Not all marine biogeographic boundaries track temperature in an eastern boundary current

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Title page

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Data Availability Statement: The larval fish records, the CalCOFI hydrographic subsets, all derived tables and the code are deposited in the Zenodo repository at https://doi.org/10.5281/zenodo.24116322 (Inda-Díaz et al. 2026); the package regenerates every number and figure of this paper. The GBIF download is at https://doi.org/10.15468/dl.xu6bxk. The IMECOCAL CTD profiles are curated by the IMECOCAL program (CICESE/UABC); the 10

dbar values used here are redistributed in the package with the custodian's permission, and no result depends on the withheld full profiles, which are available from R. Durazo on request.

Abstract

Marine biogeographic boundaries are often treated as thermal limits that should shift poleward with warming. We tested this along the Pacific coast of California and Baja California with seasonal plankton surveys (CalCOFI, 1951–1969) and hydrography measured at the same stations and, for 1997–2012, by the IMECOCAL program. Three larval fish assemblage boundaries behaved differently. The Point Conception boundary lay at 32°N in winter and 35°N in summer and autumn, moving with the 14.75°C isotherm (unresolved in spring); temperature at the boundary varied by 0.7°C among seasons, against 2.2–3.0°C for a fixed boundary. The Punta Eugenia boundary stayed at 29°N in every season; the salinity edge near it shifted by several degrees between years, but not consistently with regional temperature. The southern Baja California boundary sat on the strongest front of the coast and barely moved. Boundaries on one coast differ in mechanism and should respond differently to warming.

Keywords: biogeographic boundaries; larval fish; California Current; CalCOFI; Point Conception; Punta Eugenia

Scientific Significance Statement

Marine biogeographic boundaries, where many species reach their range limits and communities change, are usually thought to sit where water temperature changes, so ocean warming is expected to push them poleward. Whether all boundaries along one coast share this thermal control can be tested with consistent, long-term data. Using larval fish and hydrography from the California Current, we show that one boundary moves about three degrees of latitude with the seasons and keeps a nearly constant temperature, a second stays in place through the year while the water around it warms and cools, and a third lies on a permanent front at the tip of a peninsula. Boundaries on the same coast are therefore likely to respond differently to warming.

Boundaries between marine biogeographic regions are places where many species reach the edge of their ranges and community composition changes over short distances (Spalding et al. 2007; Pappalardo et al. 2015). Many coincide with changes in water temperature, and the simplest explanation is thermal tolerance (Horn and Allen 1978; Belanger et al. 2012; Sunday et al. 2012); alternatively, currents may set the limits by blocking or retaining dispersing larvae (Gaylord and Gaines 2000). The distinction matters: thermal boundaries should move poleward as the ocean warms, as many species ranges already do (Pinsky et al. 2013; Lenoir et al. 2020), whereas boundaries set by the circulation or the coast may stay put while the species around them change.

The Pacific coast of California and Baja California has three widely recognized transitions, where the cool, fresh California Current meets saltier subtropical water (Lynn and Simpson 1987; Checkley and Barth 2009). Point Conception (34.5°N) separates cool- and warm-temperate faunas and is usually described as a temperature discontinuity (Horn and Allen 1978; Blanchette et al. 2008; Fenberg et al. 2015), although intraspecific genetic breaks are often absent there (Burton 1998) while faunal turnover does occur (Miller 2023). Punta Eugenia

(about 28°N) marks a change in larval fish assemblages (Moser and Smith 1993; Peiro-Alcantar et al. 2016) that persisted through the extreme events of 2010–2016 (Aceves-Medina et al. 2024), a break in zooplankton communities (Pitz et al. 2020) and a concentration of genetic breaks (Ferrera-Rodríguez et al. 2024). At the tip of the peninsula, the temperate fauna gives way to the tropical eastern Pacific (Spalding et al. 2007; Briggs and Bowen 2012). The coast between is a transition zone with a marked seasonal cycle and large interannual variability (Bograd and Lynn 2003; Durazo 2015).

Location, strength and mechanism of boundaries have been examined together for adult range limits on the Atlantic coast of North America (Pappalardo et al. 2015), but not by locating the three boundaries of one coast with the same data and method in every season and using their seasonal behaviour as the diagnostic: a boundary set by temperature should keep a nearly constant temperature as the seasonal cycle moves it, whereas one set by the circulation or the coast should stay in place while temperature there changes. Larval fish suit this test (Moser and Smith 1993; Hsieh et al. 2009): their assemblages integrate spawning and transport over much of the fish fauna (Moser et al. 1987), and the California Cooperative Oceanic Fisheries Investigations (CalCOFI) sampled the whole coast from northern California to the tip of Baja California in all seasons with the same methods in the 1950s and 1960s.

We ask: (1) Do the three boundaries move with the seasons, and are they equally sharp in every season? (2) Does temperature at each boundary vary less among seasons than at a fixed boundary? (3) For the boundary that does not move seasonally, how do its hydrographic edge and the species turnover across it vary between years? We find that one boundary is seasonal and thermal, one is stationary and tied to the circulation rather than to temperature, and one is a broad transition anchored on a permanent front.

Methods

Larval fish data

We used CalCOFI ichthyoplankton records from a single GBIF download (GBIF.org 2026), with names resolved to the GBIF taxonomic backbone (three regional names merged by the backbone were restored; see the cleaning scripts in the data package). We kept oblique tows that filtered at least 200 m^3 from 1951 to 1969, the only period in which the survey covered 22–40°N in all four seasons with one net (1 m ring net; the standard tow depth increased from 140 to 210 m in 1969; Ohman and Smith 1995); later decades lack winter and autumn coverage off Baja California. We excluded tows more than 300 km from the coast or inside the Gulf of California. The final set had 19,337 tows with 108,757 records of 285 species identified to species (Fig. 1a).

Locating boundaries

We grouped tows into 1° latitude bands and four seasons (winter, December–February, and so on), rarefied each band and season to 20 tows drawn 20 times, and described each unit by the square-root transformed mean frequency of occurrence of each species. We computed the Bray–Curtis dissimilarity between each band and the band to its south and placed each boundary at the band with the highest dissimilarity within one of three search windows, 23–26°N, 26–30°N and 32–36°N, which bracket the known transitions (the method locates known

boundaries; it does not discover new ones). A boundary at band *b* marks the change between the bands starting at *b* − 1 and *b*; one missing band per window was tolerated, otherwise no boundary was recorded. We report the full-data position, its dissimilarity and rank among all adjacent-band pairs of the coast in that season (Fig. S4), and, from 300 bootstrap samples of years, the median latitude, the 5th–95th percentiles (90% intervals), the modal band and the number of replicates in which a boundary was found. A boundary is detected in a season when its full-data position is a local maximum of the dissimilarity profile and coincides with the bootstrap mode; otherwise it is not resolved and no hydrography is read at it. Seasonal movement is the mean latitude in the detected warm seasons minus that in the detected cool seasons within each replicate.

Physics at the boundaries

Temperature and salinity at 10 m and 50 m came from the casts at the same CalCOFI stations (NOAA SWFSC 2026), within 300 km of the coast, averaged within each year and then taken as the median across years (1951–2016) for each season and 1° band. We read the value at each boundary as the mean of the two bands on either side and the gradient as their difference. A boundary that follows an isotherm should experience a smaller seasonal range of temperature than one fixed at the same latitudes, so we compared, over the seasons in which each boundary was detected, the range at its detected positions with the range at every fixed band edge from 23 to 36°N (Table S6); salinity has almost no seasonal cycle here, so its small range is not evidence. We repeated this with 1951–1969 hydrography only, the years of the larval data (Tables S6, S6b). Water masses on either side were assigned from median profiles to 200 m with published temperature–salinity limits (Durazo and Baumgartner 2002; Portela et al. 2016).

Year-to-year position of the 33.6 isohaline

The 33.6 isohaline at 10 m lies near the Punta Eugenia boundary in the long-term medians (Results). For each year and season with at least three 0.5° bands with data on each side of 28.5°N (25–32°N), we located the first latitude from the north where the median salinity at 10 m per band in the oceanic zone (deeper than 200 m) rose above 33.6 and stayed above it in the next two bands. CalCOFI measurements south of 28.5°N are scarce after 1984, so we used three sources: CalCOFI casts of 1951–1981; CTD casts of the IMECOCAL program, which occupied CalCOFI lines 100–137 (24.3–32.3°N) about quarterly from October 1997 to March 2012 (54 cruises, 4,245 casts; Durazo 2009), using values at 10 dbar, one position per cruise, with cruises in which the whole sampled transect was above or below 33.6 kept as censored and reported separately; and the SODA 3.3.1 reanalysis (Carton et al. 2018) for 1980–2015, treated as a model because its coastal salinity is weakly constrained by observations. We related the isohaline latitude to the within-season anomaly of mean temperature at 10 m between 25 and 32°N and to the Niño 3.4 index (ERSSTv5; Huang et al. 2017) by Spearman correlation, by season and overall.

Turnover across Punta Eugenia, 1998–2000

To test whether the strength of the Punta Eugenia boundary varies, we used species lists for 11 IMECOCAL cruises (1998–2000) for the zones north (CalCOFI lines 100–120) and south (lines 123 and beyond) of Punta Eugenia (Jiménez-Rosenberg 2008), computed the Simpson dissimilarity (βsim), which measures species replacement independent of richness (Baselga

2010), related it to the difference in mean temperature at 10 m between the zones from the same source, and left out each cruise in turn (Table S7).

All analyses were done in Python (Inda-Díaz et al. 2026).

