The effect of the spatial and temporal distribution of juvenile SBT on Acoustic and Trolling Survey abundance estimates

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Summary

Acoustic tagging research has been carried out on southern bluefin tuna (SBT) on the south-west coast of Western Australia. This is the same region as a fishery-independent acoustic survey for SBT has been historically undertaken. We investigated the distribution and movement patterns of age-1 SBT in and out of the ASA (Acoustic Survey Area) during the summer migration of juvenile SBT population in the 2004/05 and 2005/06 seasons. The annual differences in spatial and temporal distribution (STD) pattern revealed by acoustic tagging were characterized by two distinctive migration runs. It would be not only the shelf- and inshore-migrating, but also different residence time in the waters of southern Western Australia during summer-autumn period. Inshore-migrating SBT could leave by the end of summer, suggesting absence in ASA. Shelf-migrating SBT moved mainly on shelf in summer-autumn period. An additional survey for SBT provides additional information that supports the migration results obtained from the acoustic monitoring. Catch information on SBT from this Piston Line survey (PLS) off Bremer bay in 2004/05 and 2005/06 were consist with the dispersed cross-shelf distribution of tagged SBT detected at the Bremer Bay line of listening stations. The differences in catchability of PLS between two years may be seen to increase trend of the recruitment index from the 2004 year class to the 2006 class and this could be expected to be a result of density-dependent catch efficiency or a density-dependent horizontal distribution through on shelf and in seamounts, where a relatively high proportion of migrating SBT out of ASA in 2004/05 season will be unavailable to the PLS.

要約

オーストラリア南西海域に越夏回遊してくるミナミマグロ 1 歳魚の音響タグ追跡調査（行動調査）を 2004，2005 年度に 3-5 ヶ月間におよび行った。行動調査は、漁業から独立したミナミマグロ音響資源加入調査エリア（ASA: Acoustic Survey Area）をカバーするように実施された。行動調査の目的は ASA

に対して、標識魚の越夏回遊経路と滞在時間の年変動機構を予備的に精査するところにあった。両年間で、標識魚の時空間分布には顕著な2パターンが認められた。2004 年度には ASA から外れた沿岸の小海山帯に回遊経路の重心があったのに加えて放流から約 50 日後の 2 月中旬まで南西海域に滞在していた。一方、2005 年度では、小海山帯での分布は前年ほどに顕著ではなく、ASA の大部分を含んだ陸棚上に散在するとともに滞在時間も前年に比べて長い傾向が認められた。特に 2004 年度のタグ追跡の結果は、ASA とミナミマグロ幼魚の分布重心がミスマッチであったことを強く示唆している。また以上の行動調査の結果は、同じく 2004-2005 年度の両年にブレマーベイ沖の陸棚上で実施された曳縄漁獲調査（PLS: Piston Line Survey）の結果とよく一致していた。2004/2005 年から 2005/2006 年に曳縄指数が増加したのは、必ずしも 1 歳魚資源量の増加とは限らないということを示唆している。つまり、両年度 PLS の漁獲尾数（2004/05: 18 尾、2005/06: 141 尾）の差は、密度依存の漁獲効率あるいは水平分布の差を示唆しているかもしれない。特に、2004/05 年度の ASA 外での SBT の分布パターンは、PLS に対しても有効でなかったと推定される。

Introduction

The use of scientific survey data for assessing for the abundance of commercially important fish stocks has become a necessity in many regions. Errors and biases in estimating abundance from such surveys may thus have great economic impact. Southern Bluefin Tuna (SBT, *Thunnus maccoyii*) spawn in the northeast Indian Ocean from August to May (Farley and Davis 1998). Young-of-the-year move down the west coast of Australia and are found as age-1 SBT in southern Western Australia. The acoustic (sonar) survey (AS) under the Recruitment Monitoring Program has been established to monitor the relative abundance of 1-year old SBT based on a line transect survey using a consistent protocol (omni scanning sonar) since 1995/96 season. The acoustic survey area (ASA) was established in the area between Albany and Esperance, where the width of continental shelf becomes narrow, with the assumption that most 1-year old SBT (and 2-year old) will pass through along the southern western coast of Australia during summer.

Acoustic estimate have been used as relative indices of the recruitment of SBT (Itoh and Tsuji, 2002).

