The effect of lunar cycle, tidal condition and wind direction on the catches and profitability of Japanese common squid *Todarodes pacificus* jigging and trap-net fishing

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Abstract

Jigging with artificial lights (squid jigging) and deploying of large scale trap-net (also known as a set-net in Japan), are the major methods to capture Japanese common squid *Todarodes pacificus* in western Japan. Squid jigging is a highly selective fishing method. However, it consumes large amount of energy for steaming to the fishing ground and for lighting. In contrast, trap-net fishing requires substantially less energy but its capture efficiency is strongly influenced by its stationary mode of capture.

The primary objective of this study was to analyze how various environmental and biological factors such as the lunar cycle, tidal condition, wind direction and squid abundance affect the capture efficiency of squid jigging and trap-net fishing. We analyzed the effect of these factors on squid catch in five Fisheries Cooperative Associations located on four islands in Nagasaki Prefecture, western Japan. Our analysis shows that squid catch in jigging and trap-net fishing is mainly influenced by the lunar cycle but also tide and wind direction play a marked role. In addition, squid abundance significantly affects the catches in trap-net fishing. Recommendations are made to improve the overall profitability of squid fishing by proper choice of the capture method, location and season.

Key words: Japanese common squid *Todarodes pacificus*, Catch analysis, jigging, trap-net, moon phase, tide, wind, abundance

Introduction

Squid fishing has attracted growing interest world-wide over the last two decades and squid catches have increased steadily with marked year-to-year fluctuations [1]. Japanese common squid *Todarodes pacificus*, swordtip squid *Photololigo edulis* and cuttlefish *Sepia esculenta* are the major targets in Japan. In 2011, they accounted for 8% of the total annual landings in weight of the Japanese capture fisheries [2]. Japanese common squid is commercially the most important Decapoda in Japan and since 1998 its harvesting has been managed by a TAC (Total Allowable Catch) system [3].

Japanese common squid is classified into three populations with different spawning seasons (summer, autumn and winter) [4]. The populations that spawn in autumn and winter are the main target populations. These populations spawn around Kyushu Island [5], and after hatching, migrate to the north for feeding and return to Kyushu to spawn a year later. Mobile squid jigging fleet follows the year-around migration path of squid whereas non-mobile trap-net fishing is seasonally and spatially more restricted.

Squid jigging is the most common method for catching squid in East Asia. It uses artificial light to attract squid in the nighttime and catches them by lures that are attached to automated jigging machines. Fishermen are competing by using increasing amount of lighting power to attract squid from further distances and consequently electric output for lighting has escalated from a few kilowatts in 1960s to 300 kW in 1990s[6]. To reduce the effects of this competition, the Nagasaki Prefectural government has limited the maximum power for lighting in coastal jigging boats of 5 to 30 GT. Similar regulations has also been provided by the Fisheries Adjustment Commission for boats less than 5 GT that do not require a license for squid jigging. Despite of these measures, squid jigging fishery has encountered financial difficulties mainly due to the recent rise in fuel price [7-9].

Trap-net fishery, also known as set-net in Japan, uses large scale trap-nets set in strictly licensed coastal locations. In general, trap-net fishing is an attracting capture method due to its low energy use and minor impacts on habitats and environment [10]. Nonetheless, the initial investment costs for constructing a large scale trap-net are high and it also requires relatively large amount of labor for its maintenance.

To provide the necessary knowledge-basis for promoting sustainable and profitable utilization of squid resources around Kyushu, it is essential to know what are the advantages and disadvantages, including the cost of operation, of these two different fishing methods targeting the same stock.

The primary objective of this study was to improve our understanding how various environmental factors such as the lunar cycle [11-15], tidal condition [14], wind direction [14] and squid abundance [12-15], and their possible interactions, affect the capture efficiency in squid jigging and trap-net fishing. This information is expected to help optimizing the utilization of squid resources with these two gear types. We used a Generalized Linear Model (GLM) analysis to study the relationship of various environmental factors. We obtained the daily catch data of squid jigging and trap-net fisheries in different islands during squid fishing seasons from 2009 to 2011 and compared the trends of squid catches in both fisheries.

Materials and methods

Fishing data

Daily squid catch records during 2009-2011 were collected from five Fisheries Cooperative Associations (FCAs) located on four islands in Nagasaki Prefecture (Fig.1). In one FCA there were both squid jigging and trap-net fisheries whereas in others there was either trap-net or jigging fishery. We identified January and February as a fishing season for Japanese common squid, whereas moderate catches with annual fluctuations were recorded before and after the season (Fig.2). Along the three years of study the numbers of jigging boats and/or trap-nets in different FCAs varied in the Table 1. Catch quantity for each fishery was provided in number of fish containers (cases), each containing approximately 6 kg of Japanese common squid. Fishing effort was provided by number of operating boats/trap-nets in the designated day (Table 2).

Fig.1

Fig.2

Table 1

Table 2

Data analysis

To explore the effects and potential interactions of various factors, we performed GLM analysis of expected catch amounts of Japanese common squid in squid jigging and trap-net fisheries in the study area. The number of squid cases caught by fishing sector i (i denotes one of six fisheries in this study), C_i was assumed to follow a negative binomial distribution [12-15] with expected mean catch μ_i:

$$C_i \sim \mathrm{NB}(\mu_i, \theta_i) \qquad (1)$$

where θ_i is a potential dispersion parameter to be estimated. Because our data set for six fishing sectors (squid jigging fisheries in A and B, trap-net fisheries in A, C, D and E) showed large dispersion (Table 2).

The expected mean catch μ_i is modeled with a log link function as,

$$\log(\mu_i) = \text{ß}_0 + \text{ß}_1 Moon + \text{ß}_2 Phase + \text{ß}_3 Tide + \text{ß}_4 (Moon \times Tide)$$

$$+ \quad ß_5 Wind \quad + \quad ß_6 N \quad + \log(E_i) \qquad (2)$$

where *Moon* is the ratio of the illuminating area of the moon at midnight. This ratio varies between zero (new moon) and one (full moon) corresponding to the age of the moon. *Phase* is a factor for the waxing and waning of the moon, expressing the time period of appearance of the moon, i.e. the moon rises before midnight in the waxing phase while it rises after midnight in the waning phase. We set a two-level categorical variable (*waxing*; from new moon to full moon, *waning*; from full moon to new moon). *Tide* is a factor expressing the tidal condition in the fishing ground. We set a three-level categorical variable (*fast*, *medium* and *slow*) from the tide table. *Moon* x *Tide* is the interaction between *Moon* and *Tide*. This factor may partially show multicollinearity with *Moon* because the periodic cycle of the tide is approximately a half of the lunar cycle. To include this factor in the analysis, however, is important because it influences the distance that jigging boats drift when they attract squid and the movement of squid aggregations. *Wind* is another factor that influences the distance that jigging boats drift. We obtained the prevailing wind direction data at Ashibe Observatory (Iki Island, Fig. 1) from the website of the Japanese Meteorological Agency (http://www.data.jma.go.jp/obd/stats/etrn/index.php "Accessed 2 June 2012") and classified the wind direction by every 90 degrees (*NE*: north-east-northeast, *SE*: east-south-southeast, *SW*: south-west-southwest, *NW*: west-north-northwest). We used these wind direction classes as a four-level categorical variable. We assumed the year-season differences in squid abundance and other possible effects *N*. Therefore, we set a six-level categorical variable (*Jan09*, *Feb09*, *Jan10*, *Feb10*, *Jan11* and *Feb11*). These factors are summarized in Table 3.

Table 3

Parameters $ß_0$ to $ß_6$ are the intercept (constant) and the coefficients for *Moon*, *Phase*, *Tide*, *Moon* x *Tide*, *Wind* and *N*, respectively. Fishing effort E_i, which is the number of jigging boats or trap-nets operated in a day, is used as an offset variable.

Parameter estimation was performed by the maximum likelihood (glm.nb function in the MASS package in R ver. 2.12.1, R Development Core Team). Based on the initial model, the model selection was performed using AIC (Akaike's information criteria). The resultant model, the lowest AIC model was "optimum model". Then, from the optimum model, the effect of explanatory variables was evaluated based on the increments of AIC (ΔAIC) [16, 17] by removing variables one by one from the optimum model.

