

Evidence of homing of black rockfish *Sebastes inermis* using biotelemetry

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ABSTRACT: The black rockfish *Sebastes inermis* is one of the most important fishery species along the coast from southern Hokkaido to Kyushu, Japan and is often found in rocks and *Zostera* areas. We conducted biotelemetry using coded ultrasonic transmitters to clarify the movement of the black rockfish that inhabited the seawall of the Kansai International Airport. We released 25 black rockfish at two points. One was the airport seawall and the other was side shallows off the Sensyu district. Seventeen black rockfish returned to their capture site after release. We used the V-test to determine whether the direction of movement was random or orientated. The black rockfish moved at random along the seawall within some hours after release ($P > 0.05$). Four hours after release, they moved to their home site intentionally ($P < 0.0025$).

KEY WORDS: biotelemetry, black rockfish, coded ultrasonic transmitters, homing.

INTRODUCTION

Some marine fish show a distinct homing ability. The understanding of their homing ability and home range can help in the effective management of fisheries. Carlson and Haight showed evidence for a home site and homing of adult yellowtail rockfish *Sebastes flavidus* using anchor 'spaghetti' tags made of vinyl plastic.¹ They found that the fish returned to the home site from as far as 22.5 km, some after displacement to other schools of the species and some after 3 months in captivity. Percy also studied 25 yellowtail rockfish on Heceta Bank, off Oregon, USA, by acoustical tagging and tracking during the summers of 1988–1990 and reported the rockfish possessed homing ability.² Matthews monitored the daily position of copper rockfish *Sebastes caurinus* and quillback rockfish *Sebastes maliger* as they proceeded back to their home site after experimental displacements of 500 m from a high relief rocky reef to a low relief rocky reef.³ The movements of olive rockfish *Sebastes serranoides* were restricted

over shallow reefs.⁴ These were common rockfish along the coast of North America.

In Japan, the black rockfish *Sebastes inermis* might have home site and homing ability like other rockfish. Black rockfish is a common species along the coast of Japan, from southern Hokkaido to Kyushu, and is often found in rocks and *Zostera* areas.⁵ The black rockfish is used in both commercial and sport fisheries. From a study of allele frequencies, the black rockfish did not seem to move on a large scale.⁶ Though the black rockfish grows slowly in comparison with other rockfish species in Japan, its life span is relatively long.^{7–10} However, until recent advances of microelectronic technology, the sample fish could not be tracked continuously so there are no reports about the black rockfish's homing ability. Clarifying the homing ability of the black rockfish would not only help the understanding of the instinct and memory of animals but also the management of fisheries resources.

One of the solutions to determining the homing ability is biotelemetry using ultrasonic transmitters and receivers. Ultrasonic transmitters and receivers of biotelemetry have been used since the 1960s and their performance has improved since then due to the rapid development of microelec-