The standard estimation procedure used in AS of SBT did not take account potential changes in the spatial and temporal distribution (STD of fish). The reliability of the surveys indices thus depends on the stability of the bias caused by STD. Evidence of differences between years in STD has been observed. Previous reports indicated that the juvenile SBT were moving inshore of the ASA, or were not moving through the area during the period of the survey (Hobday (2003) and, Hobday and Kawabe (2004), Hobday et al (2007)). These results suggest that there may be a tendency for this inshore bias to increase with decreased recruitment indices of SBT (Itoh, 2005). Thus, there is an urgent need to investigate the main causes of decline in indices in relation to the STD (migration timing, pathway and migratory speed) of 1-year SBT.

Transect line survey by hydroacoustics such as omni sonar and quantitative echo sounder cannot sample in the complete ASA. Fish distributed off the sonar beam on the sea surface may be sampled by the trolling and counted by visual observers but are less detectable by the sonar and echosounder. On the other hand, if STD of fish coincided with the sampling time of the AS research vessel, the survey may be reliable. Hence, variations in STD of fish over the AS research area may affect the SBT density/abundance estimates. This problem involves a complex set of factors, of which fish behavior is most important. Fish density estimates are affected both by natural behavior such as horizontal movement patterns and migration timing.

In the 1990s, the development of archival tags was regarded as a significant advance for tracking marine organisms. These tags allow a detailed recording of light intensity that used to estimate daily position to an accuracy of about 140km (Welch and Everson 1999). The study of more localized migration patterns, such as those in coastal waters or over the continental shelf, requires that locations be estimated with much finer spatial resolution. However, many species and age classes, such as juvenile SBT, are simply too small to be equipped with large and extensive ‘pop-up’ archival tags. The alternative is small archival tags that must be recovered opportunistically, typically by fisherman, and returned to the laboratory. This means that a relatively large number of fish must be tagged to ensure reasonable numbers of tag recoveries over the desired time scale (months to one or more years). Thus, these tags may not be suitable for questions related to movements through the acoustic sonic region (e.g., 256.5km wide sonar survey box). Recent advances in acoustic tagging technology have made available low-cost, submersible receivers that can automatically detect and identify passing fish, such as cod and tuna (Klimley and Holloway 1999, Comeau et al 2002, Hobday 2002, Hobday 2003, Kawabe et al., 2003: Heupel et al., 2006).

The object of this research was to determine the distribution and movement patterns of age-1 SBT in and out of ASA using the behavioural data obtained during the summer migration of juvenile SBT population in the 2004/05 and 2005/06 season (data from 2006/07 is still being analyzed). This objective was approached via an attempt to identify annual fluctuations in fish positioning and aggregation as a function of temporal variation in a specific habitat, and to evaluate the design of AS in relation to the summer migration of juvenile SBT population in 2004/05 and 2005/06 season.

Materials and methods

Research sites.

The research was carried out in the ASA of southern Western Australia (**Fig. 1**). The ASA under Recruitment Monitoring Program has been established to monitor abundance of age 1 SBT based on the transect survey using omni scanning sonar. The ASA was set in area between off Albany and Esperance where width of continental shelf becomes narrow, relatively.

Acoustic receivers.

Seventy VR2 acoustic receivers (Vemco) were deployed in and out of the ASA.

Each receiver was fastened to vertical wire cable on a mooring anchor (125 kg section of railway track). Listening stations with a receiver consisted of time-scheduled electronic releaser, 50 meters of release rope in a PVC canister, and four/five floats. Temperature data-loggers (Vemco) were also attached to the receivers at regularly spaced intervals (approximately every 4th station, 5 per line). When deployed, the receivers were set to be at depth of 20-25 meters, just below the sub-surface floats in waters up to 150 meters deep. Listening stations were aligned equidistantly into ‘curtains’ in three cross-shelf line initialing from coast at each location (Fig. 1, western curtain, Bald Island (BI); middle curtain, Point Henry (PH); eastern curtain, West Island (WI)). In addition, 3 listening stations were deployed at each of three small seamount (Hot spots: HS) located between Albany and Bremer Bay in depths of 40-60 meters.

In 2004 summer, listening stations were deployed on December 3 (BI), December 4 (PH and HS) and December 5 (WI) and retrieved in March 15-19, 2005. In 2005 summer, listening stations were deployed on December 1 (BI), December 2 (PH and HS) and December 3 (WI) and retrieved in May 9-11, 2006. All receivers continuously monitored the passage of any tagged individuals over 3-month period.

