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## 潮岬灯台直下の潮波と黒潮

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### White-capped breakers observed just off the lighthouse of Cape Shionomisaki and the Kuroshio

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Keiko NAKAZATO<sup>1)</sup>, Takashi KOIKE<sup>4)</sup>, and Yutaka NAGATA<sup>5)</sup>

**Abstract :** We observed regularly the white-capped breakers which are produced by strong current in the sea just off the lighthouse of Cape Shionomisaki. The white-capped breakers are classified into seventeen ranks from  $-8$  through  $+8$ . Correlations of the ranks of white-capped breaker with several quantities such as the east-west component of current speed observed with ADCP at a fixed point, the sea level difference between Kushimoto and Uragami tide gauge stations, and the separation distance of the northern edge of the Kuroshio measured southwards from the tip of Cape Shionomisaki. The separation distance was determined from the position of the temperature front seen in satellite images. These correlations are very significant, and the observation of white-capped breaker is shown to be very useful to know oceanic conditions in the vicinity of Cape Shionomisaki. We defined that white-capped breakers are clearly seen above rank 4. This means that significant currents would exist in the sea just off the lighthouse at least for ranks above rank 4 through rank 8. If we define the northern edge of the Kuroshio with the northern limit of eastward current zone of the Kuroshio, the separation distance of the northern edge of the Kuroshio should be zero for these cases. It is hard to believe that currents are geostrophic in shallow waters just near coast. The current would be flowing under the balance between sea surface gradient and friction due to existence of coast or sea bottom. MAEKAWA *et al.* (2011) showed that the distribution of sea surface height in the sea just near the tip of the Cape Shionomisaki is produced by the temperature and salinity structures in shallow water less than 300 m, and that the sea level difference between Kushimoto and Uragami is produced by the surface Kuroshio water which had been brought into near coast region off the southwestern coast of the Kii Peninsula. The east-west sea level gradient produced just off Cape Shionomisaki would create an eastward current just along the coast. Besides, significant ranks (7 and 8) of white-capped breakers can be seen relatively often in summer season. This would be related to the seasonal variation of the sea level difference between Kushimoto and Uragami discussed by NAKAMURA *et al.* (2012).

**Keywords :** *White-capped breakers off Cape Shionomisaki, Rank of white-capped breakers, ADCP observation, Sea level difference between Kushimoto and Uragami tide gauge stations, Separation distance of the northern edge of Kuroshio*

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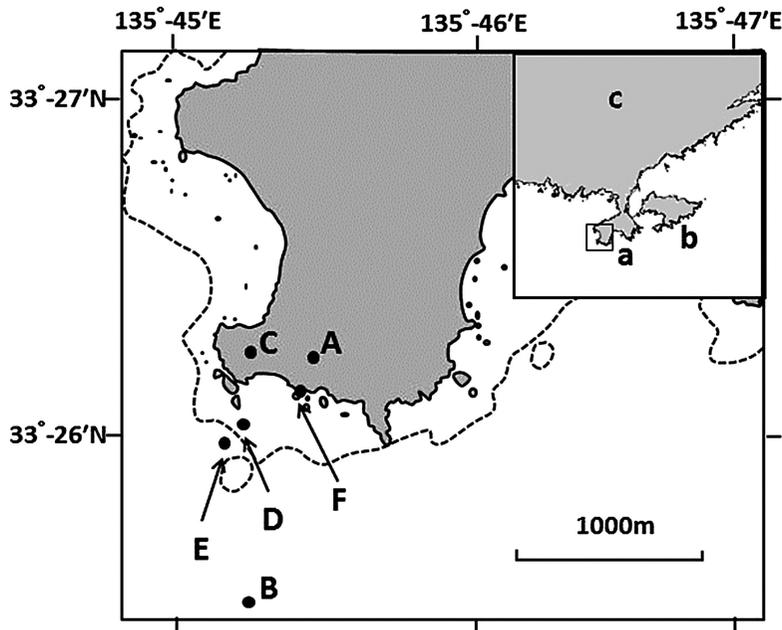


Fig. 1. Map of the area in the vicinity of observation area. A: observation point, B: the position of the direct current measurement, C: Shionomisaki lighthouse, D: Ohkura Island, E: Kometsubu rock and F: Kuroshima Fishing Port. The map shown in upper right corner shows the position of the main map relative to Cape Shionomisaki; a indicates Cape Shionomisaki, b Ohshima Island and c Kii Peninsula. Area shown in main map is shown by a square near letter a.

