Title: Swimming depths of the giant jellyfish *Nemopilema nomurai* investigated using pop-up archival transmitting tags and ultrasonic pingers

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ABSTRACT

The swimming depths of 12 individual *Nemopilema nomurai* with bell diameters of 0.8 to 1.6 m were investigated using pop-up archival transmitting tags and ultrasonic pingers, and evaluate the validity of the research method. *N. nomurai* frequently showed vertical movement. Range of swimming depths were 0 to 176 m and the mean swimming depths of most individuals were smaller than 40 m. The depths of *N. nomurai* in the northern Japan Sea in the winter were mostly deeper than the depths of this species in the southern Japan Sea in the autumn. This suggested that the range of the depths almost depends on the vertical structure of the ocean. Swimming depths during the nighttime were significantly deeper than that during the daytime. In the daytime, the swimming depths in the afternoon tended to be shallower than those in the morning. And during the nighttime, the swimming depths after midnight were deeper than those before midnight.

KEYWORDS: "Circadian rhythms", "Giant jellyfish (*Nemopilema nomurai*)", "Pop-up archival transmitting tag", "Swimming depth", "Ultrasonic pinger", "Vertical movement"

INTRODUCTION

Giant jellyfish *Nemopilema nomurai* is a large Scyphozoan, with a bell diameter attain up to 1.5 m and mainly inhabits the Bohai Sea, Yellow Sea and northern East China Sea [1, 2] . *N. nomurai* was rarely appeared in the Japanese sea area in the 20^{th} century [3]. But from 2002 to 2007, the dense aggregations have reached to seas surrounding Japan every year [4]. Especially the fisheries industries of the Sea of Japan have caused severe damage by clogging trawl nets and fixed nets and so on [5-7].

In order to alleviate the damage caused by *N. nomurai*, countermeasure techniques using mainly trawl nets and fixed nets are being developed [7-10]. In addition, trawl gears to get rid of *N. nomurai* on the ocean have been developed [11]. These techniques and gears, if used based on the behavioral and distribution characteristics of *N. nomurai*, can alleviate damage to the fisheries industries more effectively. Especially, information on the distributed depths and those patterns of *N. nomurai* will serve as basic data for the development of alleviation measures against fishery damage caused by *N. nomurai*. If the swimming depths and circadian rhythms of target fishes for fishing are different from those of *N. nomurai*, it is possible to take effective measures such as selecting times and locations for fishing, or concentrating jellyfish control measures on depth zones in which *N. nomurai* are most likely to be found. In addition, with regard to getting rid of *N. nomurai* on the ocean, this data will help in determining effective operation depths. Furthermore, to predict transport routes and emergence times of *N. nomurai*, the research using various transport prediction models is also being undertaken [5, 12-15]. In the models the swimming depth is a critical factor because ocean current have different direction and velocity at each depth. If the depth zone where *N. nomurai* are most distributed is known, it will be possible to predict the exact times when *N. nomurai* reach each fishing ground.

At present there is only spare information about the behavioral characteristics of *N. nomurai* and especially almost nothing for the swimming depth. Their large size and fragile body have rendered the development of the method for the behavior research and no method has been established yet.

In order to investigate the vertical distribution of *N. nomurai*, a method has been proposed in which the vertical distribution of *N. nomurai* is determined quantitatively using a combination of midwater trawl net and underwater video camera [16]. However, although this method is capable of measuring the distribution of a whole swarm of the jellyfish in the daytime, it cannot be used to continuously observe the behavior of individuals.

On the other hand, a method in which target underwater animals are fitted with small electronic tags such as data loggers or archival tags with built-in depth sensors and data recording memories, released, and then caught after a certain time period in order to retrieve data and determine the swimming depths of the target animals, has come into commonly use in recent years [17]. However, as *N. nomurai* are not a target species in the commercial fishing, the possibility of retrieving such electronic tags is very low.

Taking this into consideration, we applied Pop-up Archival transmitting Tags (hereinafter referred to as PATs) and Ultrasonic pingers (hereinafter referred to as pingers) to investigate the swimming depths of *N. nomurai*. The PAT is separated from the target animal when a preset time passes, floats to the surface, and while drifting on the surface of the sea, transmits data stored in the memory by radio to the Argos satellite

[18]. The pinger transmits data without separated from the target animal in the water, so that depth data for the target animal can be acquired in real time. Therefore, it is not necessary to recapture the target animal or retrieve the PAT or the pinger.

In this study, we used the above two types of electric tags for the research of the individual behavior including the swimming depths of *N. nomurai* and evaluate the validity of these research methods.

MATERIALS and METHODS

Properties for the devices

For PATs, we used the PTT-100 model (Microwave Telemetry) and the Mk10-PAT model

(Wildlife Computers). Both are similar shape with 16 cm lengths, 4 cm maximum diameter and 16 cm antenna, and weigh 65 g. Each PAT is equipped with depth, temperature and illumination sensors. Depth resolutions are 1.25 m with the PTT-100 and 0.5 m with the Mk10-PAT. The data of illumination sensor enable to estimate the rough position of PAT (longitudinal and latitudinal accuracy: approx. 1 degree) from sunrise and sunset time. The data are recorded in the memory in the PAT as continuously for PTT-100 (set at 5 minutes interval measurement) and as frequency distribution data during one hour for Mk10-PAT (set at 20 second interval measurement).

For pingers, we used the V13P (VEMCO, length: 4 cm, diameter: 1.3 mm, weight: 6 g) and the V16P (VEMCO, length: 6 cm, diameter: 1.6 mm, weight: 10 g). The pinger possesses a depth sensor (resolution: 0.5 m) and transmits measured depth data using ultrasonic signals. The signals are received by a towing type receiver (VEMCO, VR28 system) towed by a ship that tracks the pinger. The signal coverage distance is approximately 200 m on the ocean. The signal transmitting interval is approximately 30 seconds, therefore it is possible to measure depths at shorter intervals than the PAT.

How to attach the tags to the jellyfishes

We first studied how to attach PATs and pingers to the jellyfishes. It is common practice to catch target fish and attach tags onboard ships or attach tags to the body surfaces of fish using harpoons [19]. However, it is extremely difficult to lift giant jellyfish up onto the decks of ships intact. In addition, as the body surfaces of *N. nomurai* are much softer than fish, tags are easily removed when they are attached using harpoons. Thus, we contrived a method of binding plastic bands (hereinafter referred to as Bands) with PATs or pingers attached to swimming jellyfish in the water. For bands, we used industrial INSULOK Ties (HellermannTyton, SEL-R1 ties, 7.6 mm wide) and SEL-H2 locking heads. As *N. nomurai* possess strong nematocyst venoms in their tentacles [7, 8], it is necessary to avoid contact with the tentacles when in the water. Consequently, we made an attaching tool consisting of a combination of a pickup tool and a polyvinyl chloride pipe (length: 60 cm) with a preset band at the tip of the tool (Fig. 1). Each band was attached to a *N. nomurai* by letting the bell of the jellyfish go through the noose of the band and then fastening the band at a narrowed part between the oral arms and the tegula portion inside the bell, and the band with a PAT or a pinger attached does not easily fall off (Fig. 2).

Deployments of the tags to the jellyfishes

Ten PATs and two pingers were attached to a total of 12 adult *N. nomurai* using scuba diving in sea areas stretching from off Hamada City, Shimane Prefecture to off Sado Island, Niigata Prefecture from September to December during the years 2004 to 2006. Here, individuals fitted with PATs and pingers are identified as PAT1 to PAT10 and Pinger1 and Pinger2 respectively. Model types of the tags, deployed dates of PATs and pingers, positions, and sea areas are shown in Table 1. Bell diameters of these *N. nomurai* measured by a measuring tape in the water were ranging from 0.8 to 1.6 m (mean: 1.2 m).

