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Vol. 8(12), pp. 126-139, December 2016
DOI: 10.5897/IJFA2016.0546
Article Number: E2D42DD61769
ISSN 2006-9839

http://www.academicjournals.org/IJFA

International Journal of Fisheries and Aquaculture

Full Length Research Paper

Movement patterns of Chilean flounder (*Paralichthys adspersus*) inside Tongoy Bay (central northern Chile): Observations using passive acoustic telemetry

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Received 22 February, 2016; Accepted 1 September, 2016

The movement patterns of juvenile and adult Chilean flounder (*P. adpersus*) were investigated inside Tongoy Bay using ultrasound signal acoustic receivers from June 2012 to March, 2013. Flounder landings in Tongoy Bay and Puerto Aldea from December 2011 to March 2013 were examined. Multiple regression analysis indicated that the Catch per Unit of Effort of Chilean flounder was significantly and negatively related to temperature and depth. Analyses of site- and time-specific length-frequency distributions indicated movement of Chilean flounder on the time scale of weeks, which was likely due to emigration of fish >30 cm in total length. A mark-recapture study was performed. Visible elastomer paint was used to tag 7,510 Chilean flounder. A total of 12 Chilean flounder individuals of different lengths were tagged with an ultrasound transmission device to monitor their movement inside Tongoy Bay. Adults flounder showed increased activity inside Tongoy Bay during the study period, likely due of the differences in length among the released individuals. Although differences were detected in the area occupied by juvenile and adult flounders in Tongoy Bay, it was also noticed that the smaller sized individuals exhibited changes in behavior after implanting the transmitters that resulted in impaired capacity to move freely.

Key words: Chilean flounder, acoustic telemetry, movement patters, landing, mark-recapture.

INTRODUCTION

Chilean flounder (*Paralichthys adspersus*) is a flatfish with bentho-demersal habits of commercial and recreational importance distributed from the locality of Paita (northern Peru) to the Gulf of Arauco (Chile), including the Juan Fernández Archipelago (Pequeño, 1989; Sielfeld et al., 2003). As in the case of other fish, flounders exhibit remarkable bathymetric movements and horizontal migrations. Seasonal variations, the extent and direction of these movements in flounder stocks can differ considerably between species and geographic areas as a result of the large amount of biotic and abiotic factors (that is, temperature, salinity, dissolved oxygen, depth and type of substrate, currents, availability of food, competition, among others; Able et al., 2005).

In this regard, the habitat use patterns for this species may vary at different spatial, time scales, and ontogeny

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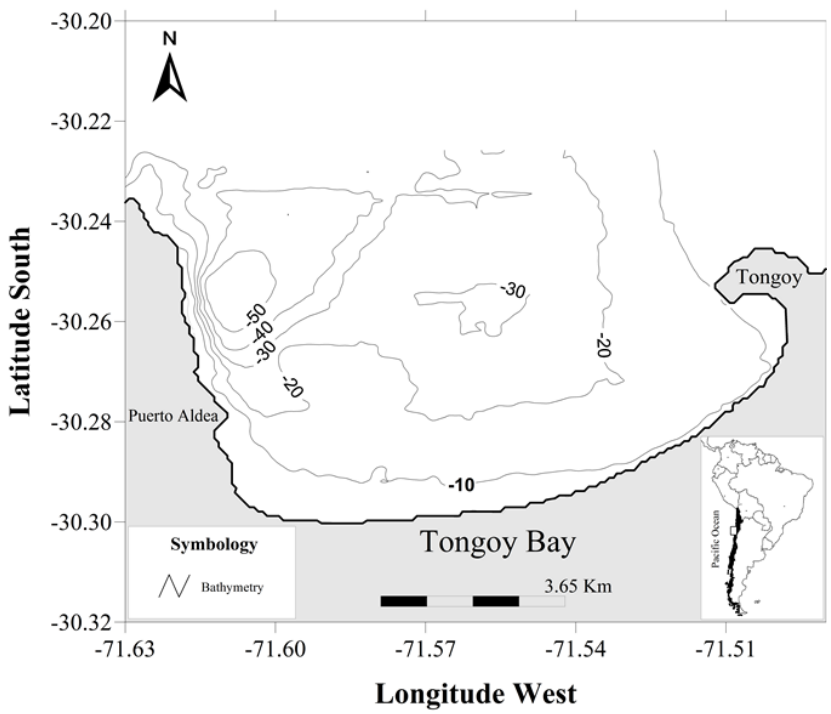

Figure 1. Location of Tongoy Bay, central northern Chile.

(Armstrong, 1997; Howell et al., 1999; Goldberg et al., 2002). The movement of individuals between habitats can affect instantaneous abundance, growth and mortality estimations, and therefore, the quality of the assessment of a specific habitat. The movement of marine fish inside coastal and estuarine systems may occur in response to resource availability (resource-directed dynamics), or as a result of migration processes (non-resource mediated migration; sensu Dingle, 1996). It is essential to study the movement and migration under short spatial and time scales in order to understand the role of coastal and estuarine systems as nursery areas for juvenile marine fish, and assess various habitats (Saucerman and Deegan, 1991; Beck et al., 2001; Burrows et al., 2004).

Seasonal distribution patterns were obtained from catch data analysis and landing records (SERNAPESCA, 2012). Nevertheless, these data sources offer a limited perspective of Chilean flounder residence patterns and habitat use. In addition, these traditional sampling sources to obtain distribution data cannot identify individual movement variability or reproductive behavior.

The magnitude of variability in individual distribution patterns of Chilean flounder is still little known, even when it comes to the most commercially valuable fish species (Able and Grothues, 2007), partially because it is still necessary to recognize the importance of learning about the behavior of a group of fish defined as cohesive fish groups within a stock that display a common movement pattern (Cadrin and Secor, 2009). To this regard, acoustic telemetry offers new opportunities to investigate the movements and individual behavior of fish at the fine scale. In addition, this technology makes it possible to recognize groups within stocks (Secor, 1999) and offer information related to the link between coastal stocks (Able, 2005).

The use of acoustic telemetry has made it possible to obtain high resolution data related to the behavior of juvenile flounder in the Gulf of Maine (Fairchild et al., 2009). Nevertheless, in Chile, the scarce experience about the use of acoustic telemetry has focused on movement patterns of fresh water fish (Piedra et al., 2012). The aim of this study was to research the seasonal distribution and movement of a group of flounder inside Tongoy Bay using passive acoustic telemetry. The movement assessment was done using two complementary strategies: (1) The abundance, distribution and length frequency of the flatfish captured in different fishing zones during an annual period was determined, and simultaneously (2) the dispersion distance of the individuals was estimated by means of a tagging and recapture study.

