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Commentary

Tagging studies on the diamond squid (*Thysanoteuthis rhombus*) in the western Sea of Japan

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This paper describes the tag-recapture experiments conducted on the diamond squid (*Thysanoteuthis rhombus*) in the western Sea of Japan in October and November during 2001–2006 to elucidate its horizontal migratory ecology. A total of 2,751 squid were tagged and released using disc-type tags off Tottori and Hyogo prefectures by researchers (Group A, 791 squid in 9 experiments) and fishers (Group B, 1,960 squid in 5 experiments), and 163 were recaptured (121 in Group A and 42 in Group B). Recapture rates were 0–22.7% (overall rate=15.3%, experiment mean=11.7%) in Group A and 0–6.4% (overall rate=2.1%, experiment mean=2.5%) in Group B, which are high compared to the results of previous tagging studies on oceanic and neritic squids. The high recapture rates were presumably due to regional oceanographic-fisheries peculiarities in the western Sea of Japan where catches of *T. rhombus* tend to be high in warm nearshore areas. Recaptures occurred both west and east of the release sites each year, but more squid were caught to the east. Distances between release and recapture sites ranged from 0.5 to 513 km, and mean movement speeds were 0–78 $km \cdot d^{-1}$, which suggest that *T. rhombus* is a slow inactive swimmer.

Key words: *Thysanoteuthis rhombus*, diamond squid, migration, Sea of Japan, tagging study

Introduction

The diamond squid (*Thysanoteuthis rhombus*) is the lone species in the family Thysanoteuthidae (Sasaki, 1929; Clarke, 1966; Okutani, 1967; Nigmatullin and Arkhipkin, 1998) and one of the largest cephalopods for marine food in the world (maximum mantle length (ML)=100 cm, Roper *et al.*, 1984; Okutani, 1995). Presently, it is an abundant and commercially important fisheries resource in the Sea of Japan, where a fishery targeting the squid began in the early 1960s (Bower and Miyahara, 2005). Annual catches in the Sea of Japan have reached more than 2,500 tons since the early 1990s, and the species is now marketed throughout Japan (Omoto *et al.*, 1998).

This large, nektonic, oceanic squid is distributed worldwide in tropical and subtropical waters, and reaches higher latitudes around Japan due to its association with the Tsushima Current (Fig. 1, Nishimura, 1966; Nazumi, 1975a; Okiyama, 1993; Nigmatullin and Arkhipkin, 1998). Back calculation using statolith and catch data suggest that *T. rhombus* stock that occurs in the Sea of Japan hatches in wide areas from southern Kuroshio region to downstream areas of the Tsushima Current in January–September, with a peak in February and March (Miyahara *et al.*, 2006b). After hatching, the young stages occur at upper epipelagic or subsurface depths (Miyahara *et al.*, 2006a) and are transported by the Tsushima Current through the Tsushima Strait into the Sea of Japan (Nishimura, 1966; Nazumi, 1975a).

Strong correlations between environmental indices around the Tsushima Strait in June and annual catch levels in September–November suggest that *T. rhombus* enters the Sea of Japan in late spring or early summer (Miyahara *et al.*, 2005). The occurrence of small (<20.5 cm ML) squid off Hyogo Prefecture in June and July (Nazumi, 1975b; Miyahara *et al.*, 2006b) also suggests this timing of immigration, but little is known about its migratory behavior after it enters the Sea of Japan. *Thysanoteuthis rhombus* is thought to be a passive migrant despite its nektonic shape with a powerful muscle mantle (Nigmatullin and Arkhipkin, 1998), but its migratory patterns in the Sea of Japan have never been directly demonstrated with conventional tag-recapture methods, which are useful to study migration mechanism in many important squid species around Japan (Nagasawa *et al.*, 1993).

The present study describes tag-recapture experiments conducted in the western Sea of Japan to track the migra-

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tion of *T. rhombus*. Horizontal movement is analyzed and discussed in relation with oceanographic conditions, which influence the distribution of this species in the western Sea of Japan (Miyahara *et al.*, 2007).

Materials and Methods

Fourteen tagging experiments were carried out in October and November during 2001–2006 off Tottori and Hyogo prefectures (Fig. 1). The experiments were divided into two groups: Group A, comprising nine experiments conducted by researchers from the Tottori Prefectural Fisheries Research Center and the Hyogo Tajima Fisheries Technology Institute with help from local fishers, and Group B, comprising five experiments conducted by local fishers in Hyogo and Tottori prefectures in a community-based voluntary tagging program.