To assess the catch amount which corresponds to daily fuel costs required to operate squid fishing by jigging and trap-net, we explored the data of daily fuel costs from the Report of statistical survey on fishery management 2009 [18]. This report shows the following values: 9,322 Japanese yen (JPY)･ day^{-1}･ trap-net^{-1} for a trap-net fishing and 9,514 - 31,844 JPY･ day^{-1}･ boat^{-1} for squid jigging, depending on boat sizes (3 to 20 GRT). Squid prices were taken from the Annual statistics on marketing of fishery products [19]. Because the annual average of squid price for the study years was 149 JPY･ kg^{-1}, we assumed the average price of a fish container as 900 JPY･ case^{-1}.

Results

Catch trends and the influence of moon age, tidal condition and wind direction

In total, 827,589 cases (about 4,965 tons) of Japanese common squid were caught during the fishing seasons (January-February) in 2009-2011 (Fig. 3), which accounted for 59 % of total catch in the study area in 2009-2011. Squid jigging in Iki and Tsushima Islands

Fig. 3

(squid jigging fisheries in A and B) captured 77% of the total catch of six fisheries during the fishing season. Total daily catch by the six fisheries varied between 0 and 18,624 cases (Fig. 4). Catches exceeding 10,000 cases were observed only for a few days during the three study years.

Fig. 4

In January 2009, squid was mainly captured in the northern part of the study area by squid jigging fisheries in A and B. Trap-net A also captured squid in January, but it peak was in early February. Then trap-nets in C, D and E captured in mid or late February (Fig. 5). Thus, catch of squid begins from the north part of the study area and trap-nets in the south part captured squid in the later period.

Fig. 5

Catch tendency 2009 was similar for January in 2010, but small amount of squid was captured in trap-nets in the south part (D and E) in February.

In 2011, total catch amount was larger than those in previous two years. Squid jigging fisheries in A and B had captured squid until mid February and their peak catches were in early February. Trap-net fisheries also maintained high catch levels during January and February. Catch in trap-net in A became poor in late January, but big hauls were again recorded for a few days in mid February. Trap-nets in C, D and E continued catching squid with a peak in early February during the fishing season.

The daily catches on squid jigging fisheries in A and B show a clear pattern with the age of the moon; catch was low in the full moon period and increased as the new moon period approached (Fig. 6a). This trend was observed also in trap-net fisheries in C, D and E. Trap-net catches in A exhibited the opposite pattern; more squid were caught in the full moon period and less in the new moon period.

Fig. 6

When daily catch is connected to the tidal current (Fig. 6b), catches on trap-net fisheries in D and E (southern part of the study area) increased when the current was slow. Other fisheries did not show clear catch tendencies against the tide. For the wind detection, the daily catches on trap-net fisheries in C, D and E decreased when it was the south wind (Fig. 6c).

GLM analysis

The GLM analysis detected the influence of *Moon* for both capture methods (ΔAIC =10.77 to 26.21, Table 4) and *Moon* showed the largest effect except for squid abundance (*N)* in any models based on ΔAIC results. The optimum models selected by AIC are as follows.

Table 4

Squid jigging A: $\log(\mu_i) = \text{ß}_0 + \text{ß}_1 Moon + \text{ß}_2\, Phase + \text{ß}_5 Wind + \text{ß}_6 N + \log(E_i)$

Squid jigging B: $\log(\mu_i) = \text{ß}_0 + \text{ß}_1 Moon + \text{ß}_2\, Phase + \text{ß}_5 Wind + \log(E_i)$

Trap-net A: $\log(\mu_i) = \text{ß}_0 + \text{ß}_1 Moon + \text{ß}_2\, Phase + \text{ß}_5 Wind + \text{ß}_6 N + \log(E_i)$

Trap-net C: $\log(\mu_i) = \text{ß}_0 + \text{ß}_1 Moon + \text{ß}_2\, Phase + \text{ß}_5 Wind + \text{ß}_6 N + \log(E_i)$

Trap-net D: $\log(\mu_i) = \text{ß}_0 + \text{ß}_1 Moon + \text{ß}_3\, Tide + \text{ß}_5 Wind + \text{ß}_6 N + \log(E_i)$

Trap-net E: $\log(\mu_i) = \text{ß}_0 + \text{ß}_1 Moon + \text{ß}_6 N + \log(E_i)$

The influence of the year-season differences in squid abundance (*N)* was not detected only in squid jigging fishery in B whereas it was detected in other fisheries. Trap-net catches in E, which is located in the southern part of the study area, were influenced only by *Moon* and *N*. The influence of *N* was larger in trap-nets in C, D and E (ΔAIC =26.21 to 133.91) while its influence was moderate for squid jigging and trap-net fisheries in A. Catches in Iki and Tsushima Islands (A, B and C), which are located in the northern part of the study area, were influenced also by *Phase* and *Wind.* The influence of *Wind* was larger in two squid jigging fisheries (ΔAIC =4.56 to 4.63). The marginal influence of *Tide* was also only detected in the catch of trap-net in D (ΔAIC =2.32), where also *Moon*, *Wind* and *N* affected. The interaction terms (*Moon* x

Tide) were not selected in any model.

A coefficient of *Moon* for trap-net in A shows a positive value while it is negative for other trap-nets (Table 4), suggesting that the squid catches of these trap-nets increases as the new moon approaches. For *Phase*, clear difference is observed between trap-net and squid jigging. Catch of squid in squid jigging increased during the waxing period (new moon to full moon), while this was the opposite in the trap-net fisheries.

We incorporated these coefficients into the optimum models for six fisheries and estimated the expected daily catch amounts. Expected catch amounts tend to match observed catch amounts, but the expected catch amounts of trap-net in E tended to be underestimated when catch was large (Fig. 7).

Fig. 7

We calculated the expected squid catch per unit effort (cases· day^{-1}· boat^{-1} or cases· day^{-1}· trap-net^{-1}) from the adopted models under the assumption that squid abundance is constant at the *Jan09* level. Expected catches ranged in 6-503 cases for trap-net in A, 20-224 cases for squid jigging fishery in A, 46-1002 cases for trap-net in C, 32-211 cases for squid jigging fishery in B, 15-539 cases for trap-net in D, and 50-235 cases for trap-net in E.

We then examined how the above mentioned ranges of daily catch amount would cover fuel costs for their capture in relation to *Moon*, the most influenced factor on daily catch amount (Fig. 8). From the daily fuel cost and squid landing price values we calculated that the average number of fish containers which would cover the fuel cost required for daily operation were 11 cases for a trap-net and 11-36 cases for a squid jigging boat. A trap-net operation does not cover the daily fuel cost when squid catch was less than 11 cases. Such a low catch is expected in A during the waxing new moon period when southern wind dominated. In other cases, trap-net catches covered the fuel costs even in the most unfavorable conditions. Squid jigging fishery has risky period

Fig. 8

around the full moon when the fuel cost exceeds landing value of squid catch. Squid jigging fishery in A has a longer duration of unstable profitability than that of B because expected squid catch was smaller.

Discussion

This study indicates that the catch quantity of squid by squid jigging and large-scale trap-net fisheries is heavily influenced by the lunar cycle. For squid jigging this relationship has been reported earlier [11-15] but for trap-net fishing this is apparently the first time this effect has been verified.

It is noteworthy that effect of lunar cycle was different in squid jigging and trap-net fisheries, and the effect was influenced also by location. In the trap-net catches in A (Tsushima Islands) were larger in the full moon period while in other areas trap-nets and squid jiggings captured more squid in the new moon period. This difference is likely due to the pattern and movement of squid aggregations and squid jigging boats. In Tsushima Islands, squid jigging boats usually operate off the western coast of the islands where also the trap-nets are set. On the other hand, in Iki island squid jigging boats in B operate in northern or western waters of the island [12-15, 20] while the trap-net fishery of C is located on the eastern coast of the island. Squid migrating in the southwestern direction for spawning would be able to reach the eastern coast of Iki Island without being captured by jigging boats. Thus, trap-net set in C have more advantageous conditions for catching squid compared to trap-net in A. Trap-nets in D and E captured more squid in the new moon period likely because no squid jigging boats are operational near these islands.