## 1. はじめに

黒潮は直進路をとっている時、その北縁が、ほぼ潮岬に接する形で流れている。潮岬の先端近くの沖合には、浅瀬が存在しており、小さな島や岩礁が多数存在している。黒潮接岸時には、強い東向流が岸のすぐ近くにも現れ、この浅瀬や島にぶつかる形で白波が立つ。これを地元では潮波と呼んでいる。沿岸漁業者（一本釣り、ひき縄漁師）あるいは磯釣り愛好者の中には、漁場の海況を知る手段として、潮岬灯台からやや東の地点で、この潮波の状況を観察している人たちがいる。和歌山県農林水産総合技術センター水産試験場（以下では和歌山水試と略記する）では、これらの人々が観察している地点を、固定観測点として選び、1994年1月から、毎日午前9時前後に、定期的な潮波の目視観測を始めた。この情報が、漁海況予報などの事業に役立つことが確かめられたので、1996年1月から潮波の日々の状況から潮波階級を設定し記録することとした。本論文では、1996年1月から2010年12月までの15年間の資料を用いて、観測結果とやや沖合に設定したADCP観測点での測流結果と対比して、潮波階級の有意

性を確かめる。また、潮波階級と黒潮の潮岬沖の離岸距離との関係や、串本・浦神の検潮所間の水位差との関係を調べる。中村ら（2012）は黒潮が一年を通して直進路をとっている年には、串本・浦神間水位差に明確な季節変化が見られることを指摘しているが、同様の季節変化が潮波階級にも現れるかどうかを検討したので、その結果を報告する。

## 2. 潮波の目視観測と、潮波の階級、および使用した他の観測資料

### 2.1 潮波の観測経過と潮波階級の決め方

潮岬の灯台の東方約350mの高台の崖上道路に設定された目視観測点と、その周辺の海域を含む地図をFig. 1に示す。地図には潮岬灯台から真南に延びる小島や岩礁列が示されており、代表的な大倉島や米粒岩の位置を示してある。目視観測点から撮られた潮波の写真の一例（2009年8月27日午前10時26分撮影）をFig. 2に示す。この写真で一隻の船が写っている船着き場は黒島漁港である。潮波が観察された海域は、Fig. 1に見られるように、潮岬南方の崖の下にあたり、潮

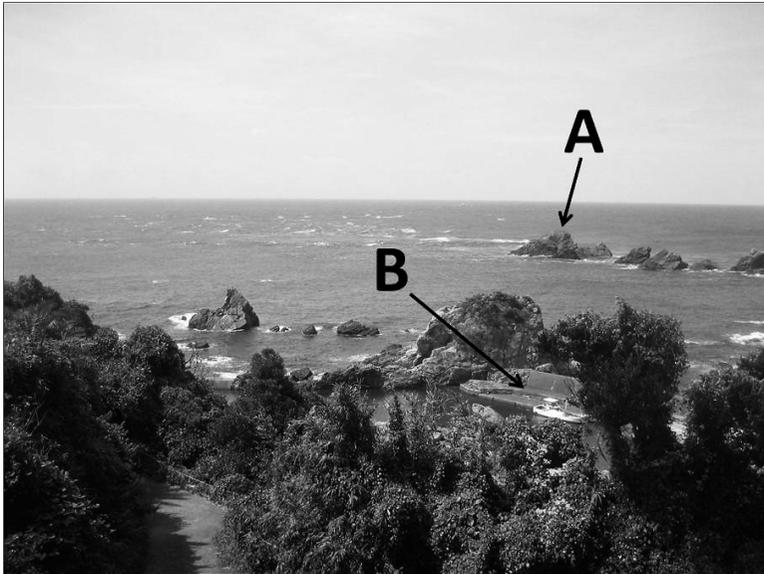


Fig. 2. An example of white-capped breaker created by strong current. This picture shows a state of white-capped breaker of rank 8. A : Ohkura Island, B: Kuroshima Fishing Port. Kometsubu rock is hidden by Ohkura Island.

岬灯台直下といえる所である。潮波階級は、潮波が全く認められない場合を0とした。小島や岩礁列の海域が、碎波やそれによって発生した泡によって白く見える場所が広範囲に広がっている場合を潮波階級8あるいは-8とする。Fig. 2の写真に写されているような場合が階級8に当たる。そうして誰が見ても潮波が存在していることが分かる程度の状態を潮波階級4と定義した。目視観測に熟練してくると、さらに詳しい分類が可能となるが、0と4、4と8の間にそれぞれ3つの階級を設けたが、階級の定め方には、人によって±1程度の違いは生じ得るだろう。なお、黒潮と同じ東向流の場合を+、中村ら(2008)が論じたような西向流の場合には-を付して表現している。東向流・西向流の区別は、泡列の延びる方向で判定できる。特に、東向流の場合には、写真(Fig. 2)大倉島と呼ばれる小島の陰になっているが、米粒岩で生じた泡列が大倉島の向こう側から、視野に出て来る様子から容易に判定できる。西向流の場合は観測例が少ないこともあり、判定は若干難しいが、馴れてくると判定が出来るようになる。ただし、-5以下の階級は観測期間中にはあらわれなかった。

観測の時間は、種々の事情で一定させることが出来なかったが、午前7時過ぎから午前11時までの間に行っている。解析した1996年1月から

2010年12月までの15年間の各年の潮波階級観測数をTable 1のA欄(括弧内は欠測数)に示す。2004までは勤務の都合等から欠測が多く、最初の1996年には最大25日の欠測があるが、2004年頃までの年間欠測数は10日程度である。しかし、欠測の日が特に決まった季節に偏る傾向は無い。2005以降は、この資料の有効性が強く認識されるようになったこともあり、欠測は、年に6日以下になっている。潮波階級別の潮波階級の観測数はTable 2のA欄に示してあるが、階級-3、-4の観測数は非常に少ない。

