

Abstract—To investigate the possibility that oil and gas platforms may reduce recruitment of rockfishes (*Sebastes* spp.) to natural habitat, we simulated drift pathways (termed “trajectories” in our model) from an existing oil platform to nearshore habitat using current measurements from high-frequency (HF) radars. The trajectories originated at Platform Irene, located west of Point Conception, California, during two recruiting seasons for bocaccio (*Sebastes paucispinis*): May through August, 1999 and 2002. Given that pelagic juvenile bocaccio dwell near the surface, the trajectories estimate transport to habitat. We assumed that appropriate shallow water juvenile habitat exists inshore of the 50-m isobath. Results from 1999 indicated that 10% of the trajectories represent transport to habitat, whereas 76% represent transport across the offshore boundary. For 2002, 24% represent transport to habitat, and 69% represent transport across the offshore boundary. Remaining trajectories (14% and 7% for 1999 and 2002, respectively) exited the coverage area either northward or southward along isobaths. Deployments of actual drifters (with 1-m drogues) from a previous multiyear study provided measurements originating near Platform Irene from May through August. All but a few of the drifters moved offshore, as was also shown with the HF radar-derived trajectories. These results indicate that most juvenile bocaccio settling on the platform would otherwise have been transported offshore and perished in the absence of a platform. However, these results do not account for the swimming behavior of juvenile bocaccio, about which little is known.

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Do oil and gas platforms off California reduce recruitment of bocaccio (*Sebastes paucispinis*) to natural habitat? An analysis based on trajectories derived from high-frequency radar

Brian M. Emery¹

Libe Washburn^{1, 2}

Milton S. Love (contact author)³

Mary M. Nishimoto³

J. Carter Ohlmann⁴

¹ Institute for Computational Earth System Science
University of California
Santa Barbara, California 93106-3060

² Department of Geography
University of California
Santa Barbara, California 93106-4060

³ Marine Science Institute
University of California
Santa Barbara, California 93106-4060
E-mail address (for M. S. Love, contact author): love@lifesci.ucsb.edu

⁴ Institute for Computational Earth System Science
University of California
Santa Barbara, California 93106-3060
and
Scripps Institution of Oceanography
La Jolla, California 92093-0213

The 27 oil and gas platforms off southern and central California have limited life spans. Many of these structures have been in place for over 20 years (Love et al., 2003), and it is expected that some of these platforms will be decommissioned in the near future. Because decommissioning may entail full removal of the platform, agency personnel tasked with determining the best course of action in regard to the platforms would likely benefit from an understanding of the role that platforms play as fish habitat (Schroeder and Love, 2004).

The platforms harbor high densities of many species of fishes, although species compositions vary with platform bottom depth (Love et al., 1999a; 1999b; Love et al., 2003). About 35 species of rockfishes (genus *Sebastes*) dominate the three distinct assemblages found around many platforms in the Santa Barbara Channel and off central California: the bottom, shell mound, and midwater assemblages. Fishes around platform bottoms tend

to be adult and subadult individuals. Those on the shell mounds are usually adults of dwarf species or juveniles of larger taxa. The midwater assemblages are composed almost entirely of juvenile fishes. Some of these juvenile fishes are one and two-year old individuals, but most are young-of-the-year (YOY) rockfishes. Densities of YOY rockfishes around platforms are usually far higher than those at nearby natural reefs (Love et al., 2003). These observations have raised a concern (e.g., Krop¹.) that platforms

¹ Krop, L. 1997. Environmental user group representative, disposition panel. In Proceedings: Public workshop, decommissioning and removal of oil and gas facilities offshore California: recent experiences and future deepwater challenges, September 1997 (F. Manago, and B. Williamson, eds.), p 172. Mineral Management Service OCS Study 98-0023. Coastal Research Center, Marine Science Institute, Univ. California, Santa Barbara, California, 93106. MMS Cooperative Agreement Number 14-35-0001-30761.

may reduce recruitment to natural reefs by functioning as catchments for pelagic juvenile rockfishes.

To investigate the possibility that an oil platform may reduce recruitment of rockfishes to natural habitat, we simulated drift pathways (hereafter referred to as "trajectories") from an existing platform to nearshore habitat using current measurements from high-frequency (HF) radars.

Materials and methods

Species modeled

Because trajectories derived from HF radar approximate transport pathways of near surface water parcels, we chose to model the movements of pelagic juvenile bocaccio (*Sebastes paucispinis*) that dwell near the surface during their time in the plankton. This historically important recreational and commercial fishing target in central and southern California (Love et al., 2002), is also among the shallowest dwelling juvenile fishes (Lenarz et al., 1991; Ross and Larson, 2003).

Off central and northern California, parturition for bocaccio occurs from January to May and peaks in February (Love et al., 2002). Off southern California, the species has a reproductive season that spans all year, but most larvae are released from October to July, although January is the peak month. Juvenile bocaccio recruit to inshore waters from February to August off central California, although May through July is the peak season (Love et al., 2002). The trajectory simulation period from May through August was chosen to span this principal recruitment season.

Bocaccio range from the Alaska Peninsula to central Baja California, and adults are usually found over high relief boulder fields and rocks in 50–250 m of water (Love et al., 2002). The fish most often settle in rocky habitat covered with various algae or in sandy zones with eelgrass. Juvenile bocaccio are commonly found in drifting kelp (Mitchell and Hunter, 1970; Boehlert, 1977) indicating that the fish recruit to natural habitat encountered in offshore surface waters. For this analysis, we assumed that waters from the shallow subtidal to the 50-m isobath represented suitable habitat for juvenile recruits. This choice reflects the lack of information about suitable habitat locations in our study area and likely results in overestimates of the abundance of such habitat.

Annual scuba surveys and submersible surveys (1995–2001) in the Santa Barbara Channel and Santa Maria Basin regions showed that YOY bocaccio inhabit the upper 35 m around one or more platforms for each year surveyed. Platform Irene (34°36.62'N, 120°43.40'W; bottom depth 73 m) was selected for analysis because fish recruited to it each year from 1995–2001 (Love et al., 2001) and it was the site of the highest density of YOY bocaccio observed from submersible surveys during these years (Love et al., 2003). Moreover, from May through August, 1999 and 2002, Platform Irene was

also in a region of good HF radar coverage, which allowed computation of extensive trajectory ensembles.