The time when moon rose was another factor that impacted on catch amount. Catches in squid jigging decreased when the moon appeared after midnight. Squid jigging boats start the fishing operation just before sunset, and continue until sunrise [20]. At the beginning of this operation, fishermen turn on all lamps to attract the dispersed squid over a wider area to the boat, and then reduce the number of illuminating lamps to keep the attracted squid in the upper water layer. This is because squid avoid strong light [21, 22]. In the case of the waning period, the moon risen after midnight delivered light and ambient illuminance in the water became relatively high in the later part of the operation process. This high illuminance condition would weaken the effect of reducing number of illuminating lamps which causes ascending behavior of attracted squid. We therefore consider that this interference of light resulted in less catch amount.

Our results indicate the marked role of other key environmental factors such as wind direction and tide. In squid jigging fisheries in A and B, catches significantly decreased when wind blew from the northwest in Tsushima Islands and from the northeast in Iki Island whereas northern winds (*NW* and *NE*) increased the catch amounts in trap-net fishery. We assume that the influence of wind in squid jigging is a combination between current and wind directions. Squid jigging boats drift with the tidal movement in order to maximize their drifting distances to attract more squid. They usually plan to move into the northern direction when lighting is started, and they drift in the opposite direction when the tide turns. In the cases when a northern wind blows, the direction of the current and wind are opposite and consequently boats are not able to drift over a longer distance. We suspect that northern wind prevented the drifting of jigging boats at the beginning of the operation which is an important phase to attract the dispersed squid. It resulted in smaller catch of squid.

In conclusion, catches in squid jigging and trap-net fisheries in the four islands in Nagasaki Prefecture are mainly influenced by the lunar cycle but also wind direction affects in particular in the squid jigging fisheries and year-season differences in squid abundance in the trap-net fisheries.

Trap-net fishery is in general associated with low fuel consumption [8]. On average, boats used in the trap-net fishery consume approximately 40% of fuel when compared to boats of the same sizes used in other coastal fisheries in Japan [8]. The low fuel consumption means low CO_2 emissions. The cumulative carbon dioxide emission per unit of production value for the trap-net fishery is 0.5 ton-CO_2/million JPY while it is 14.4 ton-CO_2/million JPY for the squid jigging fishery [9]. Ninety-nine percent of the CO_2 emission in the squid jigging fishery is made from a direct fuel consumption in daily operations and approximately 70% of fuel consumption is allocated for lighting [10]. In trap-net fishery fuel is mainly used when setting up fishing gear and when bringing the catch to the harbor. Squid jigging and trap-net fisheries have largely opposite characteristics in terms of energy consumption.

Clearly there are specific advantages and disadvantages in squid jigging and trap-net fisheries. Trap-net is a fuel-efficient fishing method, but the catch varies depending on the conditions and squid abundance in the fishing ground. Squid jigging can flexibly respond to changes in squid abundance and distribution; however, it consumes a considerable amount of fuel.

There are periods when the income from the catches in the squid jigging and trap-net fisheries clearly does not cover the fuel costs. These periods were full moon period for the squid jigging in two FCAs (A and B) and new moon period for the trap-net in A. In the case of squid jigging fisheries in A and B, when small catch is expected due to the unfavorable environmental conditions, profitable operation can be achieved only during the period of new moon to the waxing moon. Clearly, squid jigging is a fuel intensive method and current fuel cost is high [8].

In order to operate and manage the squid jigging and trap-net fisheries in a sustainable manner, non-profitable operations should be minimized. We observed non-profitable operations in both fisheries. Managers and operators in squid jigging and trap-net fisheries should be cost-consciousness. For example, jigging operators can estimate a profit-line and judge whether to operate or not on the basis of moon age and wind direction. This type of decision making is important under the present high fuel price condition. In particular, larger squid jigging boats should reconsider their operation style and strategy.

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【 Figures caption】

Fig.1 Locations of the Fisheries Cooperative Associations analyzed in the study. A operates both squid jigging and trap-net fishing. B only operates squid jigging. C, D and E only operate trap-net fishing

Fig.2 Catch amount of Japanese common squid in the squid jigging and Trap-net fisheries in five Fisheries Cooperative Associations (A to E) in 2009-2011

Fig.3 Catch amount of Japanese common squid in the 6 fisheries in January-February 2009, 2010 and 2011

Fig.4 Variation in daily total catch of Japanese common squid in the 6 fisheries in January-February 2009, 2010 and 2011

Fig.5 Variation in daily catch of Japanese common squid in the 6 fisheries in January-February 2009, 2010 and 2011. Upper graph; catch of squid jigging sectors, lower graph; catch of trap-net sectors

Fig.6 Variation of daily catch of Japanese common squid by the age of the moon (a), Tide (b) and the wind direction(c)

Fig.7 Comparison of observed and expected catch amount of Japanese common squid for the 6 fisheries. Expected catch amounts were calculated from optimum models presented in Table 4

Fig.8 Relationship between expected catch amount and the ratio of the illuminating area of the moon (*Moon*) for the six fisheries. Influences of other variables are taken into account and are presented as a maximum (max) and a minimum (min) lines. The dashed line is the number of cases corresponding to fuel costs (note that this line is indicated by a range (a portion of a rectangular) for squid jigging fishery due to the variation in boat sizes). A period of time that expected minimum catch amount covers fuel cost is designated by a gray box below the X-axis

Table 1 Five Fisheries Cooperative Associations in the study

ID	Island	position	Number of trap-net	Number of Squid jigging
A	Tsushima	East coast	5	56-64
B	Iki	North coast		67-83
C	Iki	East coast	2	
D	Hirado	Northwest coast	1	
E	Goto	North coast	2-3	

Table 2 Catch data used in the study

ID	Fishing method	Year*	Number of Boat/trap	Fishing days	Total catch (cases)	Average (cases/day)	SD (cases/day)
A	Squid jigging	2009	64	53	50721	957	1032
		2010	56	50	40181	803	845
		2011	61	55	43381	788	645
B		2009	83	41	132935	3242	1887
		2010	67	46	178316	3876	3192
		2011	75	41	191385	4667	3584
A	Trap-net	2009	5	54	26145	484	514
		2010	5	53	14331	270	358
		2011	5	53	21584	407	540
C		2009	2	50	23072	461	570
		2010	2	54	448	8	15
		2011	2	51	40118	786	595
D		2009	1	50	4819	96	176
		2010	1	52	2909	55	126
		2011	1	53	8001	150	217
E		2009	3	49	13009	265	310
		2010	2	49	12159	248	409
		2011	2	51	24075	472	677

* Daily catch data between January and February were collected each year.

Table 3 Explanatory variables in the initial generalized linear model (GLM) with a negative binomial distribution

Explanatory variables	Category
Moon (ratio of the illuminating area of the moon)	Continuous variable, (0 to 1)
Phase (waxing and waning of the moon)	*waxing*, *waning*
Tide (speed of tidal current in the fishing ground)	*fast*, *medium*, *slow*
Wind (wind direction)	*NE*(N-ENE), *SE*(E-SSE), *SW*(S-WSW), *NW*(W-NNW)
E (fishing effort, number of boats or traps per day)	Offset variable(0 to 83)
N (month-year difference in squid abundance)	*Jan09*, *Feb09*, *Jan10*, *Feb10*, *Jan11*, *Feb11*