MATERIALS AND METHODS

Study zone

Tongoy Bay is located in the center-northern zone of Chile (30°12'S - 71°34'O; Figure 1) a region with semi-arid characteristics. The bay is open toward the north and stretches across an area of 55.86 km^2,

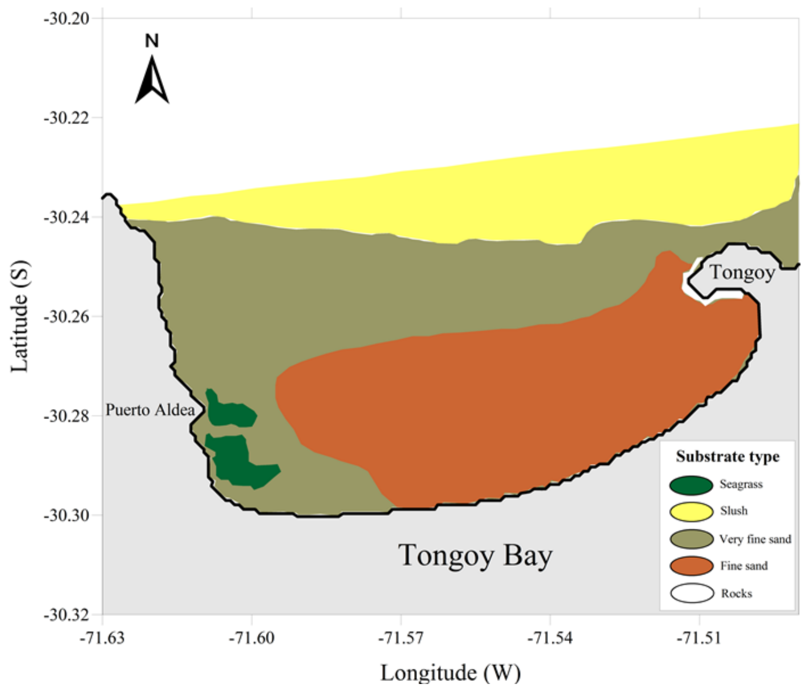

Figure 2. Distribution of surface marine sediments in Tongoy Bay.

with a volume of 2.01 km^3 and the mouth section is 0.2 km^2. The average depth of the bay is 25 m. Large part of the habitat that is available for early stages and adult Chilean flounder is relatively free from vegetation, except for the presence of seagrass (*Heterozostera tasmanica*) in the extreme southern part of the bay. The sediment in Tongoy Bay varies from very fine-to-fine sand. In general, the prevailing substrate is very fine sand (~0.11 mm diameter). Nevertheless, very fine sand largely dominates westward and fine sands eastward (Figure 2).

Flounder movement patterns

The movement of flounder was assessed using three complementary strategies. First, data obtained from landing records in Tongoy Bay were used to generate length frequency distributions for each capture zone in order to infer movement patters with respect to length. The second strategy consisted in an intensive tagging and recaptures strategy to reconstruct the individual movement of fish during the same time period. Finally, ultrasound signal transmitters were implanted in a group of flounder to monitor their movement routes inside the study area.

Spatial and time abundance of flatfish

To assess the habitat use patterns in short time and space scales, Tongoy Bay was divided into 34 zones, each of approximately 4 km^2 (Figure 3). This way, the landing information was recorded on the basis of geographical dimensions. Flounder landings in Tongoy Bay and Puerto Aldea from December 2011 to March 2013 were examined (Tongoy Bay; Figure 1). Yield estimation in terms of Catch per Unit of Effort (CPUE) was used as abundance index expressed in grams per hour. A CPUE for each catch was obtained and this value was used as a unit, in such a manner that the different CPUEs estimated by category (locality, month, depth) were determined as the average CPUEs by catch for each category. Individuals harvested with the use of gill nets (3 m width, 45 m long and 15 to 20 cm mesh size) were measured and weighed *in situ*, and later grouped according to length ranges of 2 cm total length (TL), in order to reduce measurement variability and better highlight the catch length frequency distribution.

Data analysis

A variance analysis was used to assess differences in landings of flounder in terms of time and between fishing zones (ANOVA; Spiegel, 1991). Anderson Darlingand Bartlett test (Stephens, 1974) were used to assess if the data complied with variance normality and homogeneity assumptions. A log transformation was used where appropriate (x+1) before applying ANOVA. Length frequency distributions generated for various landing periods and fishing zones in the bay were analyzed with a Kruskal-Wallis non-parametric test (Gotelli and Ellison, 2004) using the following length classes: 5-20, 21-40, 41-60, 61-80 and >80 cm TL.

Backward stepwise multiple regression analysis (F-to-remove = 1) was used to examine the relationship between the CPUE of Chilean flounder (*P. adpersus*) with temperature, salinity and depth. We checked for collinearity among abiotic variables using correlation analysis, and found none were highly correlated with each other ($r \leq 0.33$). Landing data obtained during the study were pooled into summer, autumn, winter and spring periods. CPUEs were log(x+1) transformed. Abiotic parameters deviated only slightly from normality and, therefore, were not transformed. All statistics analysis was made using the STATISTICA 7.0 statistics package (2005).

Mark-recapture

A total of 7,510 flounder individuals were tagged with elastomeric

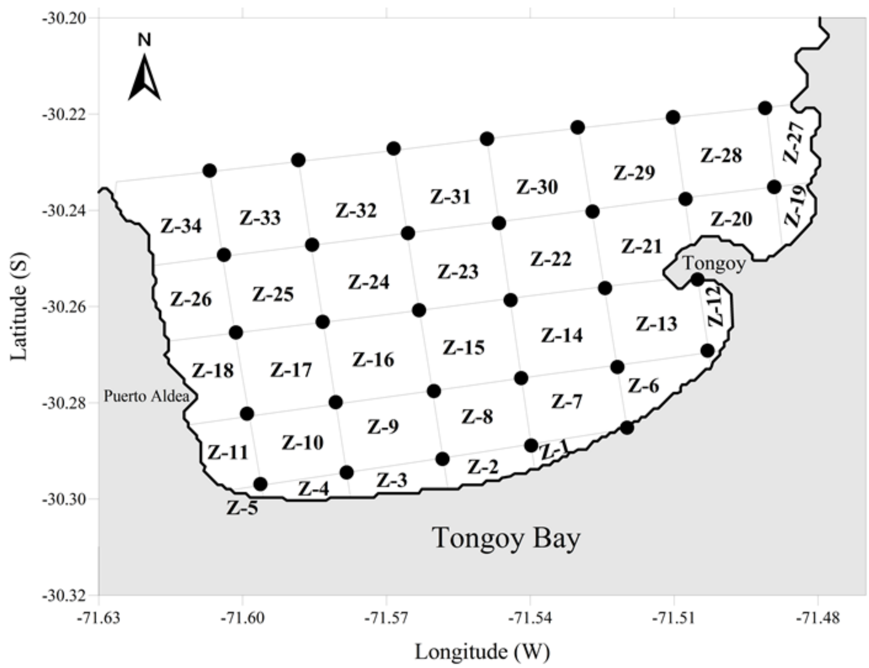

Figure 3. Grids with flounder fishing zones in Tongoy Bay.

