Report

Current Biology

High-precision localized feeding by blue whales

Highlights

- Blue whales precisely localized feeding within an extensive upwelling plume front
- Behavioral responsiveness to the front suggests whale somatosensory capacity
- Transects across and along frontal gradients indicate systematic search behaviors
- Thermal sensory perception and memory may enable blue whale foraging efficiency

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In brief

Ryan et al. use biologging and satellite remote sensing to show how blue whales (*Balaenoptera musculus*) can precisely and persistently localize feeding within a favorable foraging habitat by sensing and responding to thermal gradients near the ocean surface.

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Report

High-precision localized feeding by blue whales

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SUMMARY

Like other rorqual whale species, blue whales (*Balaenoptera musculus*) evolved to specialize in consuming large numbers of small-bodied prey through engulfment filter feeding.[1,2] Blue whales in the eastern North Pacific feed almost exclusively on ephemeral swarms of krill.[3–5] The densest and most energetically profitable krill aggregations are often associated with bathymetric features[5–8] and circulation phenomena,[8–12] but how the whales find patchy krill swarms in a vast dynamic habitat remains largely unknown. Integrating animal- and satellite-borne sensing in the eastern North Pacific, we show that blue whales can precisely localize feeding in a favorable foraging habitat by sensing horizontal thermal gradients near the ocean surface. While tracking a dynamic upwelling plume front over hundreds of kilometers, blue whales repeatedly: (1) responded to frontal encounters by sharply changing course and conducting deep exploratory dives; (2) systematically transected across and along the variable local orientation of frontal gradients—particularly during nighttime search periods that preceded intensive daytime feeding; and (3) localized temperature minima before moving toward the warm side of the front while feeding. Such persistent orientation of movement relative to thermal gradients during day and night, with or without the result of feeding, is consistent with thermal sensory perception and memory serving as the primary search modality. This case study, enabled by a rarely achievable integration of high-resolution sensing, motivates a broader examination of how highly mobile marine species track resources relative to the dynamic physical gradients that structure marine ecosystems.

RESULTS AND DISCUSSION

Biologging tag deployment

Within a Biologically Important Area[13] of the eastern North Pacific blue whale population (Figure 1A), biologging tags were deployed on September 16, 2019, on two blue whales that were traveling as a pair. During a 2.9-day period of concurrent biologging, the pair exhibited close proximity horizontally (within 100 m, based on 168 GPS location pairs) and vertically (8.9 ± 9 m within the upper 265 m), as well as synchronous feeding (within 2.9 ± 2.8 s of each other over more than 400 feeding events). The biologging tag that remained attached longer (whale track in Figures 1B and 1C) enables a more thorough examination of ecological relationships throughout the full period of feeding in the study region and is thus the focus (Figure 1D). This tag was deployed on a male blue whale, at least 24 years of age, in southern Monterey Bay (location 1 in Figure 1C). It is representative of both whales during the first four periods of intensive feeding (numbered feeding bouts in Figures 1C and 1D), and it recorded foraging activity for an additional 3 days before the whale ceased feeding and departed.

Blue whale feeding

This study focuses on horizontal localization of feeding relative to an upwelling plume front that extended hundreds of kilometers across shelf, slope, and deep-water habitat (Figures 1B and 1C); however, the patterns of feeding in time and depth are essential context (Figure 1D). During individual feeding events, called lunges, a blue whale accelerates into a krill swarm, engulfs a mass of water and krill that can weigh more than the whale itself, and filters the krill from the water.[2] Lunge feeding can be repeated several times during each breath-hold dive. The focal whale fed intensively—at rates up to 24 lunges per hour and 7 lunges per dive (Figure 1D). It fed almost exclusively during the day—with 96.5% of lunges during daylight and the remaining 3.5% during crepuscular periods. Feeding predominantly occurred far below the surface (median depth = 163 m) but shoaled during crepuscular periods. These patterns reflect the behavior of krill, which feed on plankton near the surface during the night and migrate to deeper water during the day.[14] Blue whales can efficiently lunge feed where krill are densely aggregated and accessible in the water column, as occurs at depth during the day and while krill migrate between shallow and deep occupancy.[8,15]