As the purpose of the researches using PATs were to record the rough behavior of *N. nomurai* over a relatively long period of time, the period until the PATs were released and floated to the surface of the sea was set at 3 weeks. Pingers were aimed at learning more detailed behavior over a shorter time period than those using PATs, we set a target of approximately two days of continuous tracking.

PAT1 and PAT2 were the individuals that were found near the surface of the sea by visual surveys from the ship and PAT3 to PAT10 and Pinger1 and Pinger2 were found by scuba diving at depths of approximately 15 to 35 m. The times required to attach PATs and pingers to the jellyfish were within 5 minutes for each individual. As the specific gravity of a PAT is smaller than that of seawater and that of a pinger is greater, small floats or weights are added to the bands to adjust the specific gravities of whole units (the tag and band) so that neutral buoyancy could be maintained in the sea. In addition, after being fitted with a PAT or a pinger, each *N. nomurai* was tracked and its swimming behavior was observed by a diver for approximately 5 to 20 minutes.

Pinger1 was tracked by the Mizuho-maru (156 tons, belongs to the Japan Sea National

Fisheries Research Institute, FRA) and Pinger2 was tracked by the Kaiyo-maru No. 7 (499 tons, belongs to Nippon Kaiyo Co., Ltd.). Both ships suspended a towing receiver (VR28 system) from the bow side, and each receiver was connected to a laptop computer in the ship. Tracking was performed while checking the current directions of the depths at which the jellyfish swam using the ships' ADCP. In addition, vertical distributions of water temperatures and salinities contents were measured using a STD (AST-100, ALEC ELECTRONICS) immediately before and after tracking, and this data was corresponded with swimming depth data of *N. nomurai*.

RESULTS

Behavior of jellyfishes after attaching tags

As 5 to 20 minutes tracking observations by a diver after attaching tags to *N. nomurai*, it was confirmed that the PATs, pingers, and bands did not hinder the pulsative movements of the jellyfishes and did not prevent their active swimming behavior.

PATs data retrieval rates

Except for the 100 % data retrieval for PAT2 which was recovered after floating ashore, the retrieval rates for PAT data using the Argos satellites (= amount of data received by satellite / amount of data measured by PAT) were 12 to 84 % (Table 2). For most PAT's, as missing data did not tend towards a specific time period during the measuring period, we were able to obtain amounts of data which were sufficient for grasping about the swimming depths of *N. nomurai* in subsequent analyses.

PATs surfacing positions and migration directions

In the investigations, the migration distances of *N. nomurai* were too short to estimate rough position coordinates during migrations from the illumination data of PATs. However, estimations of the positions where PATs surfaced were possible using the positioning system of the Argos satellite [18]. Surfacing positions and migration directions for each PATs are shown in Fig. 3, and the time periods over which depth data were recorded are shown in Table 2. It was confirmed from the relationships between the positions where PATs were attached and the positions where PATs surfaced, that most individuals with PATs migrated in a northeasterly direction. Only PAT3 migrated in a northwesterly direction, and the migration distance was approximately 240 km in 21 days.

Pingers tracking times and migration paths

Pinger1 was tracked for approximately 29 hours and Pinger2 was tracked for approximately 23 hours continuously. The horizontal migration paths for each pinger are shown in Fig. 4. The migration directions of the pingers were almost the same as the directions of the currents at the depths where the jellyfish were swimming that were checked during the tracking.

Swimming depths and ambient water temperatures

Time series data for swimming depths for all *N. nomurai* observed using PATs and pingers are shown in Fig. 5 and Fig. 6. It was confirmed that every individuals swam while repeating vertical movements. In particular, rhythmical vertical movements were recorded in PAT3. It was also found that there were individuals changing shallow and deep depths in the interval for several days (PAT5, PAT9). In the pingers with short depth data recording intervals, active vertical movements were observed consisting of repeated diving and surfacing spanning depth differences of over 100 m (Fig. 6).

The swimming depths for each individual and ambient water temperatures at which the jellyfish swam are shown in Table 2. The mean values of the frequency distributions of depths for all individuals are shown in Fig. 7. *N. nomurai* were found to swim at depths ranging from 0 to 176 m, and the 68 % of depths for all individuals were less than 40 m

(Fig. 7). The mean values of swimming depths for each individual were 6 to 76 m, and the mean values for 10 individuals out of 12 were 40 m or less (Table 2). Water temperatures were in the range of 7.5 to 23.4 ºC (Table 2).

Fig. 8 shows plotted swimming depths obtained from all data from PATs and pingers, and ambient water temperatures of *N. nomurai*. There was little difference in the ambient water temperature ranges in 2006 and 2005, but the individuals observed in 2006 dove deeper than those observed in 2005, and the maximum swimming depths for all individuals exceeded 100 m (Fig. 8, Table 2). Swimming depths range and temperatures range in 2004 were smaller than those in both of 2005 and 2006.

In addition, Pinger1 observed in November 2005 off Sado Island dove deeper than PAT3 to PAT6 observed in October 2005 off Kanazawa, and PAT10 observed in December 2006 off Sado Island dove deeper than PAT7 to PAT9 and Pinger2 observed in September

2006 off the Oki Islands (Fig. 8). The depths of *N. nomurai* in the northern part of Sea of Japan in the winter were mostly deeper than the depths of this species in the southern part of Sea of Japan in the autumn in both of 2005 and 2006.

Circadian rhythms of swimming depths

Fig. 9 shows the frequencies in each time zone in a day of the depths for each individual obtained from all time series data measured using PATs and pingers. Though there are a few differences in average depths depending on individuals, it was confirmed that there is a significant tendency towards deeper depths at nighttime rather than in the daytime except PAT1 (paired t-test, $p < 0.01$) (Table 3). In particular, specific circadian rhythm was confirmed in the case of PAT3 (Fig. 9). In addition, although there were a few differences depending on individuals, it was found that there was a tendency towards shallower depths in the forenoon rather than in the afternoon in the daytime (except PAT1, PAT10 and Pinger1), and deeper depths after midnight rather than those before midnight during the night time (All individuals) (Table 3).

DISCUSSION

Assessments of the tags deployment methodology

No attempt had been made in the past to observe the behavior of *N. nomurai* using biotelemetric methods employing electronic tags such as PATs. It was confirmed by these investigations that these electronic tags are effective for observing the jellyfish.

However, almost all of the PATs came loose from the jellyfishes and surfaced before reaching the end of the set up time frame. Although the reason for this was not found obviously, PAT disengagements or deaths of the jellyfish are suspected. In the short term it was confirmed from observations immediately after attaching PATs and pingers that these tags did not affect jellyfish’s behavior, but in the long term it is possible that the bodies of jellyfish may be subjected to friction from PATs and bands or excessive water flow resistance resulting in deteriorations in the activity of the jellyfish. Further considerations with regard to the attaching method and size of PATs therefore need to be made. If a smaller PAT is developed in the future, it is expected to alleviate effects on the jellyfish and reduce the rate at which they come loose.

In addition, this investigation using PATs provided us with an almost sufficient amount of data in order to learn about the depths pattern of *N. nomurai*, but when considering attempts at making more detailed and continuous observations of jellyfish behavior, data retrieval rates achieved using the Argos satellite were not high enough. The reasons for this were difficulties in receiving data due to bad weather, sea condition and the possible inability to transmit all of the data acquired due to insufficient remaining battery power, and some of the data stored in the memory might fail to be transmitted to or received by the Argos satellites. In order to increase data retrieval rates, the development of a PAT with enhanced output power and battery capacity in addition to a more compact unit is required.

In the investigation using pingers, continuous tracking was limited to almost a 24 hour period due to deterioration in sea conditions and research schedule limitations. However, the pinger battery possesses a capacity that allows for approximately two weeks of continuous operation. As it is considerably smaller than the PAT, it affects creatures fitted with it to a smaller effect. Therefore, depending on sea conditions and research schedules, it is possible to track jellyfish for longer periods than in these investigations.