黒潮は直進路をとっている時、その北縁が、ほぼ潮岬に接する形で流れている。潮岬の先端近くの沖合には、浅瀬が存在しており、小さな島や岩礁が多数存在している。黒潮接岸時には、強い東向流が岸のすぐ近くにも現れ、この浅瀬や島にぶつかる形で白波が立つ。これを地元では潮波と呼んでいる。沿岸漁業者(一本釣り、ひき縄漁師)あるいは磯釣り愛好者の中には、漁場の海況を知る手段として、潮岬灯台からやや東の地点で、この潮波の状況を観察している人たちがいる。和歌山県農林水産総合技術センター水産試験場(以下では和歌山水試と略記する)では、これらの人々が観察している地点を、固定観測点として選び、1994年1月から、毎日午前9時前後に、定期的な潮波の目視観測を始めた。この情報が、漁海況

Table 1. Number of observation of white-capped breaker created by current (column A) and that of ADCP observation (column B) in each year. Numbers in brackets in column A indicate the numbers of days without observation.

| Year  | A           | B   |
|-------|-------------|-----|
| 1996  | 341 (25)    | 28  |
| 1997  | 353 (12)    | 43  |
| 1998  | 357 (8)     | 46  |
| 1999  | 360 (5)     | 50  |
| 2000  | 360 (6)     | 52  |
| 2001  | 357 (8)     | 47  |
| 2002  | 356 (9)     | 49  |
| 2003  | 358 (7)     | 39  |
| 2004  | 353 (13)    | 36  |
| 2005  | 364 (1)     | 34  |
| 2006  | 359 (6)     | 35  |
| 2007  | 363 (2)     | 36  |
| 2008  | 365 (1)     | 36  |
| 2009  | 362 (3)     | 41  |
| 2010  | 364 (1)     | 34  |
| Total | 5,372 (107) | 606 |

予報などの事業に役立つことが確かめられたので、1996年1月から潮波の日々の状況から潮波階級を設定し記録することとした。本論文では、1996年1月から2010年12月までの15年間の資料を用いて、観測結果とやや沖合に設定したADCP観測点での測流結果と対比して、潮波階級の有意性を確かめる。また、潮波階級と黒潮の潮岬沖の離岸距離との関係や、串本・浦神の検潮所間の水位差との関係を調べる。中村ら(2012)は黒潮が一年を通して直進路をとっている年には、串本・浦神間水位差に明確な季節変化が見られることを指摘しているが、同様の季節変化が潮波階級にも現れるかどうかを検討したので、その結果を報告する。

## 2.2 ADCPによる定位置での流速測定

Fig. 1に示されたADCP観測点は、潮波目視観測と対比するために設けたADCPの観測点である。和歌山水試の観測船「わかやま」あるいは「きのくに」が、この付近を通過するときに測流を行っている地点である。和歌山水試の調査船は、浅海・沿岸・沖合定線観測等の往復時に、この目視海域を通過することが多い。通常、串本を午前

Table 2. Number of observation of white-capped breaker (column A) and that of ADCP observation (column B) for each rank of white-capped breaker.

| Rank   | A     | B   |
|--------|-------|-----|
| Rank-4 | 8     | 0   |
| Rank-3 | 0     | 0   |
| Rank-2 | 72    | 11  |
| Rank-1 | 123   | 18  |
| Rank 0 | 1,238 | 116 |
| Rank+1 | 594   | 57  |
| Rank+2 | 564   | 52  |
| Rank+3 | 415   | 49  |
| Rank+4 | 1,007 | 147 |
| Rank+5 | 512   | 50  |
| Rank+6 | 567   | 74  |
| Rank+7 | 145   | 17  |
| Rank+8 | 127   | 15  |
| Total  | 5,372 | 606 |

9時に出港し10時頃にADCP観測点(北緯33度25.7分, 東経135度45.3分)の1km以内を通過する。このとき「わかやま」では水深5mの流速を、「きのくに」では水深10mの流速を、ADCPによって測り記録している。「きのくに」は1996年11月から、「わかやま」に代わって観測を開始しているが、ここではこの両者の観測結果を海表面近くの実測流速値とみなして使用する。なお、この論文では、測流値から東西成分を求めて、その値を用いている。調査船は、串本への帰航時にもADCP観測点の近くを16時から18時の間で通過することがあるが、潮波観測が午前中に行われていることから、同時性を考えてその資料としては用いていない。

ADCP観測の年別の回数はTable 1のB欄に示してある。観測は、1996年以降では、年間28回から52回行われていて、観測回数は全部で606回である。潮波階級別に利用できる流れの直接測定回数は、Table 2のB欄に示してある。測流回数は、潮波階級が負の場合と、階級7, 8に対しては、極めて少なくなっている。