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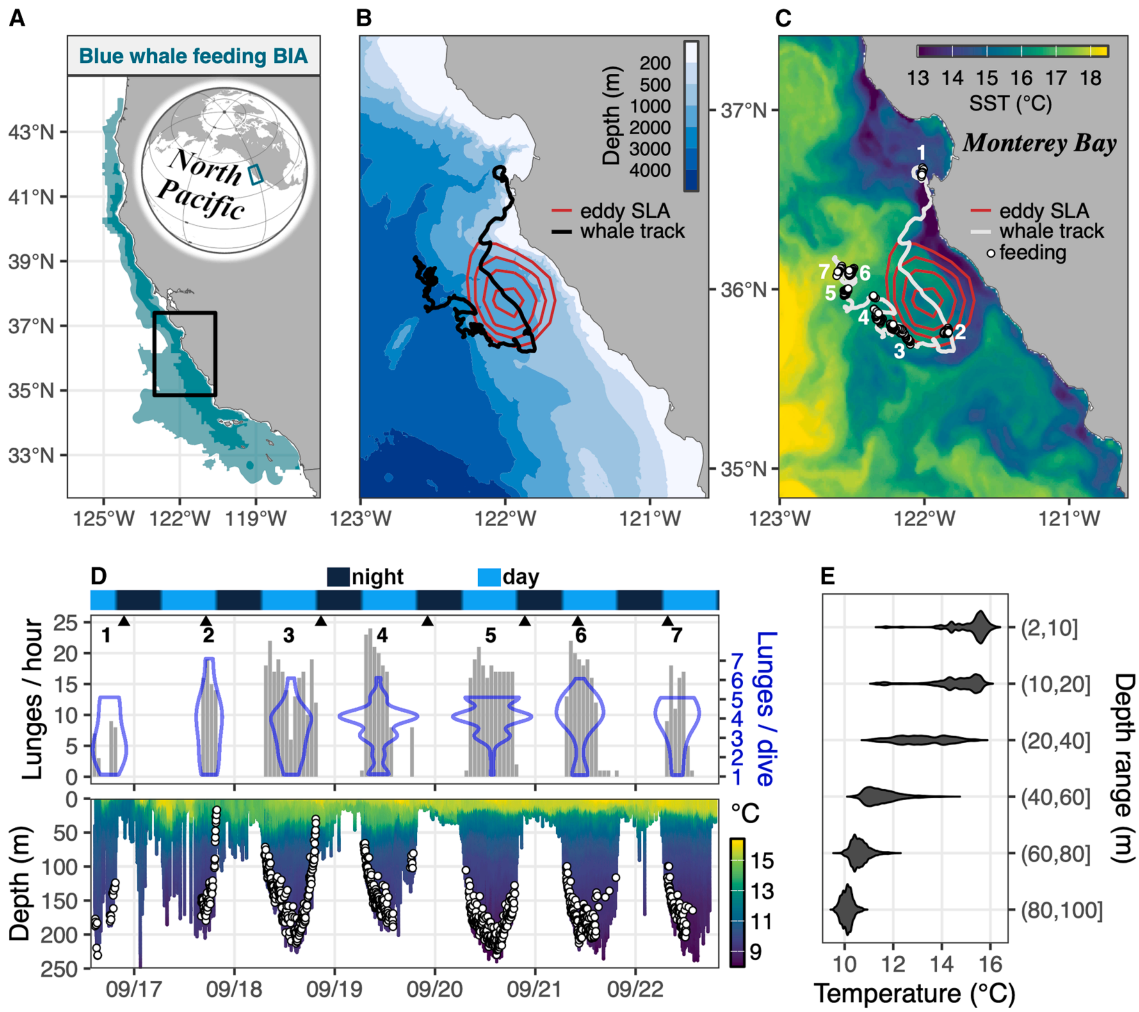

Figure 1. Case study overview

(A) Blue whale Biologically Important Areas (BIAs) for seasonal feeding in the eastern North Pacific; darker shading represents the core BIA. The inset globe shows the BIA map domain. The black box bounds the region of (B) and (C).

(B) Regional bathymetry defines shelf, slope, and deep-water foraging habitats. Overlaid are sea level anomaly (SLA) contours defining an eddy at the start of the whale tag deployment (114 to 129 mm in 5 mm increments) and the GPS track of the focal blue whale (black line).

(C) Sea surface temperature (SST, 2019-09-16 21:34 PDT) hours after biologging tags were deployed on a pair of blue whales in southern Monterey Bay (location 1). Locations where feeding occurred are marked by black and white circles. Numbers identify daily feeding bouts; bout ID numbers correspond to those in (D).

(D) Feeding lunges per hour (top, gray bars), per dive (top, blue violin plots), and individually within the context of temperature measured by the focal animal-borne tag (bottom, black and white circles). Overlaid in the top image are the times (triangles) of SST images (Figure 2B).

(E) Depth-dependent temperature distributions encountered by the focal blue whale, representing potential for somatosensory cues in horizontal thermal contrast.

See also Figure S1.