Horizontal migration and vertical position of *N. nomurai* in relation to vertical structure of the sea

The mean values of swimming depths for most of *N. nomurai* observed in this study were smaller than 40 m, and they swam mostly in the relatively high temperature surface layer. This result is similar to the results of observations for swarm of *N. nomurai* made using underwater video camera attached to midwater trawl net by Honda et al [16]. *N. nomurai* observed in the Sea of Japan are thought to originate in the shallow coastal waters of China or the Korean Peninsula [1, 2] , and enter the Sea of Japan through the Korea

Straits after joining the surface layer water of the Tsushima Current. As the Korea Straits are shallow in comparison with surrounding sea areas, inflowing seawater flows mostly near the surface layer of the Sea of Japan [20]. Therefore, the surface water which possesses a relatively high temperature and in which *N. nomurai* distributed is thought to be water mass transported from the coast of China or the Korean Peninsula.

It is known that swimming direction of *N. nomurai* and flow direction are easily matched [21], although the large sized *N. nomurai* has enough ability to swim against gentle flow [22]. It was confirmed by the investigation using pingers that horizontal migration paths of *N. nomurai* were almost the same as the directions of the currents, and it was not confirmed that *N. nomurai* migrate to specific direction with using sun-compass as *Aurelia aurita* which is a Scyphozoan other than *N. nomurai* does [23]. The Tsushima Current is almost flowing in a northeasterly direction in the Sea of Japan

[20]. It was confirmed by the investigation using PATs that most *N. nomurai* migrate by riding on the Tsushima Current in the Sea of Japan (Fig. 4). Also in the case of PAT3, which was the only tag which migrated in a northwesterly direction, it is assumed that it was drawn into an ocean current moving northwesterly and which was on the perimeter of a cold water mass that formed in the sea area at the time of this research [24].

It was showed that the depth ranges of *N. nomurai* tended to increase later in the season in the northern part of Sea of Japan. The reason for this may be that as the water of the surface layer in which the *N. nomurai* were distributed was mixed gradually and evenly in the vertical direction due to cooling of the surface and stirring caused by seasonal winds while moving northeastward with the change of seasons in the Sea of Japan, the swimming depths of the accompanying *N. nomurai* expanded in the vertical direction.

In spite of the fact that there was almost no difference in the ambient temperature ranges of *N. nomurai* in 2006 and in 2005, *N. nomurai* descended to deeper levels in 2006 than in 2005. Here for example, checking the depth range with around 15 ºC water are compared, In 2005 was approximately 40 to 90 m, on the other hand in 2006 was approximately 100 to 130 m, with the result that water temperatures were higher down to deeper in 2006 (Fig. 8).

For species other than *N. nomurai*, *Cyanea nozakii* is known to be distributed basically in the depth zone which has almost equal density water with the density of their body [25]. Density of water is mainly determined with temperture and salinity. Similarly from this fact, it is assumed that the depth ranges of *N. nomurai* basically depend on the vertical water mass structure of the ocean.

However, there were some active individuals that displayed vertical movement to and from deeper than 150 m where temperatures were more than 10 ºC lower than the temperture of the surface of the sea. From this fact, it can be said that the vertical distributions of *N. nomurai* are not limited only by the vertical structure of the ocean, but are also significantly affected by their active behavior individually. Concerning 2004, the appearances of *N. nomurai* in the Sea of Japan in 2004 were rather small in comparison with 2005 and 2006 [4], and under such circumstances, PAT1 and PAT2 were only two individual just found on the surface of the sea. That's why simply displayed less activity than those individuals fitted with PATs in 2005 and 2006, and the relatively small depth and temperature ranges were showed in 2004.

Characteristics of the vertical movement and Circadian rhythm

It was found that there was a basic circadian rhythm in the depths of *N. nomurai* in which the jellyfish swam at deeper levels during the nighttime than in the daytime although whether there were a few differences in average depths depending on individuals or there were daily changes in the swimming depth in the same individual as PAT5 or PAT9. For daily changes in the swimming depth, It has been reported that external stimulations due to environmental changes such as oceanic conditions control swimming depth of *Rhopilema esculentum* which is a Scyphozoan other than *N. nomurai* [26]. So, there was a possibility that daily changes in the swimming depth of PAT5 and PAT9 were also affected by oceanic conditions similarly *R. esculentum*.

Concerning circadian rhythm of *N. nomurai*, swimming depths became shallower from noon to the evening in the daytime, and they became deeper from midnight to dawn during the nighttime. Only in the daytime, it was also found by Honda [27] in the results of an investigation of the vertical distribution of swarms of *N. nomurai* using underwater video camera attached to midwater trawl net in the Korea Straits in July and off Noto Peninsula in October, that main distribution depths of *N. nomurai* tended to be shallower in the afternoon than in the morning. As a result of observations of similar circadian rhythms ranging from the Korea Straits to Sado Island in the period from July to December, it is assumed that there should be no significant differences in the circadian rhythm regardless of differences in season or sea area in the Sea of Japan.

On the one hand, it was found that the vertical moving rhythms were not always synchronized among individuals. This reason has not found obviously. Only the reason for the rhythm not being confirmed clearly with PAT1 is just believed to be that PAT1 was an individual with relatively low activity and the amount of data obtained was too small to allow for a sufficient analysis of circadian rhythm.

As factors that control the circadian behavior of creatures, it is assumed in general that these include photoperiods, the diurnality of prey, autogenic circadian rhythms, oceanic conditions, etc. [28]. There was a possibility that above-mentioned factors complexly affected to each individual of *N. nomurai* and their behavior was a little different each other in this study. However, the obvious factors that control the behavior and circadian rhythm of *N. nomurai* have not yet been identified and will be the subject of future research.

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Tables

Table 1 Tag's ID, model types, bell diameters of the jellyfishes, deployed dates, positions, areas of the sea of the investigations

ID of tags	Model type	Bell diameter	Deployed date		Position		Area of the Sea
		(m)	(year)	(month/day)	(N)	(E)	
PAT 1	PTT-100	0.8	2004	10/25	34.984	132.128	Off Hamada
PAT 3	PTT-100	1.4	2005	10/4	36.552	136.390	Off Kanazawa
PAT 4	PTT-100	1.0	2005	10/4	36.549	136.388	Off Kanazawa
PAT 5	PTT-100	1.5	2005	10/4	36.557	136.391	Off Kanazawa
PAT 6	PTT-100	1.3	2005	10/4	36.557	136.390	Off Kanazawa
PAT 7	Mk10-PAT	1.2	2006	9/15	36.098	132.903	Off Oki isle
PAT 8	Mk10-PAT	0.9	2006	9/15	36.106	132.909	Off Oki isle
PAT 9	Mk10-PAT	1.2	2006	9/15	36.106	132.909	Off Oki isle
PAT 10	Mk10-PAT	1.2	2006	12/1	38.272	138.527	Off Sado isle
Pinger1	V13P	1.6	2005	11/27	38.111	138.473	Off Sado isle
Pinger2	V16P	1.5	2006	9/22	36.191	133.155	Off Oki isle

Table 2 Retrieve rate of the data by the Argos satellites, observation terms, the maximum, minimum, mean value of swimming depths and ambient water temperatures

ID of tags	Data retrieve rate by Argos satellites (%)	Observation term (day)	Swimming depth (m)			Ambient water temperture (°C)		
			min.	mean	max.	min.	mean	max.
PAT 1	21	3	0	8	16	20.5	21.0	21.5
PAT 2	100	2	0	6	46	19.2	20.6	21.5
PAT 3	62	21	0	21	78	10.4	19.9	23.0
PAT 4	28	5	0	28	59	18.7	21.5	22.9
PAT 5	47	15	0	25	71	14.2	20.2	22.9
PAT 6	17	5	1	25	50	18.6	20.8	22.9
PAT 7	28	6	0	37	144	11.3	20.3	23.2
PAT 8	84	10	0	58	152	11.0	18.9	23.4
PAT 9	72	15	0	28	136	12.4	20.7	23.4
PAT 10	12	8	0	76	176	8.8	15.0	16.6
Pinger1	-	1	0	20	152	7.5	16.3	16.8
Pinger2	-	1	0	21	106	15.5	21.1	21.7