Results

One boundary is seasonal, two are stationary

The Punta Eugenia boundary lay at 29°N in all four seasons, in the full data set and in 59–99% of the replicates (Fig. 1b; Table 1; Table S1b). Its dissimilarity was modest (rank 4–8 among the 15–17 adjacent-band pairs of the coast) but its position did not change (shift −0.4°, 90% interval −2.0 to 1.0°). The southern Baja California boundary lay at 23°N, or 24°N in autumn (shift 0.6°, 90% interval 0–1.5°), and was the sharpest break of the coast in winter, spring and summer (dissimilarity 0.27–0.39, rank 1; Fig. S4), but it lies at the southern edge of the sampled domain, on a plateau of high dissimilarity reaching 25°N, and thin southern sampling left it unlocated in 92 summer and 79 autumn replicates (Table 1).

The Point Conception boundary was the only one that changed with the seasons. In summer and autumn it was a sharp break at 35°N (dissimilarity 0.26 and 0.39, the coast-wide maximum in autumn; 297 and 296 replicates). In winter it lay at 32°N, a weak local maximum (dissimilarity 0.24, rank 5 of 16; Fig. S4) that was also the modal band of the replicates (144 of 300; 90% interval 32–35°N). In spring the full-data maximum (35°N) and the bootstrap mode (33°N) disagreed, with dissimilarities 0.0001 apart, so the spring boundary is not resolved (Table S1b). Between the detected seasons it moved 2.3° northward (summer–autumn minus winter; 90% interval 0–3.0°; northward in 95% of replicates).

Temperature at the boundaries

Temperature at 10 m at the Point Conception boundary ranged over 0.7°C among the three seasons in which it was detected (14.7–15.4°C), against 3.0°C and 2.2°C for boundaries fixed at 32°N and 35°N over the same seasons (Fig. 2a; Table 1; Table S6). The boundary followed the 14.75°C isotherm at 10 m, which lay at 32.8°N in winter and 34.9°N in summer and autumn. In summer and autumn it lay within one band of the steepest temperature gradient of the region (1.0–1.5°C per degree at 34–35°N); in winter the gradient at 32°N was 0.4°C per degree. Salinity was the same on both sides and at 200 m the sides were indistinguishable (Table S2): the boundary separates warmer from cooler water of one mass.

Temperature at the Punta Eugenia boundary ranged over 3.3°C among seasons, the range of a boundary fixed at 29°N (Table S6). Salinity at 10 m falls almost linearly from 34.5 at 22°N to 33.3 at 36°N (Fig. S2); the 33.6 isohaline crosses 29°N in the long-term median of every season (28.4–29.6°N), but neither the salinity nor the density gradient at 29°N was a local maximum (Table S2a). In the upper 50 m, California Current water made up 99% of the samples north of the boundary and 90% south of it (Table S3); the sides differ at 150–200 m, where southern water was saltier and warmer (Table S2b). The boundary is stationary but sits on no surface front.

At the southern Baja California boundary, temperature ranged over 5.4°C among seasons (6.4–7.1°C at a fixed boundary) and salinity over 0.28; in spring, summer and autumn it fell on the

steepest temperature gradient of the coast (1.7–2.9°C per degree; Table 1), and across it California Current water fell from 90% to 29% of the upper 50 m, replaced mainly by subtropical surface water (Table S3). With 1951–1969 hydrography only, the Point Conception range was 1.2°C against 2.2–2.7°C fixed, no other range changed by more than 0.1°C, and boundary temperatures changed by less than 0.6°C except southern Baja California in summer (−1.9°C, 3 yr of data); in those years the summer temperature step off Point Conception lay at 34°N, one band south of the larval boundary (Table S6b).

The salinity edge near Punta Eugenia varies between years but not with regional temperature

The 33.6 isohaline moved from year to year (Fig. 3a). In the CalCOFI measurements of 1951–1981 its interannual standard deviation was 1.3–2.0° of latitude (extremes 25.4° and 31.7°N) and it reached further north in warm years (Spearman $\rho = 0.43$, $p < 0.001$, $n = 70$ year–season combinations; by season $\rho = 0.25$–0.57, $n = 14$–21; Fig. 3b). In the IMECOCAL measurements of 1997–2012 it was found in 45 of 54 cruises, lay north of the sampled transect (which reached 29.8° and 31.7°N) in the two cruises of the 1997–1998 El Niño and south of 25°N in five, and had a median position of 27.8–28.6°N by season, 0.1–1.2° south of the 1951–1981 medians. Overall it was unrelated to the temperature anomaly ($\rho = 0.01$, $p = 0.97$, $n = 45$; with censored cruises placed at the domain edges $\rho = 0.12$, $n = 52$). The only seasonal relation was negative, in spring ($\rho = -0.76$, $p = 0.006$, $n = 11$; also in SODA for the same cruises); the other seasons gave $\rho = 0.21$–0.27 ($p > 0.3$, $n = 10$–12; Table S8). With four seasons tested, we read the spring value cautiously. Neither series was related to Niño 3.4 ($\rho = 0.14$ and -0.17). SODA agreed with the IMECOCAL measurements of the same cruises ($\rho = 0.59$, bias −0.4°, root mean square difference 1.8°, $n = 44$) and over 1980–2015 showed no relation with temperature in any season ($|\rho| \le 0.22$, $p > 0.2$). The positive relation with regional temperature is therefore confined to 1951–1981.

In the IMECOCAL cruises of 1998–2000, species turnover across Punta Eugenia ranged from 0 to 0.44 and rose with the temperature difference between the zones ($\rho = 0.61$, $p = 0.044$, $n = 11$; Fig. 3c), but the relation depends on the January 1999 cruise (18 southern species, all also present in the north, $\beta sim = 0$): without it $\rho = 0.48$ ($p = 0.16$), and the Sørensen dissimilarity showed no relation ($\rho = 0.04$; Table S7). We treat it as suggestive.

Discussion

The three boundaries are not versions of one thermal limit (Fig. 4).

The Point Conception boundary behaves as a thermal and seasonal boundary: it moves about three degrees of latitude between winter and summer–autumn with the 14.75°C isotherm, experiences a quarter to a third of the seasonal temperature range of a fixed boundary, and is sharpest in summer and autumn, when the gradient off the point is strongest. This is the classic interpretation of the Point Conception break (Horn and Allen 1978), with the addition that the break moves seasonally in the larval fauna, which helps explain why it has been controversial: surveys in different seasons would place it at different latitudes, and populations that mix across a line that is weak and displaced for part of the year need not diverge genetically there (Burton 1998). The winter position is a weak maximum and spring is unresolved, so the displacement rests on three seasons.

The Punta Eugenia boundary does not move with the seasons (although 124 of 300 autumn replicates placed it at 26°N), temperature there changes as much as at any fixed latitude, and it sits on no surface front: the two sides share the same surface water mass, the salinity gradient at 29°N is unremarkable, and they differ only below 150 m. The boundary lies about one degree north of Punta Eugenia, at the northern edge of Bahía Vizcaíno, where the California Current separates from the coast and eddies retain larvae and define assemblage limits (Aceves-Medina et al. 2018; Durazo 2009, 2015); this retention is our proposed, untested mechanism. The interannual behaviour of its salinity edge is consistent: in 1951–1981 the edge reached further north in warm years, but in the better sampled 1997–2012 it did not, except during the 1997–1998 El Niño, when it left the sampled transect; and in the extreme events of 2011–2015 the 22°C isotherm moved from about 26°N to 30°N while the larval boundary stayed in place (Aceves-Medina et al. 2024). A boundary that stays in place while the water around it warms, cools and changes salinity is more plausibly set by the circulation and the shape of the coast than by any single property of the water, and such persistence would leave a lasting mark on species distributions and genetic structure (Pitz et al. 2020; Ferrera-Rodríguez et al. 2024). Whether its strength varies with the thermal contrast between its sides, as the 1998–2000 cruises suggest, needs more than eleven cruises to settle.

The southern Baja California boundary sits on the strongest front of the coast, where the California Current meets subtropical water, and is the sharpest break in the larval data in three seasons. It is also a broad transition at the southern edge of what CalCOFI sampled, so its position is resolved less precisely than the others and its southern limit not at all; with that reservation, we keep it as a frontal transition anchored by geography.

Three limitations apply. The larval data are from 1951–1969 and the hydrographic medians from 1951–2016, although 1951–1969 hydrography changed no conclusion (Table S6b). Seasonal changes in a dissimilarity maximum can arise because different species spawn in different seasons (Moser et al. 1987); whether the same taxa define the Point Conception break in each season is untested. And the step from seasonal and interannual behaviour to long-term change is a prediction, not a result.

As predictions, the three cases differ. A thermal, seasonal boundary should shift poleward with its isotherm as the coast warms; the poleward range extensions of southern species in the 2014–2016 marine heatwaves (Sanford et al. 2019) are that kind of response. A stationary boundary set by the circulation, and a frontal transition anchored at a cape, should keep their positions while the species on either side change, as the Punta Eugenia boundary did in 2011–2015. The same tests apply to other eastern boundary currents, where capes, water-mass edges and isotherms coincide in some places and not others (Camus 2001), and require only boundaries located with one method in every season, their dissimilarity profiles shown, and hydrography read at the boundary rather than averaged over a region.

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Claude (Anthropic), a large language model, was used between 4 and 10 November 2026 under the authors' direction to write and run the Python code for data processing, boundary detection, hydrographic analyses and figures; to locate and verify bibliographic records; to outline a first draft; and to edit the text for English and style (all sections of the manuscript and the Supporting Information). The authors conceived the study, defined every analysis, verified

the code and its outputs against the source data, checked every reference against the original publication, rewrote the text, and take full responsibility for the content.

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Conflicts of Interest

None declared.