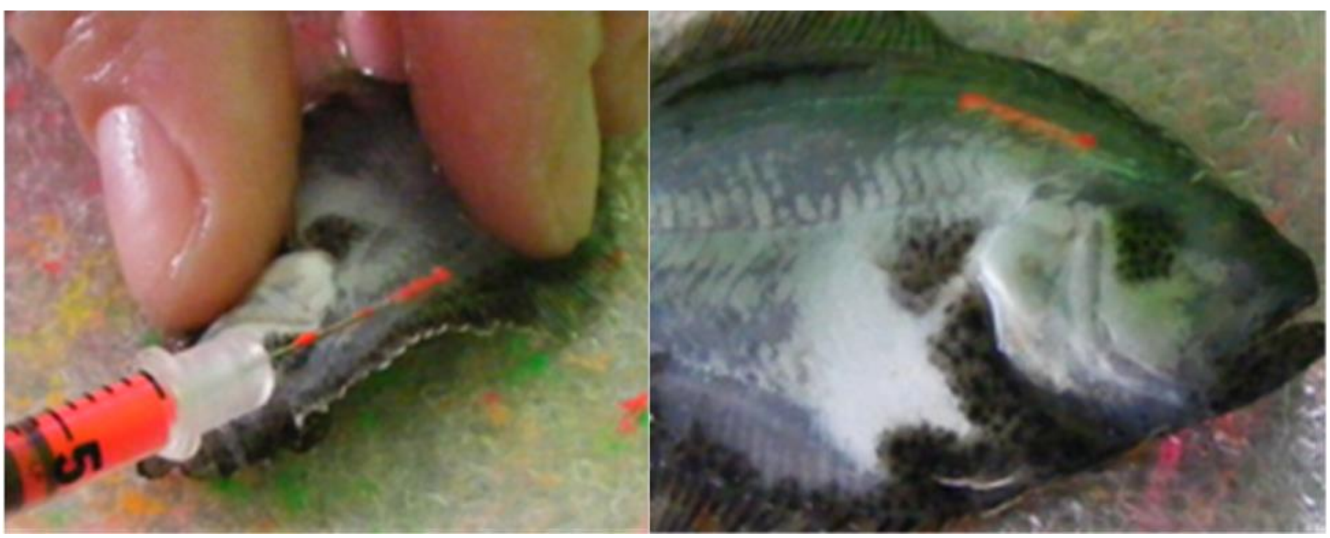

Figure 4. Tagging flounder with elastomeric paint injection.

paint. A visible implant elastomer tagging system was used (Northwest Marine Technologies, Seattle, Washington, USA). The elastomer was applied through injection with a hypodermic needle in liquid form that solidified within 24 h. The tags were implanted in the operculum on the fish's blind side, when the length allowed it, and under the dorsal fin, on the blind side (ventral) in small fish (Figure 4). The flounders were weighed and measured, and then classified in six length classes, assigning different color to each one (Table 1). After tagging the fish, they were placed in observation during 4 days in order to detect negative effects such as abnormal swimming or lack of response to tactile stimulation, and assessed the tag retention rate and if the tagging process caused mortality. The fish were released in May, 2012 off Puerto Aldea Bay, and the recapture efforts were made between June 2012 and January, 2013, with the use of transects placed parallel to the coastline.

The distance between the release zone and transects used in the recapture for each individual was calculated. Maximum and minimum dispersion distances between the central release point and the recapture point were estimated using the initial and final trawl coordinates where each individual was recaptured. Trawling operations (nets 100 m length and 2 m height, with a cod end in the mid sector) were carried out in conditions of relatively low tide (0-75

Table 1. Length classes with assigned color and number of flatfish marked with elastomeric paint.

Color mark	Size range (cm)	Number of marked fishes
Red	5.0 - 6.9	1,363
Pink	7.0 - 8.9	1,304
Orange	9.0 - 10.9	924
Yellow	11.0 - 12.9	1,319
Green	13.0 - 14.9	1,300
Blue	15.0 - 16.9	1,300
Total		7,510

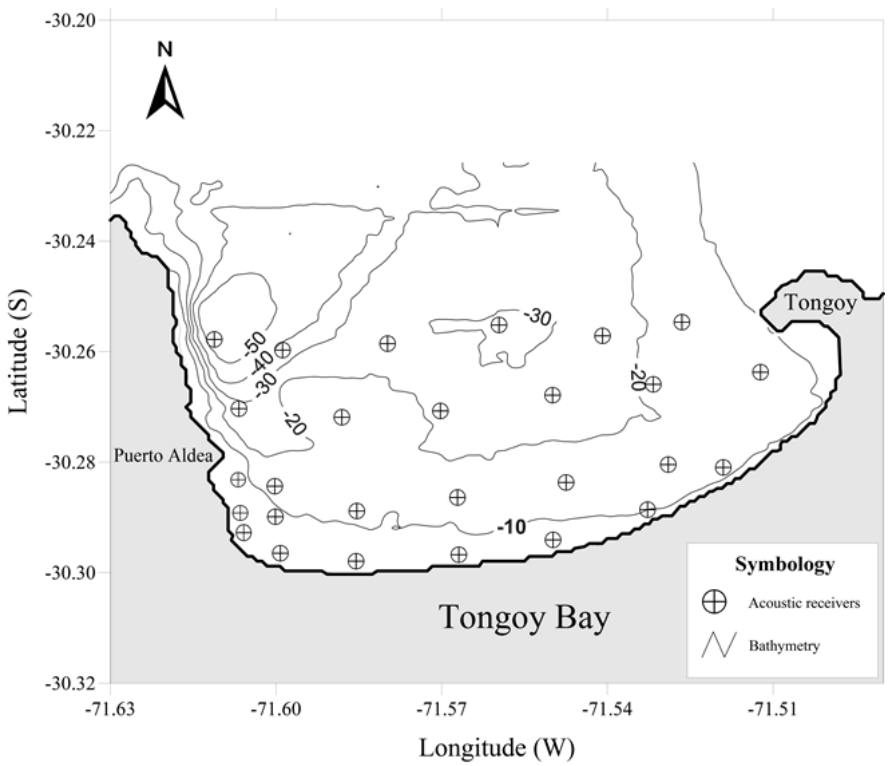

Figure 5. Tracking acoustic receivers (VR2W) anchored in Tongoy Bay.

cm above the mid-level of the lowest tide), therefore, abundance estimations by area unit were made with the low tide areas. In shallow coastal systems, flounder density might vary on the basis of tide level, implying that our stock size estimations probably underestimate the real stock size. To carry out the spatial analysis of the fish recapture information, satellite images of Tongoy Bay were used to create polygons that were representative of the study area. Habitat areas available for flounder and the perimeters of any given area in the bay were calculated with the use of the ArcMap program.

Acoustic telemetry

A total of 9 acoustic ultrasound signal receivers were anchored (Vemco VR2W-69 kHz) during a period of 9 months in order to determine the movement patterns of juvenile and adult Chilean flounder (*Paralichthys adpersus*) inside Tongoy Bay, (June 2012 - March 2013). The equipment's configuration allowed us to cover an area of approximately 42.1 km^2 accounting for 74.4% of the total (55.9 km^2) area of Tongoy Bay (Figure 5). The receivers were anchored in zones with depths up to 50 m, therefore, the anchoring operations area was limited by an isobath of 50 m depth. The position of receivers was shifted regularly to cover the entire study area, in accordance with the manufacturer's technical specifications that indicated a range of 300 to 400 m of signal reception. In addition, acoustic signal precision tests were made in the study area using a hydrophone (VR100).