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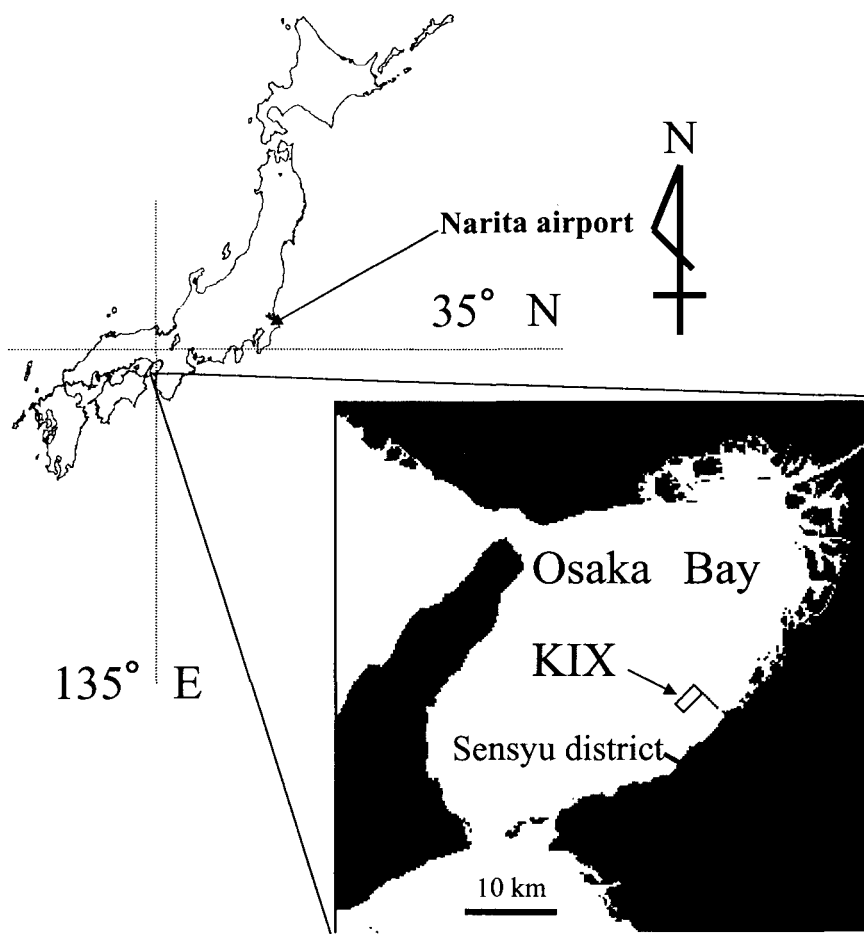


Fig. 1 Map of Kansai International Airport (KIX). The airport is located in Osaka Bay, 5 km off the Sensyu district.

tronics technologies.¹¹⁻¹³ We used coded ultrasonic transmitters (V8SC-6L, Vemco, Nova Scotia, Canada) to track many fish simultaneously. We could track up to 256 different fish using the transmitters on the same frequency. Although black rockfish usually do not form a large school, in most cases 10-20 adult black rockfish aggregate in rock crevices and holes or lurk under boulders in smaller groups or individually.⁵ The transmitters are the most suitable to track black rockfish inhabiting the same place at the same time. The objective of this study was to examine whether black rockfish possess a homing ability. We used biotelemetry with newly coded ultrasonic transmitters.

MATERIALS AND METHODS

Study site

The Kansai International Airport (KIX) was opened in 1994 and is the only marine airport in the world. It is located off the Sensyu district in the southern part of Osaka Bay, Japan and is an international

airport next to Narita airport (Fig. 1). The sea around KIX is 18 m deep and the seafloor is extremely soft. The airport is 11.2 km in circumference. To minimize the environmental influence, most of the seawall (8.7 km) of KIX is a gently sloping rubble mound. Many kinds of seaweed grow here and many marine organisms inhabit the seawall. Moreover, this seawall is a spawning ground and nursery for marine organisms. We qualitatively surveyed the bottom topography in the gently sloping rubble of the eastern seawall using an echo sounder to understand the details of our study areas.

For environmental protection and airport security reasons the Osaka Prefecture government prohibits all fishing activity within 390 m along the north, west, and south sides and within 490 m along the east side of the airport island. These areas are not disturbed by fishing efforts. Therefore, these prohibited sea areas were suitable for the research of the natural behavior of the sample fish. Moreover, some instruments, such as, ultrasonic receivers and temperature data-loggers were moored safely in the areas.