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Table

Table 1. Position, strength and hydrography of the three larval fish assemblage boundaries by season. Full data is the position obtained with all years; a boundary at band *b* marks the change between the bands starting at *b* − 1 and *b*. The bootstrap median and 5th–95th percentiles are from 300 replicates of years. A boundary is detected when the full-data position is a local maximum of the dissimilarity profile and coincides with the bootstrap mode; where fewer than 300 replicates located a boundary within the window, their number follows. Dissimilarity is the Bray–Curtis value at the full-data position, with its rank among all pairs of adjacent bands along the coast in that season (1 = coast-wide maximum). T10 and S10 are temperature and salinity at 10 m, the mean of the two bands on either side of the boundary (median across years, CalCOFI hydrography 1951–2016, within 300 km of the coast); ΔT10 is the absolute temperature difference between those two bands (°C per degree of latitude). The lower table gives, over the seasons in which each boundary was detected, the range of T10 at its detected positions against the range at a boundary fixed at the same bands, with all years and with 1951–1969 only (Table S6). Seasons: W, winter (December–February); Sp, spring (March–May); Su, summer (June–August); A, autumn (September–November).

Boundary	Season	Full (°N)	Bootstrap median (90%)	Detected	Dissimilarity (rank)	T10 (°C)	ΔT10	S10
Point	W	32	33 (32–35)	yes	0.24 (5/16)	14.9	0.39	33.40

Boundary	Season	Full (°N)	Bootstrap median (90%)	Detected	Dissimilarity (rank)	T10 (°C)	ΔT10	S10
Conception								
	Sp	35	33 (32–36)	no	0.20 (5/15)	14.3	0.51	33.39
	Su	35	35 (35–35)	yes	0.26 (5/17)	14.7	1.02	33.48
	A	35	35 (35–35)	yes	0.39 (1/15)	15.4	0.96	33.41
Punta Eugenia	W	29	29 (29–30)	yes	0.25 (4/16)	16.6	0.50	33.59
	Sp	29	29 (26–29)	yes	0.20 (7/15)	15.7	0.36	33.55
	Su	29	29 (29–29)	yes	0.26 (6/17)	17.6	0.54	33.61
	A	29	29 (26–29)	yes	0.26 (8/15)	19.0	0.79	33.64
Southern Baja California	W	23	23 (23–24)	yes	0.38 (1/16)	21.4	1.01	34.57
	Sp	23	23 (23–24)	yes, 298	0.27 (1/15)	19.3	1.67	34.35
	Su	23	23 (23–24)	yes, 208	0.39 (1/17)	23.3	2.89	34.29
	A	24	24 (23–25)	yes, 221	0.35 (2/15)	24.7	2.57	34.45

Boundary	Seasons detected	Range at boundary, 1951–2016 (°C)	If fixed, 1951–2016 (°C)	Range at boundary, 1951–1969 (°C)	If fixed, 1951–1969 (°C)
Point Conception	W+Su+A	0.7	3.0 at 32°N; 2.2 at 35°N	1.2	2.7 at 32°N; 2.2 at 35°N
Punta Eugenia	W+Sp+Su+A	3.3	3.3 at 29°N	3.3	3.3 at 29°N
Southern Baja California	W+Sp+Su+A	5.4	7.1 at 23°N; 6.4 at 24°N	5.4	7.3 at 23°N; 6.5 at 24°N

Figure legends

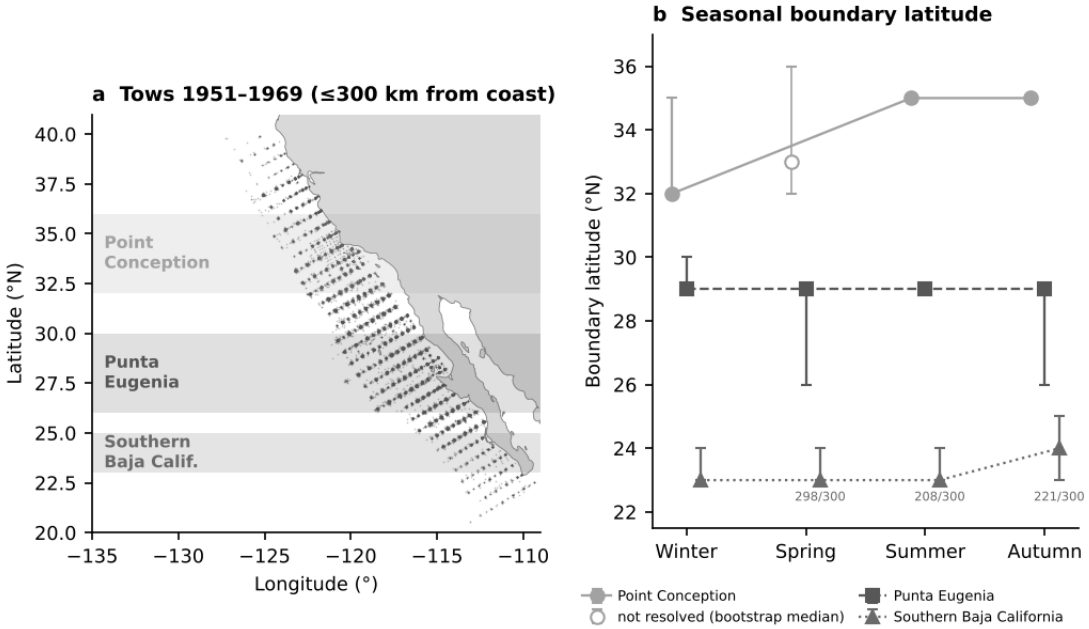


Figure 1. (a) CalCOFI oblique plankton tows used (1951–1969, within 300 km of the coast; n = 19,337). Shaded bands show the range of the 90% bootstrap intervals of each boundary over all seasons. (b) Latitude of the three larval fish assemblage boundaries by season: filled symbols at the full-data position where the boundary was detected (local maximum coinciding with the bootstrap mode) and an open symbol at the bootstrap median where it was not resolved (Point Conception, spring); bars are the 90% interval of 300 bootstrap replicates of years and, where a boundary was not found in every replicate, the number of valid replicates is given. Seasonal shift between detected warm and cool seasons: Point Conception +2.3° (summer–autumn minus winter; 90% interval 0 to +3.0°), Punta Eugenia −0.4° (summer–autumn minus winter–spring; −2.0 to +1.0°), southern Baja California +0.6° (0 to +1.5°).

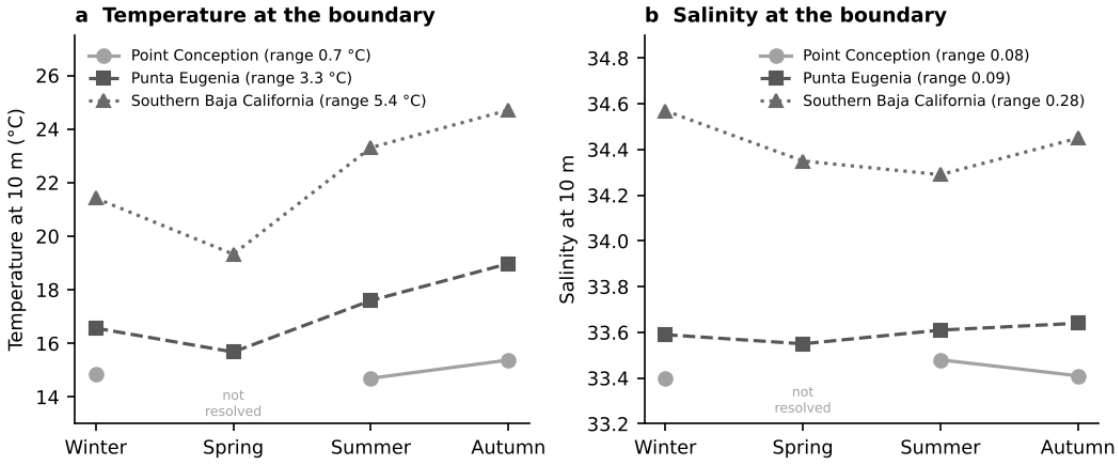


Figure 2. Temperature (a) and salinity (b) at 10 m at each boundary by season (median across years of the mean of the two 1° bands on either side of the boundary; CalCOFI hydrography 1951–2016, within 300 km of the coast). Values are shown only for the seasons in which the boundary was detected; the range among those seasons is given in the key, and the range a boundary fixed at the same bands would experience over the same seasons is in Table 1. The Point Conception boundary experiences a quarter to a third of the seasonal temperature range of a fixed boundary; the other two experience the full local range. Salinity varies little at every boundary because it has almost no seasonal cycle along this coast.

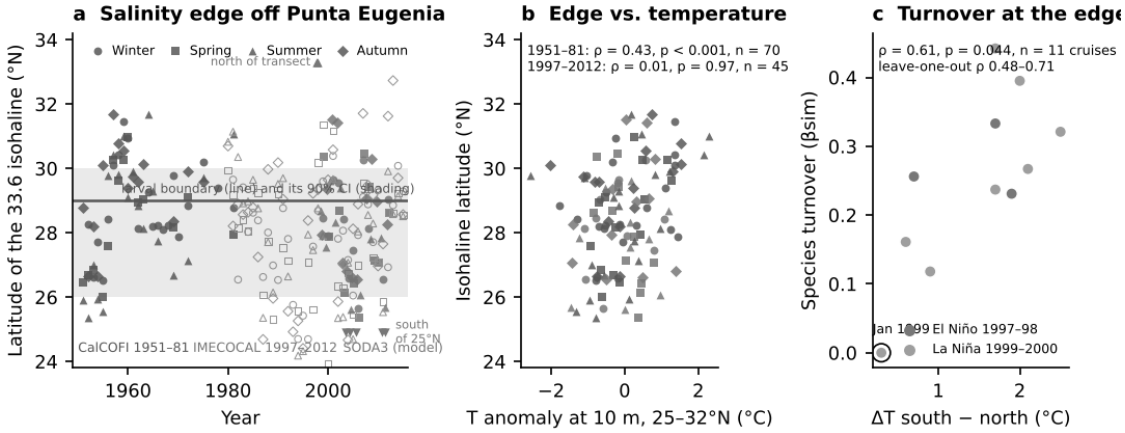


Figure 3. (a) Latitude of the 33.6 isohaline at 10 m off Baja California by year and season, from CalCOFI measurements (blue, 1951–1981, oceanic zone), IMECOCAL CTD measurements (orange, 1997–2012; triangles at the top and bottom mark cruises in which the whole sampled transect was above or below 33.6) and the SODA 3.3.1 reanalysis (open grey symbols, 1980–2015). The line and shading show the larval boundary at Punta Eugenia and the range of its 90% bootstrap intervals over the seasons. (b) Isohaline latitude against the within-season temperature anomaly at 10 m between 25 and 32°N, for the two measured periods. (c) Species turnover (Simpson dissimilarity, βsim) between the zones north and south of Punta Eugenia against the temperature difference between them, for 11 IMECOCAL cruises in 1998–2000 (species lists from Jiménez-Rosenberg 2008), with the range of the correlation when each cruise is left out in turn; the circled point is the January 1999 cruise on which the correlation depends.