Acoustic transmitters.

The transmitters used to tag SBT were V8 and V16 coded pingers (Vemco). They each transmit a unique pinging sequence at a frequency of 69 kHz, which is repeated after random delay of between 20 and 60 seconds. Battery life is rated at 365 (V8) and 700 (V16) days.

The same protocol used for the capture and selection of SBT for conventional tagging (Williams, 1983) was followed for the acoustic tagging (Hobday, 2002). In brief, fish were caught by polling or trolling at the stern of the vessel (FV Quadrant) and immediately placed in a tagging cradle. Caudal fork length (LCF) was measured to the nearest centimeter. For acoustic transmitters, a 1-1.5cm horizontal incision was made about 0.5-1 cm off the midline and anterior to the vent by about 2-3 cm. The body wall was penetrated until membranes of peritoneum were observed. The membrane was then torn by a gloved finger, and a space in visceral cavity (where the transmitter would be inserted) carefully wedged out to help ensure no damage occurred to internal organs. The incisions were closed with one (or two) sutures. The entire implantation procedure generally took less than 2 minutes. Fish were also tagged with conventional plastic dart tags placed between the pterygiophores adjacent to the insertion of second dorsal fin. All fish were tagged by a single experienced operator.

For 2004/05 season, a total of 79 fish (LCF: 41-64 cm) were tagged in the area between BI and PH, and we released 22 tagged fish at December 7 2004 and 57 tagged fish in January 3-9 2005. For 2005-06 season, a total of 81 fish (LCF: 43-73 cm) were tagged in the area between BI and PH, and we released 8 tagged fish in December 5-8 2005 and 73 tagged fish during January 6-10 2006.

Analyses.

Time, distance and speed (rate of movement) were calculated for movements recorded between receivers (curtains and HS). Time was the period between the last detection at one receiver and the first detection at next receiver. Distance was measured between the positions of two relevant receivers. We first determined the size of two relevant research areas relative to the array of acoustic receivers: one was area inside the ASA and the second was area outside of the ASA (Fig.2). The area inside the ASA was 4215.5 km^2 (54 %) and outside of the ASA was 3613.8 km^2 (46%). To compare the spatial usage and migratory direction of tagged SBT between in and out of ASA, site preference of SBT was determined using acoustic tracking data. By time spent across some listening stations in ASA to out of ASA (eg. to HS or BI), we calculated the proportion of residence time between in and out of ASA.

The movement and tagging patterns are described in the companion paper: Hobday et al (2007). Here we report on the residence patterns relative to the acoustic survey area, and the potential impact on abundance/density estimates.

Results

Residence patterns.

While the tagged SBT were present on curtains of shelf and HS (small seamounts) both in 2004/05 and 2005/06 research seasons, a change of spatial distribution patterns and residence time for all of tagged fish was found between both years. In 2004/05 season, tagged SBT were almost present at HS at every day in research period and 91.3 % in all detections (n=27,855) were recorded by the receivers deployed at seamounts, although a small number of detection were recorded at the curtains on shelf (Fig.3a). In 2005/06 season, tagged SBT were widely distributed on shelf, and there were fewer detections at the inshore seamounts.

The change in the number of tagged fish remaining in the research area is shown Fig.4. This result indicates that following the initial tagging, when tagged fish left and were never detected, the half of detected fish remained in the research area for the next 55 days following tagging and then moved out of the area in 2004/05 season (Fig.4). In contrast, in the 2005/06 season, half of detected fish moved quickly out of the area by the next 15 days following tagging and, however, 18% of tagged fish remained for over 100 days after tagging.

Spatial usage of the migration region.

While SBT tagged in 2004/05 migrated mostly around inshore, in 2005/06 fish migrated not only between the inshore seamounts and the continental shelf, but also along curtains (ie. cross shelf) (Table 1). This result indicates that the estimated residence time (85.0 %) out of ASA during 2004/05 season was greater than in ASA (15.0 %). On the other hand, unlike 2004/05 season, tagged SBT during 2005/06 stayed in ASA (61.7 %) rather than out of ASA (38.3 %).