Table 3 Mean swimming depths of *N. nomurai* by the each time zone

ID of tags	Mean swimming depth (m)					
	Daytime (sunrise to sunset)			Nighttime (sunset to sunrise)		
	All	A.M.	P.M.	All	P.M.	A.M.
PAT1	8	4	9	7	5	14
PAT2	3	3	2	12	5	19
PAT3	12	13	11	29	24	33
PAT4	19	30	8	39	31	45
PAT5	24	27	21	25	22	28
PAT6	23	28	10	29	25	34
PAT7	20	24	17	58	24	93
PAT8	56	56	55	66	62	70
PAT9	18	19	17	24	15	34
PAT10	54	37	71	67	8	82
Pinger1	10	7	17	29	28	30
Pinger2	15	17	11	24	9	76

Figure captions

Fig. 1 PATs and pingers attaching tool for the giant jellyfish *N. nomurai*

Fig. 2 The picture of attaching a PAT to a *N. nomurai* in the water

Fig. 3 Horizontal movements of the *N. nomurai* estimated by surfaced positions of PATs in the Sea of Japan. (a) and (b) squares in the map are investigation areas for pingers

Fig. 4 Horizontal movements of *N. nomurai* investigated by tracking of the pingers. (a) Pinger1 (off Sado Is.). (b) Pinger2 (off Oki Is.). Locations of the investigated areas are indicated on Fig. 3

Fig. 5 Time series data of swimming depths of *N. nomurai* investigated using PATs. The origin of *x*-axis is 0 o'clock of first date. The data of PAT1 to PAT6 were recorded at 5 minutes interval, and the data of PAT7 to PAT10 were recorded at one hour interval

Fig. 6 Time series data of swimming depths of *N. nomurai* investigated using pingers

Fig. 7 Mean frequency of depths of all observed *N. nomurai*

Fig. 8 The relationship between swimming depths and ambient water temperatures of *N. nomurai* investigated by PATs and pingers

Fig. 9 Diurnal rhythms of swimming depths of a *N. nomurai* analyzed by all data of PATs and pingers. The circles in the graphs represent the relative frequencies of the swimming depth in each three hours in a day