To monitor the movement of flounder in Tongoy Bay, a total of 12 wild different sized individuals (Table 2) were marked with ultrasound transmission devices (19 mm length; 6 mm diameter) (Vemco V7-2x). Each transmitter has an average pulse frequency

Table 2. Identification of flounders tagged with tracking devices (tag) [Codes assigned to each transmitter are represented by abbreviations ID and SN (receptor code)].

Fish size (cm)	Number fishes	Color	ID	SN
10	1	Pink 1	4451	1130187
18	1	Pink 2	3880	1127425
21	1	Red 1	4457	1130193
23	1	Red 2	4453	1130189
25	1	Yellow 1	4454	1130190
27	1	Yellow 2	4455	1130191
32	1	Green 1	3879	1127424
34	1	Green 2	4452	1130188
39	1	Blue 1	3877	1127422
40	1	Blue 2	4456	1130192
47	1	Orange 1	4450	1130186
49	1	Orange 2	3878	1127423

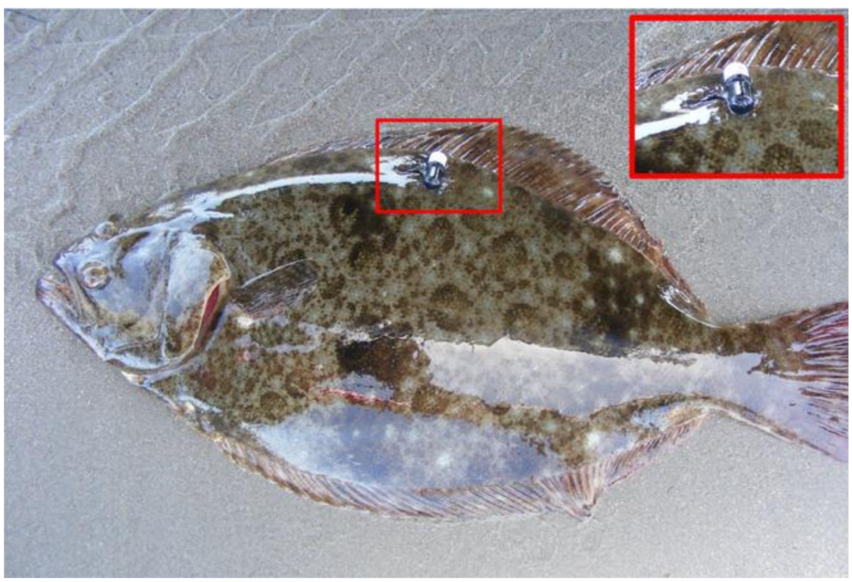

Figure 6. Ultrasonic transmission device (tag) implanted in the dorsal region of a Chilean flounder. The red square indicates the transmitter location.

of 80 s (range = 40 - 120 s) and a battery life of 384 days. Each fish was anesthetized with a benzocaine anesthetic tranquilizer for fish (BZ-20®) in a 1 mL solution: 5L BZ-20 before implanting the tags on the dorsal side of the fish (Figure 6).

After implanting the fish, the affected area was covered with an anti-inflammatory antibiotic for topical application (Terracortril Spray 125 ml) in order to avoid infections associated to the implant. In parallel, the basic data of each fish was recorded (weight and length) and the tag code number. Before being released, the tagged flounder were kept under recovery during a period of seven days to monitor the healing of the wound and the tag retention. The use of ultrasound transmission devices in fish was subject to the following previous considerations:

1. Tag implant tests: without affecting fish behavior while in captivity.
2. Receiver scope test (VR2): 300 - 400 m.
3. Accuracy test with hydrophone (VR100): positioning error of ±4.09 m.

The flounders were released following a visual inspection by divers in order to monitor the response capacity (that is, search for shelter, camouflage, etc.) displayed by each individual in the presence of potential predators.

Distance covered and distribution area

The data stored during the study period (9 months) in acoustic receivers (Vemco VR2W-69 kHz) were downloaded with a VUE 1.4.2 software (VEMCO Ltd.). The information was organized and coded in data bases, indicating if the presence of tagged fish was

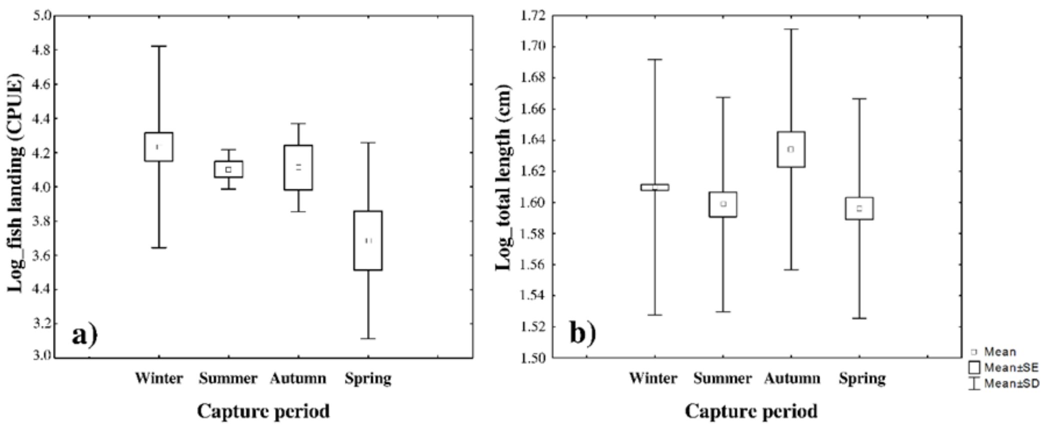

Figure 7. Abundance and length variations of Chilean flounder in Tongoy Bay during the study period, respectively.

detected within a day. The site fidelity was assessed as the probability of detection by one or several receivers with respect to the time elapsed since the release of the fish. Daily activity patterns were based on the probability of detection, according to the time of day.

Detections were used to calculate the distance in meters between successive positions ($D_{A\rightarrow B}$):

$$D_{A\rightarrow B} = \sqrt{((Lon_A - Lat_B)^2 + ((Lon_A - Lat_B)^2)}$$

Where, Lon_A y Lat_A are the geographic coordinates (UTM) of the first position, and Lon_B and Lat_B are the final geographic coordinates.

The average speed of tagged fish was obtained on the basis of the time recorded between each detection (m s^{-1}). Subsequently, the distance covered by a fish during 24 h (m $día^{-1}$) was estimated on the basis of the total covered distance and the total monitoring time. The receiving equipment data bases were introduced into an SIG and were assessed with the Animal Movement Analysis ArcView Extension (Hooge and Eichenlaub, 1997). A layer with bathymetric information (SHOA map) was introduced into the SIG. The distribution area used by tagged fish was obtained by calculating an *ad hoc* parameter that considered 50% of the contour as the area of main activity (m^2) and 95% of the contour as the distribution area (Hooge et al., 1997). On the positions obtained within the study zone were used, except for the movements of fish that left the study area permanently. The geostatistic analysis and spatial representation of detections were made using ARCGIS 10.0 software. To represent the physical characteristics (that is, bathymetry, substrate type) of Tongoy Bay, thematic data coverage was developed by interpolation IDW (ESRI, 2011). In addition, the information provided by the receivers, related to the date and location (inside Tongoy Bay) of tagged fish was assessed using a Tracking Analyst Arc Editor 9.3. This tool allowed us to display, assess and understand spatial patterns and trends in the context of time.