In Group A, 791 young to mature squid (20–81 cm ML, Table 1) caught by vertical longline gear called "*taru-nagashi*" (Miyahara and Takeda, 2005) were tagged using a disc-type (Atkins) tag with a plastic tube inserted through the fin by hand (Fig. 2). It took about 30 seconds to tag each squid, and released squid jetted immediately and showed no physical signs of injury after tagging. Size (ML to the nearest cm) data and location (latitude and longitude) of release measured using GPS locators were recorded.

In Group B, 1,960 smaller squid (ML range: 25–35 cm, Table 1) caught during fishery operations were tagged. MLs were estimated visually, but precise locations were recorded as in Group A.

Horizontal movement distance was calculated as the linear distance between the release and recapture sites. For squid recaptured in Toyama Bay, a detour distance was calculated by summing the distances from the release site to Cape Suzu (in Noto Peninsula, 37°31′N, 137°18′E) and from Cape Suzu to the recapture site. The daily mean horizontal movement speed was determined by dividing the movement distance by the days elapsed between the release and recapture dates (tagging period). For squid recaptured on the same day they were released, an elapsed time of 0.5 days was assumed.

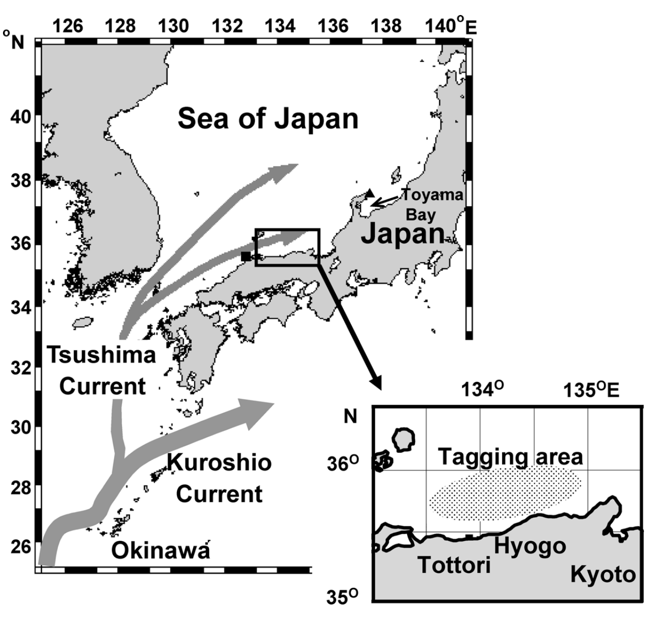

Figure 1. Tagging study area. The closed square and triangle show Cape Hinomisaki and Cape Suzu, respectively.

Results

Of the 2,751 tagged and released squid in both groups, 163 were recaptured (121 were in Group A and 42 in Group B, Table 1). Tags were retrieved from squid caught by fishers and from squid stranded on the beach. Recapture rates were higher in Group A (range: 0–22.7%, overall rate=15.3%, experiment mean=11.7%) than in Group B (range: 0–6.4%, overall rate=2.1%, experiment mean=2.5%), and higher in the squid released off Tottori Prefecture (range: 0–22.7%, overall rate=17.6%, experiment mean=13.3%) than off Hyogo Prefecture (range: 0–15.4%, overall rate=2.5%, experiment mean=4.7%). In Group A experiments conducted off Tottori Prefecture, the recapture rate was lower in 2004 (9.2%) than in 2003, 2005 and 2006 (20.5–22.7%).

Tags from 155 of the recaptured squid provided complete date-location data. Recaptures occurred both west and east of the release sites, but greater most squid (80.6%) were collected to the east (Fig. 3). Almost all the squid were recaptured between 133° and 136°E; only six were caught outside this longitude range, including two from inshore areas around Cape Hinomisaki in Shimane Prefecture in 2006, one from near the Noto Peninsula in Ishikawa Pre-

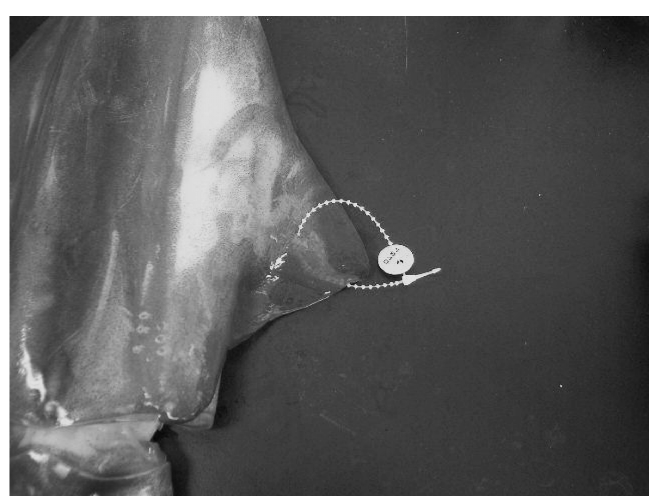

Figure 2. A tagged diamond squid. A conventional disc-type tag was attached by piercing the fin muscle using a thin plastic tube.