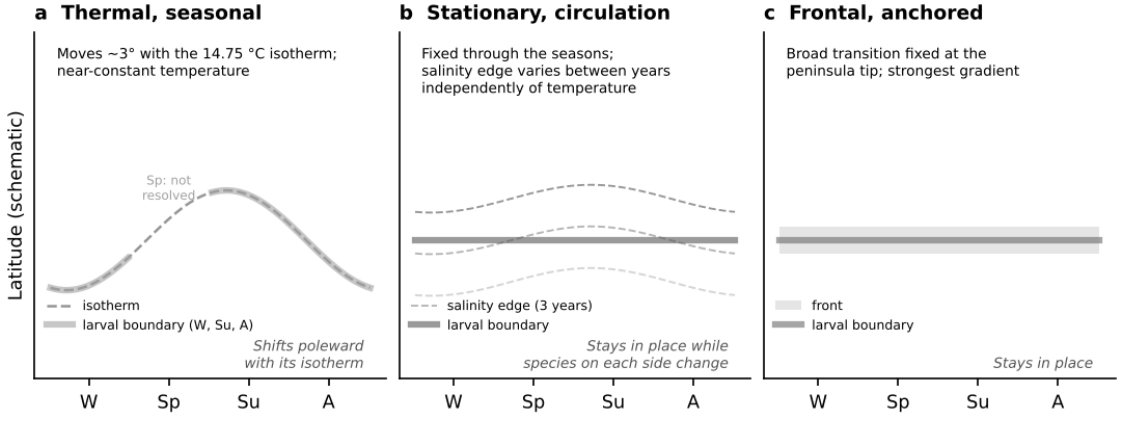


Figure 4. Three kinds of assemblage boundary along the California Current. (a) A thermal, seasonal boundary that moves with an isotherm, keeps a nearly constant temperature and is

sharpest when the temperature gradient is strong (Point Conception). (b) A stationary boundary set by the circulation, which stays in place through the seasons while the salinity edge near it shifts between years independently of regional temperature (Punta Eugenia). (c) A frontal transition anchored at the tip of the peninsula (southern Baja California). Italic text gives the expected response to ocean warming.

Supporting Information

Tables S1–S8 and Figures S1–S4 (file SI_LOLetters): bootstrap replicates, full-data estimates, coast-wide ranks and replicate frequencies (S1, S1b, S1c); hydrographic profiles by band and by zone (S2); water-mass fractions (S3); the isohaline series from CalCOFI and SODA (S4) and from IMECOCAL (S8); IMECOCAL turnover and its leave-one-out robustness (S5, S7); the seasonal-range test and the 1951–1969 sensitivity (S6, S6b); temperature–salinity diagrams (Fig. S1), latitudinal profiles (Fig. S2), stratification and dynamic height (Fig. S3) and dissimilarity profiles (Fig. S4).

Supporting Information

Not all marine biogeographic boundaries track temperature in an eastern boundary current

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Limnology and Oceanography Letters

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- Table S1. Boundary latitude in each bootstrap replicate (CSV and XLSX only; 3,600 rows).
- Table S2. Median temperature, salinity and density by latitude band and season (S2a), and median profiles by zone (S2b; CSV and XLSX).
- Table S3. Water-mass fractions by zone and layer.
- Table S4. Latitude of the 33.6 isohaline by year and season (CSV and XLSX; 212 rows).
- Table S5. IMECOCAL cruises 1998–2000: species richness and turnover across Punta Eugenia.
- Table S6. Seasonal range of temperature and salinity at each boundary against the range a fixed boundary would experience, and Table 1 recomputed with 1951–1969 hydrography only (S6b).
- Table S7. Leave-one-out robustness of the turnover–temperature relation of Table S5.
- Table S8. Latitude of the 33.6 isohaline in each IMECOCAL cruise, 1997–2012 (measured CTD).
- Figure S1. Temperature–salinity diagram of the four zones.
- Figure S2. Latitudinal profiles of temperature, salinity and density.
- Figure S3. Upper-ocean stratification and dynamic height.
- Figure S4. Full-data dissimilarity profiles along the coast by season, with the search windows and the boundaries.

All tables are also provided as `Tables_S1-S8.xlsx` and as individual CSV files in the Zenodo deposit.

Table S1

Latitude of each larval fish assemblage boundary in each of the 300 bootstrap replicates of years, by season, with the Bray–Curtis dissimilarity between the two bands that define it. Provided as `Table_S1_bootstrap_replicates.csv`. Table S1b gives, for each boundary and season, the position obtained with the full data set, the dissimilarity at that position and its rank among all adjacent-band pairs of the coast in that season (1 = coast-wide maximum), the bootstrap median and 90 % interval, the modal band among replicates with its frequency, whether the full-data position is a local maximum of the dissimilarity profile and whether the boundary is classified as detected (full-data position is a local maximum and coincides with the bootstrap mode; otherwise “not resolved”, as for Point Conception in spring), the position used

in the main text, and the number of replicates (out of 300) in which a boundary could be located within the search window. Table S1c gives the full frequency distribution of bands among replicates.

boundary	season	full_data_lat_N	dissimilarity_at_boundary	rank_along_coast	band_pairs_along_coast	bootstrap_median	p5	p95	modal_band	replicates_at_mode	full_data_is_local_maximum	detected	position_used_N	valid_replicates
Point Conception	Winter	32	0.24	5	16	33.00	32.00	35.00	32.00	144	True	True	32.00	300
Point Conception	Spring	35	0.20	5	15	33.00	32.00	36.00	33.00	152	True	False		300
Point Conception	Summer	35	0.26	5	17	35.00	35.00	35.00	35.00	297	True	True	35.00	300
Point Conception	Autumn	35	0.39	1	15	35.00	35.00	35.00	35.00	296	True	True	35.00	300
Punta Eugenia	Winter	29	0.25	4	16	29.00	28.95	30.00	29.00	246	True	True	29.00	300
Punta Eugenia	Spring	29	0.20	7	15	29.00	26.00	29.00	29.00	249	True	True	29.00	300
Punta Eug	Summer	29	0.26	6	17	29.00	29.00	29.00	29.00	296	True	True	29.00	300

boundary	season	full_data_lat_N	dissimilarity_at_boundary	rank_along_coast	band_pairs_along_coast	bootstrap_median	p5	p95	modal_band	replicates_at_mode	full_data_is_local_maximum	detected	position_used_N	valid_replicates
enia														
Punta Eugenia	Autumn	29	0.26	8	15	29.00	26.00	29.00	29.00	176	True	True	29.00	300
Southern Baja California	Winter	23	0.38	1	16	23.00	23.00	24.00	23.00	280	True	True	23.00	300
Southern Baja California	Spring	23	0.27	1	15	23.00	23.00	24.00	23.00	276	True	True	23.00	298
Southern Baja California	Summer	23	0.39	1	17	23.00	23.00	24.00	23.00	107	True	True	23.00	208
Southern Baja Cali	Autumn	24	0.35	2	15	24.00	23.00	25.00	24.00	119	True	True	24.00	221

boundary	season	full_data_lat_N	dissimilarity_at_boundary	rank_along_coast	band_pairs_along_coast	bootstrap_median	p5	p95	modal_band	replicates_at_mode	full_data_is_local_maximum	detected	position_used_N	valid_replicates
fornia														

boundary	season	23N	24N	25N	26N	27N	28N	29N	30N	32N	33N	34N	35N	36N
Point Conception	Winter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	144.00	118.00	22.00	3.00	13.00
Point Conception	Spring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.00	152.00	4.00	98.00	19.00
Point Conception	Summer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	297.00	3.00
Point Conception	Autumn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	296.00	4.00
Punta Eugenia	Winter	0.00	0.00	0.00	2.00	6.00	7.00	246.00	39.00	0.00	0.00	0.00	0.00	0.00
Punta Eugeni	Spring	0.00	0.00	0.00	29.00	14.00	4.00	249.00	4.00	0.00	0.00	0.00	0.00	0.00

boundary	season	23N	24N	25N	26N	27N	28N	29N	30N	32N	33N	34N	35N	36N
a														
Punta Eugenia	Summer	0.00	0.00	0.00	0.00	0.00	0.00	296.00	4.00	0.00	0.00	0.00	0.00	0.00
Punta Eugenia	Autumn	0.00	0.00	0.00	124.00	0.00	0.00	176.00	0.00	0.00	0.00	0.00	0.00	0.00
Southern Baja California	Winter	280.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Southern Baja California	Spring	276.00	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Southern Baja California	Summer	107.00	101.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Southern Baja California	Autumn	64.00	119.00	38.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
for														

boundary	season	23N	24N	25N	26N	27N	28N	29N	30N	32N	33N	34N	35N	36N
nia														

Table S2a

Median across years (1951–2016) of temperature (T, °C), salinity (S) and potential density anomaly (D, σ, kg m) at 10 m and 50 m in each 1° latitude band and season, from CalCOFI hydrographic casts within 300 km of the coast. Values were first averaged within each year. `years` is the number of years with data.