RESULTS

Spatial and time patterns in the use of habitat in Tongoy Bay

A total of 2,039 flounders were landed during the study period, with a total biomass of 2,074 kg. Landings recorded of 113 fishing trips used gillnets in the study area. The records are related to 19 vessels that used 5.1 fishing hours obtaining an average catch of 12.1 individuals (~11.4 kg) by vessel.

Fishing zones varied depending on the time of year. Landing records obtained from December 2011 to January 2012 (austral summer) showed a higher catch volume in three fishing zones (4, 9 and 11). From April to July 2012 (autumn and austral winter) only landings from zones 2 and 3 were recorded. Landings were recorded from January to March 2013 (austral summer) from 5 fishing zones (2, 3, 4, 10 and 28).

The CPUE displayed statistically significant differences in the different catch periods ($F_{[3;68]}$=2.958; P=0.0384; Figure 7a). These differences were explained by differences in abundance recorded in spring and summer months. Length frequency distributions of Chilean flounder harvested throughout the entire study period displayed statistically significant differences ($F_{[3;2035]}$ = 4.4193; P=0.0042; Figure 7b).

Length ranges in fish harvested in the austral summer period (December 2011 - February 2012; January 2013 - March 2013) varied from 19 to 90 cm TL, with a larger length frequency at 35 cm. During the austral autumn months (April 2012 to May 2012) landed fish displayed lengths that ranged from 28 to 49 cm TL, with a higher frequency at 39 cm. In austral winter months (July 2012 to September 2012), the lengths of landed fish ranged from 31 to 62 cm LT, with a higher frequency at 38 cm. Moreover, in austral spring (October 2012 to December 2012) lengths of landed fish ranged from 28 to 64 cm TL, with a higher frequency toward 33 cm.

Throughout the study period, length frequency distributions of flounder landed at Tongoy Bay displayed statistically significant differences (KW test; $F_{[4;15]}$=10.3064; P=0.0003). A unimodal distribution was observed during each landing period (summer, autumn, winter and austral spring). In summer, the fish showed a

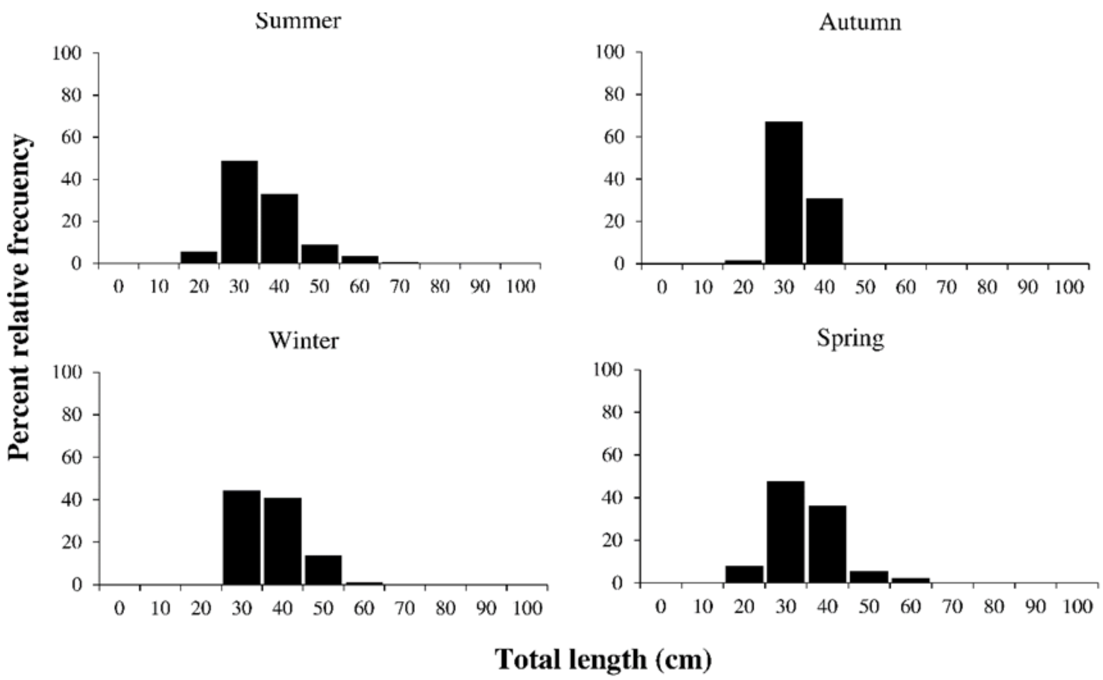

Figure 8. Length-frequency histograms of Chilean flounder (*P. adpersus*) captured in Tongoy Bay during the study period.

length frequency distribution with a main peak at 37 to 38 cm TL. In autumn, 67% of Chilean flounder measured <40 cm TL. During winter 85% of landings recorded lengths ranging from 31 to 49 cm TL. These lengths accounted for 81% of the catch in winter (Figure 8).

Relationship between CPUE and abiotic parameters

Mean water temperature was lowest in winter (13.37 ± 0.23ºC, mean ± SD) and highest in summer (17.34 ± 0.79ºC). The salinity in the Tongoy Bay ranged from 34.24 to 34.62 (S_A) during the autumn and winter months, respectively. The Chilean flounder were captured over a broad range of temperatures and depths (13-18ºC and 1.96-55.60 mt; Figure 9). Multiple regression analysis indicated a significant relationship between abiotic parameters and CPUE of *P. adpersus* ($F_{[3;68]}$ =4.0923; $P<$ 0.001). For Chilean flounder, temperature exhibited a greater influence on CPUE than depth (standardized coefficient β = 7.82 vs -0.96, respectively), and salinity was dropped from the model since it did not contribute explanatory power.

Evaluation of Chilean flounder movement using mark-recapture

Out of the total tagged and released individuals (7,510) only a 17.67% (1,327) of flatfish were recovered. The highest number of recaptured fish was made using a trawl during a period of eight months (June 2012 to January 2013). The fishing zones with the highest proportions of recaptures with this fishing gear were 3, 4, 5, 9 and 11, characterized by fine sediment (Table 3). At the time of capture, the flounder had an average weight of 220.1 ±132.6 g and measured 31.1±1.6 cm TL. Visual examination indicated that the recaptured fish appeared to be in good condition. All were recaptured in different zone of the bay in which they were released. The minimum and maximum potential distances traveled by individuals ranged from 0 m (that is, they were caught within a trawl) to <4,000 m (Table 3).

Acoustic telemetry

Of a total of nine receivers anchored in Tongoy Bay during the study period, only six of them recorded the signals from the ultrasound transmission device implanted in twelve fish. During the study period, a total of 4,770 records were made, of which 50.8% come from a one receiver while the other records were obtained by five receivers.

