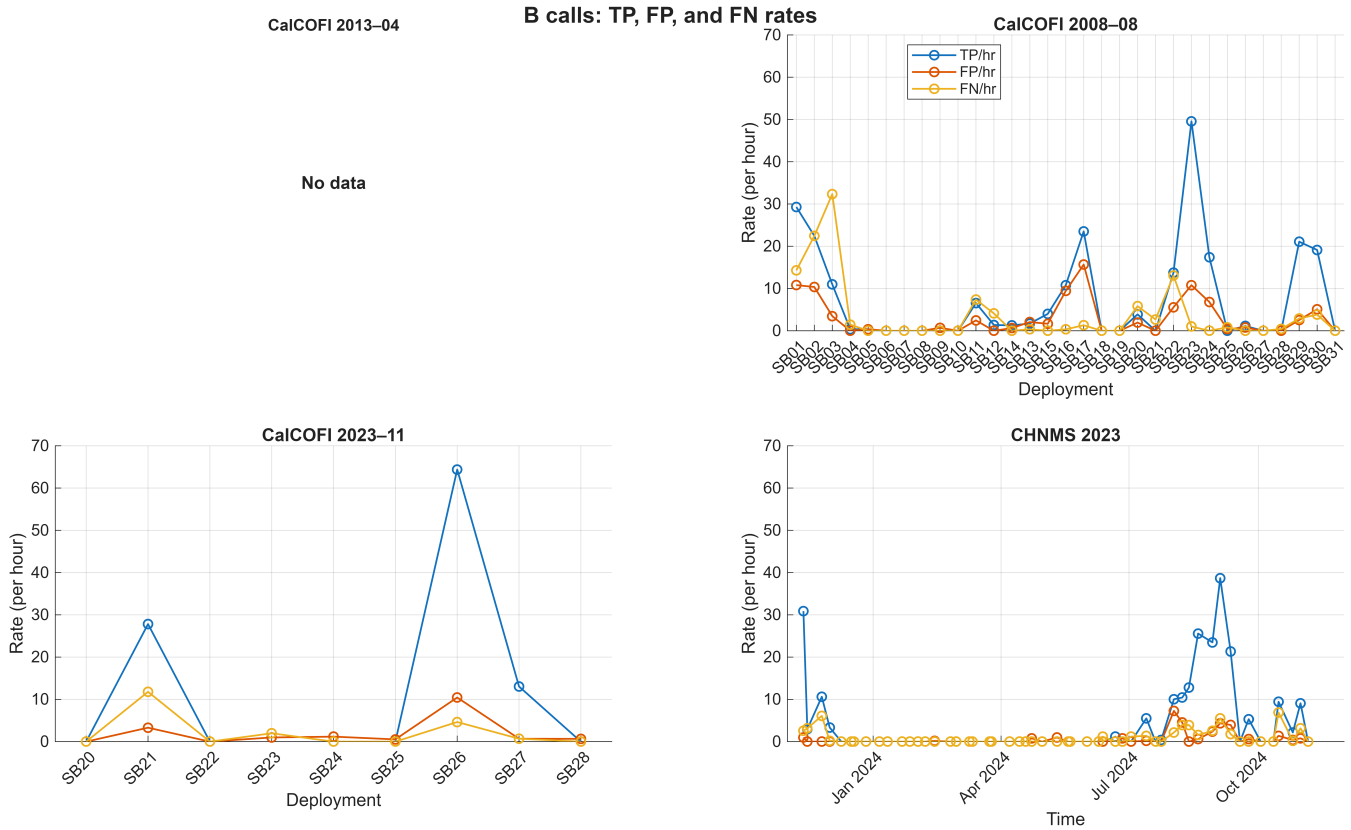
Station	Latitude	Longitude	Depth (m)	Deployed	Recovered	Role	Recording (hrs)
CINMS01	34.28°N	120.03°W	580	2011-10-24	2012-03-21	Train/Val	0.38
CINMS02	34.29°N	120.03°W	580	2012-03-22	2012-08-01	Train/Val	11.92
CINMS03	34.29°N	120.02°W	900	2012-08-02	2012-12-03	Train/Val	0.57
SOCAL	32.85°N	119.18°W	1012	2008-06-04	2008-08-03	Train/Val	28.03
DC	35.61°N	121.24°W	65	2012-11-06	2013-03-19	Train/Val	68.40
CHNMS	34.57°N	120.71°W	73	2023-11-06	2024-11-06	Test	269.17
Train/Val total							109.30
Test total							269.17

Supplementary Table S 4. Detection areas by call type at each modeled CalCOFI station. Inshore stations (86.7–60, 93.3–35, 90.0–37, 76.7–55, 86.7–35, 81.8–46.9, and 83.3–55) are located inshore of the continental slope; offshore stations (83.3–110, 90.0–90, and 83.3–70) are located offshore of the continental slope.