Discussion

To monitor recruitment level of 1-age SBT, an acoustic survey has been conducted for several years (1996-2005). For example, in 2005, the transect survey using scanning sonar and the design of the zigzag transect line in ASA was conducted between January 14 and February 17 (Itoh, 2005). When the information from the AS is combined with the spatial and temporal variation observed in the acoustic tagging, it seems obvious that most of the tagged fish recorded by acoustic receivers seemed to be moving in coastal waters (and hence out of the ASA). They would thus be 'hidden' from the acoustic survey vessel. Itoh (2005) reported that the calculated acoustic indices of 2004/05 season have been at the lowest level since 2000. While it should be noted there are some issues regarding the reliability of the acoustic indices based on the biomass of SBT schools estimated by sonar specialists (Itoh and Tsuji, 2004), our results based on tagged fish indicated that the majority of 2004/05 SBT migrated mainly inshore (ie. out of ASA). Thus, our results suggest that the sonar specialists may detect more fish schools than in recent years (2000-2003), if the AS could include more inshore regions. The two year comparisons in difference in STD pattern investigated by acoustic tagging were characterized by two distinctive migration runs. It would be not only the shelf- and inshore-migrating, but also different residence time in the waters of southern Western Australia during summer-autumn period. Inshore-migrating SBT could leave by the end of summer, suggesting the absence in ASA. Shelf-migrating SBT moved mainly on shelf in summer-autumn period.

While Japanese research vessel of AS have a high performance omni scan sonar to detect SBT schools in ASA, for this vessel it would be too dangerous to conduct the AS along inshore area as the vessel is too large, and because the coastal waters including many small seamounts and some unsurveyed bathymetry areas. An alternative method to estimate recruitment indices of SBT were proposed by Itoh and Tsuji (2005). They have proposed the trolling catch indices by using the piston lined survey set off Bremer Bay extended toward the shelf break of offshore as a line between two points (34.5 S/119.4 E, 34.8 S/119.7 E). It would be important to conduct the piston line survey

(PLS) period with migration timing across the shelf off Bremer Bay. They have already conducted the preliminary PLS in 2004/05 and 2005/06. When the catch information of SBT from the PLS is combined with the STD observed in the acoustic tagging, it seems obvious that 141 SBT catches in PLS of 9 round trips off Bremer Bay during 23-30 January 2006 (Itoh, 2007) were consistent with the tagged SBT widely distributed on shelf (curtains) in 2005/06 season, while a fewer catch (32 individuals) on the PLS of 9 round trips (under same times of 2004/05) between 14 January and 17 February 2005 (Itoh, 2007) were related to the presence of tagged SBT at HS mainly till mid-February 2005.

The differences in catchability of PLS between two years may be seen to increase trend of the recruitment index from the 2004 year class to the 2006 class (Itoh, 2007) and this could be expected to be a result of density-dependent catch efficiency or a density-dependent horizontal distribution through on shelf and in seamounts, where a relatively high proportion of migrating SBT in seamounts (out of ASA) in 2004/05 season will be unavailable to the trolling survey.

Consequently, in order to predict the migration timing and temporal and spatial distribution pattern before the recruitment survey year-by-year start, the underlying mechanism of migration dynamics in relation to the annual fluctuations of oceanographic conditions (eg. the strength of Leeuwin Current, the presence of eddy and upwelling in the inshore and on shelf) responsible for the temporal precision and annual inshore-shelf movements displayed by migratory SBT awaits further inquiry.

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Table 1 Details of the number of migration recorded between receivers (and curtains) and residence time in and out of ASA estimated by analysis based on straight-line distance –time rates.

	2004/05 season			2005/06 season		
	No. of migrations	in ASA (day)	out of ASA (day)	No. of migrations	in ASA (day)	out of ASA (day)
BI-HS	40	4.4	210.0	30	0.0	139.7
PH-HS	23	37.6	126.1	14	25.8	48.7
WI-HS	3	36.1	16.4	0		
BI-PH	11	101.5	42.3	21	140.4	105.4
PH-WI	8	30.9	38.1	28	529.4	74.7
BI-WI	2	12.7	4.7	2	103.7	12.4
Between HS	88	0.0	287.3	13	0.0	75.1
Along curtain	104	57.7	189.5	158	262.4	189.3
Between adjacent receivers along curtain	79	1.3	51.6	118	94.6	49.5
Between adjacent receivers in HS	2384	0.0	634.8	30	0.0	22.8
Total	2742	282.1	1600.8	414	1156.3	717.6
%		15.0	85.0		61.7	38.3