season	band_N	years	T10	S10	D10	T50	S50	D50
Winter	22	10	21.93	34.57	23.93	20.21	34.59	24.35
Winter	23	13	20.92	34.57	24.13	18.86	34.38	24.57
Winter	24	22	19.80	34.33	24.29	18.01	34.16	24.60
Winter	25	25	19.30	34.13	24.30	16.97	33.92	24.69
Winter	26	26	18.06	33.97	24.43	16.59	33.80	24.76
Winter	27	25	17.14	33.80	24.49	15.96	33.73	24.72
Winter	28	28	16.82	33.65	24.56	15.93	33.60	24.73
Winter	29	28	16.32	33.54	24.56	15.62	33.50	24.71
Winter	30	27	15.68	33.47	24.63	14.65	33.44	24.86
Winter	31	63	15.05	33.40	24.70	14.31	33.38	24.84
Winter	32	64	14.66	33.41	24.80	13.46	33.41	25.08
Winter	33	64	14.21	33.36	24.84	12.96	33.40	25.18
Winter	34	63	13.48	33.34	25.04	12.35	33.42	25.32
Winter	35	54	12.91	33.29	25.05	12.14	33.40	25.28
Winte	36	35	12.84	33.23	25.05	12.02	33.35	25.29

season	band_N	years	T10	S10	D10	T50	S50	D50
Winter	37	30	12.27	33.16	25.10	11.63	33.35	25.32
Winter	38	3	11.61	33.13	25.21	11.46	33.20	25.29
Winter	39	3	11.01	32.88	25.13	10.94	33.07	25.29
Winter	40	3	11.03	32.71	24.99	11.06	32.77	25.03
Spring	22	7	20.17	34.56	24.37	18.26	34.37	24.73
Spring	23	12	18.50	34.15	24.48	17.62	34.20	24.62
Spring	24	21	18.09	34.06	24.54	16.92	34.02	24.73
Spring	25	22	17.29	33.91	24.63	15.81	33.90	24.93
Spring	26	22	16.64	33.76	24.68	14.85	33.77	25.03
Spring	27	23	16.33	33.65	24.66	14.79	33.62	24.94
Spring	28	25	15.87	33.58	24.70	14.84	33.60	24.92
Spring	29	26	15.50	33.51	24.74	14.23	33.52	24.94
Spring	30	28	15.39	33.47	24.70	14.48	33.48	24.90
Spring	31	63	14.90	33.37	24.76	13.85	33.38	24.96
Spring	32	63	14.56	33.38	24.82	12.57	33.43	25.24
Spring	33	63	14.06	33.41	24.92	11.93	33.47	25.39
Spring	34	63	13.01	33.43	25.15	11.48	33.49	25.50
Spring	35	61	12.54	33.32	25.22	10.84	33.43	25.53
Spring	36	47	12.24	33.20	25.21	10.91	33.41	25.54
Spring	37	43	11.80	33.05	25.23	10.24	33.39	25.65
Spring	38	10	11.83	32.84	24.94	11.26	32.97	25.14
Spring	39	9	11.03	32.88	25.12	9.91	33.23	25.64
Spring	40	9	10.98	32.78	24.97	11.04	33.01	25.38
Summer	22	7	24.75	34.55	23.87	16.98	34.23	24.94
Summer	23	7	21.86	34.03	23.99	16.74	34.03	24.67
Summer	24	21	21.02	33.87	24.04	16.46	33.79	24.68
Summer	25	21	20.56	33.83	23.89	15.34	33.80	24.98
Summ	26	23	19.36	33.80	24.09	14.91	33.76	24.97

season	band_N	years	T10	S10	D10	T50	S50	D50
er								
Summer	27	26	18.80	33.71	24.13	14.84	33.60	24.81
Summer	28	25	17.87	33.64	24.28	14.74	33.58	24.86
Summer	29	27	17.34	33.59	24.33	14.58	33.52	24.87
Summer	30	25	16.94	33.49	24.29	14.28	33.43	24.87
Summer	31	55	17.11	33.43	24.25	13.72	33.39	24.97
Summer	32	55	17.27	33.50	24.34	12.36	33.46	25.27
Summer	33	55	16.70	33.46	24.43	12.08	33.47	25.38
Summer	34	55	15.21	33.50	24.77	11.37	33.52	25.59
Summer	35	52	14.18	33.46	24.91	11.29	33.50	25.53
Summer	36	30	13.53	33.34	24.97	10.77	33.42	25.55
Summer	37	29	13.25	33.44	25.13	10.13	33.55	25.77
Summer	38	14	12.06	33.17	25.28	10.27	33.36	25.63
Summer	39	13	12.96	33.06	24.93	10.94	33.05	25.22
Summer	40	13	14.02	32.91	24.67	10.39	33.06	25.36
Autumn	22	5	26.82	34.51	22.39	23.76	34.33	23.32
Autumn	23	5	26.00	34.53	22.67	20.75	34.23	23.97
Autumn	24	14	23.43	34.38	23.21	18.07	33.93	24.39
Autumn	25	19	23.02	34.33	23.26	17.10	33.87	24.57
Autumn	26	19	21.80	34.10	23.52	17.13	33.73	24.54

season	band_N	years	T10	S10	D10	T50	S50	D50
Autumn	27	20	20.43	33.89	23.70	15.86	33.64	24.77
Autumn	28	20	19.37	33.69	23.89	16.48	33.55	24.51
Autumn	29	20	18.59	33.60	24.01	15.25	33.50	24.67
Autumn	30	22	18.32	33.51	24.02	15.29	33.41	24.67
Autumn	31	54	17.91	33.40	24.07	14.82	33.31	24.70
Autumn	32	54	17.83	33.47	24.14	13.50	33.33	25.01
Autumn	33	55	17.04	33.44	24.31	12.59	33.38	25.18
Autumn	34	54	15.85	33.42	24.57	12.25	33.38	25.28
Autumn	35	46	14.90	33.41	24.75	12.28	33.46	25.34
Autumn	36	18	14.29	33.34	24.82	11.85	33.40	25.33
Autumn	37	17	14.15	33.34	24.85	11.63	33.44	25.49
Autumn	38	4	13.84	33.15	24.78	12.23	33.31	25.21
Autumn	39	4	15.25	32.91	24.52	11.97	33.13	25.14
Autumn	40	4	13.07	32.78	24.37	11.73	33.27	25.30
Autumn	41	1	18.00					

Table S2b

Median across years of absolute salinity (SA, g kg) and conservative temperature (CT, °C) at standard depths from 0 to 300 m in the four zones defined by the larval boundaries, for the oceanic (bottom deeper than 200 m) and shelf domains. Provided as `Table_S2b_zone_profiles.csv`. At 200 m in the oceanic domain, water south of Punta Eugenia is saltier and warmer than water to the north, whereas the two sides of Point Conception are indistinguishable (main text).

Table S3

Fraction of hydrographic samples assigned to each water mass, by zone, domain and depth layer (mean across years of the within-year fraction). Water masses follow the temperature–salinity limits of Portela et al. (2016; CCW California Current Water, TSW Tropical Surface Water, GCW Gulf of California Water, StSsW Subtropical Subsurface Water, PIW Pacific Intermediate Water) and Durazo and Baumgartner (2002; SAW Subarctic Water, StSW Subtropical Surface Water, ESsW Equatorial Subsurface Water). The zone south of the southern Baja California boundary has 12 yr of sampling. The table below shows the oceanic domain and the water masses that reach at least 5 % in some layer; the full table is `Table_S3_water_mass_fractions.csv`.

zone	layer	California Current Water	Subarctic Water	Transitional (21–25.1 °C, SA < 34.6)	Subtropical Surface Water	Subtropical Subsurface Water	Equatorial Subsurface Water	Pacific Intermediate Water	North Pacific Intermediate (< 8 °C, SA < 34.6)	Cold, unassigned (8–10 °C)	years
Point Conception – Punta Eugenia	0–50 m	0.99	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	61
Point Conception – Punta Eugenia	75–150 m	0.56	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.07	59
Point Conception – Punta Euge	200–400 m	0.01	0.08	0.00	0.00	0.00	0.02	0.00	0.55	0.34	59

zone	layer	California Current Water	Subarctic Water	Transitional (21–25.1 °C, SA < 34.6)	Subtropical Surface Water	Subtropical Subsurface Water	Equatorial Subsurface Water	Pacific Intermediate Water	North Pacific Intermediate (< 8 °C, SA < 34.6)	Cold, unassigned (8–10 °C)	years
nia											
Point Conception – Punta Eugenia	500–1000 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.00	59
North of Point Conception	0–50 m	0.97	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	59
North of Point Conception	75–150 m	0.36	0.53	0.00	0.00	0.00	0.00	0.00	0.01	0.10	57
North of Point Conception	200–400 m	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.65	0.28	57
North of Point Conception	500–1000 m	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.98	0.00	57
Punt	0–50	0.90	0.00	0.06	0.03	0.00	0.00	0.00	0.00	0.00	28

zone	layer	California Current Water	Subarctic Water	Transitional (21–25.1 °C, SA < 34.6)	Subtropical Surface Water	Subtropical Subsurface Water	Equatorial Subsurface Water	Pacific Intermediate Water	North Pacific Intermediate (< 8 °C, SA < 34.6)	Cold, unassigned (8–10 °C)	years
a Eugenia – southern Baja California	m										
Punta Eugenia – southern Baja California	75–150 m	0.91	0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.02	27
Punta Eugenia – southern Baja California	200–400 m	0.09	0.04	0.00	0.00	0.26	0.17	0.10	0.16	0.20	27
Punta Eugenia – southern Baja Califo	500–1000 m	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.63	0.00	27

zone	layer	California Current Water	Subarctic Water	Transitional (21–25.1 °C, SA < 34.6)	Subtropical Surface Water	Subtropical Subsurface Water	Equatorial Subsurface Water	Pacific Intermediate Water	North Pacific Intermediate (< 8 °C, SA < 34.6)	Cold, unassigned (8–10 °C)	years
rnia											
South of the southern Baja California boundary	0–50 m	0.29	0.00	0.06	0.58	0.01	0.00	0.00	0.00	0.00	12
South of the southern Baja California boundary	75–150 m	0.46	0.00	0.00	0.01	0.50	0.00	0.00	0.00	0.00	12
South of the southern Baja California boundary	200–400 m	0.02	0.00	0.00	0.00	0.78	0.02	0.18	0.00	0.00	12
South of the	500–1000 m	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	12

zone	layer	California Current Water	Subarctic Water	Transitional (21–25.1 °C, SA < 34.6)	Subtropical Surface Water	Subtropical Subsurface Water	Equatorial Subsurface Water	Pacific Intermediate Water	North Pacific Intermediate (< 8 °C, SA < 34.6)	Cold, unassigned (8–10 °C)	years
southern Baja California boundary											