Table 4 Parameters and output for the selected optimum generalized linear models

Explanatory variable	Squid jigging A		Squid jigging B		Trap-net A		Trap-net C		Trap-net D		Trap-net E	
	Estimate (*SE*)	*P*	Estimate (*SE*)	*P*	Estimate (*SE*)	*P*	Estimate (*SE*)	*P*	Estimate (*SE*)	*P*	Estimate (*SE*)	*P*
β_0 (Intercept)	4.81 (0.28)	<0.01	4.67 (0.16)	<0.01	2.84 (0.46)	<0.01	5.67 (0.48)	<0.01	4.78 (0.49)	<0.01	5.46 (0.28)	<0.01
β_1 (*Moon*)	Δ AIC = 26.21		Δ AIC = 21.86		Δ AIC = 25.08		Δ AIC = 10.77		Δ AIC = 25.93		Δ AIC = 21.02	
	-1.22 (0.20)	<0.01	-0.77 (0.15)	<0.01	1.91 (0.33)	<0.01	-1.24 (0.32)	<0.01	-2.06 (0.32)	<0.01	-1.54 (0.29)	<0.01
β_2 (*Phase*: relative to 'waning')	Δ AIC = 6.81		Δ AIC = 14.57		Δ AIC = 6.65		Δ AIC = 4.33					
	0.44 (0.14)	<0.01	0.46 (0.10)	0.01	-0.78 (0.24)	<0.01	-0.57 (0.22)	0.01	/		/	
β_3 (*Tide*: relative to 'fast')									Δ AIC = 2.32			
medium	/		/		/		/		0.04 (0.28)	0.88	/	
slow	/		/		/		/		0.65 (0.28)	0.02	/	
β_5 (*Wind*: relative to 'SE')	Δ AIC = 4.56		Δ AIC = 4.63		Δ AIC = 2.55		Δ AIC = 0.23		Δ AIC = 0.10			
NE	-0.27 (0.25)	0.29	-0.43 (0.17)	0.01	1.25 (0.43)	<0.01	1.01 (0.43)	0.02	0.47 (0.41)	0.26	/	
NW	-0.61 (0.22)	<0.01	-0.00 (0.14)	0.98	1.25 (0.39)	<0.01	0.88 (0.39)	0.02	0.86 (0.37)	0.02	/	
SW	0.17 (0.40)	0.68	0.21 (0.27)	0.42	1.03 (0.69)	0.13	1.25 (0.66)	0.06	-0.13 (0.70)	0.85	/	
β_6(*N* relative to 'Feb09')	Δ AIC = 2.96				Δ AIC = 3.09		Δ AIC = 133.91		Δ AIC = 27.63		Δ AIC = 26.21	
Jan09	-0.53 (0.24)	0.02	/		0.33 (0.41)	0.41	-0.93 (0.38)	0.02	-1.27 (0.40)	<0.01	-0.63 (0.35)	0.07
Jan10	-0.40 (0.25)	0.12	/		-0.62 (0.41)	0.14	-4.01 (0.40)	<0.01	-0.91 (0.40)	<0.02	0.32 (0.34)	0.35
Feb10	-0.09 (0.24)	0.72	/		-0.24 (0.41)	0.56	-5.15 (0.40)	<0.01	-1.36 (0.39)	<0.01	-1.81 (0.35)	<0.01
Jan11	-0.74 (0.25)	<0.01	/		0.31 (0.42)	0.47	0.01 (0.39)	0.99	-0.79 (0.41)	0.05	0.83 (0.34)	0.02
Feb11	-0.04 (0.23)	0.88	/		-0.96 (0.40)	0.02	0.71 (0.40)	0.07	0.75 (0.37)	0.04	0.47 (0.34)	0.17

Δ AIC indicates the increment in AIC if the explanatory variable is removed from the optimum models

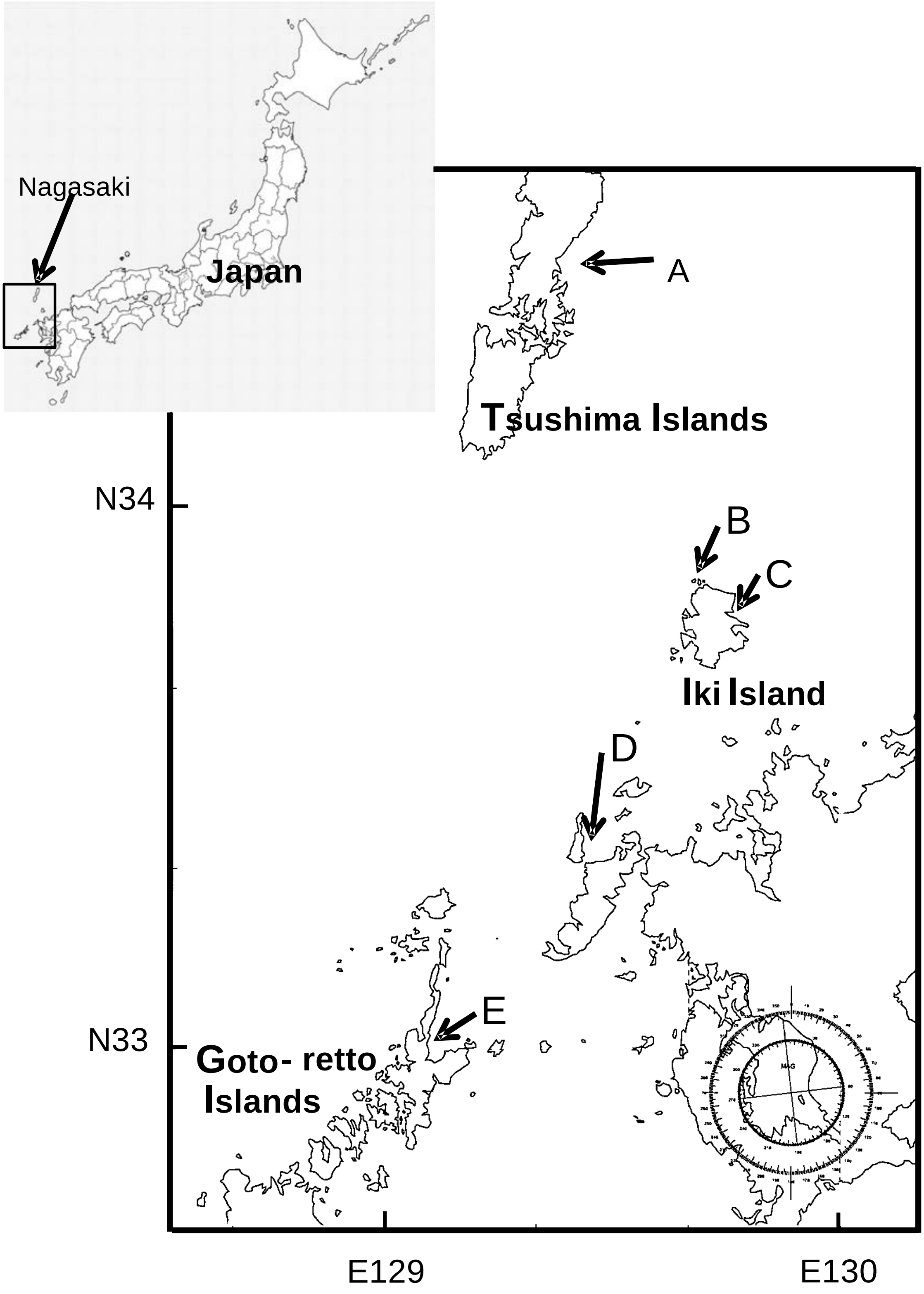


Fig.1 Masuda et al.