## 2.3 串本・浦神の海面水位と水位差

串本、浦神それぞれの水位はあらかじめTP(東京湾中等潮位)上に換算した後、タイドキラー・フィルター(花輪・三寺, 1985)をほどこしたデータから、毎日の正午の値を選び出してその日の代

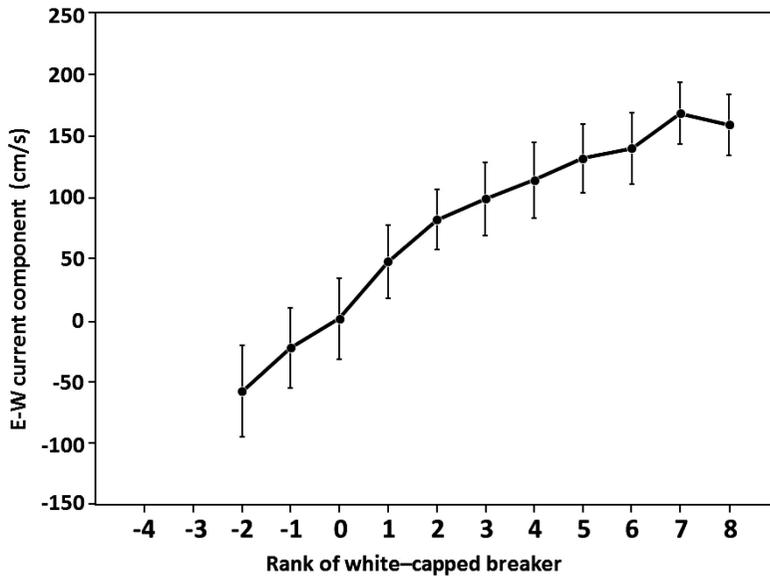


Fig. 3. Correlation between current speed measured at B shown in Fig. 1 and observed rank of white-capped breaker. Vertical bars indicate variability range ( $m + \sigma$ ,  $m - \sigma$ ).

表値として使用している。水位の気圧補正は近傍の気象観測点である潮岬測候所の海面気圧データを使った。ただし、串本・浦神の両地点とも、最も近い測候所は潮岬であり、この補正は水位差の値には影響を与えない。

#### 2.4 黒潮北縁の離岸距離

本論文で使用している黒潮北縁の離岸距離は、和歌山水試が NOAA/HRPT 受信解析装置 (TeraScan) を用いて、その映像に現れる水温フロントの位置を、潮岬先端から南方に測った距離として定義している。衛星の画像の分解能は 1.1 km 程度とされているが、実際の画像からはより細かく黒潮北縁の離岸距離を読み取ることが可能であり、ここでは 0.1 km 単位で決めた値を用いている。ただし、陸と海とのコントラストが大きいこともあり、北縁が 3.7 km (2 海里) 以下に近づくとその位置の決定が難しくなる。海岸線と北縁の見分けがつかない場合には、便宜上離岸距離を 3.7 km として解析を行った。極沿岸近くの潮波現象を解析するため、公称の分解能以下のデータまで扱っているため、その正当性は結果から逆に判断する必要がある。

なお、黒潮北縁の定義自体が曖昧であることに注意する必要がある。例えば海洋情報部が発行している海洋速報によると、「黒潮の流軸は、流路

の中で最も流速が速い海域 (強流帯) を示し、黒潮北縁から概ね 13 海里に位置します」と説明されている。この定義によると、離岸距離が 24 km 以下になると北縁は陸上に来ることになってしまう。また、顕著な潮波が観測される場合は離岸距離は 0 とするべきかもしれない。この問題についても解析結果から考察を加える。

### 3. ADCP 実測値と潮波階級

#### 3.1 ADCP 実測値と潮波階級の相関

横軸に潮波階級をとり、縦軸に流速の東西成分をとって、相関を示したのが Fig. 3 である。各潮波階級について、流速成分の平均値 (cm/s) と標準偏差 ( $\sigma$ ) を求め、平均値を黒丸で、 $m + \sigma$  と  $m - \sigma$  までの範囲を縦線で示してある。データ数が少ないこともあり、標準偏差も大きいですが、両者の間には明確な相関関係が認められ、潮波階級の観測結果が、潮岬すぐ沖の流れの東西成分に良い指標を与えていることが分かる。

潮波階級の増加に伴う測流値の増加の勾配が、潮波階級 2 以下と場合に比べて、3 以上では緩やかになっており、階級 8 に対する測流値は 7 に対するものよりむしろ小さくなっている。これは、ある程度以上の流速を超すと、見かけ上の白波の立ち方の度合いが余り変化しなくなることを示唆している。