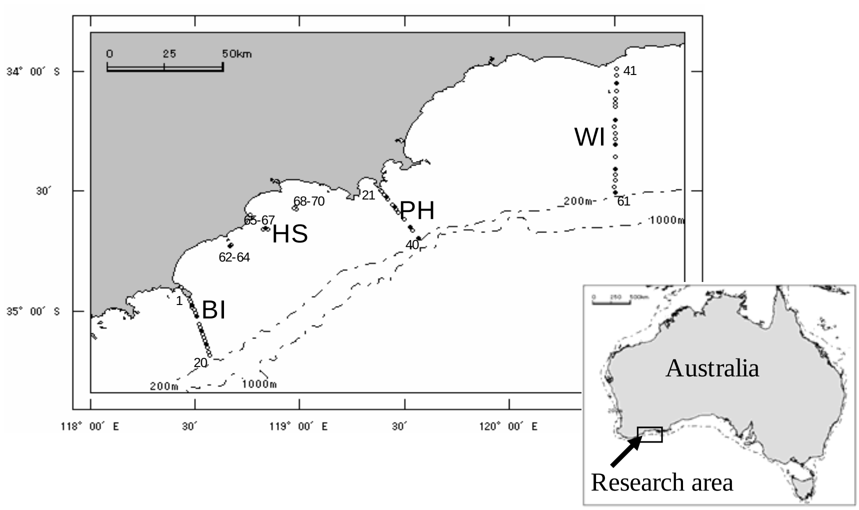


Fig.1 Research area in southern Western Australia, showing the location of acoustic receivers with (black circles) or without TDR (white circles). BI: Bold Island; PH: Point Henry; WI: West Island; HS: three Hot spots. Each filled circle represents one VR2 receiver with TDR (unfilled circle without TDR). Receivers were aligned into 'curtain' on shelf.