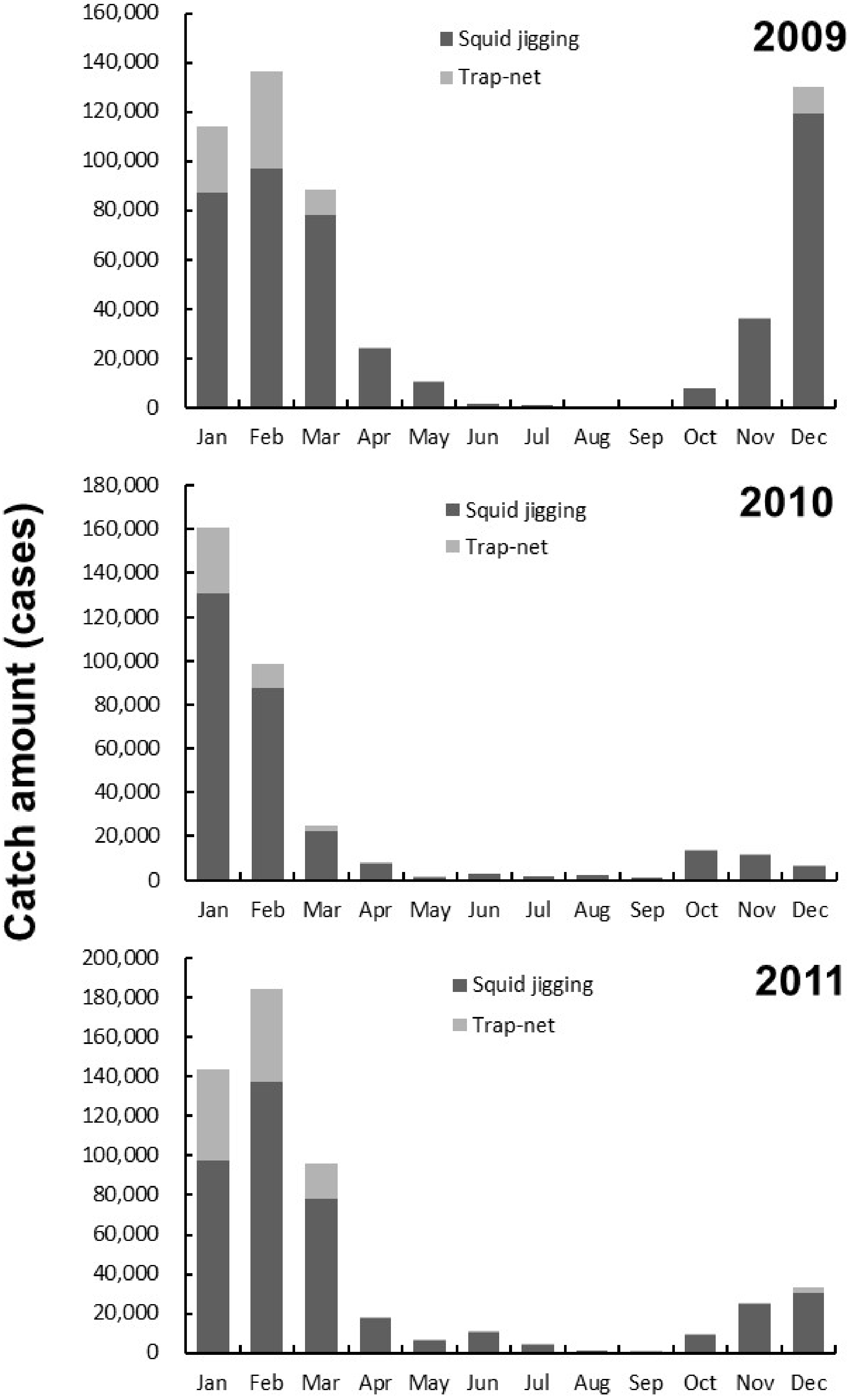
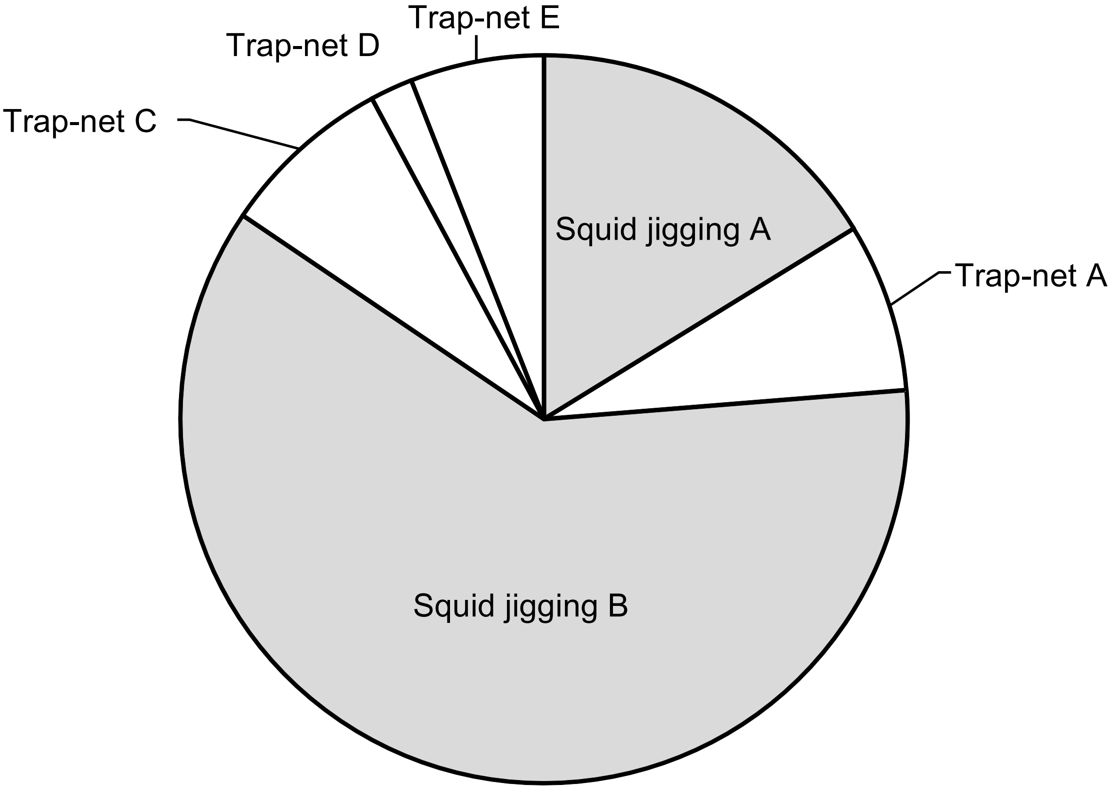


Fig.2 Masuda et al.



827,589 cases (approx. 4,965 t)

Fig.3 Masuda et al.