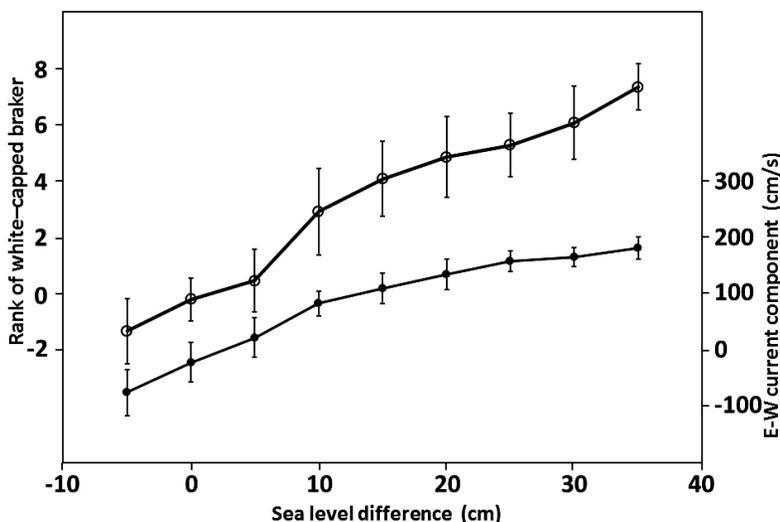


Fig. 4. Correlations between rank of white-capped breaker and sea level difference between Kushimoto and Uragami tide-gauge stations (white circle) and between east-west current components measured by ADCP (black circle). Vertical bars indicate variability range ( $m + \sigma$ ,  $m - \sigma$ ).

なお、潮波階級は-4まで観測されているが、残念ながら-3以下の場合の ADCP 観測は行われていない。

### 3.2 串本・浦神間水位差を媒介とした潮波階級と ADCP 実測値の比較

ADCP 実測値が利用できるデータ (606 個) を用い、串本・浦神間の水位差を、 $-2.5 \sim 2.5$  cm,  $2.5 \sim 7.5$  cm という具合に 5.0 cm 間隔で分割し (ただし上端の数値に当たるものはその範囲に含める)、それぞれの範囲に含まれる潮波階級および ADCP 実測値のそれぞれの平均値を (白丸) と (黒丸) で示したものが Fig. 4 である。また、それぞれの値に付した縦線は分散値の大きさを示している。この図を見ると潮波階級も ADCP 実測値も、串本・浦神間水位差とよい相関を示しており、対応関係も細部を除くとほぼ同じである。この図では階級 8 に対する水位差は、階級 7 に対する水位差よりも明らかに大きくなっている。

### 3.3 潮波階級の分解精度

前節で論じたように潮波階級については、前述のように-8から+8までの17の階級を設定したが、潮波の立ち方については、観測者の個人差によって、同じ状況でも階級の決め方に若干の差が生じ得る。また、同一人でも天候条件による視程の違いや、風あるいは波浪条件によって差異が生

じ得る。また、観測時間や観測場所についても両者の間に若干のずれがある。したがって、ここで用いている細かい階級分けが意味を持つかどうか検討する必要がある。

ADCP による実測値の利用できる 606 個のデータを用いて、各階級がどのような測流値に対応しているかを見てみよう。階級が-3以下の潮波が観測された時には、いずれの場合にも ADCP 観測が行われていないので、階級-2から階級8までの11の階級のそれぞれに対して、どのような流速値が得られているかの頻度分布を示したものが Fig. 5 である。統計をとった流速値の幅は 10 cm/s 毎にとっており、例えば  $-5$  cm/s から  $5$  cm/s (上端の値はこの範囲に含める) に現れる測定数の合計を 0 cm/s の位置にプロットしてある。流速値幅を小さく取ったためにデータ数が少なく分布形が離散的になったり、凹凸のある形を取ったりしているがそれぞれの階級に対して、それぞれ1つの山形の分布が得られている。その分布範囲は階級-2から階級2までは、階級の増加にともない高速度側に明瞭に移っていく。階級2から上については、この移動の度合いはかなり減少するものの、階級2から8の範囲でも明確に認められる。したがって、ここで採用した潮波階級の設定は、十分意味を持っていると思われる。ただし、隣り合った階級間の分布型の重なり方は、特に階級の大きい部分で、大きくなっており、こ