Table 1. Results of tag-recapture experiments on the diamond squid in the eastern Sea of Japan.

Group	Year	Date	Tagging site	Number of squid			ML*[3] range (mean±sd) of squid (cm)		Range of days elapsed*[4]
				Rel*[1]	Rec*[2]	Rate (%)	Rel*[1]	Rec*[2]	
A	2001	25 Oct.	36°00′–36°03′N, 134°32′–134°37′E (off Hyogo Pref.)	91	5	5.5	31–60 (53.5±9.2)	37–56 (49.2±7.6)	0–2
A	2002	11 Oct.	35°53′–35°57′N, 134°22′–134°27′E (off Hyogo Pref.)	94	5	5.3	32–81 (55.1±9.7)	37–80 (63.5±10.4)	0–38
A	2003	3–10 Oct.	35°40′–35°43′N, 133°50′–134°17′E (off Tottori Pref.)	286	65	22.7	24–72 (44.2±8.7)	37–80 (47.2±9.7)	1–68
A	2003	5 Nov.	35°41′–35°42′N, 134°32′–134°36′E (off Hyogo Pref.)	13	2	15.4	41–69 (54.5±8.1)	47–49	1–5
A	2004	7 Oct.–17 Nov.	35°40′–35°52′N, 133°52′–134°11′E (off Tottori Pref.)	130	12	9.2	29–74 (46.6±12.4)	38–80 (50.5±12.0)	1–38
A	2005	2 Sep.–21 Oct.	35°41′–35°52′N, 133°53′–134°16′E (off Tottori Pref.)	76	16	21.1	34–69 (54.4±8.4)	51–70 (61.4±6.3)	2–44
A	2005	21 Oct.	35°47′–35°50′N, 134°34′–134°36′E (off Hyogo Pref.)	19	1	5.3	45–71 (60.7±7.1)	60	27
A	2006	20 Oct.	35°45′–35°50′N, 134°35′–134°45′E (off Hyogo Pref.)	9	0	0.0	33–50 (42.3±6.7)	–	—
A	2006	20–27 Oct.	35°40′–35°45′N, 133°56′–134°12′E (off Tottori Pref.)	73	15	20.5	30–70 (50.2±8.4)	40–64 (52.8±6.5)	1–52
			Subtotal	791	121	15.3 *[5]			
B	2001	23 Sep.–9 Nov.	35°38′–36°07′N, 134°20′–134°55′E (off Hyogo Pref.)	580	7	1.2	20–42 (30.7±3.8)	25–48 (32.9±8.0)	0–45
B	2002	15 Sep.–19 Nov.	35°37′–36°06′N, 134°08′–134°58′E (off Hyogo Pref.)	676	18	2.7	9–44 (29.0±4.6)	29–60 (35.4±8.7)	0–62
B	2003	16 Oct.–24 Nov.	35°41′–36°53′N, 134°18′–134°59′E (off Hyogo Pref.)	640	14	2.2	25–45 (33.8±4.3)	34–52 (39.0±4.9)	1–51
B	2004	7 Oct.–11 Nov.	35°31′–36°53′N, 133°51′–134°22′E (off Tottori Pref.)	47	3	6.4	25–49 (36.0±6.1)	33–45 (38.0±6.1)	0–38
B	2005	6 Oct.–26 Oct.	35°36′–35°45′N, 133°49′–134°07′E (off Tottori Pref.)	17	0	0.0	—	—	—
			Subtotal	1960	42	2.1*[5]			
			Total	2751	163	5.9*[5]			

*[1]: Released squid
*[2]: Recaptured squid
*[3]: Dorsal mantle length at release
*[4]: Between release and recapture
*[5]: Experimental mean = 11.7% in Group A, 2.5% in Group B and 8.4% in total