Ocean current measurement and trajectory calculation

Near-surface ocean currents were measured hourly by using an array of three HF radars (SeaSondes, manufactured by CODAR Ocean Sensors, Ltd. of Los Altos, CA) operating at 12–13 MHz. At these frequencies, the measurement is an average over the upper 1 m of the water column (Stewart and Joy, 1974). The radars were located at Pt. Sal, Pt. Arguello, and Pt. Conception (Fig. 1A). HF radars measure components of surface currents by means of a Doppler technique, at spatial increments of 1.5 km in range and 5° in azimuth from the radar location. Surface current vectors in an east-north coordinate system were computed on a 2-km grid by using the least square technique described by Gurgel (1994). With this technique, all current components obtained within a 3-km radius around each grid point were combined to estimate the surface current every hour. The 3-km radius limits the spatial resolution of the near-surface current fields. Emery et al. (2004) have described the processing of the HF radar data in more detail. Further discussion on the use of HF radars for measuring near surface currents is given by Paduan and Rosenfeld (1996) and Graber et al. (1997).

Emery et al. (2004) assessed performance of the three HF radars by comparing them with *in situ* current meters at 5 m depth. They found that root-mean-square differences in radial speed measurements between HF radars and current meters ranged from 0.07 to 0.19 m/s. Recent observations comparing surface currents from HF radars and drifters have indicated that differences are substantially reduced if spatial variability in current fields is accounted for (Ohlmann, 2005).

The areas used for computing trajectories were offshore of Pt. Conception and Pt. Arguello as shown in Fig. 2A for 1999 and Fig. 3A for 2002. These areas were selected to maximize the spatial coverage, and to minimize the inclusion of grid points with low temporal coverage. Variable coverage from individual radars results in differences in coverage between years. Boundaries of nominal coverage areas were oriented along and perpendicular to isobaths. Platform Irene is about 2 km from the inshore boundaries, which lie along the 50-m isobath (Figs. 2A and 3A). At times actual radar coverage exceeded nominal coverage boundaries as may be seen by comparing sample computed trajectories (black lines, Fig. 1A) with the 2002 boundary (gray closed curve, Fig. 1A). Coverage in 2000 and 2001 for May through August was inadequate for producing trajectory ensembles around Platform Irene.

A new trajectory was begun at the location of Platform Irene every 4 hours from 1 May through 31 August for 1999 and 2002. Positions along the trajectories were determined by integrating current vectors forward in time using a fourth order Runge-Kutta algorithm. Trajectories ended where they encountered spatial gaps or where they reached the edge of radar coverage.

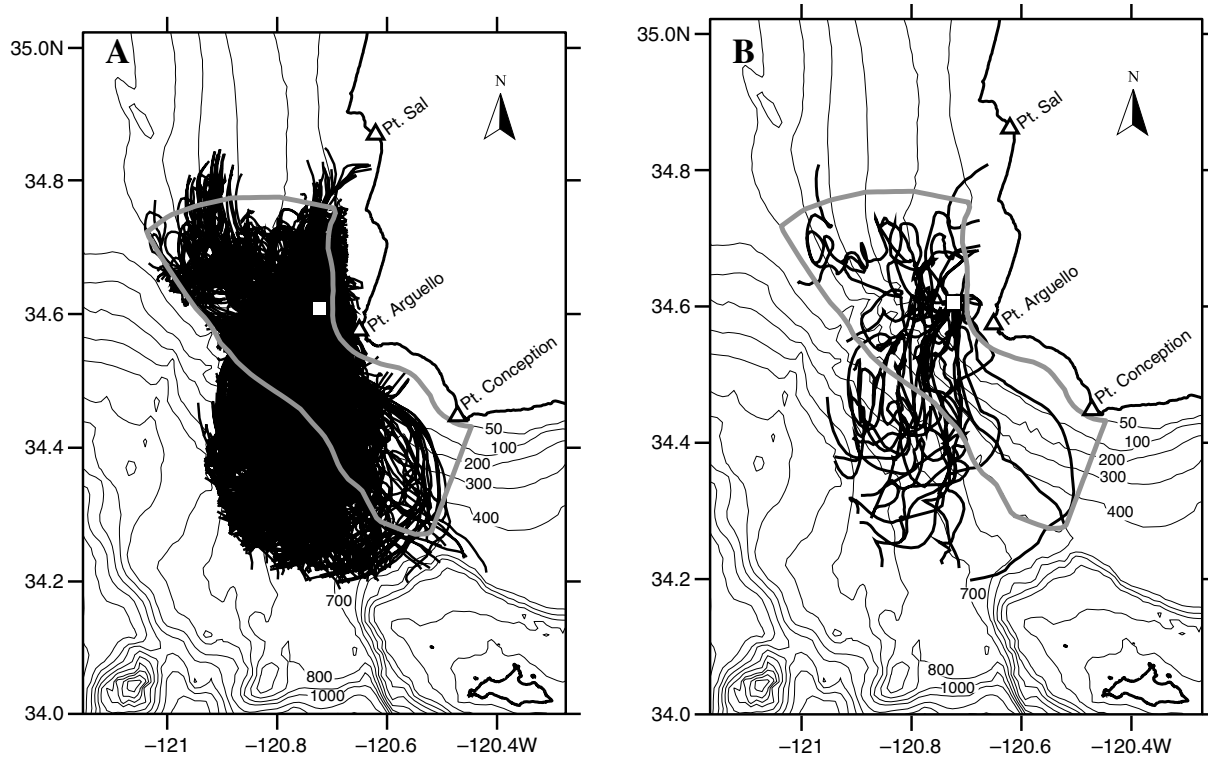


Figure 1

(A) Map of study area near Pt. Conception, California, showing trajectories derived from high-frequency (HF) radar from 1 May–31 Aug 2002. Triangles show HF radar locations and the white square shows Platform Irene. Gray curve superimposed on trajectories is the coverage boundary used for 2002. Labeled thin black lines are bathymetric contours. (B) Heavier black lines are 25 sample trajectories that intersect the coverage boundary. Gray curve is the same as in panel A. The trajectories in panels A and B were created from velocity time series that were interpolated with empirical orthogonal functions (EOFs).