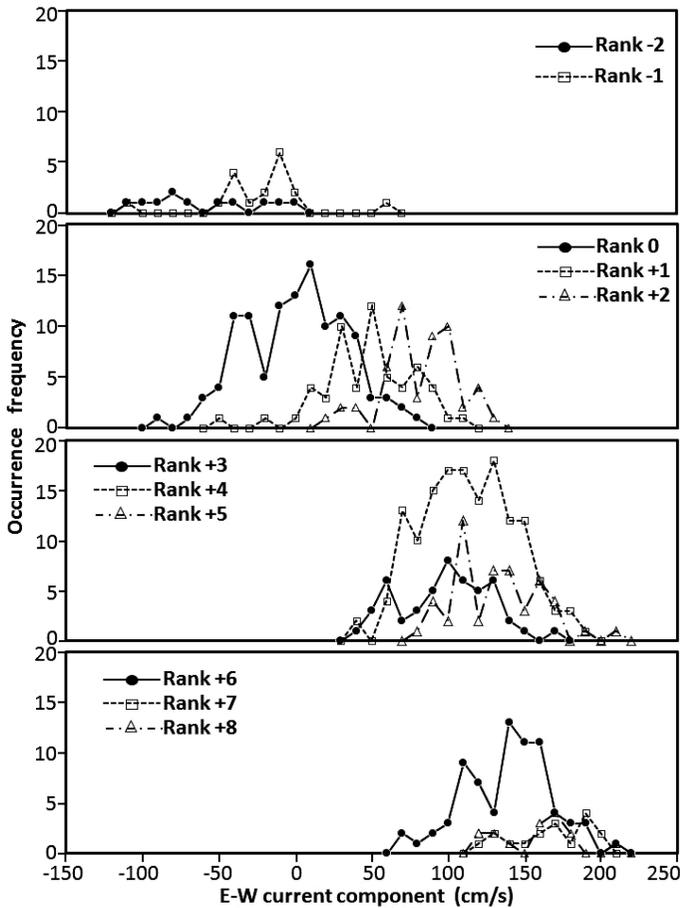


Fig. 5. Occurrence frequencies of east-west current components measured by ADCP for rank -2 through rank 8 of white-capped breaker. Occurrence frequencies are given for each segment of 10 cm/s which is centered at -150 cm/s, -140 cm/s, -130 cm/s, and so on. The frequency at upper end of each segment is included to that segment.

の部分では±1ないし±2程度、測定条件によつてずれが生じている可能性は大きい。結果の解釈に当たっては、このことを十分考慮に入れる必要がある。

また、ここでは示さないが、潮波階級を解析した5,372個の全データについて、横軸に測流値の代わりに串本・浦神間の水位差をとって、同様の図を作成して検討した。分布はいずれの階級についても一つの山を持つ形になり、潮波階級の増大に伴う水位差の増大傾向は階級0から階級8にいたるまで認められる。

階級が負の場合、すなわち西向流の場合については、中村ら(2008)が詳しい解析を行っているが、西向流には、黒潮北縁が潮岬に近づいた状態

で、北縁と岸の間の非常に狭い部分に生じる狭い西向流と、黒潮北縁が岸から離れた蛇行路を取っている時に、岸近くに現れる幅の広い西向流があることが指摘されている。現在扱っているデータでは、このような西向流の特性を知る手段がないし、出現頻度も非常に少ないので、以下の議論では階級-3以下の階級については触れないことにする。

#### 4. 潮波階級と串本・浦神間の水位差、黒潮離岸距離との関係

##### 4.1 潮波階級と串本・浦神間の水位差

串本・浦神の検潮所間の海面水位の差が、本州南岸の黒潮流路が直進路をとるか、蛇行路をとる

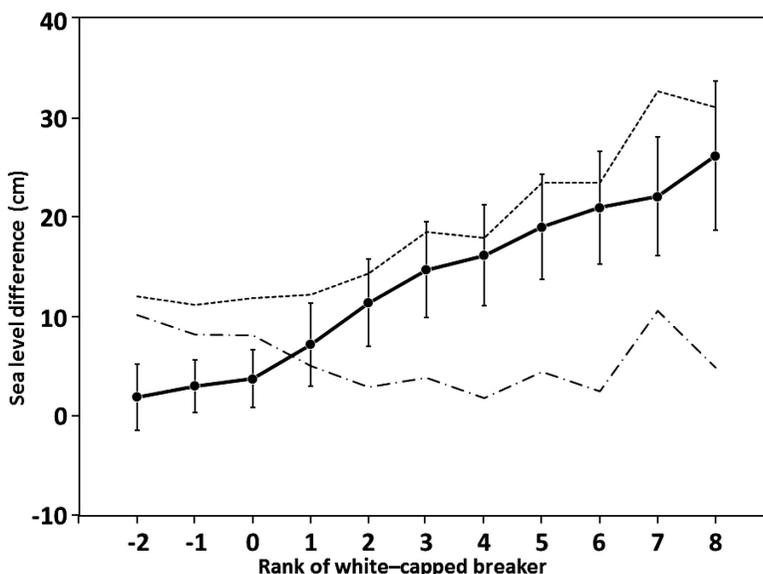


Fig. 6. Relation between sea level difference between Kushimoto and Uragami tide gauge stations and rank of white-capped breaker (black circles). Vertical bars indicate variability range ( $m + \sigma$ ,  $m - \sigma$ ). Sea level heights at Kushimoto and Uragami tide gauge stations measured from TP are shown with dashed line and dash and dotted line, respectively. The scales of these lines are common with that of the sea level difference.