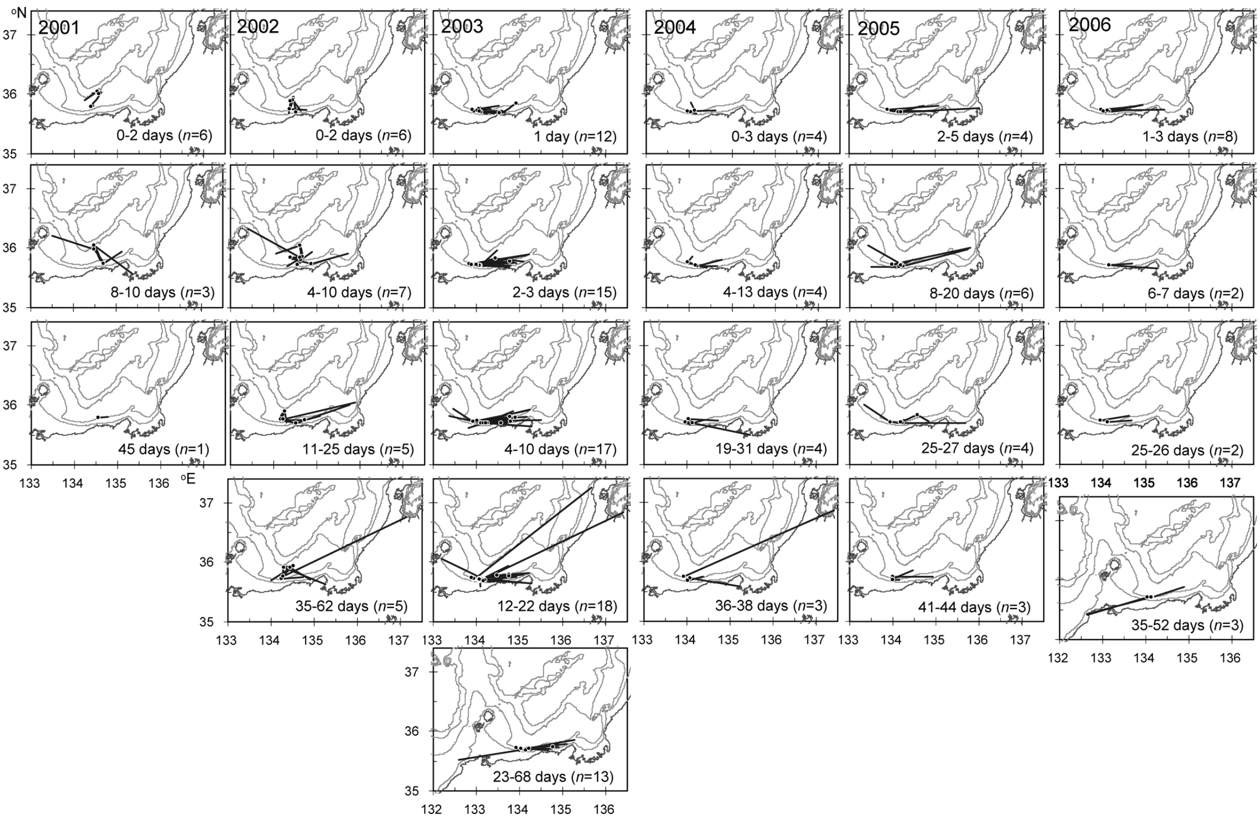

Figure 3. Horizontal migration of the recaptured diamond squid in 2001–2006. Closed circles show the release sites. Ranges of elapsed number of days between release and recapture are also shown.

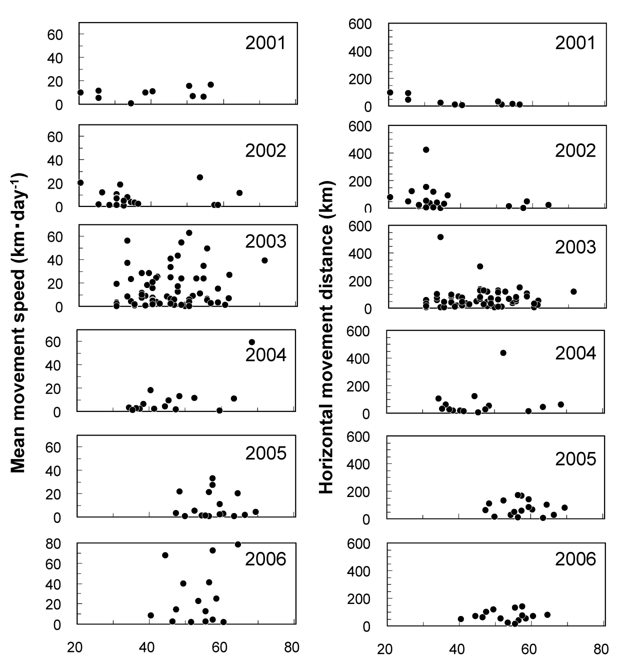

Figure 4. Scatter plot of mean movement speed (left) and horizontal movement distance (right) versus mantle length of the tagged diamond squid in 2001–2006.