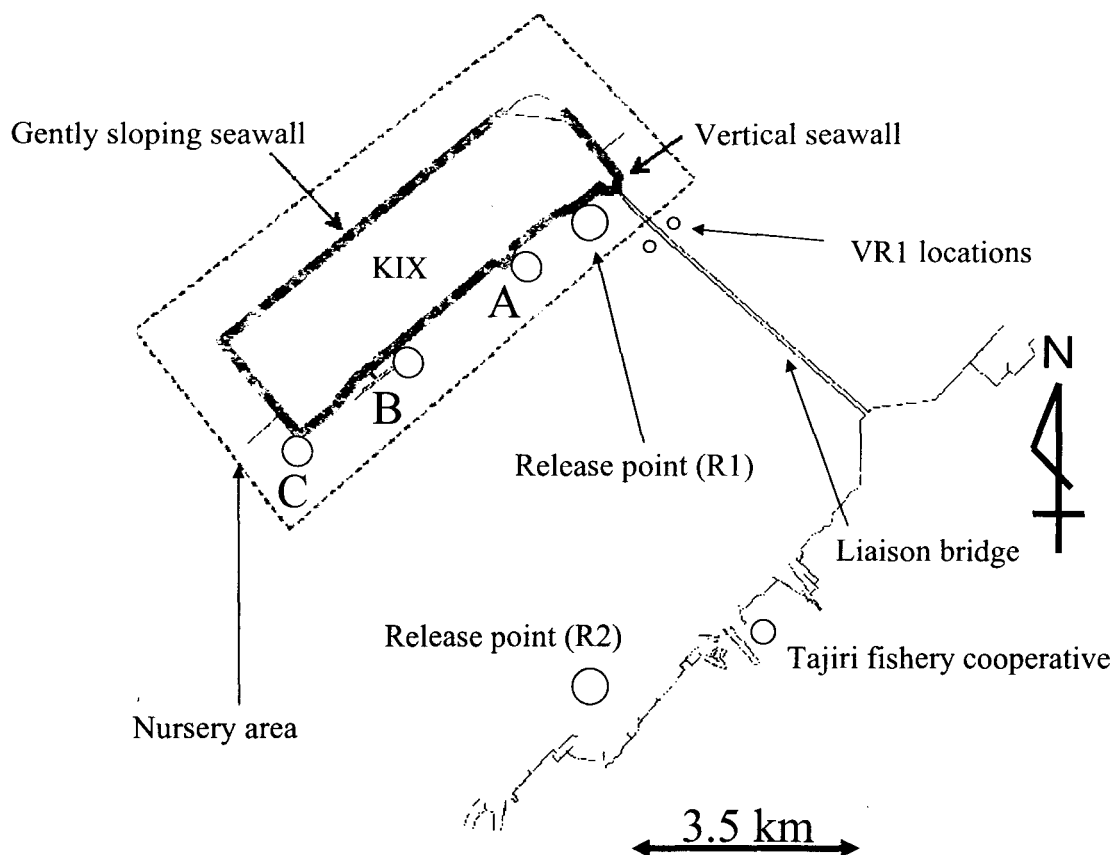


Fig. 2 The study area and two release points, R1 and R2. The marks A, B and C indicated the fishing points where the sample rockfish were caught. The two VR1 systems were set up at the no. 4 girder of the liaison bridge.

Tagging with coded ultrasonic transmitters

Twenty-five sample rockfish were collected at three points (A, B and C), within a radius of approximately 100 m of the eastern seawall of the airport island from September to November 2000 (Fig. 2). Special permission was obtained from the Osaka Prefecture government. The fish were mature because sexual maturity is first attained when the fish are 2 years of age and >150 mm of the total length (Table 1).^{9,10} The fish were held for 4–5 days in tanks at the Tajiri fishery cooperative before the implantation of the coded transmitters. The Tajiri fishery cooperative is the nearest fishery cooperative to KIX at the southern foot of the liaison bridge (Fig. 2).

We used an ultrasonic coded transmitter (V8SC-6L, Vemco) that was 8.5 mm in diameter, 25 mm long, and weighed 2.2 g in water. The transmitter was used to transmit complex codes of up to six pulses. We could identify up to 256 different fish on the same frequency.¹⁴

The transmitters were implanted surgically into the abdomen of the fish. The surgical treatment

was carried out under anesthesia using 0.1% 2-phenoxyethanol. The implant operation took about 5 min. The fish was placed between some sponge rubbers in a bath of fresh bubbling seawater during the operation. An incision of about 10 mm in length was made in the abdomen of the fish and the transmitter was inserted. The wound was closed with an operating needle and suture. An antibiotic was applied. After the surgical treatment the fish were held in fish tanks for 4 days.