The number of trajectories reaching the coverage boundaries defined in Figures 2A and 3A were reduced by gaps in spatial and temporal radar coverage. For example, of the 670 possible trajectories in 2002, 541 (81%) ended within the radar coverage area and 129 (19%) intersected the coverage boundary. Changes in spatial coverage on diurnal and longer time scales resulted from several factors, such as broadcast interference, and are a characteristic of HF radars (Paduan and Rosenfeld, 1996). Gaps in the velocity time series were also caused by outages of individual radars. The average durations of these gaps were 4.4 ± 22.3 h and 5.9 ± 7.9 h in 1999 and 2002, respectively. Outages of individual radars also produced a few long gaps in the velocity time series for each year across the entire coverage area. In 1999 two long gaps occurred: one from 1800 coordinated universal time (UTC) 28 June through 2000 UTC 22 July, and a second from 2300 UTC 24 July through 2200 UTC 13 August. In 2002 a single long gap occurred from 1700 UTC 16 May through 0100 UTC 21 May. These longer gaps were not filled.

Shorter gaps were filled by interpolation by using empirical orthogonal functions (EOFs; (Emery and Thomson, 1998)). EOFs incorporate the underlying spatial

structure of all velocities recorded at all locations where data existed at a given time. Any velocity component, u say, at grid point j may be expressed as

$$u_j(t) = \sum_{i=1}^N a_i(t) \varphi_{ij} + \bar{u}_j, \quad (1)$$

where t = time;

\bar{u}_j = the time average at location j (computed from available data at location j);

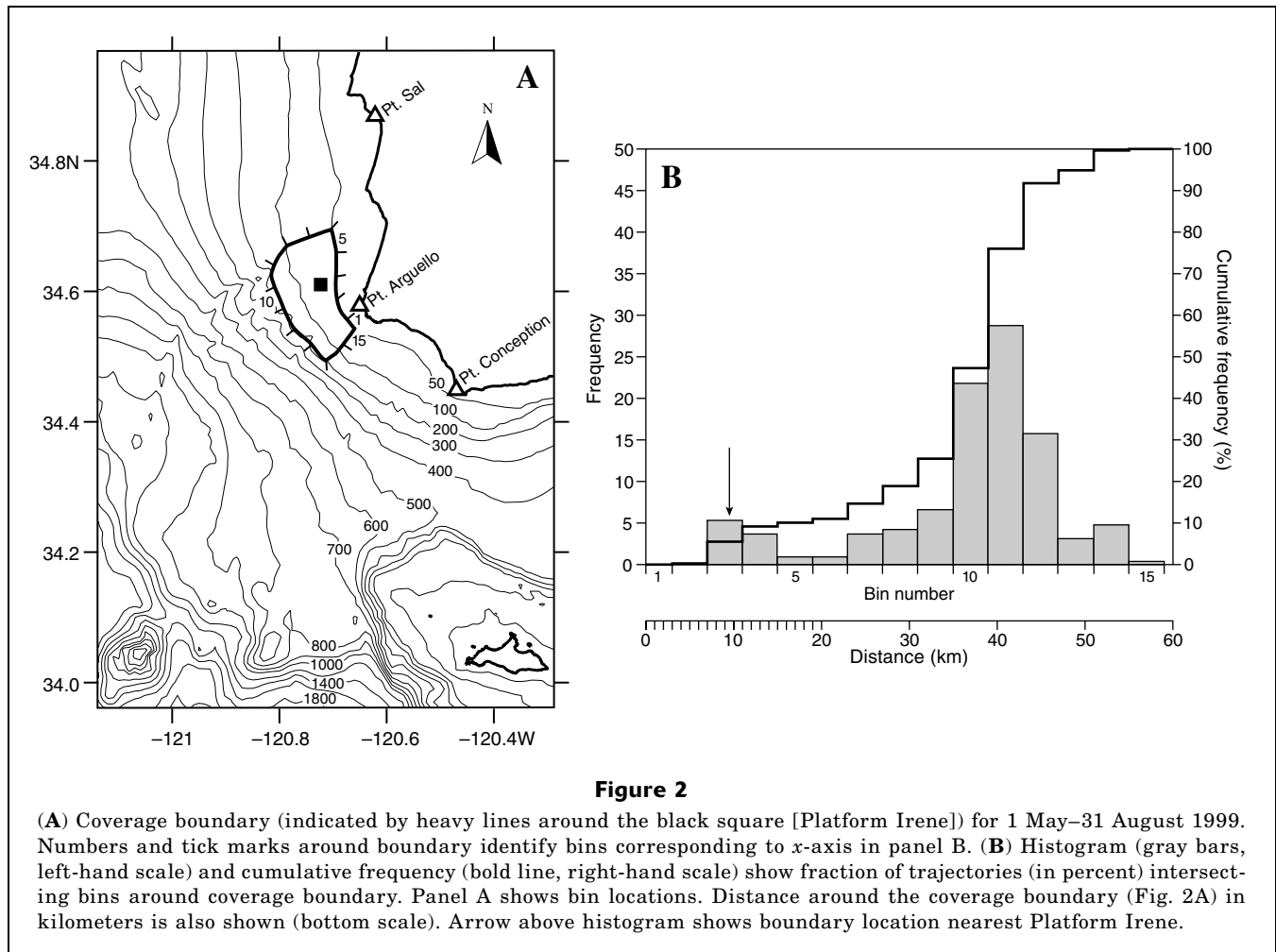
a_i = the time-varying amplitude function;

φ_{ij} = the i th spatial EOF mode at location j ; and

N = the number of modes.