Because blue whales increase lunges per dive at higher prey densities to maximize energy intake,[15] the number of lunges per dive can serve as a proxy for prey density. During each daily feeding bout, the maximum number of lunges per dive ranged between 5 and 7 (Figure 1D). In the context of previous work using simultaneous echosounders and whale-borne tags,[15–17] these results indicate relatively high krill densities that predictably result in high foraging energetic efficiencies. Probability densities indicate that the distribution of lunges per dive shifted upward as the whales moved into offshore habitat (violin plots in Figure 1D; locations in Figure 1C). This suggests that krill swarms targeted by the whales farther offshore were more consistently dense.

Precisely targeted feeding along a dynamic front

When they were tagged, the whales were feeding along the northern boundary of an upwelling plume front (location 1 in Figure 1C; bout 1 in Figure 1D). The upwelling plume spanned approximately 80 km along the coast south of Monterey Bay, and it was coldest near the coast where upwelling originates (Figure 1C). Entrained offshore by an anticyclonic eddy (red contours in Figures 1B and 1C, clockwise flow), the southern part of

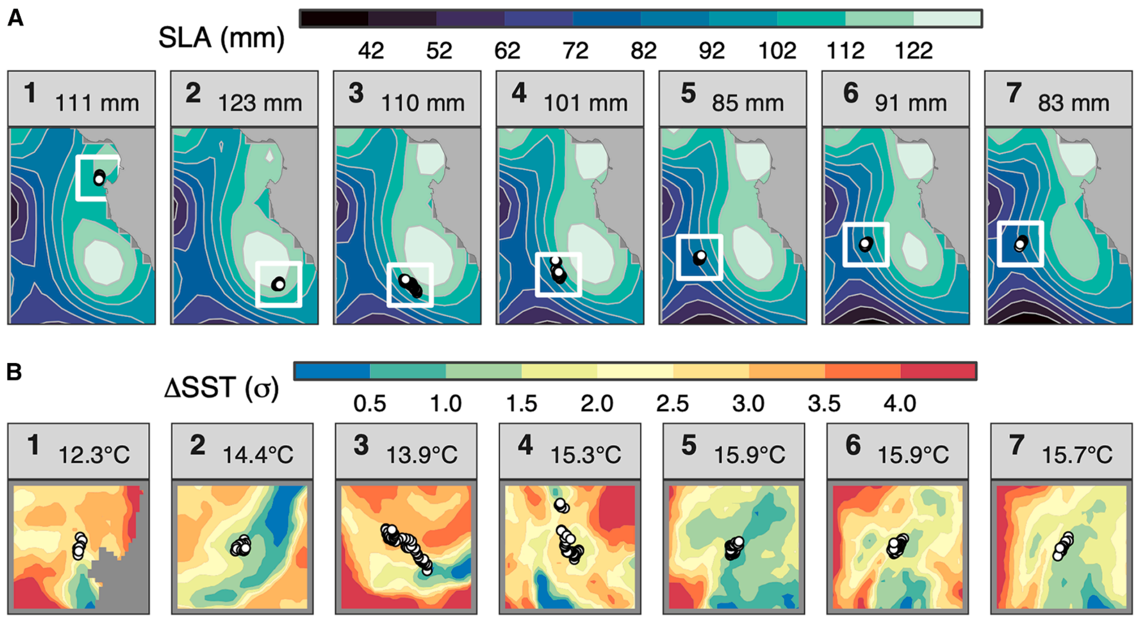

Figure 2. High-precision localized feeding by blue whales in thermal frontal areas

(A) Locations of feeding dives (black and white circles) relative to ocean dynamic topography defined by SLA. White boxes define 40 × 40 km areas centered on the mean latitude and longitude of lunge locations for each daily feeding bout (bouts defined and numbered in Figure 1). SST for these areas is shown in (B). Mean SLA values at feeding dive locations for each daily bout are noted in the headers.

(B) Locations of feeding dives (black and white circles) relative to spatiotemporally local SST, normalized as standard deviations above the minimum SST within the domains defined by the white boxes in (A). The minimum SST values within each image domain are noted in the headers. SST image times are shown relative to whale feeding activity in Figure 1D.

See also Figure S1.

the upwelling plume extended as a filamentous structure around the eddy's southern and offshore periphery. All feeding over the following 6 days occurred where the upwelled water was transported offshore by the eddy (locations 2–7 in Figure 1C).