Four release experiments were carried out on 18 September, 6, 22, and 25 November 2000. The fish were released one at a time into a basket at a water depth of approximately 15 m at two release points (R1 and R2). R1 was located at the northern end of KIX, where the seawall is not gently sloping rubble. The other point (R2) was located at the opposite side in the shallows of KIX. We released 13 fish in R1 on 18 September, three fish in R1 and three fish in R2 on 6 November, two fish in R1 and two fish in R2 on 22 November and two fish in R1 on 25 November (Table 1). The distance from the point of initial capture at A, B, and C to the release point (R1) was about 1 km, 2.5 km and 3.5 km, respec-

Table 1 Summary of total lengths, date tracking began, recovery duration, homing duration, captured point, release point and site of final destination of the sample fish.

ID	Total length (mm)	Date tracking began	Recovery duration (days)	Homing duration (days)*	Captured point [†]	Release point [‡]	Site of final destination [§]
64	238	18-Sep-00	2	N	B	R1	Other
73	207	18-Sep-00	53	1	B	R1	B
74	215	18-Sep-00	8	N	B	R1	A
75	220	18-Sep-00	2	N	B	R1	Other
76	218	18-Sep-00	8	1	B	R1	B
108	190	18-Sep-00	2	1	A	R1	A
109	237	18-Sep-00	2	1	A	R1	A
110	212	18-Sep-00	43	7	A	R1	A
111	208	18-Sep-00	67	N	C	R1	Other
112	206	18-Sep-00	8	7	C	R1	C
113	203	18-Sep-00	32	1	C	R1	C
114	206	18-Sep-00	53	1	C	R1	C
115	208	18-Sep-00	73	1	C	R1	C
171	235	6-Nov-00	40	2	B	R1	B
172	222	6-Nov-00	4	4	B	R2	B
174	223	6-Nov-00	2	Recaptured	B	R2	-
175	237	6-Nov-00	40	11	C	R2	C
176	215	6-Nov-00	40	4	C	R1	C
177	213	6-Nov-00	35	N	C	R1	A
57	215	22-Nov-00	24	2	B	R1	B
98	223	22-Nov-00	24	2	B	R2	B
180	205	22-Nov-00	1	N	C	R2	Other
181	210	22-Nov-00	24	4	C	R1	C
99	230	25-Nov-00	10	1	C	R1	C
185	200	25-Nov-00	2	N	C	R1	A

*Homing duration means the days it took to return to point of capture.

[†]Captured point A, B and C in Fig.2.

[‡]Release point R1 and R2 in Fig.2.

[§]Site of final destination, means the place of the fish at the end of the experiment.

N, no homing; Recaptured, the sample fish (ID:174) was recaptured by a fisherman at the place between the captured point and the release point; A, B and C, were captured points in Fig.2; Other, means a point that is different from A, B and C.

tively. The distance from the release point R2 to the points of initial capture (A and B) was about 4.5 km. We tracked the fish continuously for 25 h after release on 18–19 September and for 8 h on 6, 22 and 25 November. After the initial continuous tracking the fish were tracked intermittently for 8 h every 2–3 days until 15 December 2000. We tracked the sample fish around the KIX island and along the opposite side in the shallows of the KIX.

Tracking system

We used two different types of system, one VR28 and two VR1 systems (Vemco) to track the tagged fish. The VR28 system had four hydrophones that could detect the direction of the fish with a transmitter. The hydrophone array was installed in the research vessel. Signals from coded transmitters were received through a 4-channel receiver by the hydrophone system. The receiver was connected to a personal computer. The receiving strength

from the four hydrophones was used to determine the direction of individuals on the monitor of the computer. The ID number of the coded transmitter and the position of the vessel from global positioning system (GPS; Garmin, Olathe, KS, USA) were recorded. Garmin GPS receivers are accurate to within 15 m on average. We managed the research vessel along the east seawall of KIX, and we considered the point where all of the 4-channel receivers detected the signals, within about 20 m from the tagged fish, as the position of the fish.