かの指標として有効であることは良く知られている（例えば、藤田，2001）。これに関連して、われわれは紀伊半島南西岸に現れる振り分け潮が重要な働きをしていることを明らかにしてきた（TAKEUCHI *et al.*, 1998, NAGATA *et al.*, 1999, UCHIDA *et al.*, 2000）。また、前川ら（2011）は、黒潮の流路の指標となる水位差は、実質的には潮岬を挟む東西約 6 km の部分で生じていることを示すとともに、潮岬周辺の海況特性を決定する重要な要素は、潮岬先端から黒潮北縁がどれだけ離れているかの黒潮離岸距離であることを指摘した。この論文で論じている潮岬すぐ沖に発生する潮波の立ち方が、串本・浦神間の水位差や、黒潮離岸距離とどのように関わっているかを見ることにしよう。

潮波観測が利用できる全データを用いて、潮波階級ごとに対応する串本・浦神間水位差を選び出して、その平均を太い実線でつないだ黒丸で示したものが Fig. 6 である。また、図には、データの分散を ( $m + \sigma$ ,  $m - \sigma$ ) の縦の線分で示してある。水位差の値は、階級 -2 から 0 の時の水位差 0 に近い値から、右上がりに階級数の増加にしたがって増加している。階級 8 にあたる 20 数 cm の水位差はほぼ典型的な直進路に対応する値であ

る。（ただし、分散値は全般に大きく統計的な信頼度は限定される。これは、黒潮が直進路をとっている場合にも、潮岬東西の沿岸水の交換が時折生じ得る（例えば、NAGATA *et al.*, 1999）ことに関連していると考えられる。）

Fig. 6 には TP（東京湾中等潮位）からの偏差として現した串本の水位を点線で、浦神の水位を一点破線で示してある。（図を見易くするため、分散の値は省略しているが、分散の値は、この場合にも全般に大きい。）一般に串本・浦神の水位が共に増大または減少するような変動がしばしば見られることもあり、分散値は水位差に比べて 3 倍に近い値をとる。この図から、串本・浦神間の水位差を生み出す主な要因は串本側の水位の変動にあることが分かる。しかし、浦神側の水位変動も若干寄与することにも留意する必要がある。

#### 4.2 潮波階級と黒潮離岸距離

全データを用いて、潮波階級ごとに対応する黒潮離岸距離の平均値を示したのが Fig. 7 である。また、データの分散を ( $m + \sigma$ ,  $m - \sigma$ ) の縦の線分で示してある。階級 0 以下では離岸距離の平均値が 40 km 以上の値をとっており、これらの階級に対して、通常黒潮は典型的な蛇行路をと

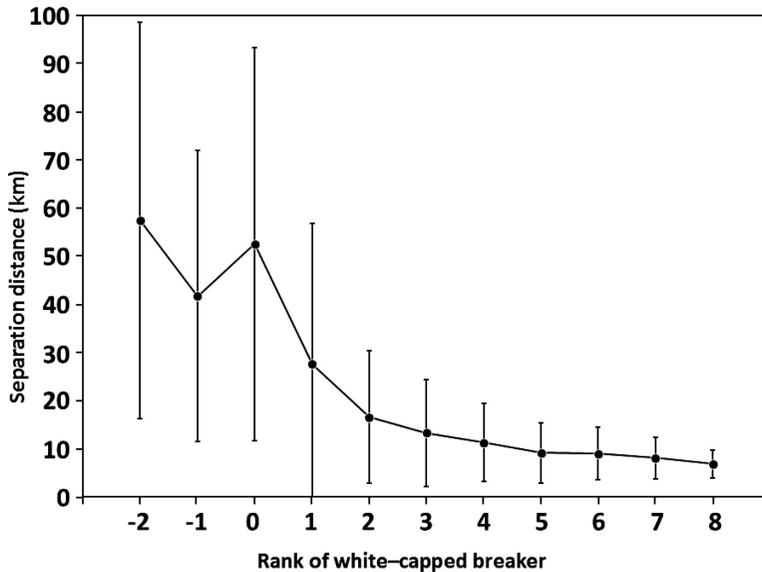


Fig. 7. Relation between separation distance of the northern edge of the Kuroshio measured southward from the tip of Cape Shionomisaki and rank of white-capped breaker. Vertical bars indicate variability range ( $m + \sigma$ ,  $m - \sigma$ ).

ていることが示されている。階級0の離岸距離は約50 kmであり、これは、蛇行路と直進路の境目である（例えば藤田，2001）。

階級1から階級8まで、階級が進むにつれ離岸距離が単調に減少していく。これは、黒潮北縁が潮岬先端に近づけば近づくほど、潮岬直下の東向流の速度が増し、激しく潮波が立つことを示している。以前の論文（前川ら，2011，中村ら，2012）で、典型的な直進路を離岸距離15 km以下として論じているが、Fig. 7で平均的な離岸距離が階級3以上で、この15 km以下の値を取り、その値が階級3から階級8まで明らかに減少傾向を示すことは注目される。ここで用いた衛星画像から決めた離岸距離は、最小値を3.7 kmと設定しているから、この減少傾向は、より小さな離岸距離が読み取れていれば、より顕著に示されていたと考えられる。潮波階級4以上が、誰が見ても潮波が存在していることが分かる状態として定義した。潮波階級とやや沖合のADCP観測点（岸から約1 km沖）での流速値の間の相関が良いこと（Fig. 3）から考えると、潮波の観測場所の東西流はより沖合まで広がっていると考えられる。もし潮波を立てている流れが黒潮の流れそのものであるならば、階級4以上では黒潮の流れは潮岬灯台直下の岸まで及んでいることになる。したがっ