Table S4

Latitude of the 33.6 isohaline at 10 m in the oceanic zone off Baja California, by year and season, from CalCOFI measurements (years and seasons with at least three 0.5° bands with data on each side of 28.5°N) and from the SODA 3.3.1 reanalysis, with the mean temperature at 10 m between 25 and 32°N and the Niño 3.4 index (ERSSTv5). Provided as `Table_S4_isohaline_33_6.csv`.

Table S5

IMECOCAL cruises of 1998–2000 (species lists from Jiménez-Rosenberg 2008): number of larval fish species recorded north (CalCOFI lines 100–120) and south (lines 123 and beyond) of Punta Eugenia, species shared and exclusive, Simpson dissimilarity (βsim), Sørensen dissimilarity (βsor) and its nestedness component (βsne; Baselga 2010), and mean temperature at 10 m in each zone with their difference (ΔT, south minus north).

cruise	ENSO_phase	month	richness_north	richness_south	shared	only_north	only_south	beta_sim	beta_sor	beta_sne	T10_north	T10_south	delta_T
0001	La Niña	1	43	49	26	17	23	0.40	0.43	0.04	15.90	17.90	2.00
9801	El Niño 1997–98	1	78	42	28	50	14	0.33	0.53	0.20	18.30	20.00	1.70

cruise	ENSO_phase	month	richness_north	richness_south	shared	only_north	only_south	beta_sim	beta_sor	beta_sne	T10_north	T10_south	delta_T
9901	La Niña	1	44	18	18	26	0	0.00	0.42	0.42	15.60	15.90	0.30
0004	La Niña	4	67	31	26	41	5	0.16	0.47	0.31	15.80	16.40	0.60
9904	La Niña	4	52	34	30	22	4	0.12	0.30	0.18	14.70	15.60	0.90
0007	La Niña	7	78	56	38	40	18	0.32	0.43	0.11	18.20	20.70	2.50
9807	El Niño 1997–98	7	56	52	40	16	12	0.23	0.26	0.03	19.60	21.50	1.90
9908	La Niña	8	75	59	45	30	14	0.24	0.33	0.09	18.50	20.20	1.70
0010	La Niña	10	69	45	33	36	12	0.27	0.42	0.15	19.30	21.40	2.10
9810	El Niño 1997–98	10	57	39	29	28	10	0.26	0.40	0.14	19.50	20.20	0.70
9910	La Niña	10	55	52	29	26	23	0.44	0.46	0.02	19.10	20.80	1.70

Table S6

Test of the “constant property” argument. For each boundary, the seasonal range (maximum minus minimum across the four seasons) of temperature and salinity at 10 m experienced at its detected positions (rows labelled “detected positions”; the seasons used are listed in the `seasons` column and exclude the unresolved Point Conception spring), compared with the range over the same seasons that a boundary fixed at each band edge from 23 to 36°N would experience (rows labelled with that band). A boundary that follows an isotherm should

experience a much smaller temperature range than a fixed boundary at the same latitudes; because salinity has almost no seasonal cycle anywhere along this coast, a small salinity range is expected for any stationary boundary and is not evidence of water-mass control. The last rows repeat the test with hydrography from 1951–1969 only, the years of the larval data. Table S6b gives the entries of Table 1 (temperature, temperature gradient and salinity at 10 m at each boundary) computed with all years (1951–2016) and with 1951–1969 only; for the unresolved Point Conception spring the row is given at the bootstrap median (33°N) for completeness and flagged as not detected.

boundary	position	seasons	hydrography	seasonal_range_T10_degC	seasonal_range_S10
Point Conception	detected positions	DEF+JJA+SON	1951-2016	0.68	0.08
Punta Eugenia	detected positions	DEF+JJA+MAM+SON	1951-2016	3.30	0.10
Southern Baja California	detected positions	DEF+JJA+MAM+SON	1951-2016	5.38	0.28
Point Conception	23	DEF+JJA+SON	1951-2016	4.98	0.28
Punta Eugenia	23	DEF+JJA+MAM+SON	1951-2016	7.07	0.28
Southern Baja California	23	DEF+JJA+MAM+SON	1951-2016	7.07	0.28
Point Conception	24	DEF+JJA+SON	1951-2016	4.35	0.51
Punta Eugenia	24	DEF+JJA+MAM+SON	1951-2016	6.42	0.51
Southern Baja California	24	DEF+JJA+MAM+SON	1951-2016	6.42	0.51
Point Conception	25	DEF+JJA+SON	1951-2016	3.67	0.50
Punta Eugenia	25	DEF+JJA+MAM+SON	1951-2016	5.53	0.50
Southern Baja California	25	DEF+JJA+MAM+SON	1951-2016	5.53	0.50
Point Conception	26	DEF+JJA+SON	1951-2016	3.73	0.40
Punta Eugenia	26	DEF+JJA+MAM+SON	1951-2016	5.45	0.40

boundary	position	seasons	hydrography	seasonal_range_T10_degC	seasonal_range_S10
Southern Baja California	26	DEF+JJA+MAM+SON	1951-2016	5.45	0.40
Point Conception	27	DEF+JJA+SON	1951-2016	3.51	0.24
Punta Eugenia	27	DEF+JJA+MAM+SON	1951-2016	4.63	0.29
Southern Baja California	27	DEF+JJA+MAM+SON	1951-2016	4.63	0.29
Point Conception	28	DEF+JJA+SON	1951-2016	2.92	0.12
Punta Eugenia	28	DEF+JJA+MAM+SON	1951-2016	3.81	0.17
Southern Baja California	28	DEF+JJA+MAM+SON	1951-2016	3.81	0.17
Point Conception	29	DEF+JJA+SON	1951-2016	2.41	0.05
Punta Eugenia	29	DEF+JJA+MAM+SON	1951-2016	3.30	0.10
Southern Baja California	29	DEF+JJA+MAM+SON	1951-2016	3.30	0.10
Point Conception	30	DEF+JJA+SON	1951-2016	2.46	0.05
Punta Eugenia	30	DEF+JJA+MAM+SON	1951-2016	3.01	0.06
Southern Baja California	30	DEF+JJA+MAM+SON	1951-2016	3.01	0.06
Point Conception	31	DEF+JJA+SON	1951-2016	2.75	0.03
Punta Eugenia	31	DEF+JJA+MAM+SON	1951-2016	2.97	0.04
Southern Baja California	31	DEF+JJA+MAM+SON	1951-2016	2.97	0.04
Point Conception	32	DEF+JJA+SON	1951-2016	3.02	0.06

boundary	position	seasons	hydrography	seasonal_range_T10_degC	seasonal_range_S10
Punta Eugenia	32	DEF+JJA+MAM+SON	1951-2016	3.14	0.09
Southern Baja California	32	DEF+JJA+MAM+SON	1951-2016	3.14	0.09
Point Conception	33	DEF+JJA+SON	1951-2016	3.00	0.09
Punta Eugenia	33	DEF+JJA+MAM+SON	1951-2016	3.13	0.09
Southern Baja California	33	DEF+JJA+MAM+SON	1951-2016	3.13	0.09
Point Conception	34	DEF+JJA+SON	1951-2016	2.60	0.13
Punta Eugenia	34	DEF+JJA+MAM+SON	1951-2016	2.92	0.13
Southern Baja California	34	DEF+JJA+MAM+SON	1951-2016	2.92	0.13
Point Conception	35	DEF+JJA+SON	1951-2016	2.18	0.17
Punta Eugenia	35	DEF+JJA+MAM+SON	1951-2016	2.60	0.17
Southern Baja California	35	DEF+JJA+MAM+SON	1951-2016	2.60	0.17
Point Conception	36	DEF+JJA+SON	1951-2016	1.72	0.14
Punta Eugenia	36	DEF+JJA+MAM+SON	1951-2016	2.20	0.14
Southern Baja California	36	DEF+JJA+MAM+SON	1951-2016	2.20	0.14
Point Conception	detected positions	DEF+JJA+SON	1951-1969	1.17	0.03
Punta Eugenia	detected positions	DEF+JJA+MAM+SON	1951-1969	3.33	0.08
Southern Baja California	detected positions	DEF+JJA+MAM+SON	1951-1969	5.36	0.36