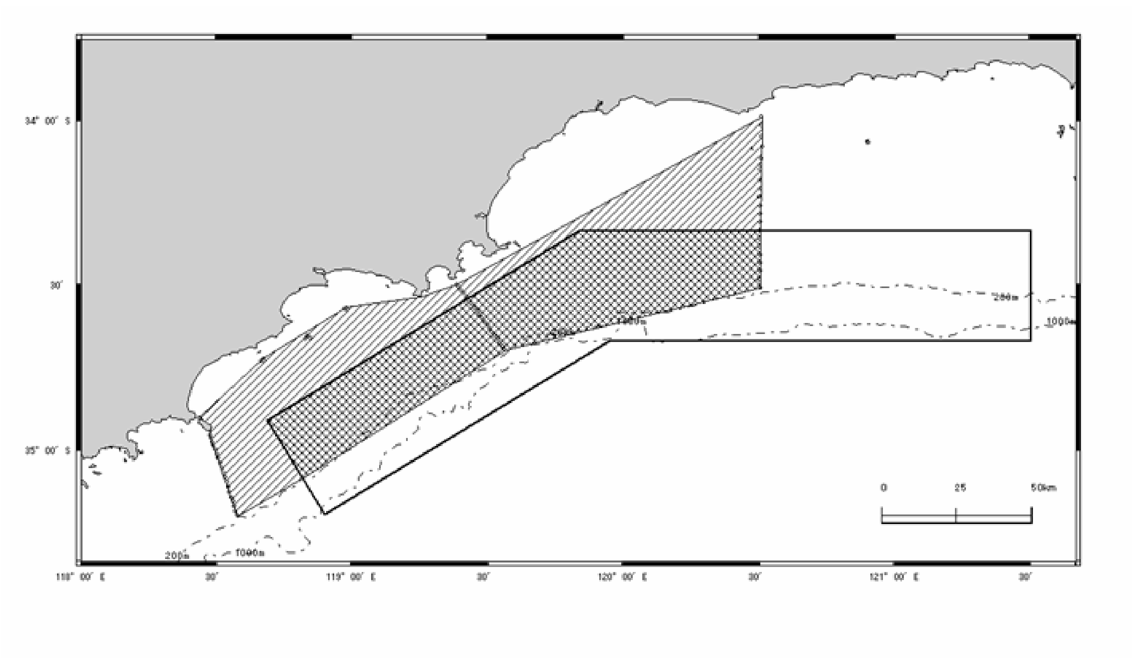
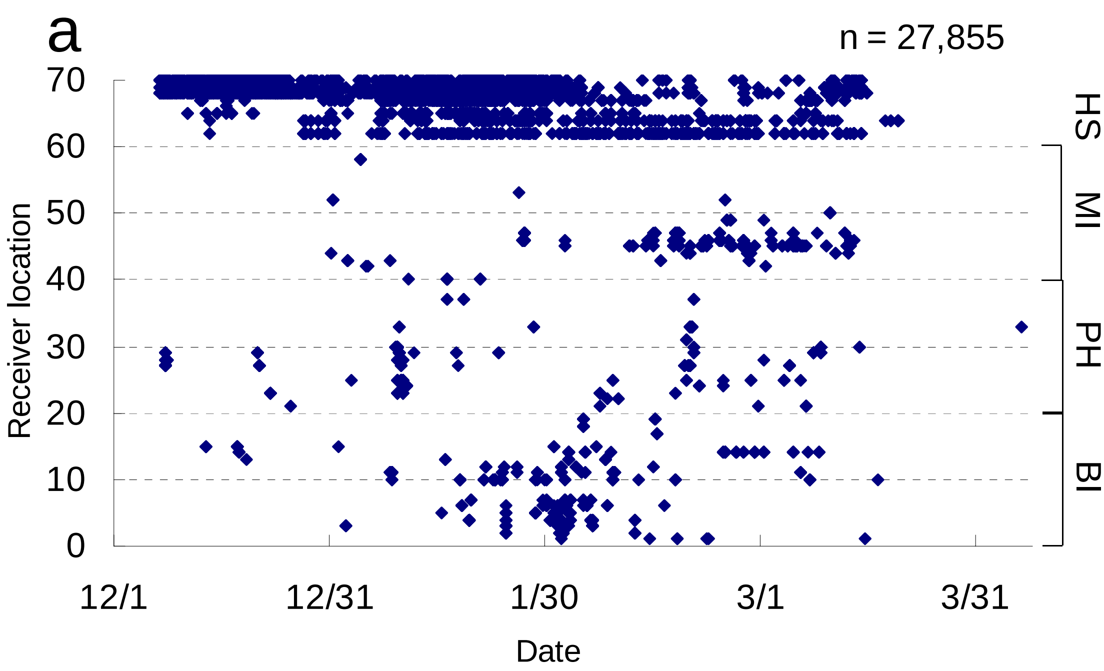


Fig.2 Research area showing Acoustic Survey Area (ASA: solid line), in ASA (dark diagonaling area) and out of ASA (light diagonaling area).