The first seven modes (i.e., $N=7$) were used for interpolation and explained 64% (1999) and 56% (2002) of the variance. EOF interpolation increases the number of trajectories reaching the coverage boundary to 99%. As a test, gaps were also filled with linear, spline, and moving average interpolation, but EOF interpolation resulted in the most trajectories reaching the coverage boundaries. Otherwise, results did not depend strongly on the interpolation method.

The fraction of filled data with EOF interpolation compared with the total possible data was 4% in 1999,



12% in 2002, and 14% with the 2002 data for the 1999 coverage boundary. Here the total possible data were the number of grid points within the coverage boundary for either 1999 (45 grid points) or 2002 (291 grid points) multiplied by the number of hours between 1 May and 31 August minus the long gaps discussed above (2952 hours–1057 hours in 1999, 2952 hours–104 hours in 2002). Examples of 25 EOF-filled trajectories that started every 120 hours and intersected the 2002 coverage boundary are shown in Figure 1B.

The principal quantity used in our study to estimate how Platform Irene might affect transport to nearshore habitat was the histogram of points where trajectories crossed the boundaries of the coverage areas. To determine this quantity, coverage boundaries were divided into 4-km-long segments, or bins. The first bin of each histogram was less than 4 km because distances around the coverage boundaries were not exactly divisible by 4. Bin numbers increased counter-clockwise around the boundaries starting from 1 in the southeastern corner (Figs. 2A and 3A). The smallest numbers identified bins lying along the 50-m isobath.

Results

Trajectories originating at Platform Irene were sufficiently dense to fill in much of the surrounding area. In 2002 for example, EOF-filled trajectories spread over an area of about 20 km in the cross-shore direction by 60 km in the alongshore direction (Fig. 1A). North of Pt. Arguello, several trajectories crossed the 50-m isobath and some ended very near shore. South of Pt. Arguello, only a few trajectories approached the 50-m isobath. Instead, most turned southward or southwestward and moved offshore. A tendency for trajectories to align parallel to isobaths was evident in the northern end of the ensemble, although in other areas, such as the southeast, many trajectories lay across isobaths.

A histogram of points where trajectories crossed the coverage boundary for May–August 1999 exhibited a peak in bin 11 on the offshore side along the 500-m isobath (Fig. 2B, left-hand axis). Table 1 and the cumulative histogram (Fig. 2B, right-hand axis) showed that 76% of the trajectories crossed the offshore side corresponding to bin numbers 9–13. A second peak oc-