As detected in sea level anomalies (SLA), the eddy persisted for the duration of the recorded feeding activity (Figure 2A). However, the whales' feeding was not consistently located relative to the eddy. The first feeding bout was located more than 40 km north of the eddy periphery. After moving into the eddy's southern and southwestern periphery for feeding bouts 2–4, the focal whale moved westward away from the eddy for feeding bouts 5–7 (Figure 2A). Decreased mean SLA at feeding locations (noted in the map headers) emphasizes this departure. Although clearly an influential dynamical feature, the eddy itself was not the essential target of the foraging whales.

Feeding was consistently localized along the thermal front created by the upwelling plume and its eddy-entrained filament (Figure 2B). Further, where stirring by ocean circulation isolated pools of cool upwelled water from the transported filament, the whales precisely localized and fed at the fronts around each individual pool (feeding bout 4 in Figure 2B). From its origin near the coast to its transported tendrils offshore of the eddy, the upwelling plume front was the essential target of the foraging whales.

Behaviors enabling precisely targeted feeding

Integration of remote sensing from biologging tags and satellite-borne instruments enables the assessment of behaviors and search strategies underlying the precise localization of feeding. Classification of dive profiles shows that exploratory dives were prevalent throughout the tag deployment (Figure S1), which supports the consideration of horizontal movement patterns in the context of search behavior. While tag data define the immediate conditions encountered by the whales (Figure 1D), synoptic satellite remote sensing reveals the oceanographic features that determined the conditions encountered by the whales (Figure 2). Tag data show that the greatest thermal contrast accessible to sensory perception was near the surface, where a wide range of relatively cool temperatures—associated with upwelled water that has aged to varying degrees—contrast with predominantly warmer temperatures (Figure 1E, 2–10 m). Near-surface temperature is thus considered as a local environmental reference relative to the patterns of the whales' horizontal movement.

Because the tags were deployed when the whales were already feeding along the northern boundary of the upwelling plume (Figures 1C, 1D, and 2B), the behaviors that may have enabled the initial response to the front cannot be examined for feeding bout 1. Between feeding bouts 1 and 2, the whales traveled approximately 120 km and exhibited multiple behaviors upon encountering the thermal front of the upwelling plume (Figure 3). After the whales transitioned from southward near-coastal alongshore movement to offshore movement (Figure 3A), they encountered the front twice (F1 and F2 in Figure 3B). At each encounter, the whales' geographic trajectory turned sharply counterclockwise, toward the source of upwelled water (highlighted by the magenta arrows in Figure 3B), and they conducted deeper

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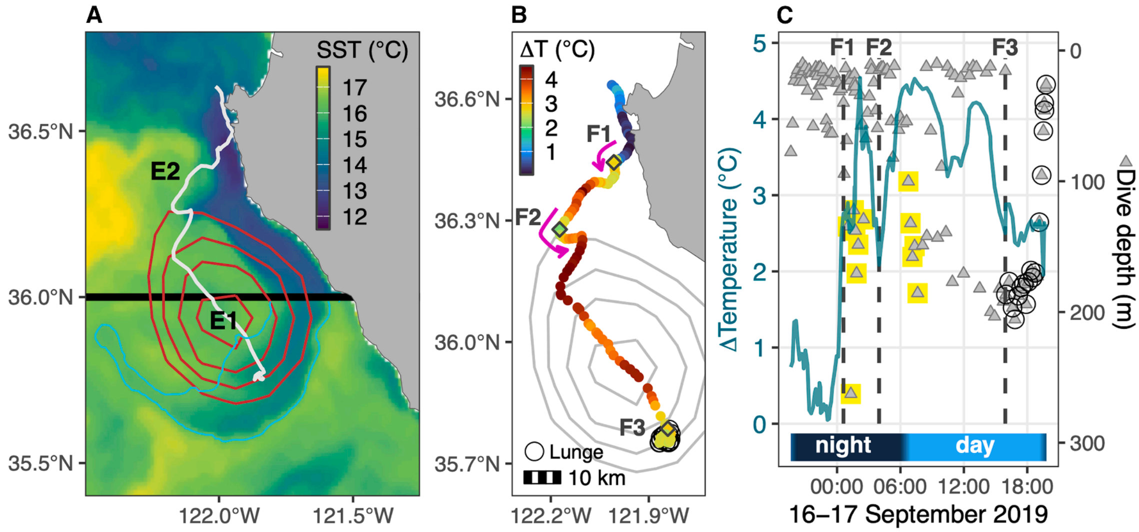

Figure 3. Behavioral responses to encounters with upwelling plume fronts

(A) SST images from the first two times indicated in Figure 1D were joined at 36°N so that SST closest in time to whale habitat occupancy is represented over a long (~120 km) north to south transit (white line) between feeding bouts 1 and 2. SLA contours (red) are as in Figures 1B and 1C; E1 marks the core of the large eddy. The cyan contour (16.25°C isotherm) emphasizes the filament of cool upwelled water transported offshore by E1. The label E2 marks the center of a smaller eddy (~20 km diameter) north of E1.