The VR1 system was the data logger to record attendance of tagged fish with coded transmitter. The dimension was 60 mm in diameter with 205 mm length. The system was powered by a lithium battery that lasted for 180 days and had flush-memories inside to record data. This receiver was installed in the place at a middle water depth where the tagged fish passed through in advance. The ID number, the date and time were recorded when the tagged fish passed within 300–500 m of the receiver. We installed two VR1 systems in

this study at the no. 4 girder of the liaison bridge (Fig. 2).

RESULTS

The attendance of any tagged fish near the VR1 system was recorded. However, the VR1 systems at the liaison bridge recorded few attendances of the fish after release. Therefore, we used the first attendance of the fish recorded by the VR1 system. When we tracked all the fish using the VR28 system along the seawall of the KIX, we identified the fish. However, we found no fish except for just after release at R2 when we tracked around the opposite side in the shallows of KIX.

Throughout the experiment, the tagged fish released at the point R1 moved north-east or south-west along the east seawall of the KIX or stayed around the release point just after the release. Most of the sample fish moved along the east seawall from the release point (R1) to the south-western direction after 4–5 h release (Fig. 2). Fourteen of the 20 fish caught at the three points, A, B, and C on the gently sloping seawall and released at R1, were identified at their original habitat by the VR28 system. We identified three of three individuals from A to A (100%); four of seven individuals from B to B (57%); and seven of 10 individuals from C to C (70%). Of these, 12 fish migrated to their habitat within 4 days and two fish migrated to their habitat after 7 days. Six fish released at R1 did not return to the site where they were captured. The fish that migrated to their original sites did not move out of these habitats during our investigation (Table 1). The six fish that did not home stayed around the release point R1 or moved back and forth on the east seawall. None of them passed their original sites. The echo sounder suggested that the bottom topography of points A, B, and C featured rough rubble bottoms. The tagged fish migrating to their home were often found at these featured bottoms. That is, the tagged fish stopped at the featured bottom area and went to one after another during migration and then they homed.

Five tagged fish released at R2 moved north-east or south-west along the coast of Sensyu after the release. Three of the five fish (ID: 98, 172 and 175) migrated to their habitat within 2–11 days. One fish (ID: 174) was recaptured by a fisherman a day after release at a place between the release point and the fish's habitat. One fish released at R2 was only tracked for 1 day and did not return to the original site of capture. The VR1 systems did not record the five fish that were released at R2. These fish might have moved directly to their home site while not

passing near the VR1 receiver. The rate of homing migration in all experiments were as follows, three of three individuals from A to A (100%); six of 10 individuals from B to B (60%); and eight of 12 individuals from C to C (67%; Table 1).

The Rayleigh test is often used to ascertain whether animals move at random.¹⁵ But the Rayleigh test does not detect if the direction of the return route and the animal's habitat are the same. So instead of the Rayleigh test, we applied the *V*-test to verify two migration patterns of the black rockfish.¹⁵ The *V*-test was used when the investigator had reason to expect that if the sampled distribution was not uniform it would have a certain specific direction. In this study, the specific direction of the *V*-test shows 231.6° to the initial sites from the release point R1. Figure 3a shows a direction to the position we found each black rockfish for the first time after the release of 12 fish that migrated from release point R1. ID: 76 and 109 were not included because their data within 4 h from release were not useful. The circles indicate elapsed time after the release. The testing procedure considers: H_0 , the population was distributed uniformly around the circle (i.e. $H_0: \rho=0$) versus H_A , the population was not distributed uniformly around the circle (i.e. $H_A: \rho \neq 0$), but has a mean of 231.6°. The behavior of the black rockfish was random within 4 h after the release (*V*-test, $P>0.05$).

Figure 3b shows directions from the release point R1 to the positions of 13 rockfish that migrated where we found them for the first time 4 h after the release. ID: 176 was not included because there were insufficient data for this fish. The circles indicate elapsed time after the release. The black rockfish moved at random immediately after release but most (ID: 73, 76, 99, 108, 109, 112, 113, 114, 115 and 171) began to move toward their habitat more than 4 h after the release. Namely, the movement of the black rockfish was significantly different from random after 4 h from release (*V*-test, $P<0.0025$).