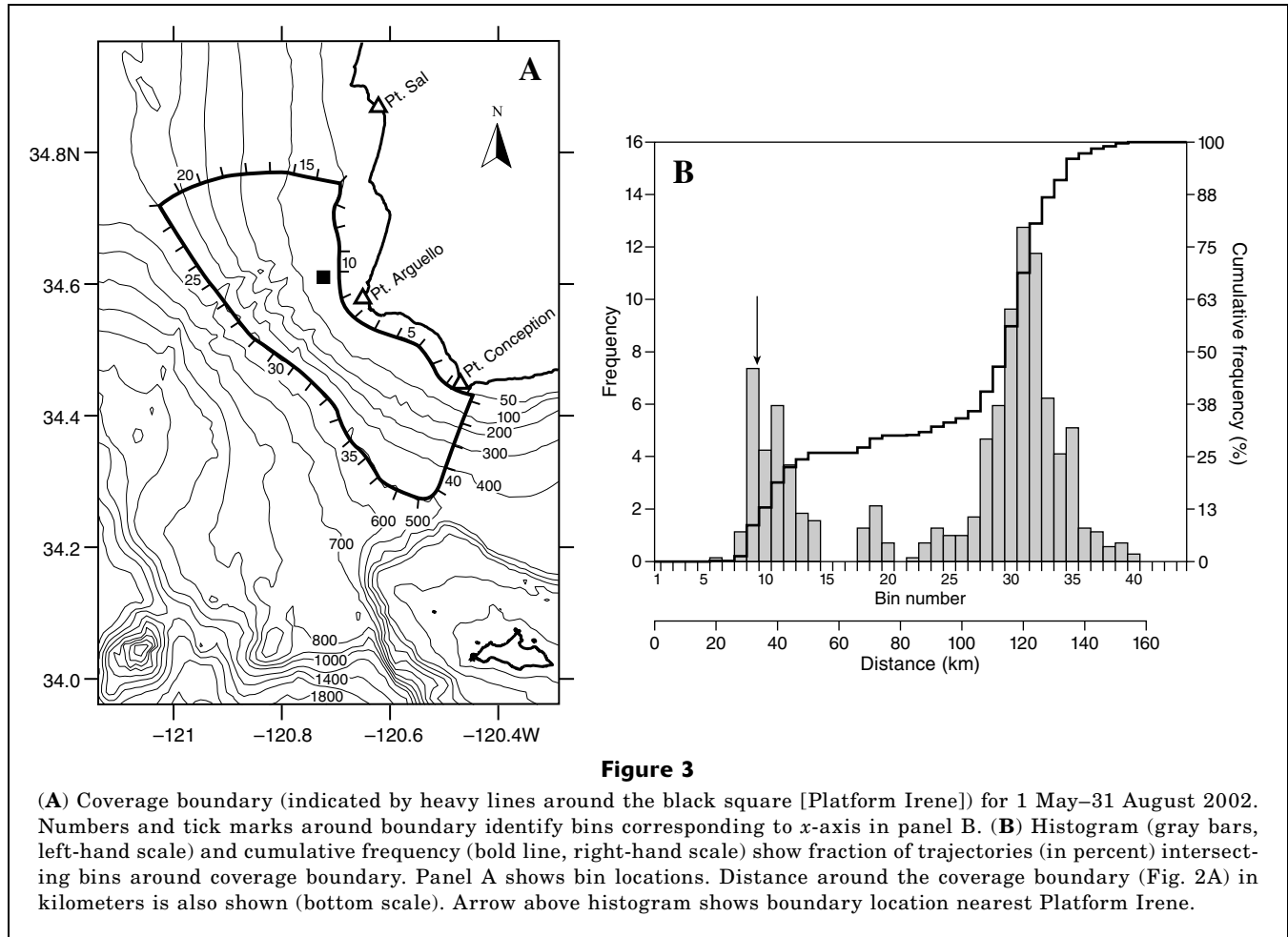


Table 1

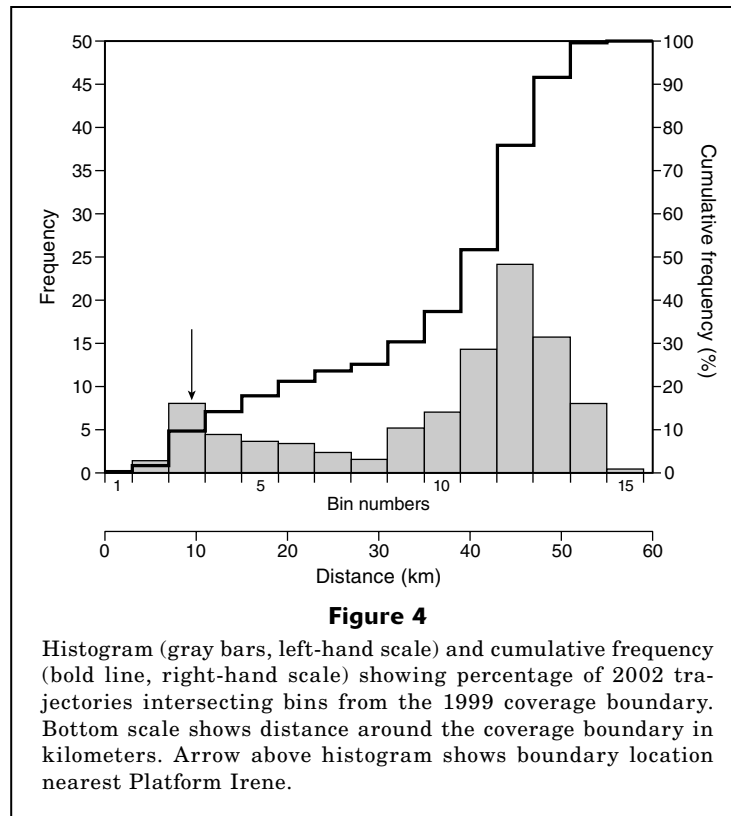
Statistics for trajectories using empirical orthogonal function (EOF) interpolation, and Scripps Institution of Oceanography drifters.

Year	Coverage boundary	Total trajectories	Trajectories intersecting coverage boundary	Trajectories intersecting inshore boundary (50-m isobath) (%)	Trajectories intersecting offshore boundary (%)	Trajectories intersecting northern boundary (%)	Trajectories intersecting southern boundary (%)	Mean residence time in coverage area (h ±1 SD)	Maximum residence time in coverage area (h)
1999	1999	590	546	10	76	9	5	19 (±12)	86
2002	2002	716	706	24	69	6	1	47 (±34)	163
2002	1999	716	712	18	66	7	8	22 (±18)	116
SIO drifters	2002	21	17	18	71	12	0	38 (±21)	79

occurred in bin 3 and about 10% of trajectories crossed the inshore boundary on the 50-m isobath (bins 1–5). The remaining trajectories crossed either the northern (9%) or southern (5%) sides of the coverage boundary.

In 2002 the radars covered a substantially larger area (Fig. 3A), including about 50 km of the 50-m isobath, 70 km of the 500-m isobath along the offshore bound-

ary, and a portion of the western entrance of the Santa Barbara Channel. The histogram of coverage boundary crossings for May–August 2002 also exhibited two peaks, one between bins 9–11 along the 50-m isobath and a second in bin 31 along the offshore side of the coverage boundary (Fig 3B). In 2002, 24% of trajectories crossed the 50-m isobath (bins 1–13), 69% crossed the



offshore side (bins 22–39), and the remainder crossed the northern side (6%) or the southern side (1%).

To compare results more directly between years, a histogram of crossings was generated from the 2002 trajectories, using the 1999 coverage boundary. The 1999 coverage boundary was completely contained within the 2002 coverage boundary. With the 2002 trajectories, a peak in the histogram again occurred along the offshore boundary (Fig. 4, left-hand scale), this time at bin 12 compared with bin 11 when the 1999 trajectories were used. A second, but much smaller peak occurred along the 50-m isobath at bin 3, consistent with the small peak along the 50-m isobath of Fig. 2B. Table 1 and the cumulative histogram (Fig. 4, right-hand scale) showed that 18% of trajectories crossed the 50-m isobath, 66% crossed the offshore side of the coverage boundary, and the remainder crossed either the northern (7%) or southern (8%) sides.

The time required for trajectories to cross the coverage boundary, defined in our study as the residence time, varied between years and mainly depended on the size of the coverage area. In 1999 the mean and standard deviation for the residence time was 19 ± 12 hours, and the maximum was 86 hours (Table 1). In 2002 they were 47 ± 34 hours and the maximum was 163 hours. When the 2002 trajectories were computed over the 1999 coverage boundary, residence times were comparable to the 1999 values: 22 ± 18 hours and a maximum of 116 hours.

Discussion

Because of limitations in spatial coverage, the HF radar-derived trajectories could not be used to examine the full range of length and time scales over which actual trajectories may extend. We used a trajectory data set resulting from the release of Argos drifters in the region to examine these scales. Drifters were deployed in the Santa Barbara Channel and Santa Maria Basin at irregular intervals from October 1992 through December 1999 as part of a circulation study conducted by the Scripps Institution of Oceanography (SIO; see Dever [1998] and Winant et al. [2003] for a description of the drifter data set). Drifter positions were obtained up to six times per day, typically for 40 days, and had a spatial accuracy of about 1 km. Several trajectories ended earlier when the drifters beached.