(B) Upper layer (2 to 10 m) average temperatures measured by a biologging instrument on one of the two closely associated whales (Figure 1D, lower). Values are represented as degrees Celsius above the locally measured minimum (ΔT). Gray SLA contours define E1, as in (A). Dark gray diamonds mark the locations immediately preceding sharp changes in course exhibited by the whales upon encounter with strong thermal fronts (F1 and F2); magenta arrows highlight the course changes; F3 marks the third frontal encounter. Open black circles mark the locations of feeding lunges; lunge symbols are plotted behind ΔT to avoid obscuring the thermal patterns of environmental features and are scaled to be visible around the colored temperature points.

(C) ΔTemperature (cyan line, same as ΔT in B) relative to dive depths (gray triangles) and feeding lunge depths (open black circles) of the focal whale. Times indicated by dashed lines (F1–F3) correspond to the locations of frontal encounter marked by diamonds in (B). Yellow boxes highlight exploratory dives below 100 m during movement toward the warm side of the upwelling front.

See also Figure S1.

exploratory dives indicative of prey search (highlighted in yellow in Figure 3C). In both of these frontal encounters, the deeper exploratory diving occurred as the whales moved from the cool to the warm side of the front (Figure 3C); however, no feeding resulted. Following subsequent transit through the center of the large eddy (E1), the whales reached the front along the primary offshore transport pathway of the upwelling plume that was driven by eddy circulation (Figures 3A and 3B; F3). There, they fed intensively at depth and then sustained feeding while tracking krill vertical migration toward the surface during dusk (Figure 3C).

After localizing the primary offshore transport of the upwelling plume, the whales demonstrated more systematic search patterns during the nighttime periods preceding daytime feeding bouts (Figure 4). The searches consistently began with transects oriented approximately perpendicular and then parallel to the local physical gradients of the eddy and transported upwelling plume (highlighted by the magenta arrows in the Figure 4 maps). As the whales progressed clockwise from the southern to the southwestern periphery of the anticyclonic eddy across daily feeding bouts 3 through 5, transect orientation accordingly rotated clockwise. These transects consistently resulted in encounters with a temperature minimum of the upwelling plume before the whales progressed from the cool toward the warm side of the front while feeding intensively and tracking the vertical migration of krill (Figure 4, lower). Interruption of feeding bout 4 upon encounter with relatively warm water represents the movement from one cool patch of the upwelling plume to another, crossing a warm filament in between (Figures 4B and 2B). Feeding bout 5 was the furthest of these three bouts from the eddy periphery (Figure 2A); however, the focal (still tagged after bout 4) whale's systematic search pattern remained consistent even amid the weaker thermal gradients of the transported upwelling plume (Figure 4C).

Feeding bouts 6 and 7 occurred at the most distal extent of the transported upwelling plume (Figure 1C). Compared to bouts 3–5, the focal whale traversed less distance and a smaller range of SLA during bouts 6 and 7 (Figures 4 and S2). Although these feeding bouts occurred in a region of relatively weak thermal gradients (Figure 1C), feeding was localized within or immediately adjacent to the strongest local thermal gradients encountered by the whale during daytime or crepuscular periods (Figure S2).

The survival of Earth's largest predators, rorqual whales (Balaenopteridae), requires that these gigantic mammals locate and consume dense prey patches that are sparsely distributed within vast habitats. The high energetic cost of rorqual lunge feeding and their large overall energy demands at extreme body sizes necessitate efficient foraging.[15–17] Foraging efficiently requires the precise localization of feeding within dynamic features that generate dense krill swarms. Within the California Current Ecosystem, dense krill swarms are known to develop with upwelling plumes,[9] and blue whales are known to track variable flows of upwelling plumes[10] and target aggregative surface