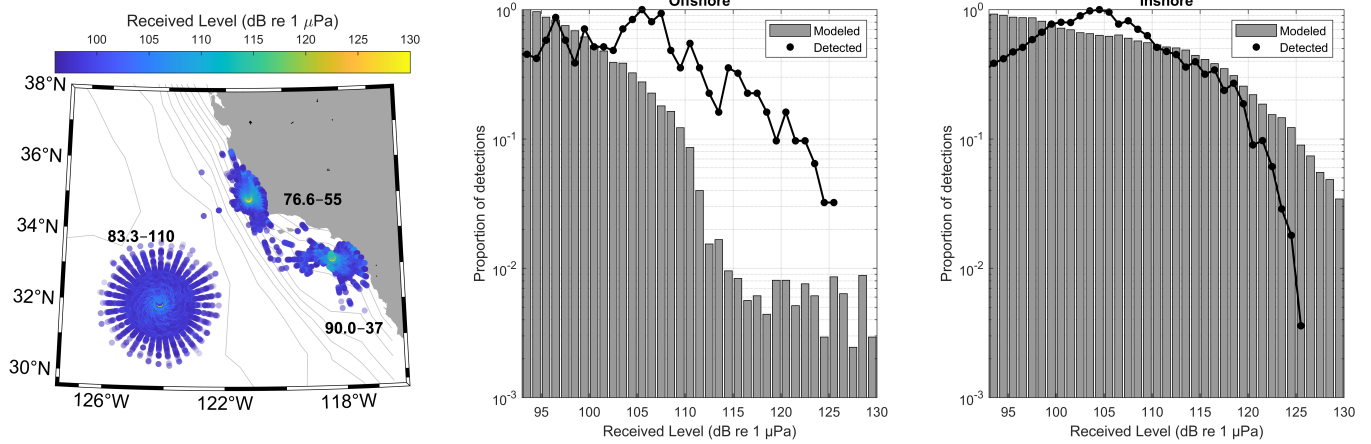
Station	Latitude	Longitude	A (km ²)	B (km ²)	D (km ²)	20 Hz (km ²)	40 Hz (km ²)
<i>Inshore stations</i>							
86.7–60	32.99°N	120.35°W	21,646	24,954	26,418	24,915	25,617
93.3–35	32.68°N	117.87°W	18,484	21,746	22,480	21,431	22,196
90.0–37	33.18°N	118.39°W	13,349	13,842	14,507	13,855	14,253
76.7–55	34.89°N	121.20°W	11,619	12,848	13,638	12,564	12,986
86.7–35	33.82°N	118.63°W	8,006	8,661	9,402	8,494	8,802
81.8–46.9	34.27°N	120.03°W	4,629	4,813	4,916	4,824	4,874
83.3–55	33.75°N	120.41°W	17,238	20,127	21,819	20,115	20,971
<i>Offshore stations</i>							
83.3–110	31.91°N	124.17°W	38,427	40,095	40,798	40,267	40,576