No drifters were released at Platform Irene although many approached the platform after release elsewhere (130 drifters were deployed to the north of Platform Irene, and 440 were deployed to the south). To approximate trajectories originating at Platform Irene, all drifters released during all seasons for all years, and approaching within 10 km of the platform, were identified. This distance is a compromise between proximity to the platform and ensemble size; 93 trajectories approached within 10 km of Platform Irene (white circle in Fig. 5 is 10 km in radius and is centered on Platform Irene). Of these, 34 were released north and 59 south of Platform Irene. The ensemble of trajectories beginning

within 10 km of Platform Irene (gray and black dots, Fig. 5) mainly followed the trend of southward advection by the California Current System, although a smaller number extended northward from the platform and a few reached Monterey Bay. Four trajectories entered the Santa Barbara Channel.

A further sorting of the ensemble of 93 trajectories approaching within 10 km of Platform Irene to include only those during 1 May–31 August of all years produced a subset of 21 trajectories (black dots, Fig. 5). Of these, 17 crossed the 2002 coverage boundary: 3 on the 50-m isobath, 12 on the offshore boundary, 2 on the northern boundary, and 0 on the southern boundary. Although the ensemble was small, the fraction of drifters crossing the inshore boundary of the 2002 coverage area (18%) was comparable to the fraction of HF radar-derived trajectories that did so (24%), as shown in Table 1. Most trajectories crossing the offshore boundary continued offshore and southward, consistent with advection by the California Current System. Others crossing the offshore boundary extended north of Platform Irene before turning southward or offshore. The two trajectories crossing the northern boundary remained near shore and crossed the 50-m isobath north of the platform. None of these 17 trajectories entered the Santa Barbara Channel. Except for three drifters that beached, all the drifters remained offshore for the duration of Argos data logging.

Trajectories crossing the 50-m isobath tended to do so north of platform Irene, as shown by most of the computed trajectories and three of the SIO drifters (Figs. 2B and 3B). This movement indicates that transport from the platform to shallow water habitat along the mainland coast mostly occurred during times of northward, or poleward, currents. Poleward flow in the region north of Pt. Conception results from weakening or reversal of the prevailing upwelling favorable winds, the so-called “relaxation” flow state described by Dever (2004), Harms and Winant (1998), and Winant et al. (2003). They also described two other flow states, “upwelling” and “convergent,” which produce offshore and equatorward transport near Platform Irene. Together these flow states have a 69% probability of occurring during May–Aug (36% for upwelling and 33% for convergent), whereas the relaxation state has a 23% probability of occurring (Winant et al. [2003], their Table 3). For comparison, 19–30% of trajectories (HF radar-derived plus actual drifters) crossed the inshore and northern boundaries, consistent with the relaxation probability and 70–81% crossed the offshore and southern boundaries, consistent with the upwelling plus convergent probability.

The trajectories can also be used to estimate recruit survival, based on the time required for transport to habitat. Recruit survival is estimated from a simple exponential decay model:

$$P(t) = P_0 e^{-mt}, \quad (3)$$

where m = mortality (0.02 or 0.06/day, Ralston²);

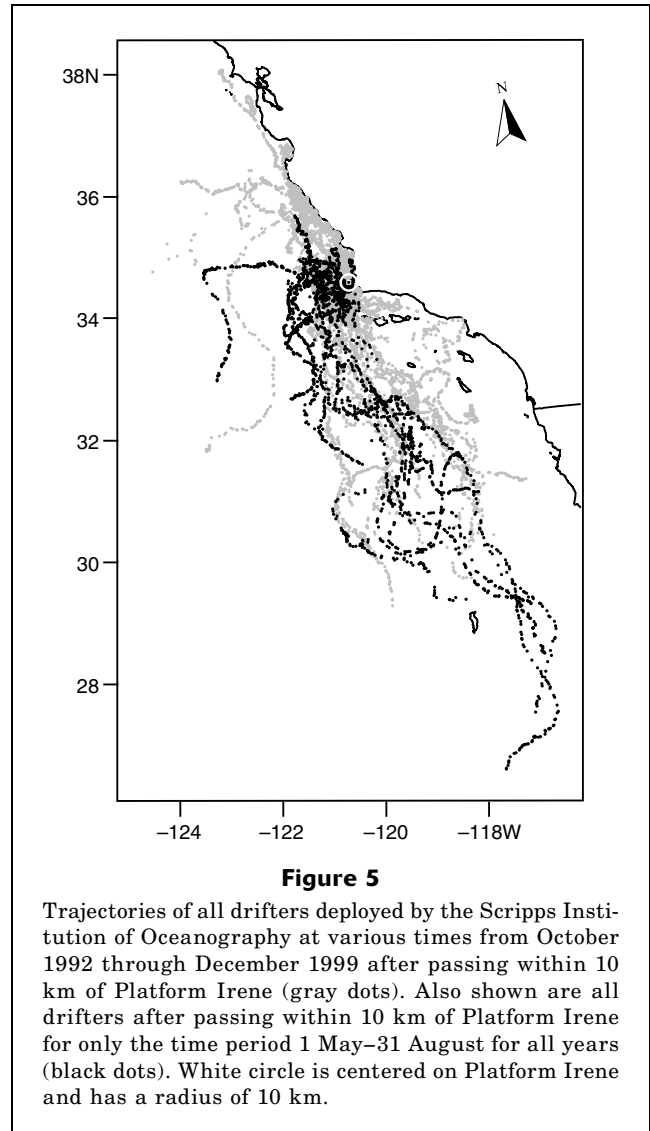


Figure 5

Trajectories of all drifters deployed by the Scripps Institution of Oceanography at various times from October 1992 through December 1999 after passing within 10 km of Platform Irene (gray dots). Also shown are all drifters after passing within 10 km of Platform Irene for only the time period 1 May–31 August for all years (black dots). White circle is centered on Platform Irene and has a radius of 10 km.

P = population at time t ; and
 P_0 = the initial population.