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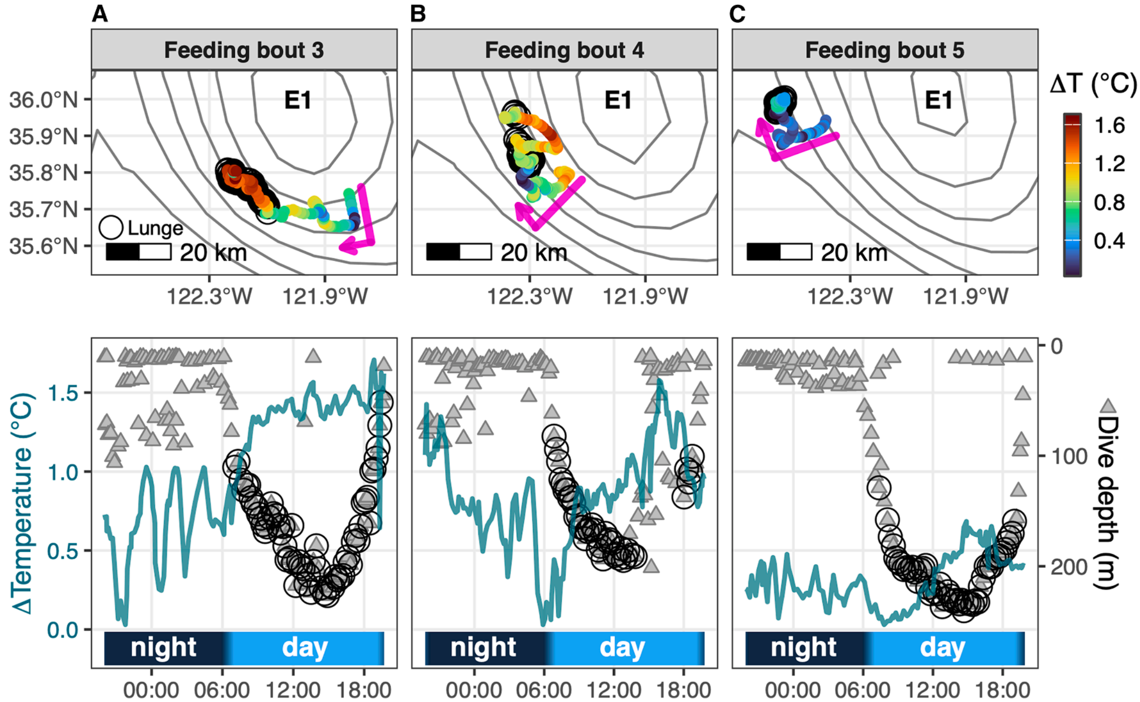

Figure 4. Systematic orientation of search and feeding relative to local frontal gradients

(A–C) For each feeding bout, near-surface (2 to 10 m) average temperatures are represented geographically (top), relative to feeding locations (open black circles), and temporally (bottom, cyan lines), relative to the depths of dives (gray triangles) and feeding lunges (open black circles). Temperatures are represented as degrees Celsius above the minimum within each subset period. In the maps, dark gray contours identify the large eddy (E1; maximum SLA at the eddy center is contoured at 128 mm, 10 mm contour spacing below). Lunge symbols are plotted behind ΔT to avoid obscuring the thermal patterns of environmental features and are scaled to be visible around the colored temperature points. Magenta arrows indicate systematic patterns of horizontal movement that were oriented across and along local physical gradients.

See also Figures S1 and S2.

current features.[11,12] The present study reveals searching behaviors that may enhance foraging efficiency via precise localization of feeding within favorable fine-scale habitat. Further, whale movements relative to local physical gradients and strong behavioral responses to these gradients indicate underlying sensory capabilities and foraging strategies.

The primary sensory cue indicated in this study is thermal contrast caused by the essential physical processes that shape this dynamic ecosystem: coastal upwelling and the transport of upwelled water through ocean margin habitats. The prevalence of systematic and temperature-responsive search behavior during the night, when feeding did not occur, emphasizes the potential role of thermal sensing. Temperature gradients offer strong, sharp cues that define relevant fine-scale ecological features. Between feeding bouts, the focal whale dove to shallow depths (<20 m) in 48% of all dives, thus indicating the potential for accumulating information about near-surface thermal features through systematic search behaviors such as those illustrated. Use of thermal contrast as a sensory cue would require not only the somatosensory capacity but also the use of memory and comparison to perceive near-surface changes in space and time. Blue whales use memory over seasonal timescales when returning to previously known favorable foraging habitat,[18] which supports the potential for memory to play a role across spatiotemporal scales.

Blue whales are globally distributed, and several populations of this species remain endangered. The California Current Ecosystem is representative of the major Eastern Boundary Upwelling Systems in both hemispheres, where frontogenesis is an essential consequence of wind-driven coastal upwelling. Association of marine predators with fronts—including turtles, sharks, seabirds, and mammals—has long been recognized,[19–26] and this has motivated the promotion of fronts as high-priority conservation areas.[27] A greater understanding of blue whale ecology is essential to inform conservation, and the movement ecology revealed by this study also defines how essential resource tracking may influence the whales' exposure to the risk of collision with large vessels—because upwelling plumes often flow across regional shipping corridors. Although our study focused on one baleen whale species, this research is relevant to understanding the scale-dependent multimodal sensory strategies,[28] ecology, and conservation of many marine species that rely on patchy and ephemeral prey to sustain their populations.