90.0–90	31.42°N	122.00°W	37,712	39,644	40,389	39,703	40,283
83.3–70	33.25°N	121.44°W	35,880	37,475	38,512	38,096	38,168



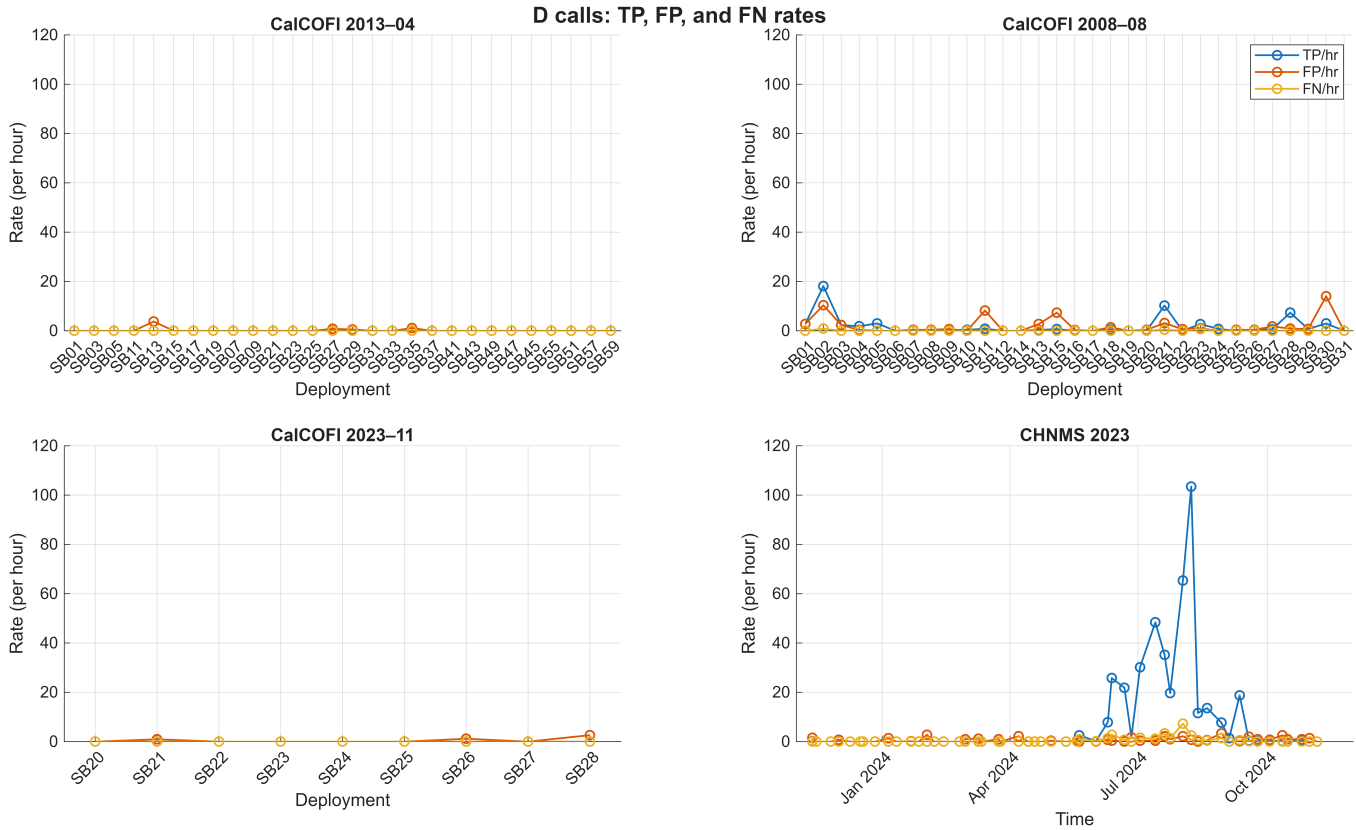
Supplementary Figure S 2. Received level distributions for blue whale A calls used for density estimation. Left: Modeled received levels (dB re 1 μ Pa) across the southern California Current Ecosystem for representative offshore and inshore stations. Center and right: Distributions of received levels for detected calls in offshore (center) and inshore (right) environments. Gray bars show modeled received level distributions from propagation modeling, while black points show received levels from detected calls.