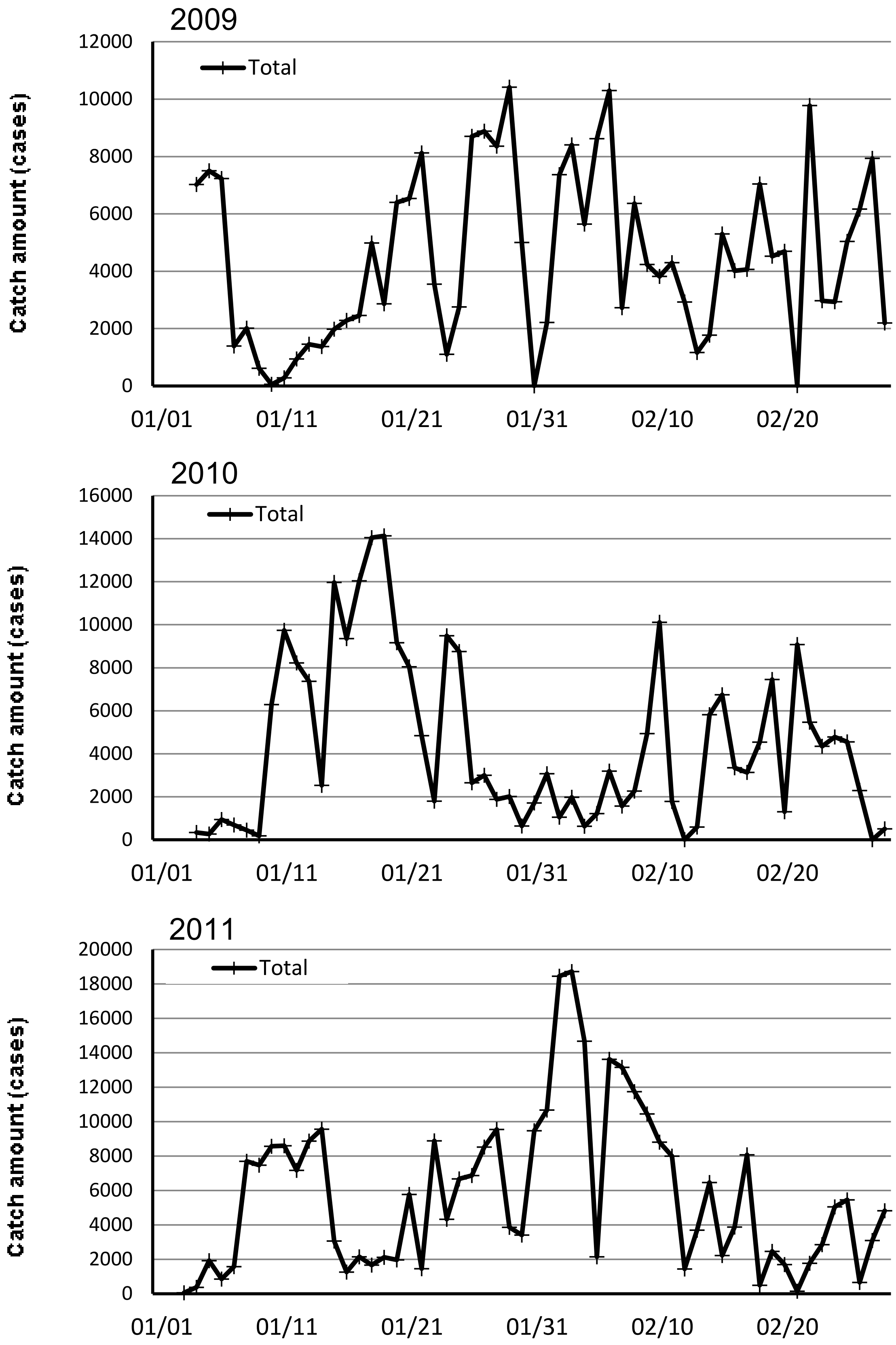


Fig. 4 Masuda et al.

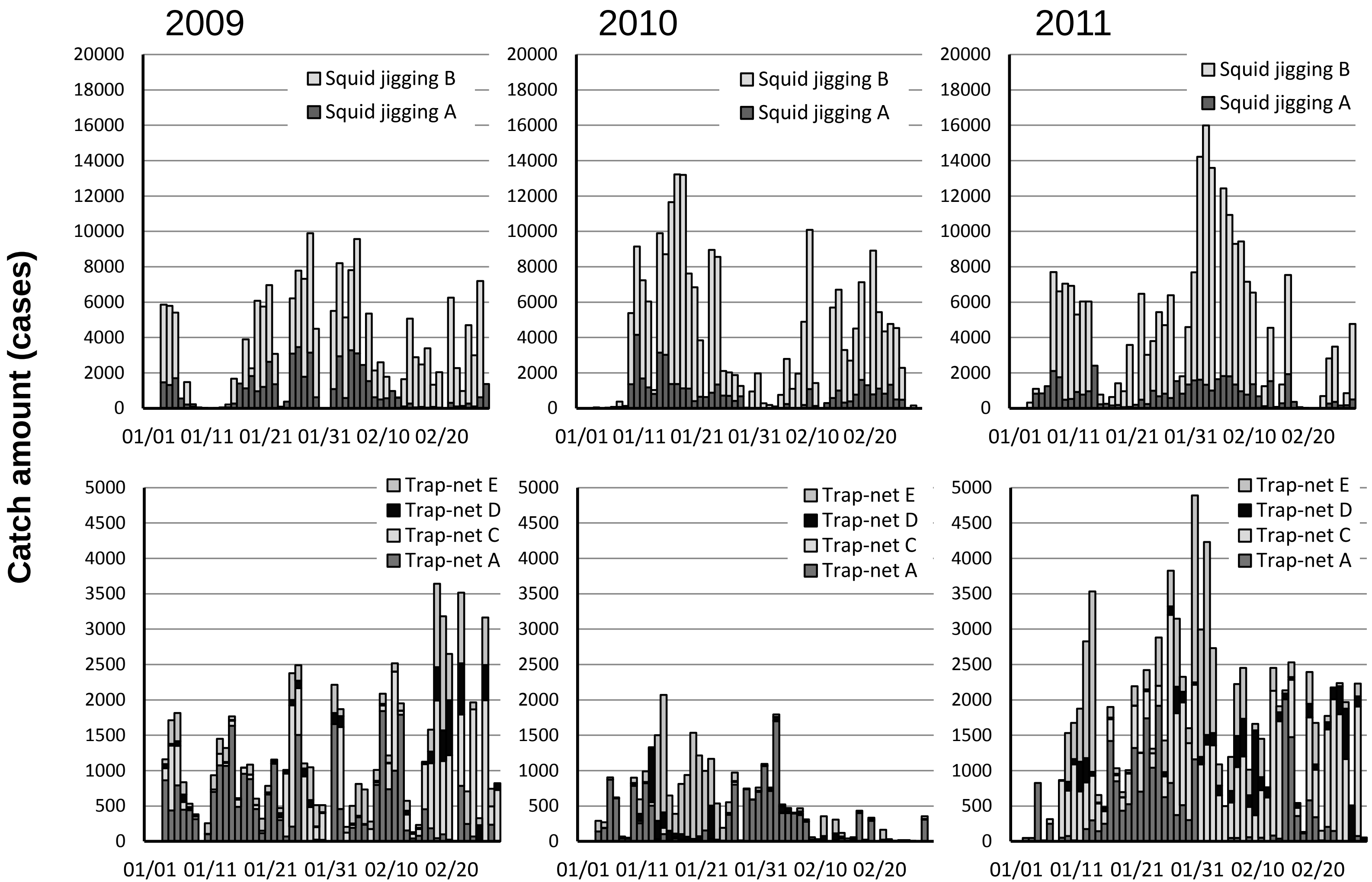


Fig. 5 Masuda et al.

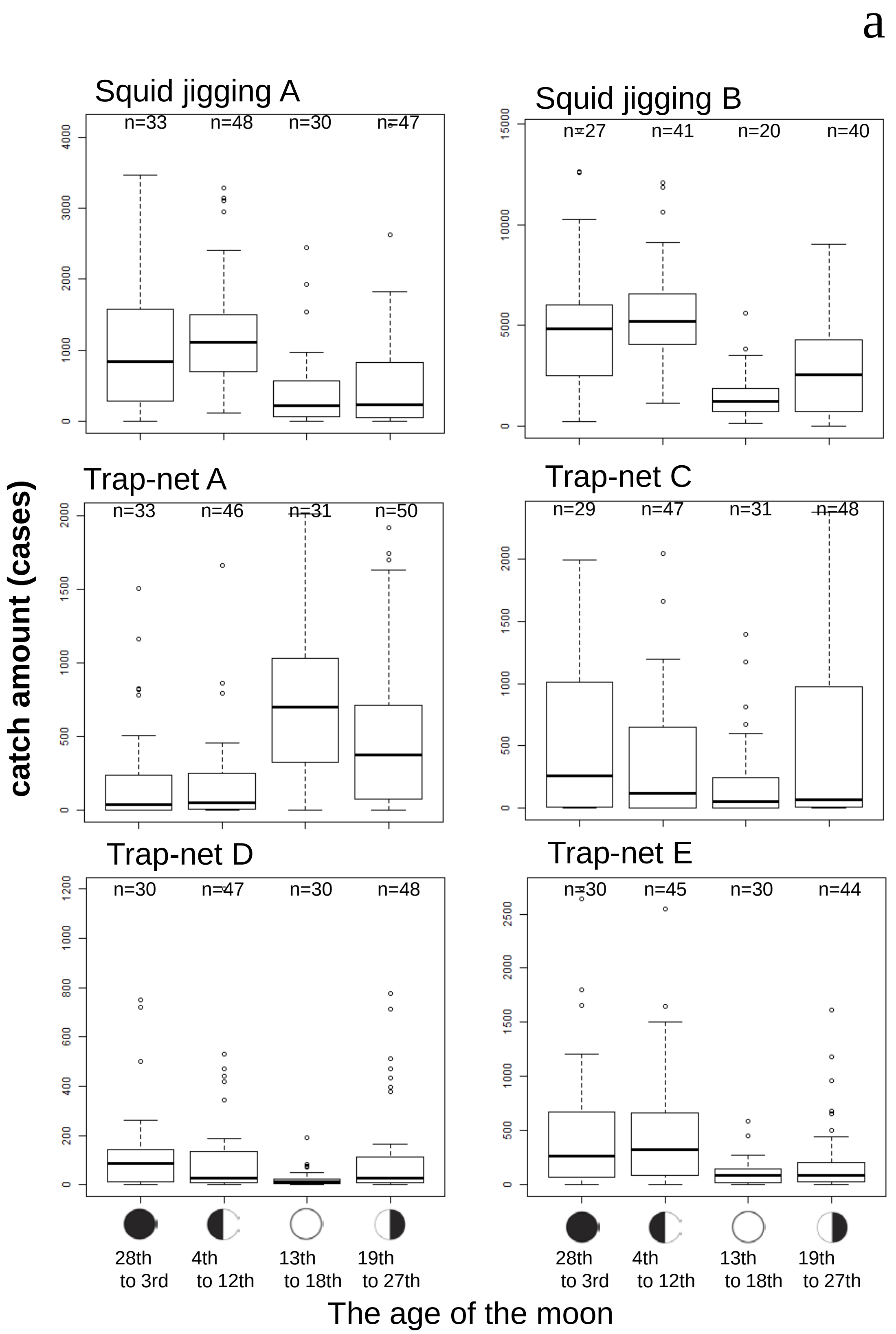


Fig. 6a Masuda et al.