Here, P_0 represents the population of juvenile bocaccio that recruited at Platform Irene, and survival estimates are used to predict their survival in the absence of the platform. In 1999 and 2002, trajectories to habitat from Platform Irene crossed the 50-m isobath within 19–47 hours (Table 1), indicating a high percentage of survival for bocaccio (96–98%). In contrast, offshore and southward drifter trajectories from the SIO drifter data indicated much lower survival. Pelagic juvenile bocaccio transported by these flows would be carried southward by the California Current and remain far from the mainland and the Northern Channel Islands (Fig. 5)

² Ralston, S. 2004. Personal commun. NOAA National Marine Fisheries Service, 110 Shaffer Road, Santa Cruz, CA 95060.

for at least 40 days, the nominal time the drifters were tracked. Survival after 40 days along these trajectories ranged from 9 to 45%.

It is possible that juvenile bocaccio spend time away from near surface waters during their planktonic larval phase and therefore their trajectories may depend on deeper currents. Previous observations in the study region show strong correlation between near surface and deeper flows, indicating that inferences from surface trajectories apply to deeper trajectories. Comparing moored current meters at 5 and 45 m depth, Dever (2004), Harms and Winant (1998), and Winant et al. (2003) generally found a high correlation between current directions, and a decreased flow speed at depth. They also found that poleward flow at 45 m occurs during the convergent and relaxation states, and equatorward flow occurs during the upwelling state. Therefore, during relaxation and upwelling states, currents at 45 m likely have similar directions, but lower speeds compared with surface currents. During the convergent state, currents at 45 m are opposite surface currents, indicating that surface currents represent deeper currents only to some shallower depth.

We assumed in this trajectory analysis that juvenile bocaccio effectively behave like passive particles. We made this assumption for two reasons: 1) this assumption allowed us to focus on the lower bound of their range of possible swimming behaviors; and 2) such an assumption also eliminated the need to account for their actual swimming behavior in the open ocean, about which little is known. We do not assume that juvenile bocaccio do not swim; rather, we assume that they swim randomly such that their effective transport is similar to that of passive particles. The other behavioral limit of rapid, consistently directional swimming behavior would likely alter the fraction of bocaccio encountering shallow habitats versus the fraction being advected offshore. Flume experiments with visual cues for directional orientation demonstrate that coral reef fish in the late pelagic stage can swim up to ~100 km in 8 days (Stobutzki and Bellwood, 1997); therefore behavioral modification of trajectories could be very important. Larval and pelagic juvenile fish may possess swimming and sensory abilities to overcome passive drift in currents; however, some kind of external reference is necessary for fish to detect and respond to the direction of a current. In a review of the behavior of larval and juvenile fish in the pelagic environment, Leis and McCormick (2002) pointed out that it is yet to be demonstrated that these early-stage fish in offshore "blue water" can effectively modify current-driven trajectories by orienting to cues from settlement habitat located at a scale greater than several kilometers away. A variety of near-field stimuli, such as light and temperature gradients, sound, and visible prey affect swimming behavior. Clearly more research is needed to evaluate the effects of swimming behavior of temperate reef fishes, such as bocaccio, in order to model their dispersal. We speculate, however, that the assumption of passive dispersal will remain

an important lower bound on constraining effects of swimming behavior.

Smoothing and interpolation in the processing of the HF radar velocity data limit the spatial resolution of current fluctuations to scales of ~6 km, the diameter of circles used to compute velocity vectors. Velocity structures smaller than this scale are not resolved but may be important in determining trajectories. For example, Helbig and Pepin (2002) found that errors in modeling the spatial distributions of fish eggs in an embayment increased as spatial resolution of a circulation model decreased. Assuming effects of unresolved velocity structures on smaller scales act as a diffusive process, we speculate that incorporating diffusion would cause the locations of the boundary intersections to spread to adjacent bins. In this case, peaks in the histograms (such as in Figs. 2B, 3B, and 4) would decrease as diffusion spreads boundary intersections to adjacent bins. Velocity statistics at scales of the order of a few km and smaller in our study area, however, are not available for incorporating the effects of diffusion into the trajectories. Results from actual drifters, which do contain velocity structure unresolved by the HF radars, are not very different from HF-radar-derived trajectory results (Table 1), indicating that the effects of unresolved variance are not large. For predicting settlement to habitat, trajectory improvements gained through the incorporation of smaller scale flow features may be offset by assumptions of swimming behavior and habitat location.

Questions and issues have arisen in the decommissioning process about the regional importance of platform fish assemblages (Schroeder and Love, 2004). For example, does removal of a platform impact the bocaccio population? Based on our annual research submersible surveys (detailed in Love et al., 2003) conducted in 1997, 1998, 1999, and 2001, estimates of YOY bocaccio at Platform Irene ranged from 61 (2001) to 41,000 (1999) (Lenarz³). YOY bocaccio abundances can be even higher than those observed at Platform Irene. We have recently estimated that, during 2003, Platform Grace, located in the Santa Barbara Channel, harbored over 300,000 YOY bocaccio (Lenarz³). Under even the most conservative parameters, this would translate into many thousands of adults (MacCall⁴). In addition, there is evidence that some of the bocaccio that recruit to platforms as YOYs migrate, and thus seed, natural reefs. Fish tagged at Platform A, located off Summerland, CA, in the Santa Barbara Channel, were later recovered over natural reefs over 100 km to the north and south of that platform (Hartmann, 1987). In another study, recruiting bocaccio became resident on a deep-water platform and formed the highest density of adult fish observed in the Southern California Bight

³ Lenarz, W. 2004. Personal commun. P.O. Box 251, Kentfield, CA 94914-0251.

⁴ MacCall, A. 2004. Personal commun. NOAA National Marine Fisheries Service, 110 Shaffer Road, Santa Cruz, CA 95060.

(Love et al., 2003). Thus, bocaccio that recruit as YOYs to a platform may benefit natural reefs either through emigration to these reefs or through increased larval production.