DISCUSSION

Transmitter attachment

Mellas and Haynes reviewed three areas of transmitter attachment (external, surgical, and stomach tag) on rainbow trout and white perch.¹⁶ They concluded that stomach tagging is the best method of transmitter attachment. Moore *et al.* concluded that intraperitoneal implantations had no significant effect on growth, feeding or swimming behavior in juvenile Atlantic salmon.¹⁷ Starr *et al.*

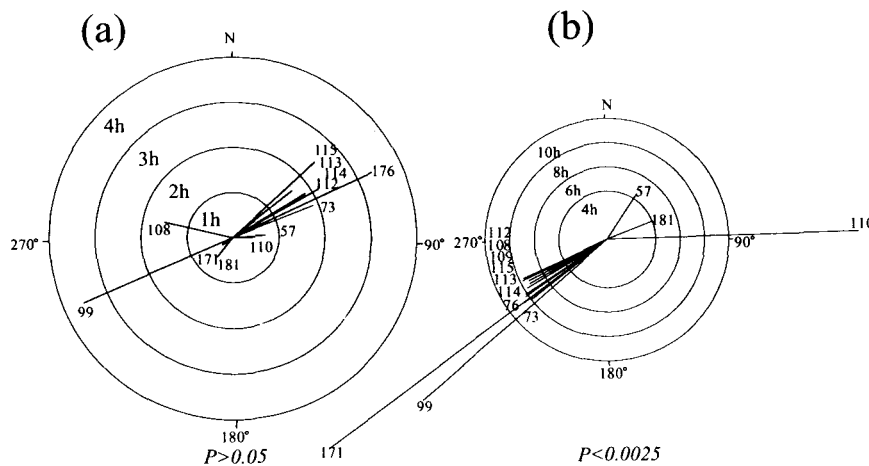


Fig. 3 Circular distributions show the direction and relative times traveled from the release site to next site where we found the tagged fish. (a) Left is circular distribution within 4 h after release; and (b) right is 4 h after release. Numbers represent ID numbers of tagged fish. P -values are results of the V -test of null hypothesis: H_0 , the population was uniformly distributed around the circle; and H_A , the population was not uniformly distributed around the circle.

used scuba divers to surgically implant acoustic transmitters at a depth of 20 m in two species of rockfish, *Sebastes chlorostictus* and *Sebastes paucispinis*, that were captured at depths of 100–200 m.¹⁸ This was done to reduce temperature and pressure stress caused by bringing fish to the surface. However, the black rockfish, *Sebastes inermis*, is a shallow water species (<18 m in our study) and did not experience wide pressure change in the course of our study. In addition, we caught about 50 fish carefully and slowly to reduce temperature and pressure stress. We observed no sign of embolism, stress, or mortality from capture at depth. The implantation had no significant effect on the appearance of swimming behavior, judging from 4 days of observation. No fish died during the holding and surgical procedures at the Tajiri fishery coop.

We could identify many tagged fish at the same place for a long time using coded ultrasonic transmitters. The transmitters are suitable for the tracking of fish, such as black rockfish, that inhabit the same place at the same time. In addition, the VR1 system recorded the attendance of tagged fish automatically. The system does not require a great deal of labor and is suitable for the tracking of fish that do not move on a large scale. The combination of the VR28 receiver system and the VR1 receiver system is a powerful tool to provide useful data about the position of tagged fish and the time of fish attendance in certain areas.