Fig.1
84 mm

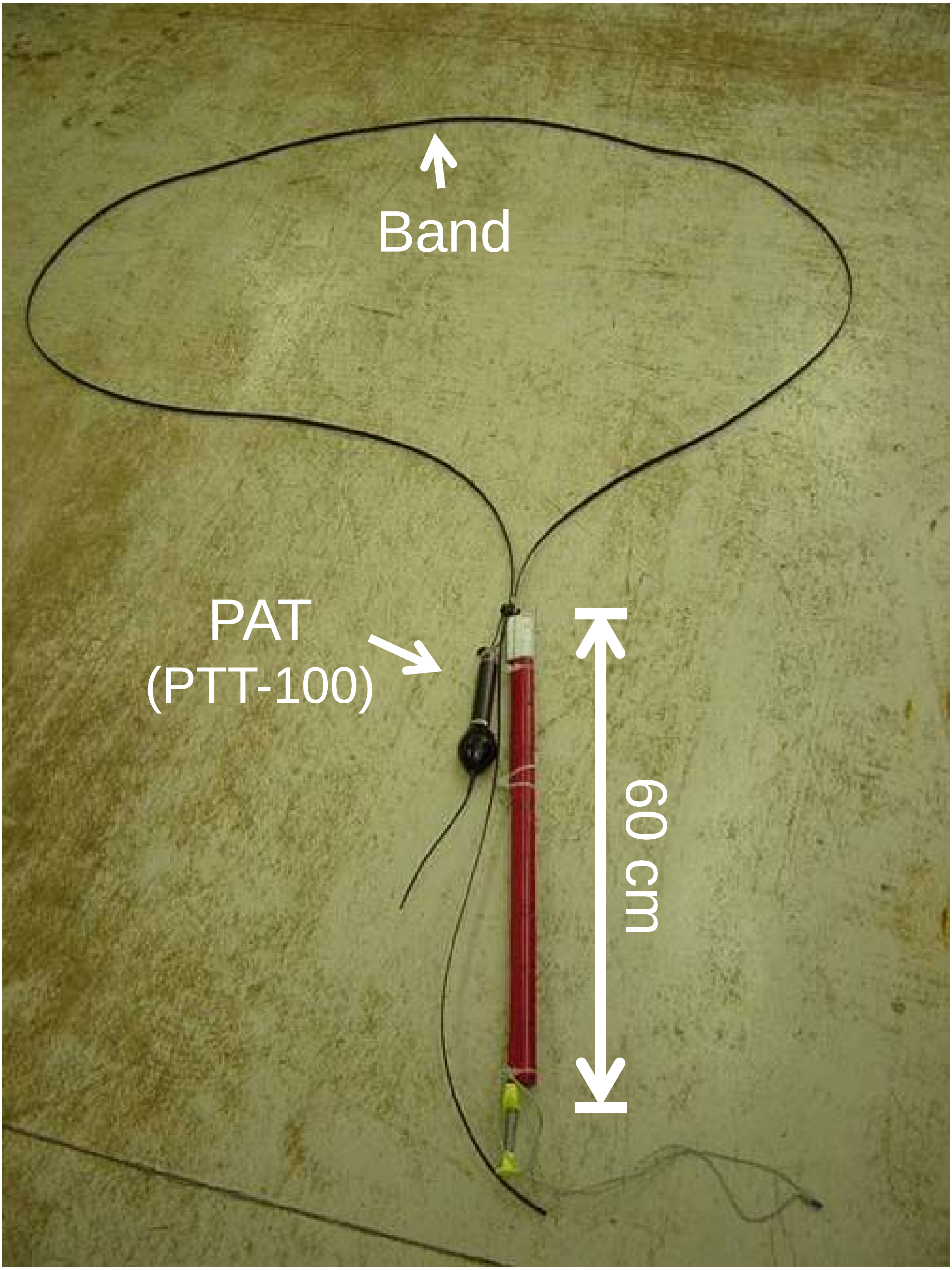


Fig.2
84 mm

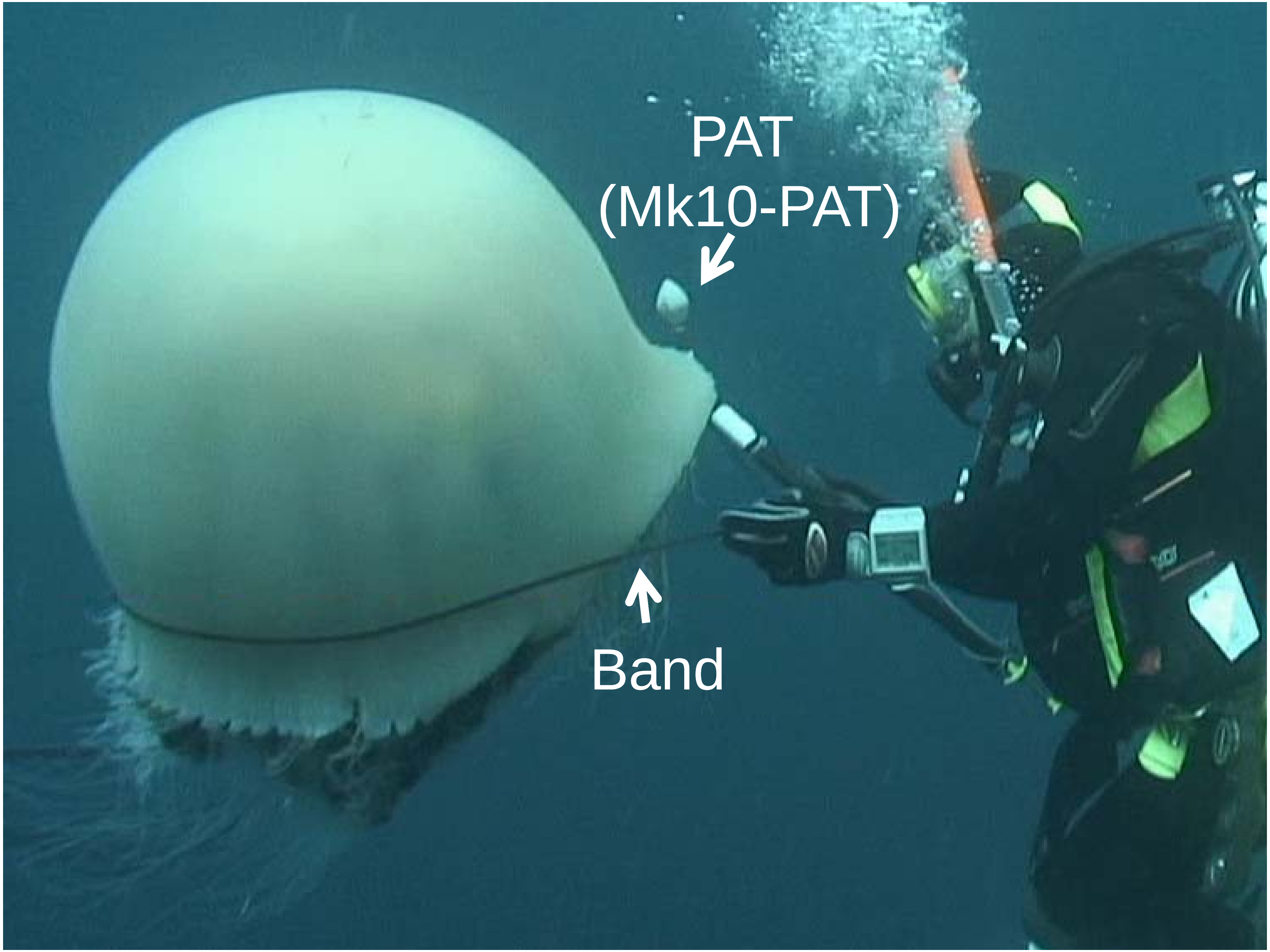
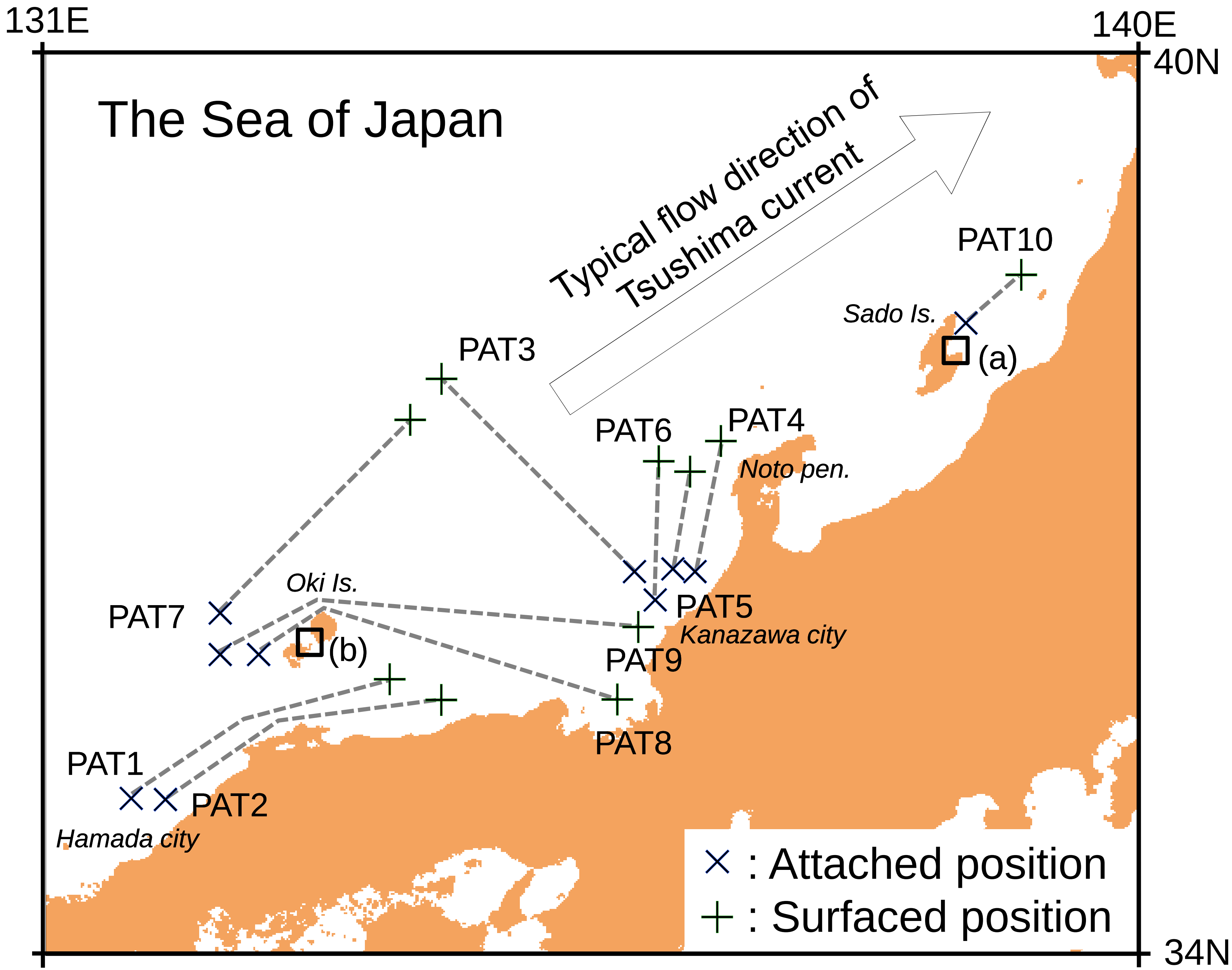


Fig.3
84 mm



131E
140E
40N
34N
The Sea of Japan
Typical flow direction of Tsushima current
PAT10
Sado Is.
(a)
PAT3
PAT6
PAT4
Noto pen.
PAT5
Kanazawa city
PAT9
PAT8
Oki Is.
PAT7
(b)
PAT1
PAT2
Hamada city
× : Attached position
+ : Surfaced position