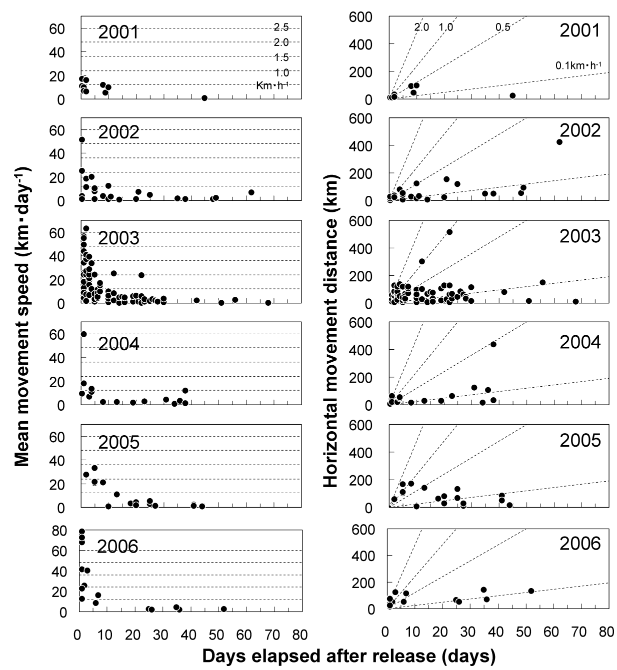

Figure 5. Scatter plot of mean movement speed (left) and horizontal movement distance (right) versus days elapsed after release of the tagged diamond squid in 2001–2006. Dotted lines show guide speeds converted in $km \cdot h^{-1}$.

fecture in 2003 and three from Toyama Bay in Toyama Prefecture (one each year in 2002–2004). Horizontal movement distances ranged from 0.5 to 513 km, and mean movement speeds were 0–78 $km \cdot d^{-1}$. No close relationships were observed between the movements (*i.e.*, speed and distance) and the size range of the tagged squid (Fig. 4). The longest tagging period was 68 days, but most squid were recaptured shortly after tagging; 67 squid (43.2%) were recaptured during the first five days and 89 (57.4%) were recaptured during the first 10 days (Fig. 5). No clear relationship was observed between the tagging period and the movement distance, and the mean movement speed was higher in the squid recaptured after shorter periods.

Discussion

Recapture rates of tagged squid were high compared to the results of previous squid tagging studies (Table 1), especially in Group A, which shows that *T. rhombus* is a suitable species for tagging studies. This large squid can be easily tagged with conventional disc-type tags and showed no signs of injury due to tagging. Recaptured squid also showed little external injury around the tags, suggesting post-release survival is high if proper tagging methods are used.

There are two possible reasons why recapture rates were lower in Group B than in Group A. Smaller squid were used in Group B (Table 1), and size-dependence of return rates have been reported in another large oceanic squid, the jumbo flying squid (*Dosidicus gigas*, Markaida *et al.*, 2005). Another possible reason is a difference in the skill level of the taggers. Group B experiments were conducted voluntarily by local fishers during their fishing operations, and their relatively less skillful tagging ability may have resulted in higher post-release mortality.

In a tagging study of *T. rhombus* near Okinawa, Watanabe (2004) recaptured only 5 of 2,367 tagged squid (0.2%). In other oceanic squids, recapture rates have generally been low, and few studies have yielded higher recapture rates than those in the present study (*e.g.*, Nagasawa *et al.*, 1993; Markaida *et al.*, 2005). Recapture results in Group A were even higher than those reported for neritic loliginid squids (Nagasawa *et al.*, 1993; Moriwaki, 1994; Sauer *et al.*, 2000). The high rates are presumably due in part to regional oceanographic-fisheries peculiarities in the western Sea of Japan. Catches of *T. rhombus* tend to concentrate in the warm nearshore areas during the fishing season (Miyahara *et al.*, 2007), and the largest *T. rhombus* fishery in the Sea of Japan operates off Hyogo Prefecture (Bower and Miyahara, 2005). Higher recapture rates in Group A (20.5–22.7%) were observed in 2003, 2005 and 2006, when warm water areas occurred close to shore off Hyogo Prefecture (Japan Coast Guards, 2007) due to a cold water mass named the '*Sanin-Wakasa Oki Reisui*', and intensive fishing pressure was presumably applied to the squid released at upstream areas off Tottori Prefecture. Increased efforts to publicize the tagging studies to local fishers in wider areas in the Sea of Japan would have also worked to increase tag returns.