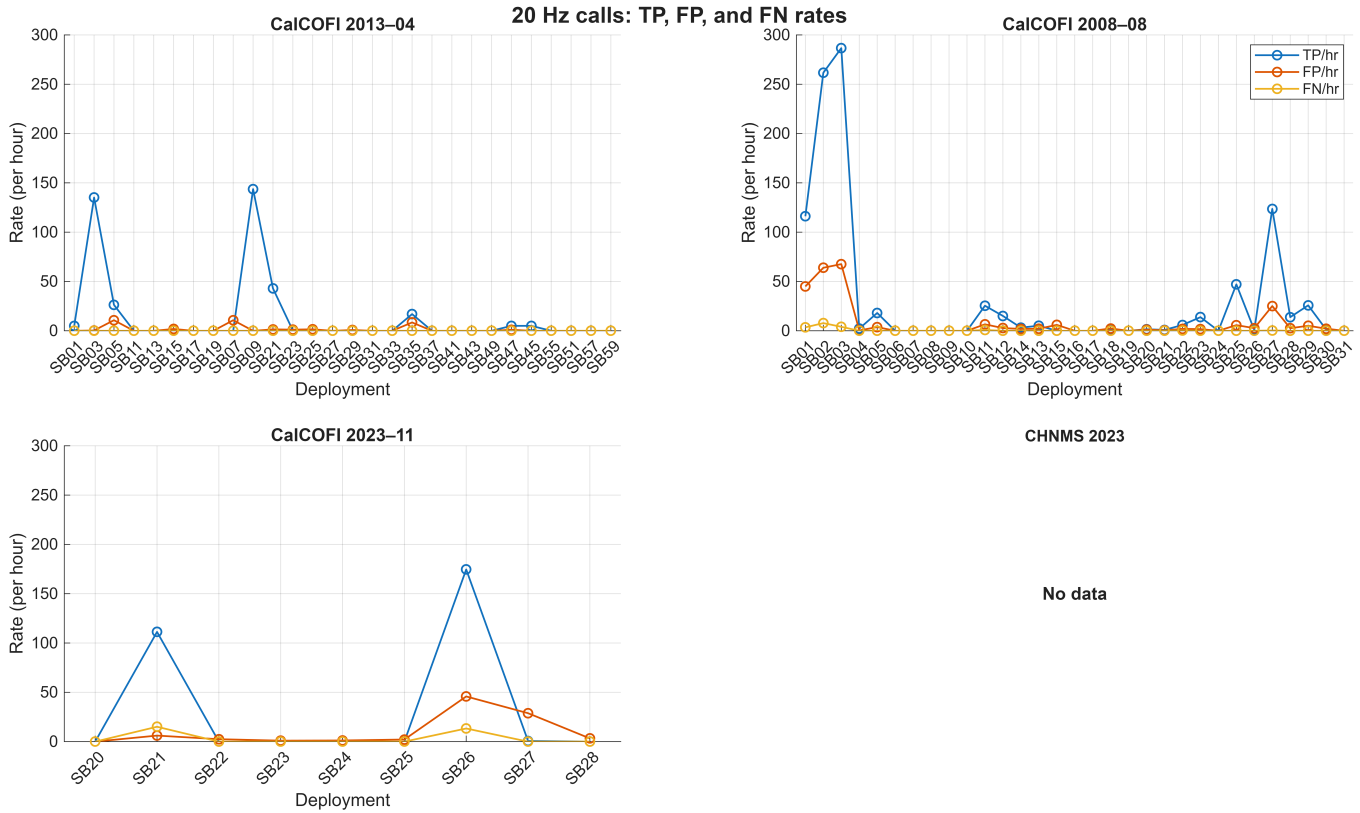
Supplementary Figure S 3. True positive, false positive, and false negative rates for B calls across evaluation datasets. Four panels show the rate of true positives (TP/hr), false positives (FP/hr), and false negatives (FN/hr) for B-call detections, standardized by recording effort (counts divided by effort duration in hours) at the deployment/encounter level. CalCOFI datasets (2013–04, 2008–08, 2023–11) are summarized by individual sonobuoy deployment (x-axis labeled by deployment ID), while CHNMS 2023 is summarized over verified encounter windows (5-hrs) through time. Rates are shown as lines with markers to highlight variability in detection outcomes among deployments/encounters and differences in error structure across datasets.