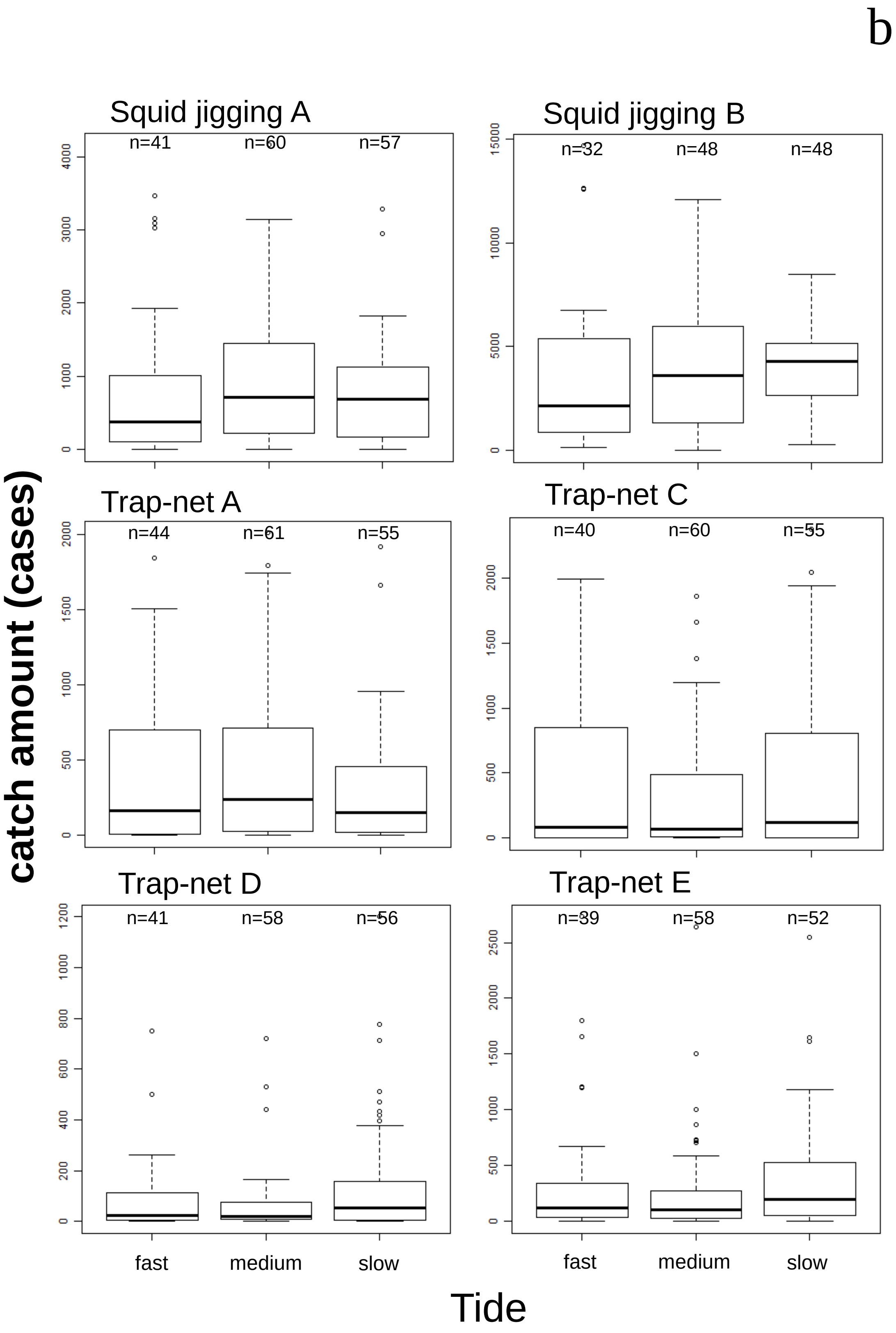


Fig. 6b Masuda et al.

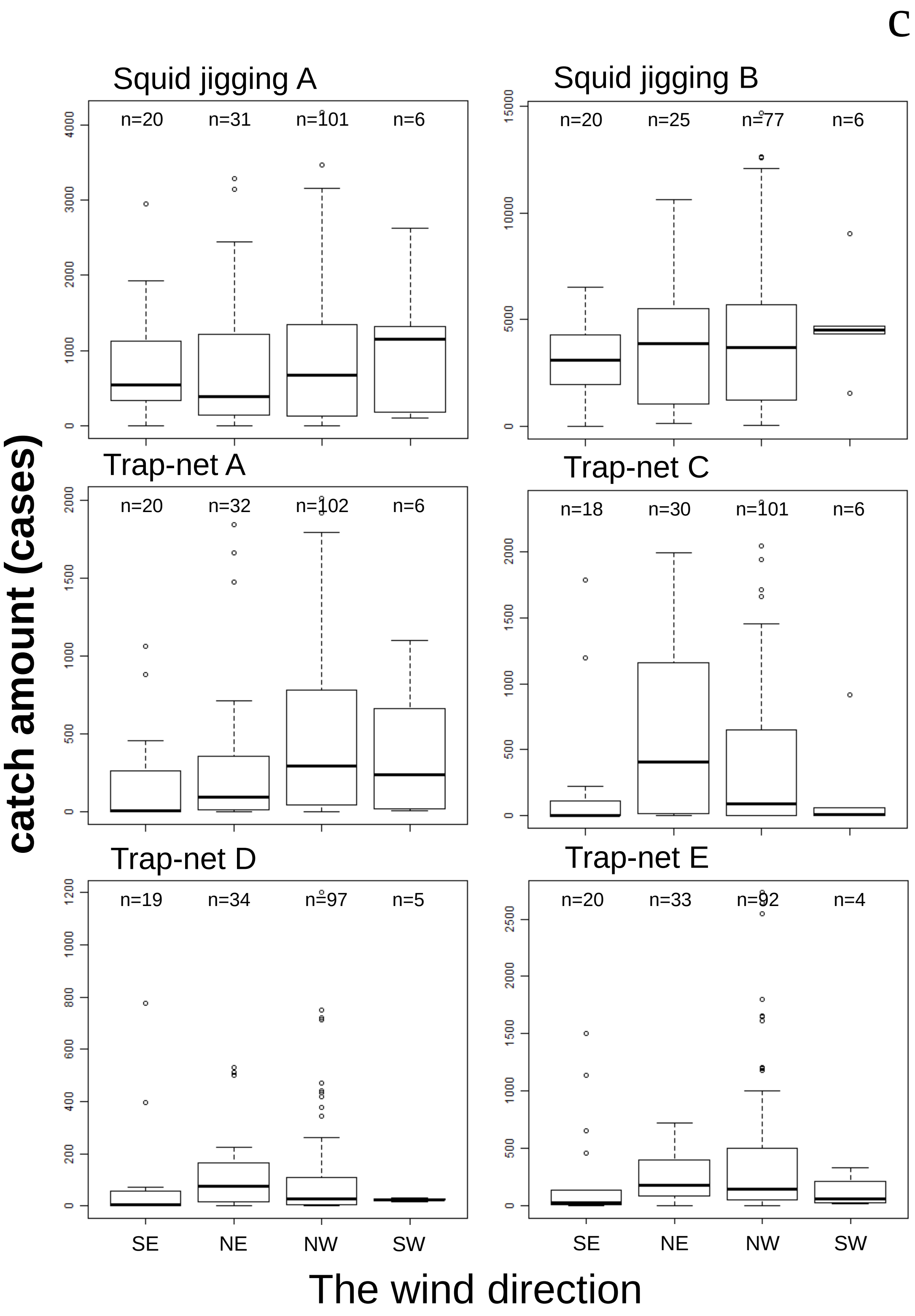


Fig. 6c Masuda et al.