RESOURCE AVAILABILITY

Lead contact

Requests for further information and resources should be directed to and will be fulfilled by the lead contact, John Ryan (ryjo@mbari.org).

Materials availability

This study did not generate any new, unique reagents.

Data and code availability

This paper analyzes existing, publicly available data, accessible as defined in the key resources table. Processed data from the focal biologging tag and satellite-borne sensors, together with all original code, have been deposited with Zenodo.org as https://doi.org/10.5281/zenodo.20720500 and are publicly available as of the date of publication.

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AUTHOR CONTRIBUTIONS

Conceptualization, J.P.R., A.I.V.L., and J.A.F.; data curation, J.A.F. and J.P.R.; formal analysis, J.P.R., A.I.V.L., and J.A.F.; funding acquisition, J.C. and J.A.F.; investigation, J.P.R., A.I.V.L., and J.A.F.; methodology, J.P.R., A.I.V.L., J.A.F., J.C., and J.A.G.; software, J.P.R. and J.A.F.; visualization, J.P.R., A.I.V.L., J.A.F., W.K.O., and K.J.B.-B.; writing—original draft, J.P.R.; writing—review and editing, J.P.R., A.I.V.L., W.K.O., K.J.B.-B., J.A.G., J.C., and J.A.F.

DECLARATION OF INTERESTS

The authors declare no competing interests.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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- EXPERIMENTAL MODEL AND STUDY PARTICIPANT DETAILS
- METHOD DETAILS
  - Blue whale biologging
  - Satellite remote sensing

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.cub.2026.08.010.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
Analyzed data	This paper	https://doi.org/10.5281/zenodo.20720500
Sea level anomalies	Copernicus Data Server	https://doi.org/10.48670/moi-00148
Sea surface temperature	NOAA ERDDAP Data Server	https://coastwatch.pfeg.noaa.gov/erddap
Software and algorithms		
R version 4.4.2	Comprehensive R Archive Network	https://cran.rstudio.com/
MATLAB version 2025b	MathWorks	https://www.mathworks.com/
Tagtools	Biologging Tools Project	http://www.animaltags.org

EXPERIMENTAL MODEL AND STUDY PARTICIPANT DETAILS

All tagging efforts and tag deployments on blue whales were conducted under authority of a scientific research permit under the Marine Mammal Protection Act and Endangered Species Act (NMFS Permits # 21678) and under Cascadia Research Collective IACUC protocols. The two blue whales tagged in this study were known adult individuals, identified based on their natural markings as CRC-747 (Tag 15) and CRC-1163 (Tag 14). CRC-747 has been identified 11 times between 1992 and 2019 and as early as 23 July and as late as 29 September, all off southern and central California. CRC-1163 has been identified 6 times between 1995 and 2019 between 22 August and 16 September, all off Central California. Before they were encountered and tagged on 16 September 2019, these two whales had been seen associated together multiple times in the Monterey Bay area on 12 and 13 September 2019.

METHOD DETAILS

Blue whale biologging

By recording spatial occupancy, movement and other behaviors together with local environmental conditions, biologging enables unprecedented observations of behavioral ecology from the perspective of marine predators.[29,30] On 16 September 2019 two blue whales were tagged in Monterey Bay, California for ecological research. Biologging tags were deployed from a 7 m rigid-hull inflatable boat using a 5 m carbon fiber pole and were attached to the whales with four stainless steel darts that were 65 mm long with 2 rows of petals.[11] Biologging data were acquired using a Wildlife Computers TDR10FX tag that sampled temperature at 1 Hz, depth and accelerometry at 32 Hz, and fast-acquisition GPS during periods when the whales were at the ocean surface. Following detachment, the tags were found via ARGOS satellite positions and VHF telemetry and recovered for data download and analyses. Analyses focused on classification of dive types, quantification of feeding intensity, and patterns of horizontal movement relative to oceanographic features defined by satellite remote sensing of sea level anomalies and sea surface temperature.

Raw kinematic data were pre-processed in MATLAB (MathWorks, Inc., v2017a) to calculate the animal's pitch, roll, and an estimate of speed from the accelerometer sensor data, and individual feeding events (i.e., lunges) were identified manually using stereotypical signatures in kinematic data.[31] All processed tag data were down-sampled to 1Hz for analysis and subsequent processing of the blue whale kinematic and geographic movement data were conducted in R, version 4.4.2. Raw GPS location data were filtered for unrealistic whale speeds (> 6 m s^{-1}) using the ArgosFilter package in R, v0.62. We used linear interpolation (interpolateTime function of the move package, v4.0.6) to estimate locations for dives with short intervals between known GPS locations (i.e., a gap < 15 minutes).