An assessment of the information of the equipment anchored in the study area revealed that the highest number of records (3,285) was obtained in October, of which, 2 receivers showed the highest number of readings. Out of the total tagged fish (12) only 66.6% of them were recorded 6 of the 9 anchored equipment

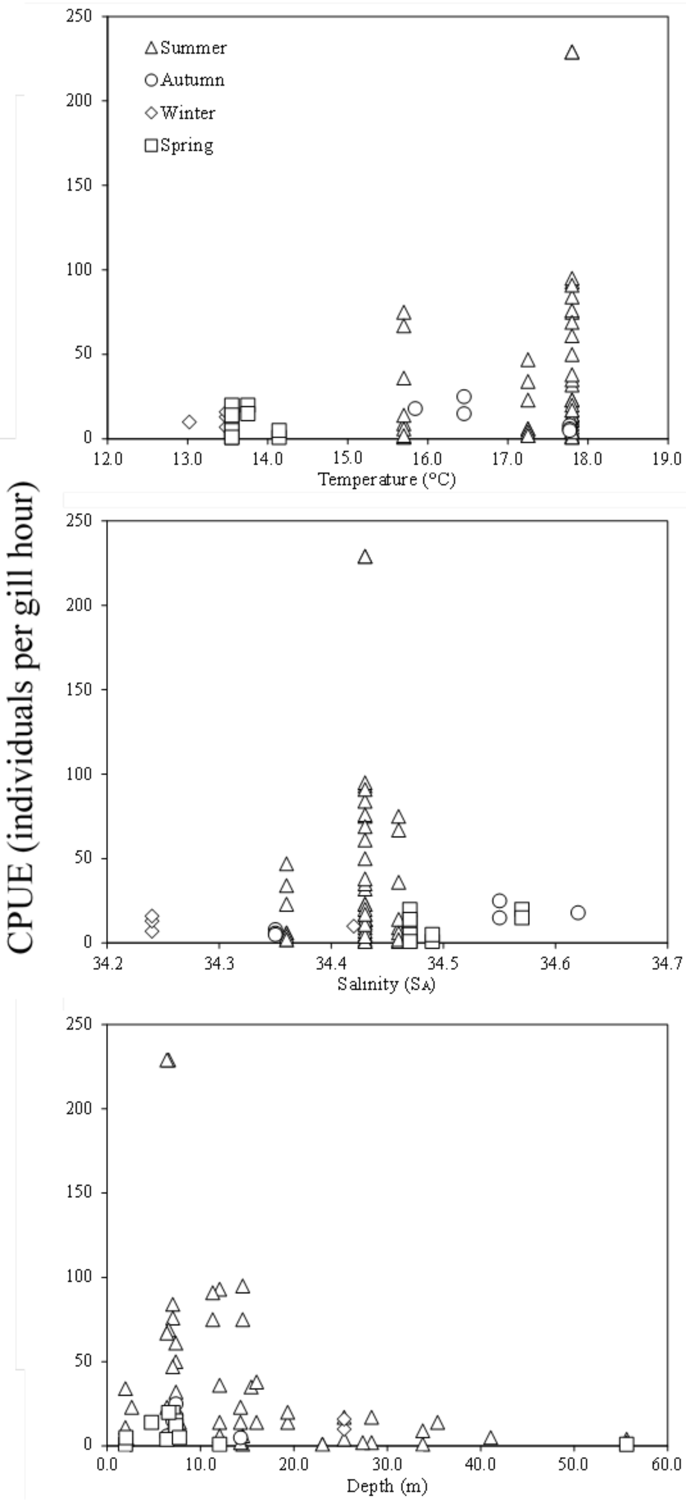

Figure 9. Catch per unit effort (CPUE, individuals per gill hours) of Chilean flounder vs abiotic parameters measured in Tongoy Bay during 2012.

(Table 4). In August 2012, the receivers recorded the presence of six fish (50%) with a total of 123 records (Table 4). The lowest records of tagged fish were made in October and December, 2012, and in January 2013. It is noted that in the months of June, July and September, 2012, the receivers did not record the presence of tagged fish.

Movement patterns of Chilean flounder in Tongoy Bay

The assessment of the landing records of Chilean flounder, added to data from the fish marked with elastomeric paint, and a spatial analysis of the total records obtained from the acoustic receivers during the study period, the presence of corridors and/or movement routs for juvenile and adult flounder were identified in Tongoy Bay.

Early juvenile stages (10-23 cm TL) displayed a movement mainly circumscribed to the coastline (limited to 5 m isobath), and associated to fine and very fine sandy bottoms. The movement track for this group of fish showed a preferential distribution area, with a higher frequency during the day and night, and mainly grouped in bottoms with seagrass (Figure 10).

Juvenile flounders displayed movements across a larger area of Tongoy Bay, compared to the previous group, extending from the coastline up to approximately 30 m isobath. The movement data assessment for this group of juvenile fish (25 to 34 cm TL) allowed us to establish a distribution area during the day and the night. The records indicated that juvenile flounder in this group increased their distribution area during the night within Tongoy Bay (Figure 11).

Adult flounder individuals (35 to 50 cm TL) monitored during the study period showed a movement track that covered the entire area up to 50 m isobath. A spatial analysis was made to establish an occupation area inside Tongoy Bay, and the location of a preferential zone for this group of fish during the night, which was different in terms of size and location from the two juvenile groups (Figure 12).

DISCUSSION

Patterns of habitat use into Tongoy Bay

The highest CPUE of Chilean flounder was found towards shallow areas of the bay near the shore. It is likely that spatial distribution patterns of juvenile and adults were influenced by the seasonal variations in the environmental conditions found among zones of the bay, as well as by recruitment and emigration events (Kramer, 1990, 1991b; Gibson, 1997; Fodrie and Mendoza, 2006). The results of the multiple regression analyses, coupled with the distribution and variable CPUE of Chilean flounder into Tongoy Bay, indicate that the temperatures

Table 3. Number of flatfish marked with paint marking and recovered during June 2012 - January 2013 into Tongoy Bay (Colors account for length classes with assigned color).

Color mark	Size fishes marked released (cm)	Number fishes released	Release zone	Size fishes marked recovered (cm)	Recapture zone of fishes marked	Number fishes recapture	Min. distance moved (m)	Max. distance moved (m)
Red	5.0 - 6.9	1,304	13	29.0 - 32.0	5	160	122	2,431
Pink	7.0 - 8.9	1,363	10	29.0 - 31.0	3	75	471	3,084
Orange	9.0 -10.9	1,319	13	-	-	-	-	-
Yellow	11.0 - 12.9	1,300	10	29.0 - 33.0	4	212	362	1,877
Green	13.0 - 14.9	1,300	10	30.0 - 35.0	11	93	748	2,335
Blue	15.0 - 16.9	924	13	34.0 - 36.1	9	18	200	900
Total		7,510				558		

Table 4. Monthly summary of records and presence of marked flounder in area covered by acoustic receivers.