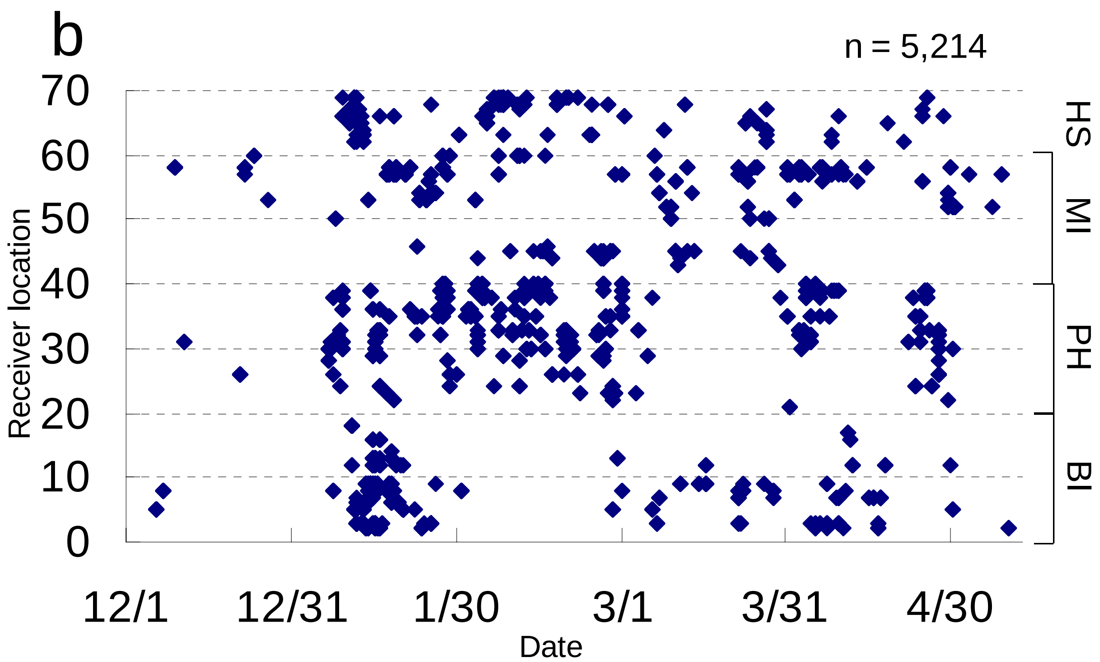


Fig.3 Time series of acoustic detections (represented by dots) for all tagged SBT by VR2 receivers from Dec 2004 to March 2005 (a) and from Dec 2005 and May 2006. VR2 receiver's locations and numbers (No.1-20 (BI), No. 21-40 (PH), No. 41-61(WI) and No.62-70 (HS)) are illustrated on Fig.1.

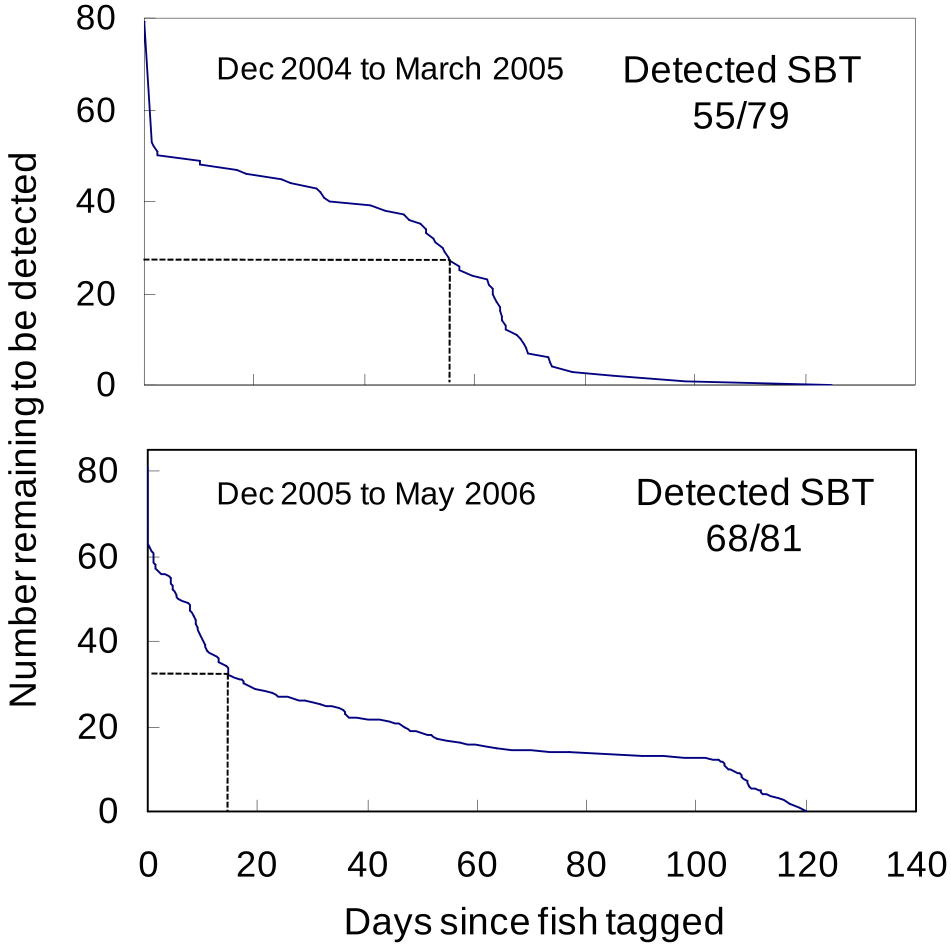


Fig.4 Persistence of tagged SBT in the research area. Note the graph shows the days since the fish tagged. Dotted lines show when 50% of detected fish remained.