Blue whale dives, defined as excursions to a depth of greater than 10 m, were identified using the Tagtools package (see key resources table). Foraging dives were defined by the presence of feeding lunges. From the feeding lunge detections, which showed feeding exclusively during daytime (96.5%) and crepuscular (3.5%) periods, daily periods of feeding bouts were defined between the first and last feeding lunge detections of each day. Non-foraging dive types were classified manually by examining the time-depth profile of each dive relative to attributes of dive categories previously defined from blue whale biologging research.[32,33] Feeding dives were mapped relative to all other types to examine spatial relationships. Exploratory dives indicated search behavior, and their spatial distribution and density were examined relative to encounter with thermal fronts detected by temperature sensing from biologging.

Temperature profile data from the tags were processed to ensure consistent characterization of horizontal thermal gradients available to sensory perception. To accurately compare depth-dependent temperatures between dives, tag data processing must eliminate potential bias that would result from the whale spending different amounts of time at different depths from dive to dive. This was achieved by first averaging the original 1 Hz temperature data within 2 m depth bins for each dive. To characterize depth dependence of horizontal thermal contrast, we examined the distributions of the 2 m bin-averaged temperature profile data within larger depth ranges. The shallowest depth range examined (2–10 m) showed the greatest horizontal thermal contrast, and this near-surface layer is most relevant to comparison with satellite remote sensing of SST. Therefore, mean temperature values within this depth range from each dive were used to examine changes in animal movement (course, dive depth), in relation to encounters with physical oceanographic features described by both satellite remote sensing and tag data.

We present data from only the tag having the longer duration for two reasons: (1) data from this tag is representative of both whales, which exhibited movement and feeding behaviors that corresponded closely (summarized in Results), and (2) its longer duration allows examination of physical-biological relationships across all areas of feeding activity within the study region. This tag was deployed off Monterey, California (36.6456°N, 122.0155°W) at 14:32:01 PDT on 16 September 2019. At the time of deployment, the whale was engaged in an intensive daytime feeding bout – immediately diving to successfully feed and continuing to feed for the remainder of that day. We examine the tag data through the end of the daytime feeding bout of 22 September 2019, after which the focal whale departed from the study region. Its behavioral changes upon transitioning to southward migration were documented in a previous study.[34]

Satellite remote sensing

To examine dynamic oceanographic features within the whale foraging habitat, we used the daily Global Ocean Gridded L4 Sea Surface Heights, having a resolution of 0.125° in latitude and longitude. These gridded sea level anomalies (SLA) were computed with respect to a twenty-year (1993–2012) mean based on along-track satellite radar altimeter measurements from multiple altimeter missions. SLA contours were overlaid on SST maps, biologging data were overlaid on SLA maps, and SLA values from daily maps were interpolated to the locations of foraging lunges to derive mean SLA for each daily feeding bout (noted in the headers of Figure 2A).

To examine fine-scale oceanographic features immediately surrounding the foraging whales, we used NOAA POES AVHRR SST data. The spatial resolution of these images is 0.0125 degrees in latitude and longitude. These nearly instantaneous single-scan images represent SST patterns without smearing actual synoptic structure by averaging across time and associated spatial offsets of dynamic physical features. The data underlying the SST product, specifically the all-surface temperature data (Dataset IDs erdATastdhday and erdATastnhday for day and night, respectively), were used to avoid loss of valid SST data from inaccurate automated cloud flagging that is used to produce the SST data product. All images from the biologging period of 16–22 September 2019 were downloaded from the NOAA ERDDAP server, and the image having the clearest coverage closest in time to each daily blue whale feeding bout was selected for examination.

Distinguishing fine-scale features relevant to foraging ecology requires analysis that adapts to variation in the strength of the physical signal that is accessible to remote sensing. Owing to oceanic stirring and mixing, and heat exchange with the atmosphere, temperature is not a conservative tracer of the focal physical feature: an upwelling plume. In this study, thermal distinction of the upwelled water diminished along its flow trajectory offshore. To consistently describe the local thermal structure, we transformed SST to a local spatial anomaly within a 40x40 km area surrounding the mean position of the whale during each daily feeding bout. The temperature minimum within each local domain (noted in the headers of Figure 2B) represents the local strength of the upwelling plume thermal anomaly, and the anomaly is quantified as standard deviations above the minimum.