boundary	position	seasons	hydrography	seasonal_range_T10_degC	seasonal_range_S10
Point Conception	23	DEF+JJA+SON	1951-1969	5.13	0.36
Punta Eugenia	23	DEF+JJA+MAM+SON	1951-1969	7.26	0.36
Southern Baja California	23	DEF+JJA+MAM+SON	1951-1969	7.26	0.36
Point Conception	24	DEF+JJA+SON	1951-1969	4.19	0.54
Punta Eugenia	24	DEF+JJA+MAM+SON	1951-1969	6.50	0.54
Southern Baja California	24	DEF+JJA+MAM+SON	1951-1969	6.50	0.54
Point Conception	25	DEF+JJA+SON	1951-1969	3.80	0.54
Punta Eugenia	25	DEF+JJA+MAM+SON	1951-1969	5.71	0.54
Southern Baja California	25	DEF+JJA+MAM+SON	1951-1969	5.71	0.54
Point Conception	26	DEF+JJA+SON	1951-1969	3.86	0.39
Punta Eugenia	26	DEF+JJA+MAM+SON	1951-1969	5.54	0.39
Southern Baja California	26	DEF+JJA+MAM+SON	1951-1969	5.54	0.39
Point Conception	27	DEF+JJA+SON	1951-1969	3.56	0.24
Punta Eugenia	27	DEF+JJA+MAM+SON	1951-1969	4.83	0.28
Southern Baja California	27	DEF+JJA+MAM+SON	1951-1969	4.83	0.28
Point Conception	28	DEF+JJA+SON	1951-1969	3.10	0.12
Punta Eugenia	28	DEF+JJA+MAM+SON	1951-1969	4.01	0.15
Southern	28	DEF+JJA+MA	1951-1969	4.01	0.15

boundary	position	seasons	hydrography	seasonal_range_T10_degC	seasonal_range_S10
Baja California		M+SON			
Point Conception	29	DEF+JJA+SON	1951-1969	2.60	0.07
Punta Eugenia	29	DEF+JJA+MAM+SON	1951-1969	3.33	0.08
Southern Baja California	29	DEF+JJA+MAM+SON	1951-1969	3.33	0.08
Point Conception	30	DEF+JJA+SON	1951-1969	2.67	0.05
Punta Eugenia	30	DEF+JJA+MAM+SON	1951-1969	3.07	0.05
Southern Baja California	30	DEF+JJA+MAM+SON	1951-1969	3.07	0.05
Point Conception	31	DEF+JJA+SON	1951-1969	2.63	0.07
Punta Eugenia	31	DEF+JJA+MAM+SON	1951-1969	2.95	0.07
Southern Baja California	31	DEF+JJA+MAM+SON	1951-1969	2.95	0.07
Point Conception	32	DEF+JJA+SON	1951-1969	2.74	0.09
Punta Eugenia	32	DEF+JJA+MAM+SON	1951-1969	3.16	0.09
Southern Baja California	32	DEF+JJA+MAM+SON	1951-1969	3.16	0.09
Point Conception	33	DEF+JJA+SON	1951-1969	3.05	0.13
Punta Eugenia	33	DEF+JJA+MAM+SON	1951-1969	3.28	0.13
Southern Baja California	33	DEF+JJA+MAM+SON	1951-1969	3.28	0.13
Point Conception	34	DEF+JJA+SON	1951-1969	2.56	0.13
Punta	34	DEF+JJA+MA	1951-1969	2.95	0.13

boundary	position	seasons	hydrography	seasonal_range_T10_degC	seasonal_range_S10
Eugenia		M+SON			
Southern Baja California	34	DEF+JJA+MAM+SON	1951-1969	2.95	0.13
Point Conception	35	DEF+JJA+SON	1951-1969	2.19	0.13
Punta Eugenia	35	DEF+JJA+MAM+SON	1951-1969	2.60	0.13
Southern Baja California	35	DEF+JJA+MAM+SON	1951-1969	2.60	0.13
Point Conception	36	DEF+JJA+SON	1951-1969	1.88	0.08
Punta Eugenia	36	DEF+JJA+MAM+SON	1951-1969	2.50	0.14
Southern Baja California	36	DEF+JJA+MAM+SON	1951-1969	2.50	0.14

boundary	season	hydrography	lat_N	detected	T10	gradient_T10	S10	years
Point Conception	Winter	1951-2016	32	True	14.86	0.39	33.40	63
Point Conception	Winter	1951-1969	32	True	14.88	0.44	33.44	18
Point Conception	Summer	1951-2016	35	True	14.70	1.02	33.48	52
Point Conception	Summer	1951-1969	35	True	14.11	0.03	33.42	16
Point Conception	Spring	1951-2016	33	False	14.31	0.51	33.39	63
Point Conception	Spring	1951-1969	33	False	14.21	0.39	33.43	17

boundary	season	hydrography	lat_N	detected	T10	gradient_T10	S10	years
Point Conception	Autumn	1951-2016	35	True	15.38	0.96	33.41	46
Point Conception	Autumn	1951-1969	35	True	15.28	0.52	33.45	12
Punta Eugenia	Winter	1951-2016	29	True	16.57	0.50	33.59	28
Punta Eugenia	Winter	1951-1969	29	True	16.21	0.29	33.57	18
Punta Eugenia	Summer	1951-2016	29	True	17.60	0.54	33.61	25
Punta Eugenia	Summer	1951-1969	29	True	17.35	0.79	33.61	19
Punta Eugenia	Spring	1951-2016	29	True	15.68	0.36	33.55	25
Punta Eugenia	Spring	1951-1969	29	True	15.48	0.25	33.56	17
Punta Eugenia	Autumn	1951-2016	29	True	18.98	0.78	33.64	20
Punta Eugenia	Autumn	1951-1969	29	True	18.81	0.69	33.64	17
Southern Baja California	Winter	1951-2016	23	True	21.42	1.01	34.57	10
Southern Baja California	Winter	1951-1969	23	True	21.59	0.75	34.57	9
Southern Baja California	Summer	1951-2016	23	True	23.31	2.89	34.29	7
Southern Baja California	Summer	1951-1969	23	True	21.45	0.82	34.21	3
Southern Baja	Spring	1951-2016	23	True	19.33	1.67	34.35	7

boundary	season	hydrography	lat_N	detected	T10	gradient_T10	S10	years
California								
Southern Baja California	Spring	1951-1969	23	True	19.33	1.67	34.35	7
Southern Baja California	Autumn	1951-2016	24	True	24.71	2.57	34.45	5
Southern Baja California	Autumn	1951-1969	24	True	24.69	2.54	34.41	4

Table S7

Robustness of the relation between species turnover (βsim) across Punta Eugenia and the temperature difference between its two sides (Table S5, n = 11 cruises): Spearman correlation after removing each cruise in turn, the same for Sørensen dissimilarity (βsor), and the correlation of βsim with the species richness recorded south of Punta Eugenia. The relation depends on the January 1999 cruise (18 species recorded in the south, βsim = 0) and is not present in βsor; we therefore treat it as suggestive.

cruise_removed	rho_bsim_dT	p_bsim_dT	rho_bsor_dT	p_bsor_dT	rho_bsim_riq_sur_full	p_bsim_riq_sur_full
none	0.61	0.04	0.04	0.92	0.55	0.08
0001	0.61	0.06	-0.02	0.96	0.55	0.08
9801	0.68	0.03	0.04	0.91	0.55	0.08
9901	0.48	0.16	-0.08	0.83	0.55	0.08
0004	0.51	0.13	0.26	0.46	0.55	0.08
9904	0.55	0.10	-0.04	0.91	0.55	0.08
0007	0.63	0.05	-0.03	0.93	0.55	0.08
9807	0.68	0.03	0.17	0.65	0.55	0.08
9908	0.61	0.06	0.04	0.91	0.55	0.08
0010	0.63	0.05	-0.03	0.93	0.55	0.08
9810	0.61	0.06	-0.02	0.96	0.55	0.08
9910	0.71	0.02	0.09	0.81	0.55	0.08

Table S8

Latitude of the 33.6 isohaline at 10 m in each IMECOCAL cruise (CTD, 1997–2012; 54 cruises, 45 with a crossing between 25 and 32°N), with the number of casts, the latitude range sampled, the number of 0.5° bands, the crossing status, the mean temperature at 10 m between 25 and 32°N and its within-season anomaly, the seasonal Niño 3.4 index and the SODA 3.3.1 estimate for the same season. Across cruises the isohaline latitude is unrelated to the temperature anomaly (Spearman ρ = 0.006, p = 0.9671, n = 45; with censored cruises placed at the domain edges ρ = 0.121, p = 0.3919, n = 52) and to Niño 3.4 (ρ = -0.172, p = 0.2591); SODA agrees with the measurements (ρ = 0.593, bias -0.37°, RMSE 1.78°, n = 44). Provided as `Table_S8_IMECOCAL_isohaline_1997_2012.csv`.