Conclusion

Observations of evolving surface current patterns obtained by HF radar are used to estimate dispersal pathways for juvenile bocaccio in the vicinity of Platform Irene, an oil production platform off the central California coast. Results indicate that most of YOY bocaccio settling around Platform Irene would not survive in the absence of the platform. Instead, prevailing currents would likely advect them offshore where they would have a very low probability of survival. Although it is possible that some individuals would encounter acceptable nursery habitat on offshore banks or islands, it is likely that most would perish. Thus, the presence of Platform Irene almost certainly increases the survival of young bocaccio in the Point Conception–Point Arguello region.

These results indicate that knowledge of regional ocean circulation patterns is essential for evaluating the effects of oil production platforms, or other artificial habitats, on dispersal pathways of juvenile fishes. Platform location, local current patterns, and natural habitat distribution determine the balance between settlement at a specific platform and settlement on natural habitat. The approach used in this study, an analysis of trajectories derived from HF radar current measurements, can provide insights into this balance. Additional research on small-scale circulations features unresolved by the radars and on swimming behavior of juvenile rockfishes will sharpen these insights.

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Literature cited

- Boehlert G. W.
1977. Timing of the surface-to-benthic migration in juvenile rockfish, *Sebastes diploproa*, off southern California. *Fish. Bull.* 75:887–890.
- Dever E. P.
2004. Objective maps of near-surface flow states near Pt. Conception, California. *J. Phys. Oceanogr.* 34:444–461.
- Dever E. P., M. C. Henderschott, and C. D. Winant.
1998. Statistical aspects of surface drifter observations of circulation in the Santa Barbara Channel. *J. Geophys. Res.* 103:24,781–724,797.
- Emery B. M., L. Washburn, and J. A. Harlan.
2004. Evaluating radial current measurements from CODAR high-frequency radars with moored current meters. *J. Atmos. Oceanic Technol.* 21:1259–1271.
- Emery W. J., and R. E. Thomson.
1998. Data analysis methods in physical oceanography, 634 p. Pergamon, Elsevier Science, Inc., New York, NY.
- Graber H. C., B. K. Haus, R. D. Chapman, and L. K. Shay.
1997. HF radar comparison with moored estimates of current speed and direction: expected differences and implications. *J. Geophys. Res.* 102:18,749–18,766.
- Gurgel K. W.
1994. Shipborne measurement of surface current fields by HF radar. *L'Onde Electrique* 74:54–59.
- Harms S., and C. D. Winant.
1998. Characteristic patterns of the circulation in the Santa Barbara Channel. *J. Geophys. Res.* 103:3041–3065.
- Hartmann A. R.
1987. Movement of scorpionfishes (Scorpaenidae: *Sebastes* and *Scorpaena*) in the Southern California Bight. *Calif. Fish Game.* 73:68–79.
- Helbig J. A., and P. Pepin.
2002. The effects of short space and time scale current variability on the predictability of passive ichthyoplankton distributions: an analysis based on HF radar observations. *Fish. Oceanogr.* 11:175–188.
- Leis J. M., and M. I. McCormick.
2002. The biology, behavior and ecology of the pelagic, larval stage of coral reef fishes. *In* Coral reef fishes: dynamics and diversity in a complex ecosystem (P. F. Sale, ed.), p. 171–199. Academic Press, San Diego, CA.
- Lenarz W. H., R. J. Larson, and S. Ralston.
1991. Depth distributions of late larvae and pelagic juveniles of some fishes of the California Current. *Calif. Coop. Ocean. Fish. Invest. Rep.* 32:41–46.
- Love M. S., J. Caselle, and L. Snook.
1999a. Fish assemblages around seven oil platforms in the Santa Barbara Channel area. *Fish. Bull.* 98:96–117.
1999b. Fish assemblages on mussel mounds surrounding seven oil platforms in the Santa Barbara Channel and Santa Maria Basin. *Bull. Mar. Sci.* 65:497–513.

- Love M. S., M. M. Nishimoto, and D. M. Schroeder.
2001. The ecological role of natural reefs and oil and gas production platforms on rocky reef fishes in southern California: 1998–1999 survey report, 115 p. U. S. Department of the Interior, U.S. Geological Survey, Biological Resources Division, Seattle, Washington, 98104.
- Love M. S., D. M. Schroeder, and M. M. Nishimoto.
2003. The ecological role of oil and gas production platforms and natural outcrops on fishes in southern and central California: a synthesis of information. U.S. Department of the Interior, U.S. Geological Survey, Biological Resources, Seattle, WA.
- Love M. S., M. Yoklavich, and L. Thorsteinson.
2002. The rockfishes of the northeast Pacific, 405 p. Univ. California Press, Berkeley, CA.
- Mitchell C. T., and J. R. Hunter.
1970. Fishes associated with drifting kelp, *Macrocystis pyrifera*, off the coast of southern California and northern Baja California. Calif. Fish Game 56:288–297.
- Ohlmann J. C., P. F. White, A. L. Sybrandy, and P. P. Niiler.
2005. GPS-Cellular drifter technology for coastal ocean observing systems. J. Atmos. Oceanic Technol. 22:1381–1388.
- Paduan J. D., and L. K. Rosenfeld.
1996. Remotely sensed surface currents in Monterey Bay from shore-based HF radar (coastal ocean dynamics application radar). J. Geophys. Res. 101:20,669–620, 686.
- Ross J. R., and R. J. Larson.
2003. Influence of water column stratification on the depth distributions of pelagic juvenile rockfishes off central California. Calif. Coop. Ocean. Fish. Invest. Rep. 44:65–75.
- Schroeder D. M., and M. S. Love.
2004. Ecological and political issues surrounding decommissioning of offshore oil facilities in the Southern California Bight. Ocean Coast. Manag. 47:21–48
- Stewart R. H., and J. W. Joy.
1974. HF radio measurements of surface currents. Deep-Sea Res. 21:1039–1049.
- Stobutzki I. C., and D. R. Bellwood.
1997. Sustained swimming abilities of the late pelagic stages of coral reef fishes. Mar. Ecol. Prog. Ser. 149: 31–41.
- Winant C. D., E. P. Dever, and M. C. Henderschott.
2003. Characteristic patterns of shelf circulation at the boundary between central and southern California. J. Geophys. Res. 108:3021.