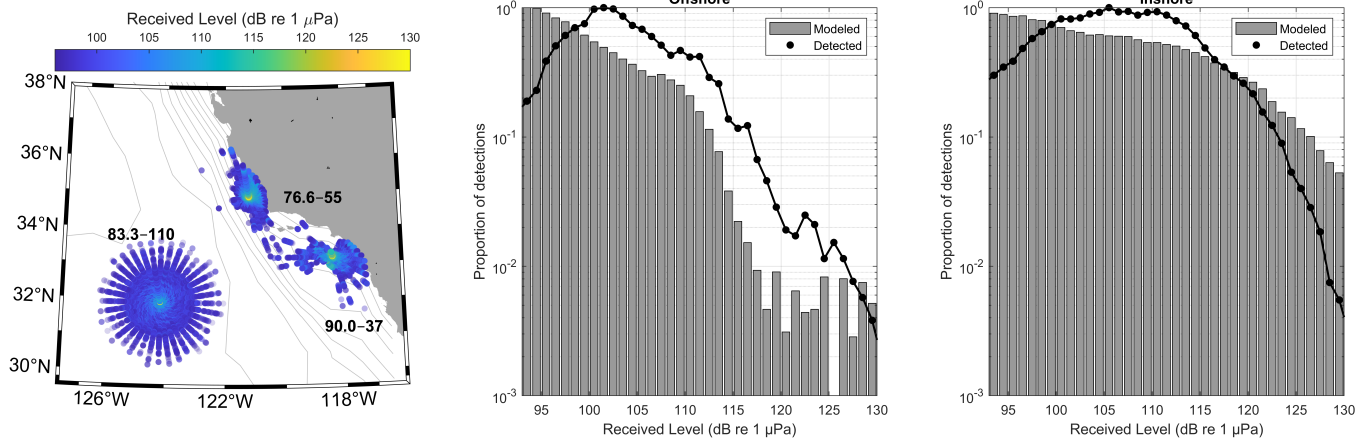
Supplementary Figure S 4. Received level distributions for blue whale B calls used for density estimation. Left: Modeled received levels (dB re 1 μ Pa) across the southern California Current Ecosystem for representative offshore and inshore stations. Center and right: Distributions of received levels for detected calls in offshore (center) and inshore (right) environments. Gray bars show modeled received level distributions from propagation modeling, while black points show received levels from detected calls.