Our tagging experiments included mature squid (>59 cm ML in female and >47 cm in male, Takeda and Tanda, 1998), but size-dependent movements such as spawning migration were not clearly observed (Fig. 4). No clear relationships were observed between the tagging period and the horizontal movement distance, and the mean movement speeds were higher in the squid recaptured after a shorter tagging period (Fig. 5), suggesting that the migration of *T. rhombus* in the Sea of Japan is not be linear.

Thysanoteuthis rhombus is thought to be a passive migrant (Nishimura, 1966; Nigmatullin and Arkhipkin, 1998). In the present study, horizontal movement speeds ranged from 0 to 78 $km \cdot d^{-1}$ (=0–3.3 $km \cdot h^{-1}$, Fig. 4), and more than 80% of the recaptures occurred in the Tsushima Current downstream (to the east) from the release sites. Sea surface currents in the western Sea of Japan estimated on the basis of NOAA and TOPEX/ERS-2 satellite observations had speeds <3.5 $km \cdot h^{-1}$ when and where the tagging studies were conducted in 2001–2006 (Japan Coast Guards, 2007). In a biotelemetric tracking study of *T. rhombus*, Iizuka (1990) estimated the swimming speed of two tagged squid (ML: 48–49 cm) in the Sea of Japan to be 0.9–1.3 $km \cdot h^{-1}$. Horizontal movement speeds (estimated based on distance between release and recapture sites) recorded near Okinawa include 0.4–7.3 $km \cdot h^{-1}$ for two 63–72 cm ML squid (Kanashiro *et al.*, 2000), 1.7–2.3 $km \cdot h^{-1}$ for three 75–77 cm ML squid (Yano *et al.*, 2000), and 1.2 $km \cdot h^{-1}$ for an 82-cm ML female (Kanashiro *et al.*, 2001). Mean movement speeds recorded in the present study suggest that *T. rhombus* swims slower than surface current speeds, which are usually greater than those at deeper depths.

Adult *T. rhombus* in the Sea of Japan migrates vertically between 50–150 m depth in the day and 0–50 m at night (Iizuka, 1990; Our unpublished data). Thus, when considering the effect of currents on the distribution of squid, it is important to look at both surface currents (Nishimura, 1966; Ikeda *et al.*, 2003) and currents at 50–150 m depth, which often flow differently from those at the surface (Matsuyama *et al.*, 1986; Matsuyama, 1990; Kato *et al.*, 1996; Hase *et al.*, 1999; Yamada *et al.*, 2006). Further investigations using ultrasonic telemetry combined with ADCP observations are needed to directly compare swimming behavior and ambient current velocities. Moreover, oceanographic conditions in the Sea of Japan can now be simulated using models such as the RIAM ocean circulation model (Hirose, 2003) to model the migration of aquatic species (*e.g.*, for the Japanese common squid *Todarodes pacificus*; Fujii *et al.*, 2004). Such models could help clarify the migratory ecology of *T. rhombus* by tracking its migratory patterns and to check how passively its migration is regulated by oceanographic conditions.

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日本海西部におけるソデイカの標識放流調査

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日本海におけるソデイカの移動回遊生態を明らかにするため，2001～2006年の10～11月に鳥取–兵庫県沖海域でディスクタグによる標識放流調査を実施した．研究機関による放流が791尾，漁業者による放流が1,960尾，合計2,751尾のうち、再捕は前者で121尾（放流回次別の再捕率は0～22.7%），後者で42尾（同0～6.4%）の合計163尾であった．再捕率は他の外洋性沿岸性イカ類のそれよりも高く，調査海域の水産海洋学的特性が関係していると考えられた．再捕は，毎年，放流海域の東西両方向から報告されたが，80.6%が東方からであった．水平直線移動距離は0.5～513 kmであり，日平均移動速度は0～78 km·d^{-1}であった．ソデイカが海流速度よりも速く移動したという再捕事例は見当たらず，長期的水平移動に関しては，ソデイカは不活発で受動的な回遊者である可能性が示唆された．

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