Fig.4
84 mm

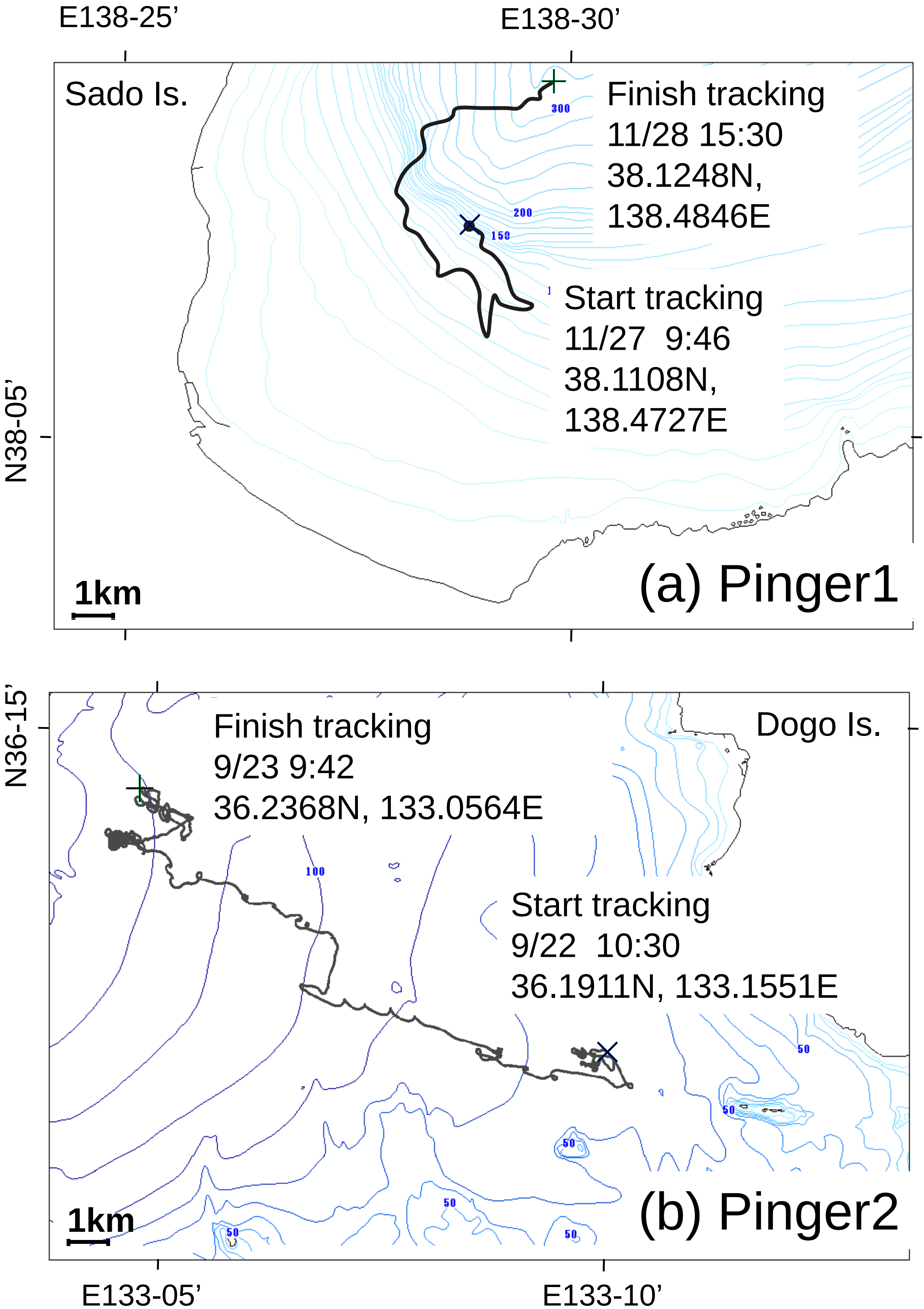
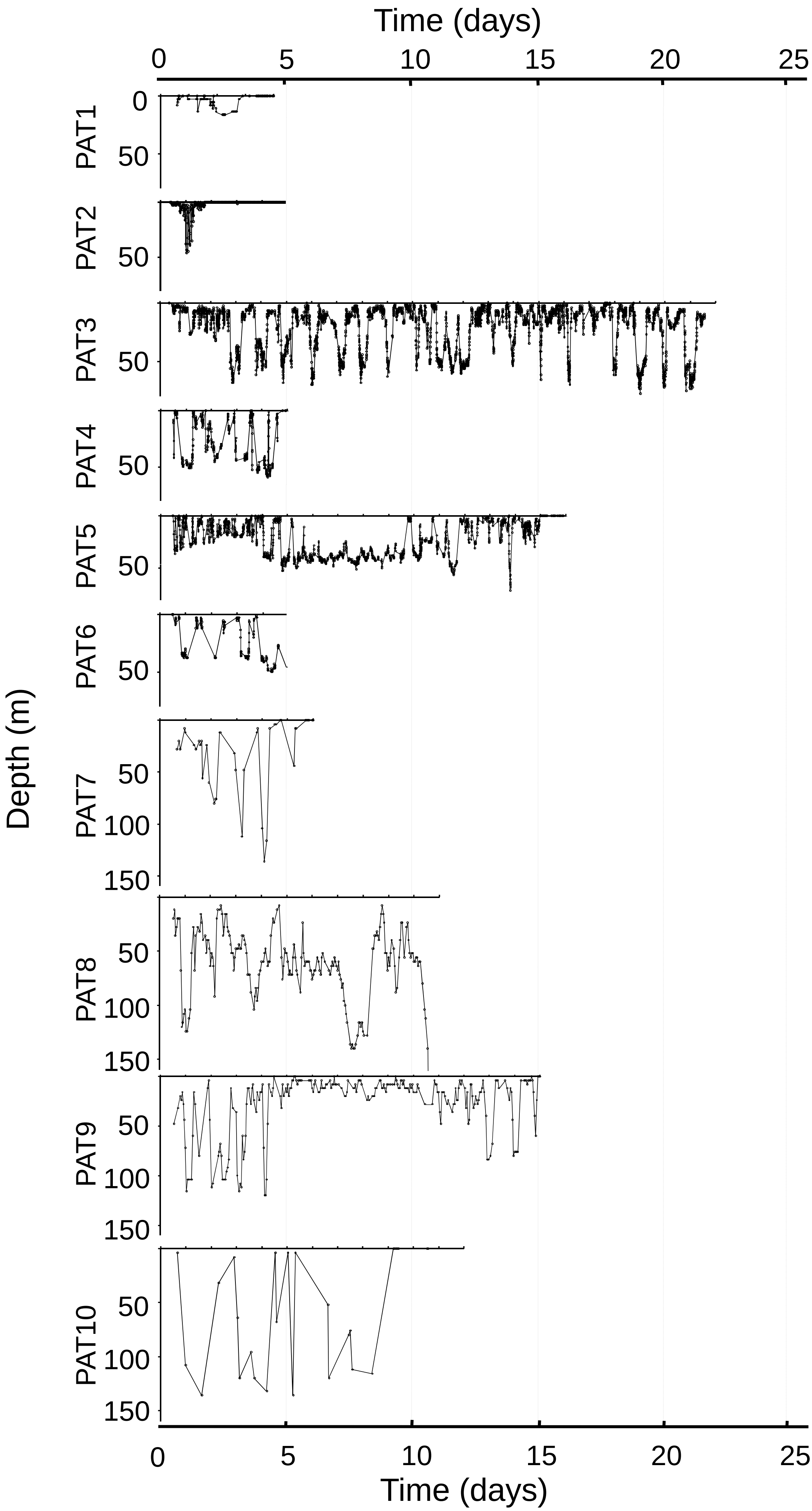

E138-25'
E138-30'
Sado Is.
Finish tracking
11/28 15:30
38.1248N,
138.4846E
300
200
150
Start tracking
11/27 9:46
38.1108N,
138.4727E
N38-05'
1km
(a) Pinger1
N36-15'
Finish tracking
9/23 9:42
36.2368N, 133.0564E
Dogo Is.
100
Start tracking
9/22 10:30
36.1911N, 133.1551E
50
1km
(b) Pinger2
E133-05'
E133-10'

Fig.5
84 mm



Time (days)
0
5
10
15
20
25
Depth (m)
PAT1
PAT2
PAT3
PAT4
PAT5
PAT6
PAT7
PAT8
PAT9
PAT10
0
50
100
150