Figure S1

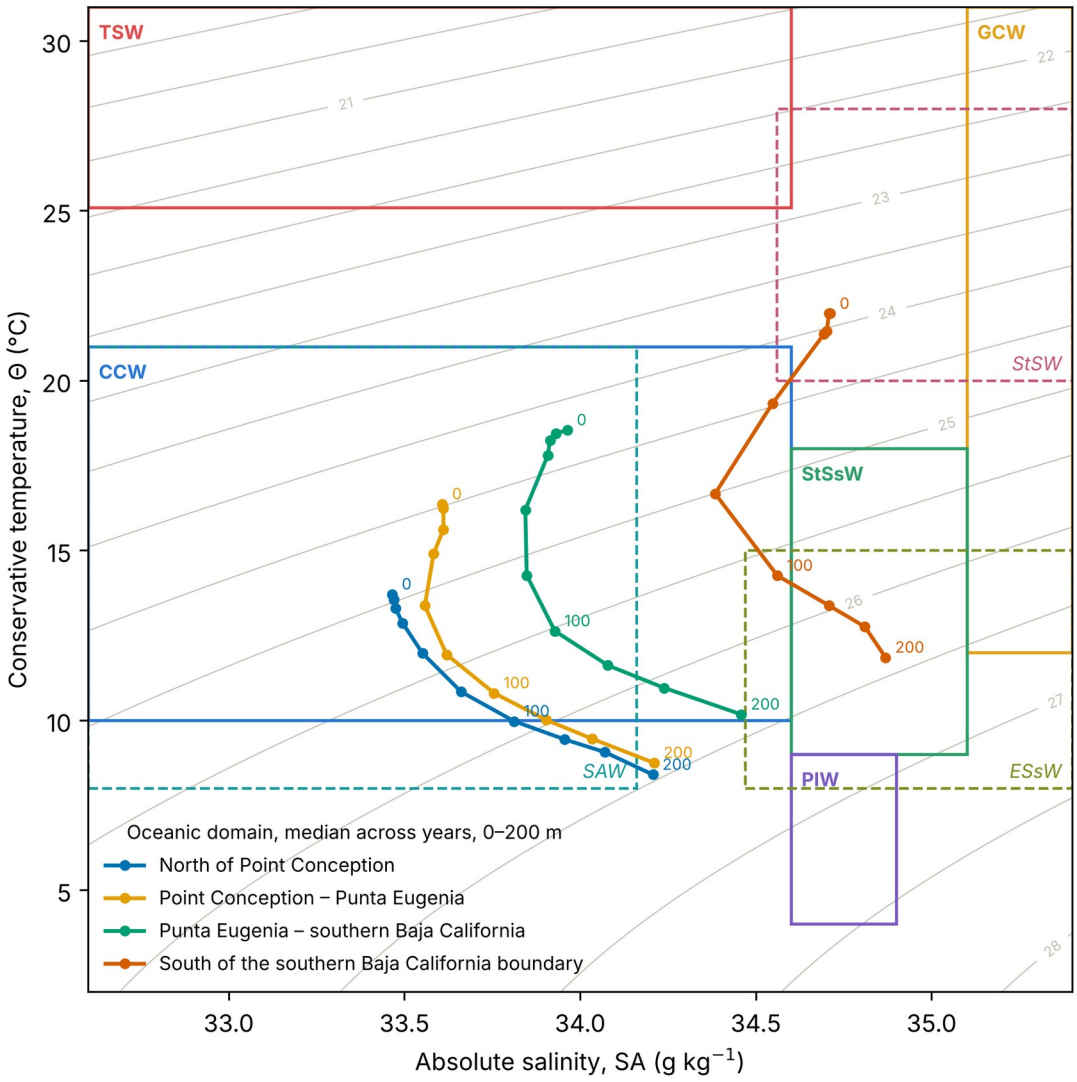


Figure S1. Temperature–salinity diagram (TEOS-10) of the median profiles from 0 to 200 m in the oceanic domain of the four zones defined by the larval fish boundaries (CalCOFI

hydrography 1951–2016, within 300 km of the coast). Numbers mark 0, 100 and 200 m. Solid boxes are the water-mass limits of Portela et al. (2016) and dashed boxes those of Durazo and Baumgartner (2002), converted to TEOS-10; abbreviations as in Table S3. Grey lines are σ isopycnals.

Figure S2

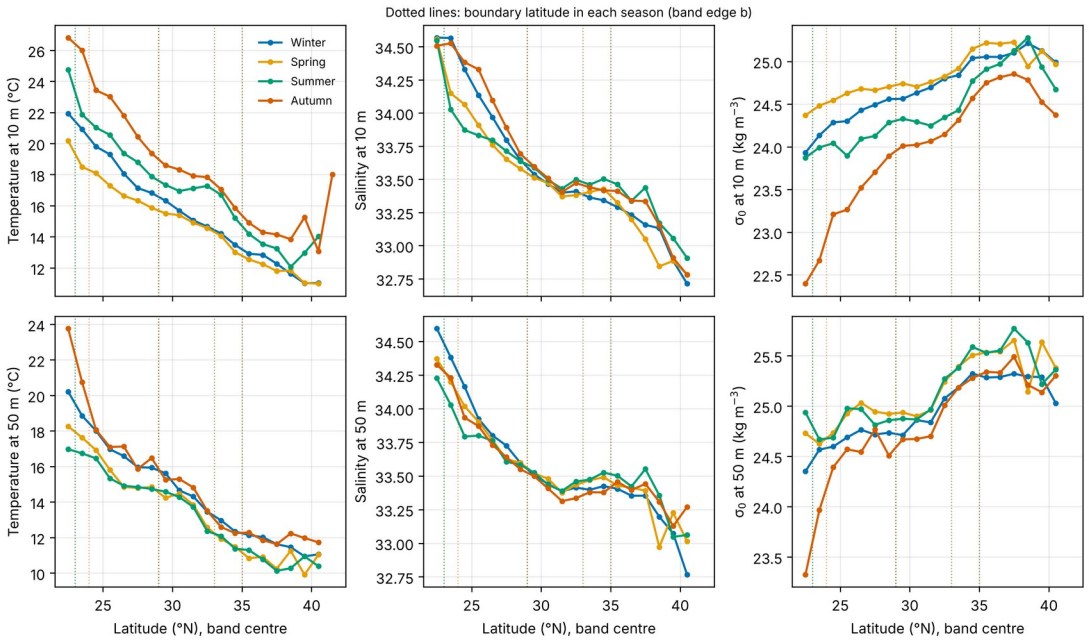


Figure S2. Median across years of temperature, salinity and potential density anomaly at 10 m (top) and 50 m (bottom) in 1° latitude bands, by season (CalCOFI hydrography 1951–2016, within 300 km of the coast). Dotted vertical lines mark the latitude of the three larval boundaries in each season (Table 1).

Figure S3

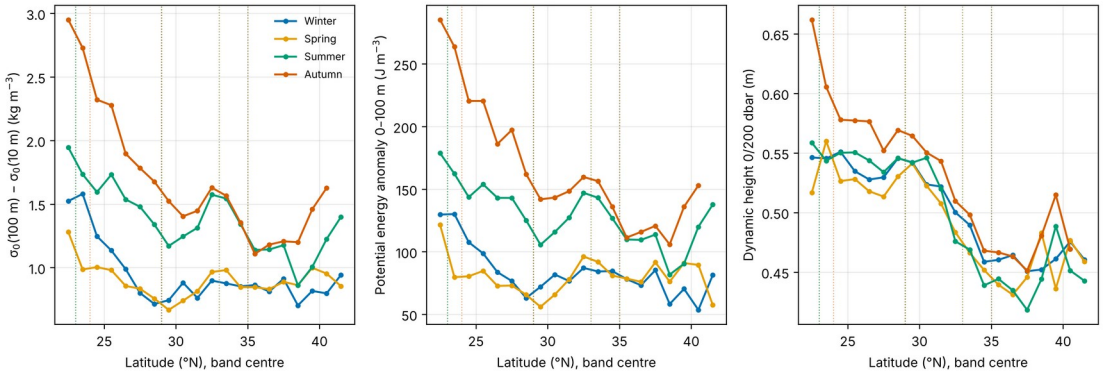


Figure S3. Upper-ocean stratification and dynamic height by 1° latitude band and season, from CalCOFI casts with data from 10 to at least 100 m (stratification; n = 17,006) or from 0 to 200 m (dynamic height; n = 15,888), within 300 km of the coast: density difference between 100 and 10 m, potential energy anomaly of the upper 100 m, and dynamic height of the surface relative to

200 dbar. Dotted vertical lines mark the three larval boundaries in each season. The southern Baja California boundary lies on the largest increase in stratification of the coast in spring and autumn but not in winter; neither variable marks the Point Conception or Punta Eugenia boundaries consistently, so neither was used in the main text.

Figure S4

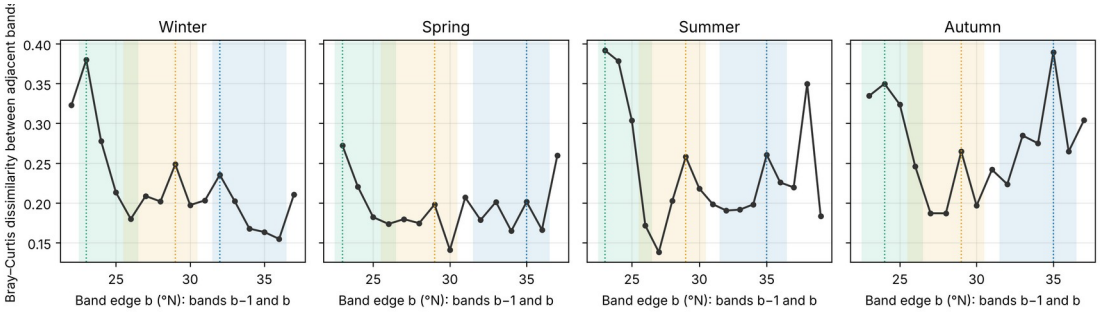


Figure S4. Bray–Curtis dissimilarity between adjacent 1° latitude bands of larval fish assemblages (rarefied to 20 tows, square-root frequencies) along the coast in each season, computed with the full 1951–1969 data set; the value at band edge *b* compares the bands starting at *b* − 1 and *b*. Shaded areas are the three search windows (southern Baja California 23–26°N, Punta Eugenia 26–30°N, Point Conception 32–36°N) and dotted lines the full-data boundary positions (Table S1b). The Point Conception boundary is a coast-wide maximum in autumn and a clear local maximum in summer, but in winter and spring the profile is flat across the window; the Punta Eugenia boundary is a modest but consistent local maximum at 29°N; the southern Baja California boundary is the coast-wide maximum in three seasons but lies at the southern edge of the sampled domain on a broad plateau of high dissimilarity.

References cited in the Supporting Information

Baselga, A. 2010. Global Ecology and Biogeography 19: 134–143. Durazo, R., and T. R. Baumgartner. 2002. Progress in Oceanography 54: 7–31. Jiménez-Rosenberg, S. P. A. 2008. PhD diss., CICIMAR-IPN. Portela, E., et al. 2016. Journal of Physical Oceanography 46: 3069–3081. Full references are in the main text.