Year	Months	Color mark	No.registers	Code signal receptor	Record duration
2012	June	Not recorded	-	-	-
	July	Not recorded	-	-	-
	August	Blue 1	25	1127422	0 h 28 min
	August	Blue 2	5	1130192	0 h 5 min
	August	Pink 2	2	1127425	0 h 3 min
	August	Green 1	8	1127424	0 h 32 min
	August	Orange 1	78	1130186	2 h 58 min
	August	Orange 2	5	1127423	0 h 36 min
	September	Not recorded	-	-	-
	October	Yellow 1	107	1130190	10 h 10 min
	October	Orange 1	1,349	1130186	95 h 0 min
	October	Green 1	1,829	1127424	131 h 0 min
	November	Blue 2	3	1130192	0 h 1 min
	November	Orange 1	631	1130186	33 h 3 min
	November	Yellow 1	106	1130190	19 h 0 min
	November	Green 1	1	1127424	0 h 10 min
	December	Orange 1	414	1130186	59 h 0 min
	December	Yellow 1	126	1130190	3 h 48 min
	December	Green 2	46	1130188	3 h 31 min
2013	January	Orange 1	31	1130186	3 h 55 min
	January	Green 2	2	1130188	0 h 20 min
	January	Yellow 1	2	1130190	0 h 20 min

and bathymetry that occur during the summer months drive habitat utilization patterns. Adults and juveniles were consistently caught throughout the system at temperatures and salinities that included the warmest and most saline conditions of the year (Figure 9; Álvarez-Borrego and Álvarez-Borrego, 1982). This is consistent with the tolerant nature of the juvenile stage of California halibut (Madon, 2002; Fodrie and Mendoza, 2006). We do not know studies that evaluate the tolerance level in adults and juvenile of Chilean flounder to temperature or salinity. The CPUE of Chilean flounder was significantly related to depth. The highest values were found in shallow water less than 7 m deep, and very few individuals were captured in water depths greater than 50 m. This agrees with previous studies on California halibut (Krammer, 1991b; Fodrie and Mendoza, 2006), which also identified a relationship between abundance and depth.

Evaluation of the mark-recapture strategy

The recapture rate for Chilean flounder (2.65%) is widely lower than that reported by Haaker (1975) (8.8 and 4.6%

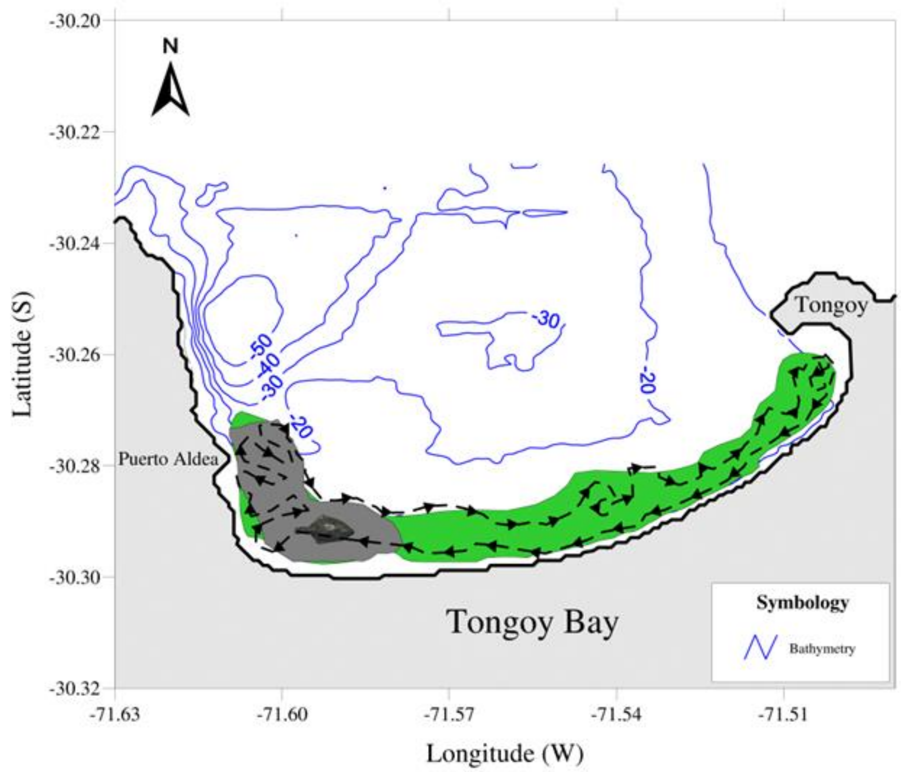

Figure 10. Movement track by early juvenile flounder and preferential distribution area for juvenile-early stages of flounder during the day (green) and night (grey) inside Tongoy Bay. The black line (segmented) indicates the used route.

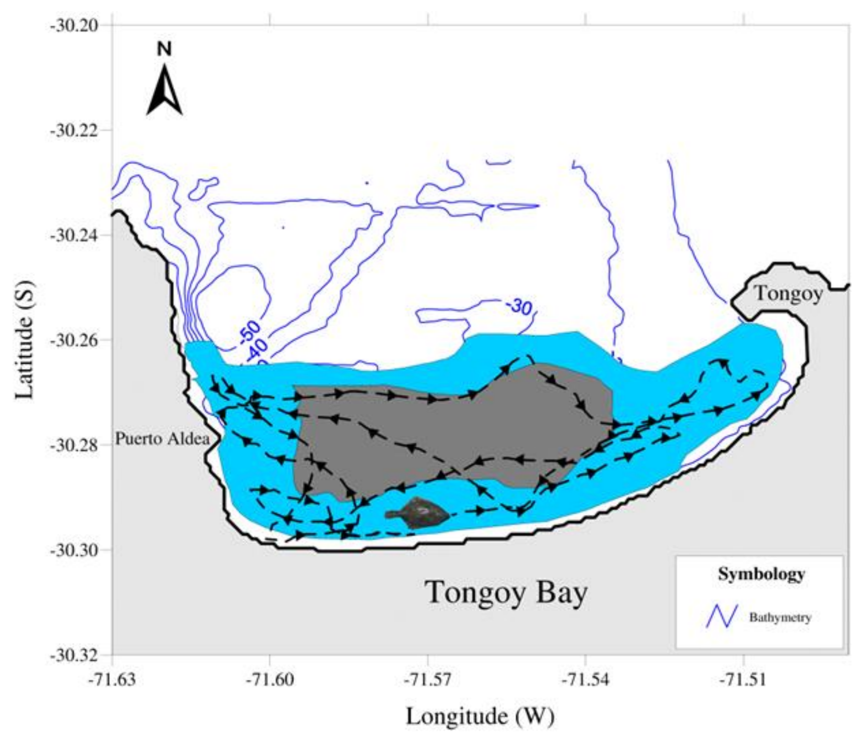

Figure 11. Movement track by juvenile flounder and preferential distribution area for juvenile flounder during the day (light blue) and night (grey) inside Tongoy Bay. The black line (segmented) indicates the used route.