Homing

This study shows that the black rockfish around KIX have homing ability. The olive rockfish *Sebastes serranoides*, off Santa Barbara, California, USA, rarely move between shallow water reefs.⁴ Like the olive rockfish, the black rockfish in this study might

rarely move because the black rockfish did not do large-scale movement after homing. Also, the rocks around the place where we fished the sample fish had cracks. It was thought that the black rockfish in this study lived in the cracks of rocks of the same reef for a long time. Dodson reported that fish migration was based on the interaction of experience and instinct.¹⁹ Reese mentioned that site-specific coral reef fish learn routes and foraging paths by recognizing specific landmarks such as coral heads.²⁰ He hypothesized that site-specific fish, in comparison with mobile, pelagic fish, would be more likely to learn landmarks because they inhabit areas with easily noticeable features.²⁰ The black rockfish grow slowly but they live relatively long lives.^{8–10} The black rockfish that have long lives and do not move far away from their habitat might remember the form of the sea bed and environment around their habitat. In this study, the black rockfish that migrated to their home site were found many times in the rock areas during migration. Also, our study areas had been studied very well by divers who monitor the seawall environment. This monitoring found that many black rockfish were in rock crevices and underneath boulders. In addition, Matthews reported that because all of the displaced rockfish were found on or near the reef area on their return route and some stayed for several days, perhaps rockfish use high relief rock outcrops and rocks as landmarks.³ Therefore, the black rockfish seemed to use specific rocks on the sea bed as landmarks or underwater guideposts.

Matthews reported that copper and quillback rockfish moved in the direction of tidal currents just after release and perhaps rockfish used the strong currents to assist in their movements, or used the currents as a directional cue.³ The black rockfish released at R1 in this study moved along the seawall that restricted the movement direction

of the tagged fish. Matthews mentioned that the current was not flowing in the direction of the home site from the release site. In our study, the black rockfish were displaced from 1000 to 3500 m, about 2–7 times the distance of 500 m used in Matthews' study. However, in our study the home sites and release sites were along the seawall. Matthews also reported that most of the copper and quillback rockfish needed more than 15 days to return to the captured site. In our study 12 of the black rockfish released at R1 returned within 4 days. The seawall was the direction of the home site from the release site and there were many specific rocky areas and artificial structures as landmarks in this study site. Therefore the black rockfish might migrate to their habitat within a few days. If there were more landmarks, artificial structures and currents in the habitat of the study site, the black rockfish might have returned to their habitat in less time.

Three fish released at R2 homed within 2, 4 and 11 days, respectively. Eleven days was the longest homing duration in our study. Because there were no artificial structures, such as, the seawall around the release point (R2), the fish might not have moved to the initial site of capture directly. Also, the distances from R2 to the capture sites, respectively, were longer than the distance from R1. Therefore, fish might have needed 11 days to home because of the longer distance from release point to the capture site and the lack of a landmark, such as, the seawall. The fish that did not home stayed around the release point R1 or moved back and forth on the east seawall. The fish that did not home might have never learned the landmarks to the home site around the release point until release. So the fish moved back and forth along the seawall seeking familiar landmarks. If the fish cannot find their familiar landmarks, they might give up homing or find a more comfortable habitat than their initial habitat.

The black rockfish homing behavior can be classified in two by the *V*-test. One is the behavior 1–4 h after the release. The *V*-test shows that the fish moved at random during this period ($P > 0.05$). The black rockfish either stayed around R1, moved in a north-eastern direction, or in a south-western direction just after the release. The release point R1 was not on the gently sloping rubble mound seawall. This area had few featured rocky areas and artificial structures. The other homing behavior occurred several hours after the release. The *V*-test shows that the fish would move intentionally in the period 4 h after release ($P < 0.0025$). The black rockfish moved along the seawall after the release and may have seen a landmark learned before, for example, the gently sloping rubble mound

seawall and the liaison bridge. Once they knew the direction of each habitat they would begin to migrate. None of the black rockfish that began to migrate turned back greatly in the opposite direction of each habitat until they finished homing. That is, once they started to migrate the black rockfish seemed to return to their habitat without getting lost.

In this study, we found evidence of the homing behavior of the black rockfish around the KIX island. The black rockfish that homed moved at random within 1–4 h after release, and then they moved to their habitat. It suggests that the rockfish are seeking familiar cues, such as, landmarks as well as olfaction, bottom current or acoustic cues before starting to home. However, the main question, 'what is the real cue' remains to be answered.

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