Fig.6
84 mm

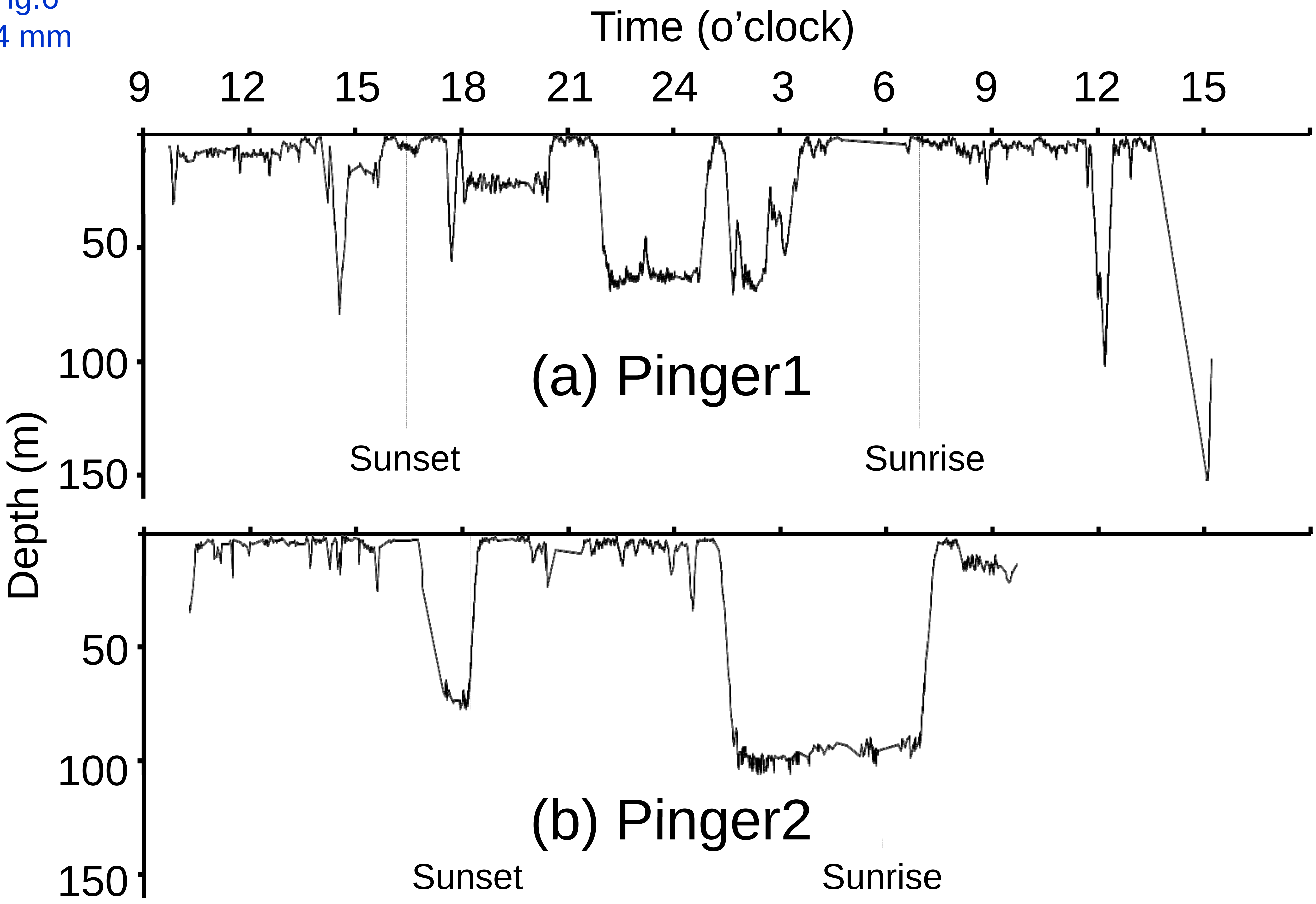
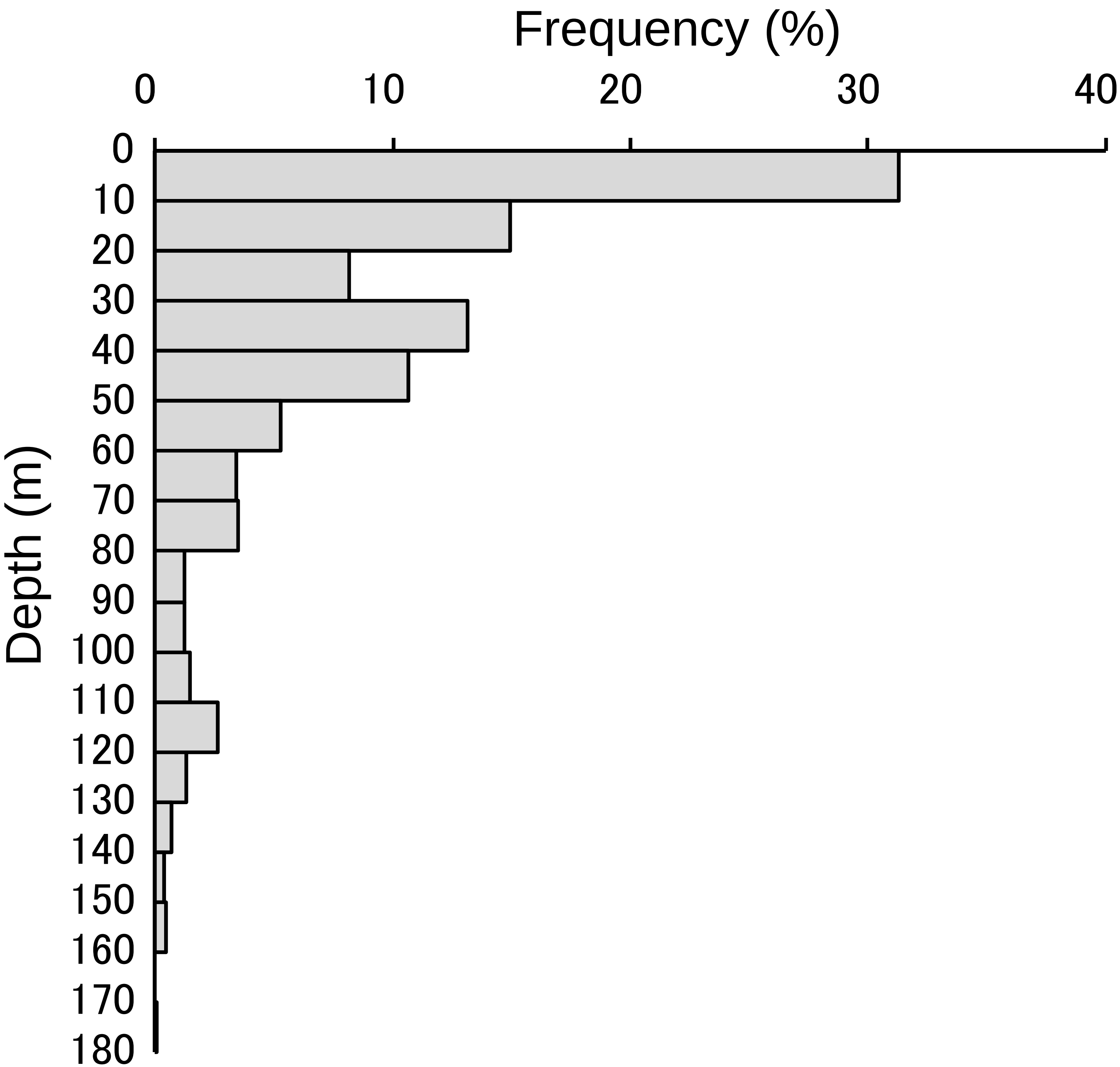
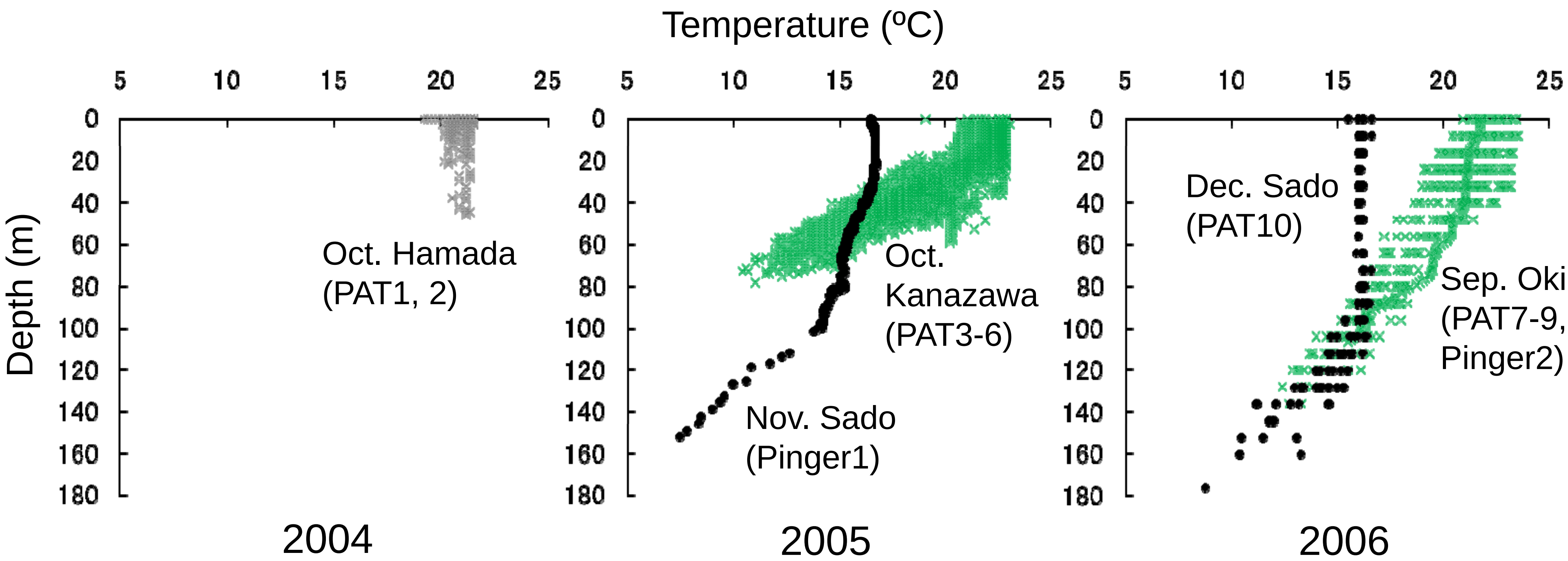