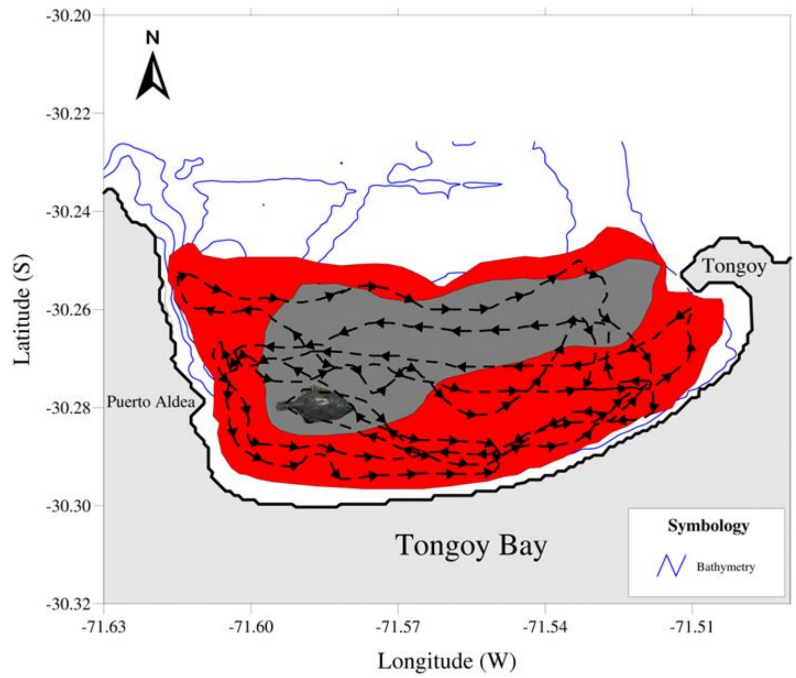

Figure 12. Movement track by adult flounder and preferential distribution area for adult flounder during the day (red) and night (grey) inside Tongoy Bay. The black line (segmented) indicates the used route.

using spaghetti clips and fin tagging, respectively), in a similar study conducted in Anaheim Bay. Comparatively, low recapture rates of Chilean flounder is similar to other studies performed on California halibut adults (Domeier and Chun, 1995; Posner and Lavenberg, 1999). The higher recapture rates obtained by other researchers may be related to differences in the sampling strategies employed to recapture tagged fish, including longer recapture periods and a more intensive recapture effort. The size-selective mortality of juveniles (Sogard, 1997) and the emigration of individuals out of the system may have also contributed to low recapture rates. One other possibility is that the tagging method used in this study was responsible for the low recaptures; however, the laboratory evaluation of the elastomer tags indicated that neither tag loss nor tag-induced mortality were substantial. VIE tags have also been used successfully in tagging studies involving black drummer (*Girella elevate*, Griffiths, 2002), common bully (*Gobiomorphus cotidanus*, Goldsmith et al., 2003), bridled goby (*Cryphopterus glaucofraenum*, Malone et al., 1999), and Atlantic cod (*Gadus morhua*, Olsen et al., 2004). Hence, it is unlikely that significant tag loss influenced these results.

Short-term movement of Chilean flounder in Tongoy Bay using acoustic telemetry

This is the first study that uses acoustic telemetry in Chilean flounder (*P. adpersus*) in their natural environment. There are experiences in the use of this type of technology with other flounder species (that is, *Pseudopleuronectes americanus*) with similar results, despite the higher time scale in such studies (DeCelles and Cadrin, 2010; Sagarese and Frisk, 2011).

The use of passive tracking allowed assessing the movement and presence of Chilean flounder (*P. adpersus*) near the coast. This species of flatfish remains in Tongoy Bay throughout the entire year, and the abundance of monitored individuals reached its maximum point in spring. Most fish do not leave coastal waters when the bottom temperatures exceed 15°C, unlike the behavior reported for the Winter flounder (*P. americanus*; McCracken, 1963; Howe and Coates, 1975; Phelan, 1992; Wuenschel et al., 2009). From October to November 2012, a total 84.4% were made when the water column temperature in Tongoy Bay began to increase (~14°C) to around 17°C in the summer period.

In contrast few fish were detected in winter (June-September), during the spawning period. In general, movement tracks displayed by flounder in Tongoy Bay revealed that individuals of this species are capable of living at great depths and occupying a greater area in the bay as they reach larger sizes. The movements of this species were classified according to the three most common movement patterns: (1) Movement of fish within the bay; (2) Dispersion of fish outside the bay (offshore), and (3) Connectivity with other coastal areas.

Residence patterns displayed by Chilean flounder (*P. adpersus*) in Tongoy Bay are consistent with the information reporting the use of shallow gulfs and bays with soft sandy bottoms as habitat, as well as to other flounder species such as *P. dentatus* and *P. californicus*, that search for protection from predators, more appropriate temperatures and abundance of food (Able et al., 1990; Kramer, 1991; Acuña and Cid, 1995).

Adult Chilean flounders showed increased activity within Tongoy Bay during the study period, possibly as a result of differences in lengths between the released individuals. Although the juvenile and adult flounder individuals showed differences in the space occupied into bay, this results must be interpreted cautiously because flounders possibly experiment changes in behavior after being implanted, especially those smaller sized individuals that may have with less movement capacity.

Evidence shows that the Chilean flounder species (*P. adpersus*) is present in Tongoy Bay throughout the entire year, although it is not clear if these individuals represent: (1) A single group within a stock; (2) A genetically different stock, or (3) a portion of individuals of a stock that shift to other locations outside the bay or remain within. To this regard, it is probable that a significant number of flounder from other adjacent bays constantly enter Tongoy Bay to spawn.

Although it has commonly been considered flounders shift toward the high seas near the coast when the temperatures increase during the summer period, it has been demonstrated that adult flounder individuals are capable of resisting warm temperatures by changing their behavior, which includes burying into the sediment, reducing their swimming speed and inactivity (Olla et al., 1969; He, 2003). In addition, flounders may escape the warm bottom waters and bury themselves up to 6 cm in the sediment, where the temperatures remain at more or less 4°C colder (Olla et al., 1969). Nevertheless, this behavior drastically reduces its detectability with the use of telemetry. Field tests indicate that the transmitters buried in the sand are detectable, but at a lower range, leading to a reduced detection area. Apart from burying themselves in the sediment, flounders can reduce their swimming speed or remain inactive to save energy (Olla et al., 1969; He, 2003).

The biotelemetry technique used in this research has great potential to study the movements and use of habitats of other species of commercial importance. Nonetheless, the movement track results of tagged flounders must be considered as preliminary. Future studies along the same line must necessarily include a higher number of tagged fish and improve the long-term viability of tags. In this regard, before carrying out field experiments in telemetry studies, it is important to determine the transmitter retention and mortality rates, and assess the variables that affect animal behavior (Pine et al., 2003; Fabrizio and Pessutti, 2007). The use of surgery is frequently a good option in long-term telemetry research, considering that the internally implanted tags may remain in fish during many years without any problem (Jepsen et al., 2002). Nevertheless, surgical implants are complicated and have been associated with a high risk of mortality, infection and loss of tags, all of which have been used as arguments in favor of external implants (Jepsen et al., 2002).

The results of this study provide valuable information regarding the movement of Chilean flounder in Tongoy Bay, which can help identify the possible causes of the general decrease of this resource, and may also serve as a platform for future research that deal with the ecological aspects of this species. Nevertheless, due to its preliminary character, they must be used with caution when managing the fish stock due to the information gaps that still exist to fully understand the population structure of this species.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This research was financed by INNOVA-CORFO 07CN13IPM-69. The authors express their appreciation to Mr. Helmo Pérez from Instituto de Fomento Pesquero, and the fishermen from Tongoy and Puerto Aldea fishing coves. We would also like to extend our thanks to the anonymous assessment experts for their important contributions to this work.

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