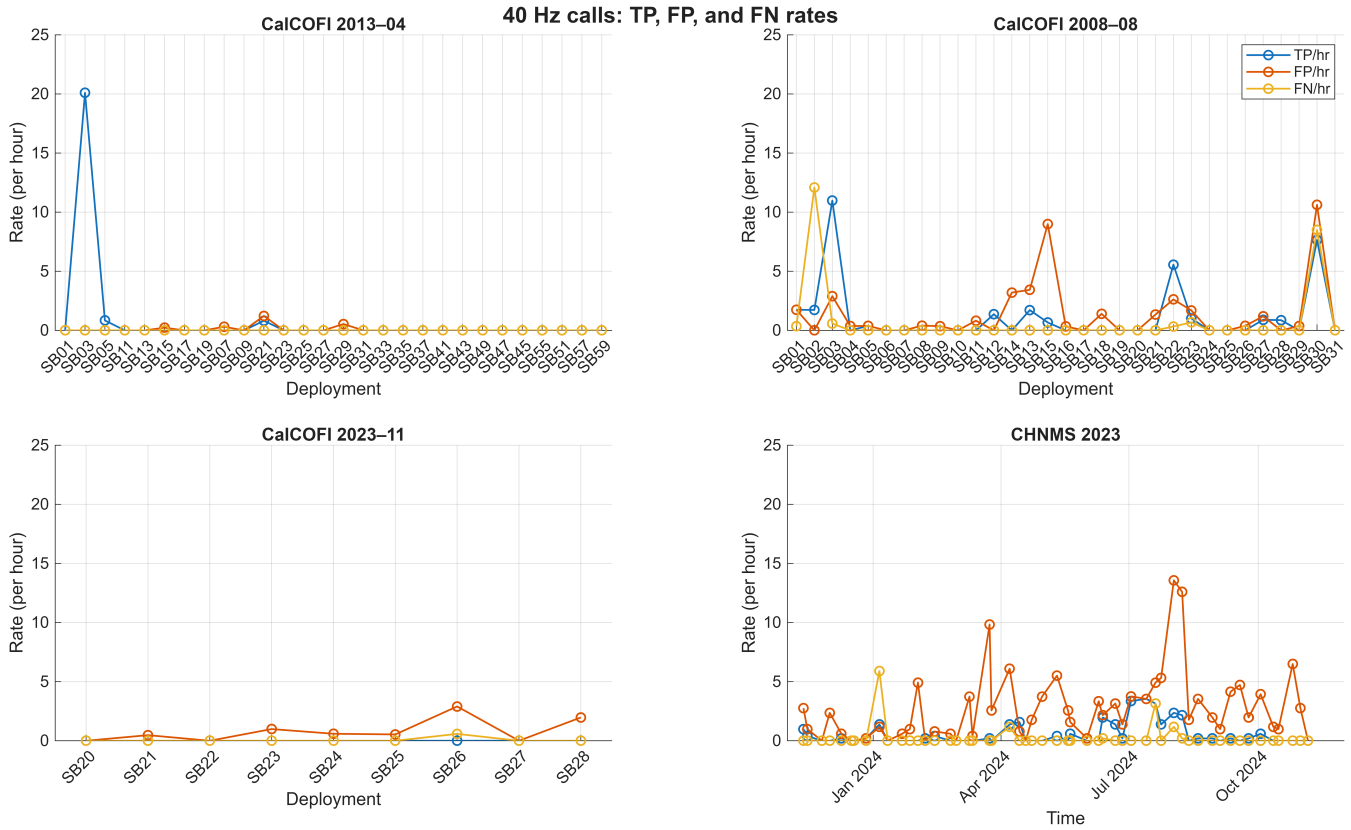
Supplementary Figure S 5. True positive, false positive, and false negative rates for D calls across evaluation datasets. Four panels show the rate of true positives (TP/hr), false positives (FP/hr), and false negatives (FN/hr) for D-call detections, standardized by recording effort (counts divided by effort duration in hours) at the deployment/encounter level. CalCOFI datasets (2013–04, 2008–08, 2023–11) are summarized by individual sonobuoy deployment (x-axis labeled by deployment ID), while CHNMS 2023 is summarized over verified encounter windows (5-hrs) through time. Rates are shown as lines with markers to highlight variability in detection outcomes among deployments/encounters and differences in error structure across datasets.