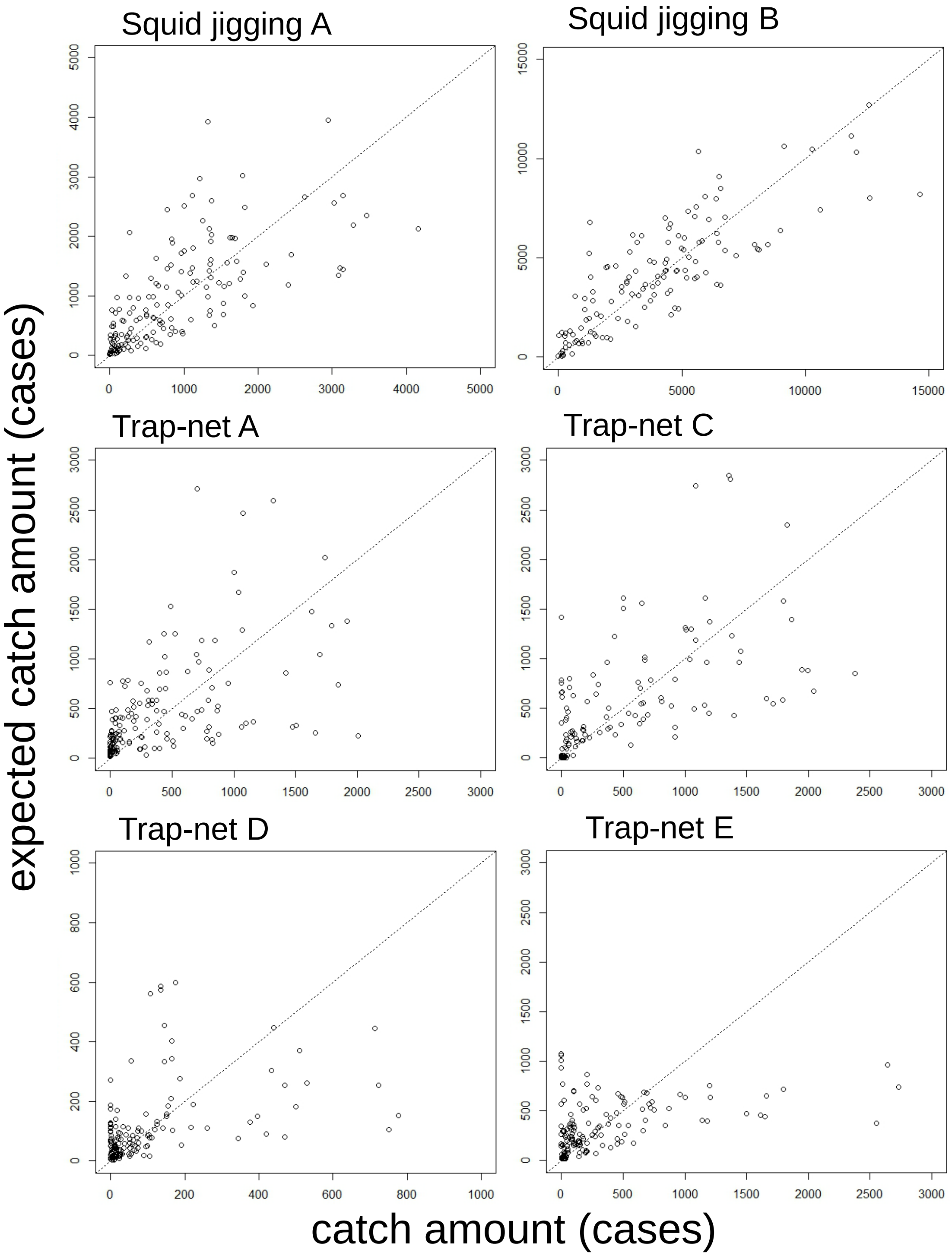


Fig. 7 Masuda et al.

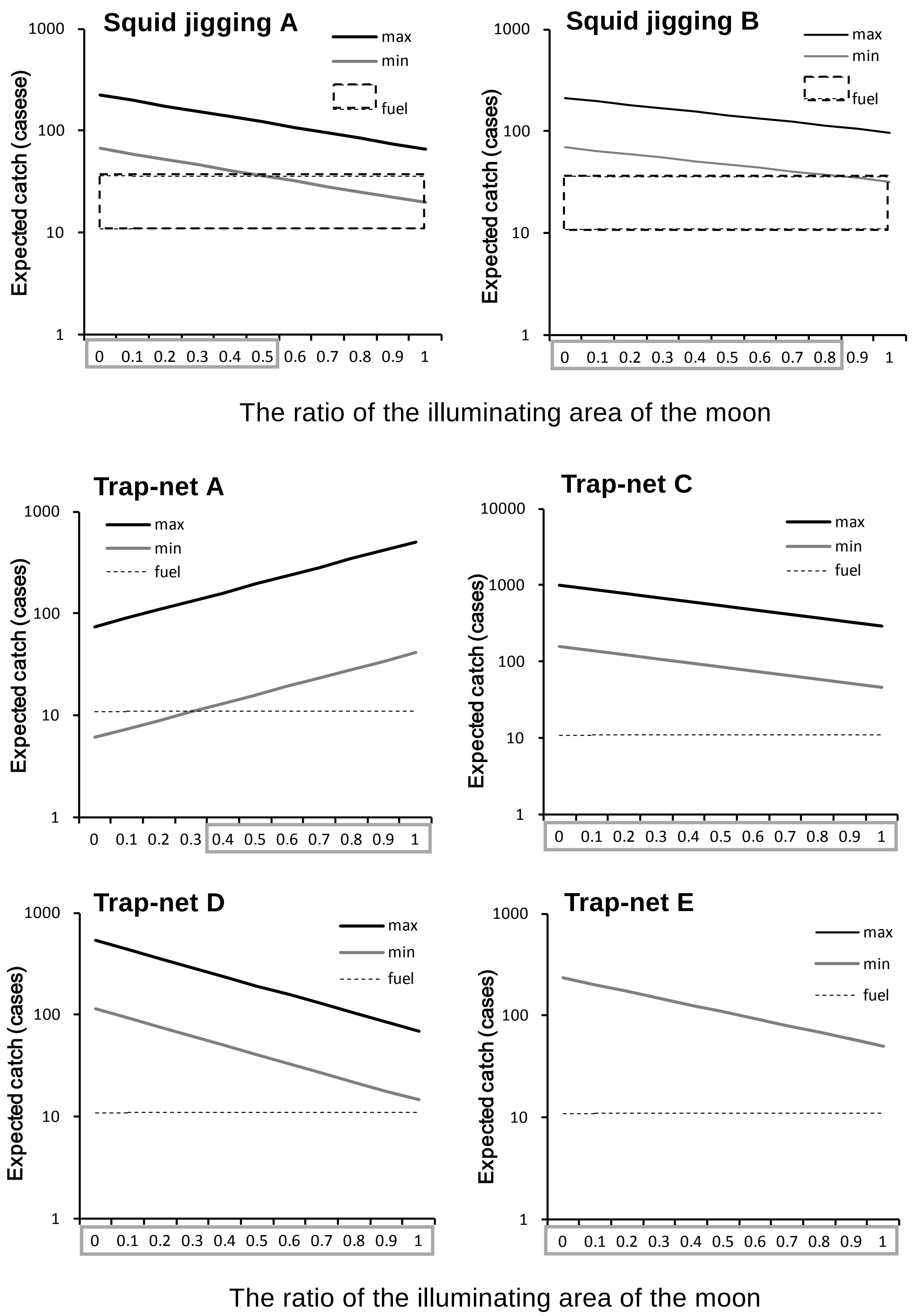


Fig. 8 Masuda et al.