Time (o'clock)
9
12
15
18
21
24
3
6
9
12
15
Depth (m)
50
100
150
(a) Pinger1
Sunset
Sunrise
50
100
150
(b) Pinger2
Sunset
Sunrise

Fig.7
84 mm



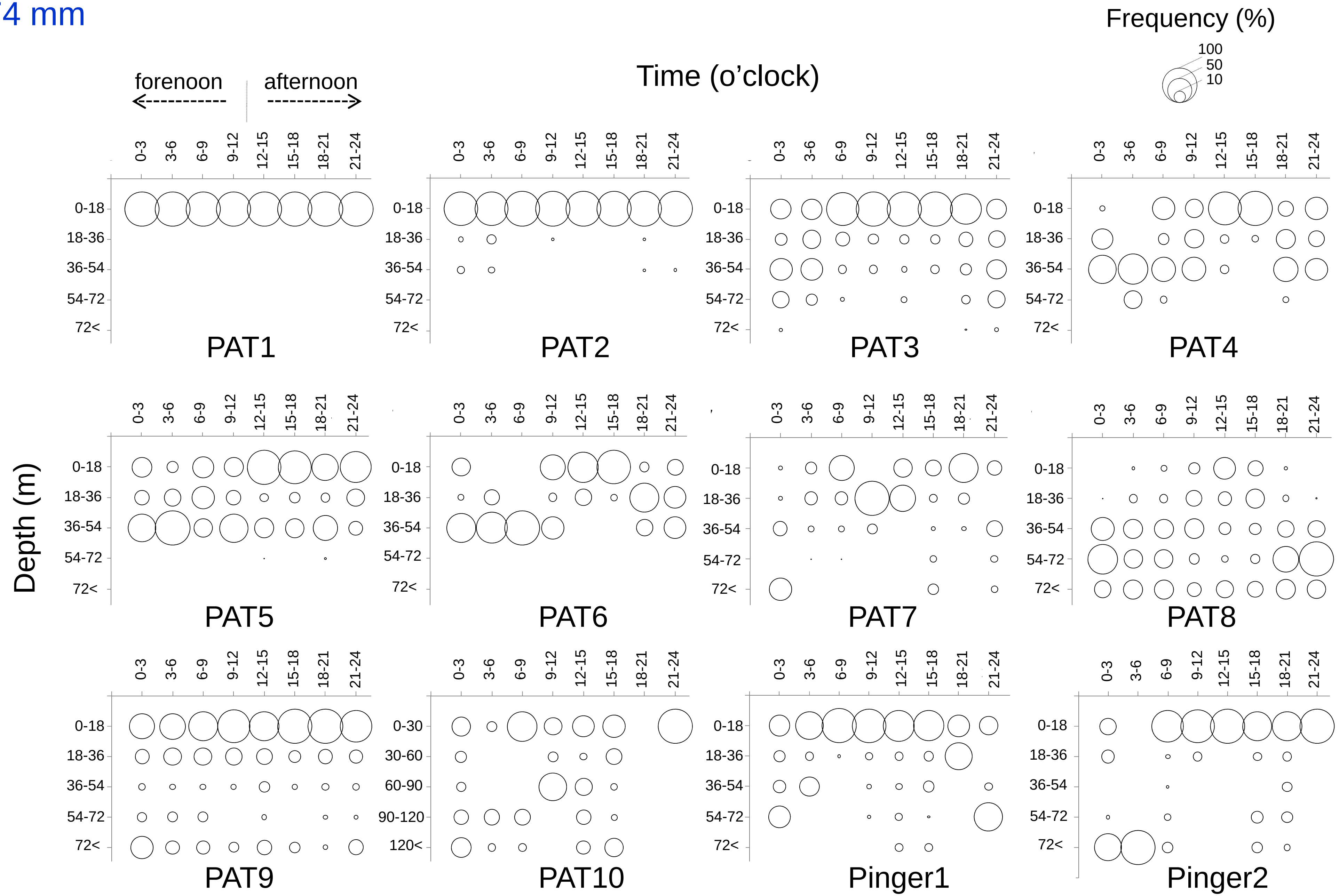
Frequency (%)
0
10
20
30
40
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180

Fig.8
129 mm



Temperature (ºC)
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180
Depth (m)
Oct. Hamada
(PAT1, 2)
Oct.
Kanazawa
(PAT3-6)
Nov. Sado
(Pinger1)
Dec. Sado
(PAT10)
Sep. Oki
(PAT7-9,
Pinger2)
2004
2005
2006

Fig.9
174 mm



Frequency (%)
100
50
10
Time (o'clock)
forenoon
afternoon
0-3
3-6
6-9
9-12
12-15
15-18
18-21
21-24
Depth (m)
0-18
18-36
36-54
54-72
72<
0-30
30-60
60-90
90-120
120<
PAT1
PAT2
PAT3
PAT4
PAT5
PAT6
PAT7
PAT8
PAT9
PAT10
Pinger1
Pinger2

ポップアップアーカイバルタグおよび超音波発信器で調べたエチゼンクラゲの遊泳深度

本多直人（水研セ水工研），渡部俊広（水研セ本部），松下吉樹（長大水）

要旨

エチゼンクラゲ計 12 個体の遊泳深度をポップアップタグや超音波発信器により調べるとともに，調査手法の妥当性を確認した。エチゼンクラゲは活発な鉛直移動を繰り返していた。遊泳深度は 0～176m の範囲で，ほとんどの個体の平均遊泳深度は 40m より浅かった。遊泳深度は秋の日本海南部よりも冬の日本海北部の方が深くなる傾向があり，基本的に滞在深度範囲は海洋の鉛直構造に依存していると推測された。遊泳深度は日中よりも夜間の方が深かった。日中には午前より午後の方

が浅く，夜間には前半夜よりも後半夜の方が深くなる日周性が確認された。

キーワード: “エチゼンクラゲ”, ”鉛直移動”, ”超音波発信器”, ”日周行動”, ”ポップアップアーカイバルタグ”, ”遊泳深度”