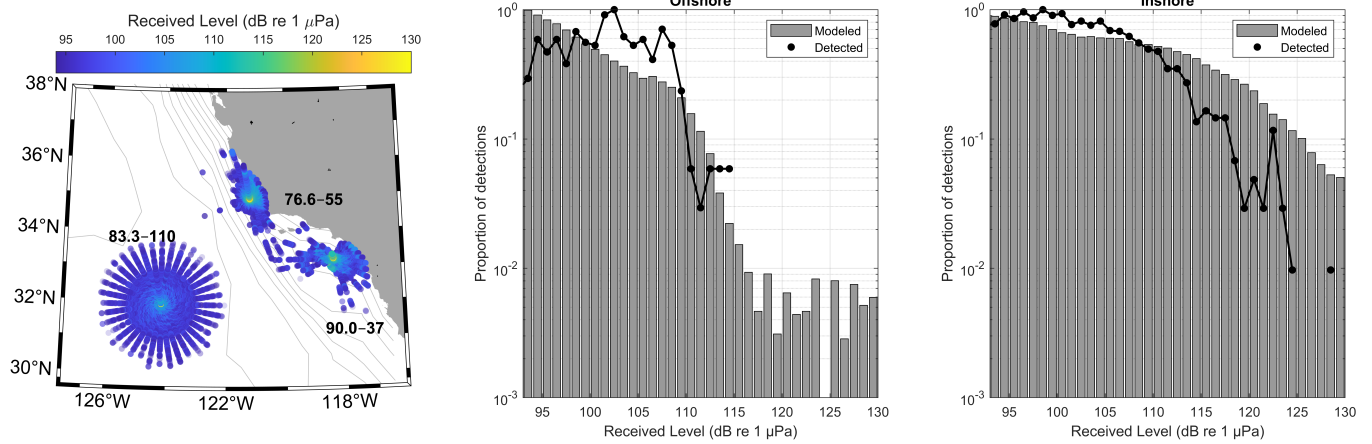
Supplementary Figure S 6. True positive, false positive, and false negative rates for 20 Hz calls across evaluation datasets. Four panels show the rate of true positives (TP/hr), false positives (FP/hr), and false negatives (FN/hr) for 20 Hz-call detections, standardized by recording effort (counts divided by effort duration in hours) at the deployment/encounter level. CalCOFI datasets (2013–04, 2008–08, 2023–11) are summarized by individual sonobuoy deployment (x-axis labeled by deployment ID), while CHNMS 2023 is summarized over verified encounter windows (5-hrs) through time. Rates are shown as lines with markers to highlight variability in detection outcomes among deployments/encounters and differences in error structure across datasets.



Supplementary Figure S 7. Received level distributions for fin whale 20 Hz calls used for density estimation. Left: Modeled received levels (dB re 1 μ Pa) across the southern California Current Ecosystem for representative offshore and inshore stations. Center and right: Distributions of received levels for detected calls in offshore (center) and inshore (right) environments. Gray bars show modeled received level distributions from propagation modeling, while black points show received levels from detected calls.



Supplementary Figure S 8. True positive, false positive, and false negative rates for 40 Hz calls across evaluation datasets. Four panels show the rate of true positives (TP/hr), false positives (FP/hr), and false negatives (FN/hr) for 40 Hz-call detections, standardized by recording effort (counts divided by effort duration in hours) at the deployment/encounter level. CalCOFI datasets (2013–04, 2008–08, 2023–11) are summarized by individual sonobuoy deployment (x-axis labeled by deployment ID), while CHNMS 2023 is summarized over verified encounter windows (5-hrs) through time. Rates are shown as lines with markers to highlight variability in detection outcomes among deployments/encounters and differences in error structure across datasets.



Supplementary Figure S 9. Received level distributions for fin whale 40 Hz calls used for density estimation. Left: Modeled received levels (dB re 1 μ Pa) across the southern California Current Ecosystem for representative offshore and inshore stations. Center and right: Distributions of received levels for detected calls in offshore (center) and inshore (right) environments. Gray bars show modeled received level distributions from propagation modeling, while black points show received levels from detected calls.