て、黒潮強流帯の北限を黒潮北縁と定義するならば、潮波階級4以上の状態では黒潮北縁の離岸距離は0となるはずである。衛星画像からみた温度フロントが厳密に黒潮北縁のどのような構造に対応しているのかについては、今後の研究に待つ以外はないが、このことは多くの示唆を与えるものである。

分散の大きさも階級1以下で大きな値を示しているが、これはこの時、黒潮が蛇行路をとっており、陸岸の束縛を受けなくなることから、流路の変動が大きくなることを示していると考えられる。階級1から階級8に向かうと、Fig. 6に示されたように串本・浦神間の水位差が大きくなり、黒潮は直進路をとるようになる。Fig. 7で、分散の値が階級の増加とともに小さくなっていく傾向が見られるが、これは、より典型的な直進路をとるようになるにつれ、流路の変動性が抑えられることを示している。

##### 5. 潮波階級に現れる季節変化

中村ら（2012）は黒潮離岸距離が小さく、安定した直進路（離岸距離15 km以下）が一年を通して維持される場合に、串本・浦神間の水位差に明確な季節変化が現れることを指摘し、その原因を黒潮表層水の季節変化に求めている。すなわち、

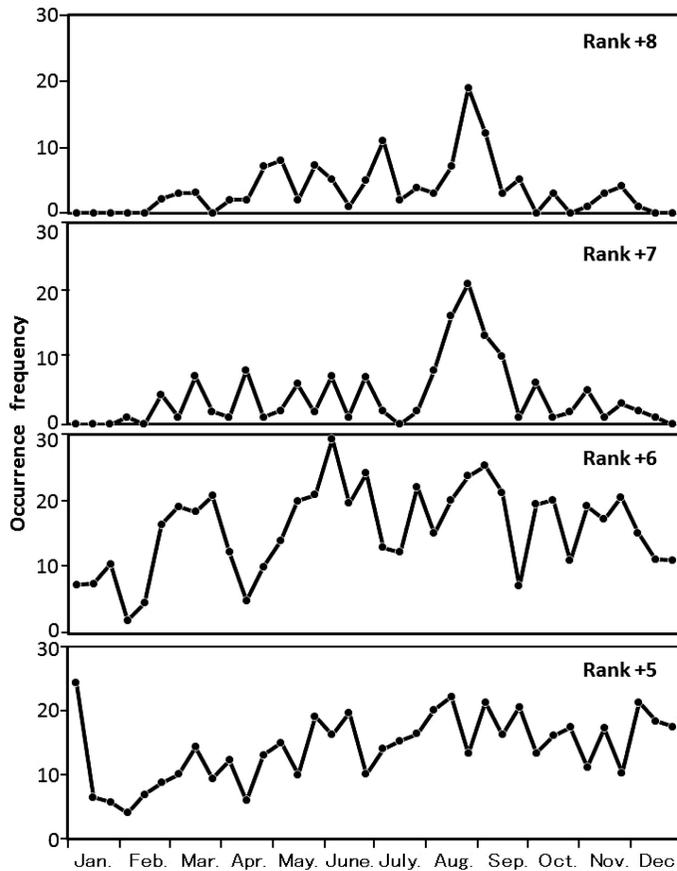


Fig. 8. Seasonal variations of occurrence frequencies for ranks from 5 through 8 (from top to bottom) for each ten days. See manuscript for details.

季節変化する黒潮表層水が振り分け潮に伴って潮岬西方に侵入して、串本検潮所沖の水位を高めると考えている。そうであるならば、顕著な潮波が観測される階級4以上の潮波の立ち方にも季節変化が現れても不思議ではない。

潮波階級5から8について、各階級に対して解析した15年間の旬毎の観測回数を示したのがFig. 8である。ここでの旬は、大の月では、1~10日を上旬、11~20日を中旬、21~31日を下旬と定義し、2月を除く小の月では、これに対して下旬を21~30日と定義した。2月については1~10日を上旬とするのは変わらないが、11~19日を中旬とし、20日から28日、あるいは29日までを下旬と定義した。観測数に関しては、それぞれの旬の日数の違いを補正するため、例えば、11日で定義された旬では、10日間で定義さ

れた旬に比べ、15年間で15日観測日数が多くなって、観測日数が165日となる。ただし、欠測日があると観測日数はそれだけ減るので、165日から欠測日数を減じた数で頻度を割り、それに欠測のない10日間からなる旬の日数150を掛けて日数の差を補正してある（ただし、この補正はほとんど結果に影響していない）。

Fig. 8において、階級5あるいは階級6については、相互に変動のパターンが異なると共に、季節変化らしいものは現れない。しかし、階級7と8については、共に8月下旬に大きなピークが現れると共に、12月中旬から2月中旬にかけて、観測数がほとんどゼロの値を示し、季節変化と思われる形状が認められる。中村ら（2012）が、1994年から2010年までの17年間について、黒潮離岸距離が15 kmの場合だけを選び出し、各

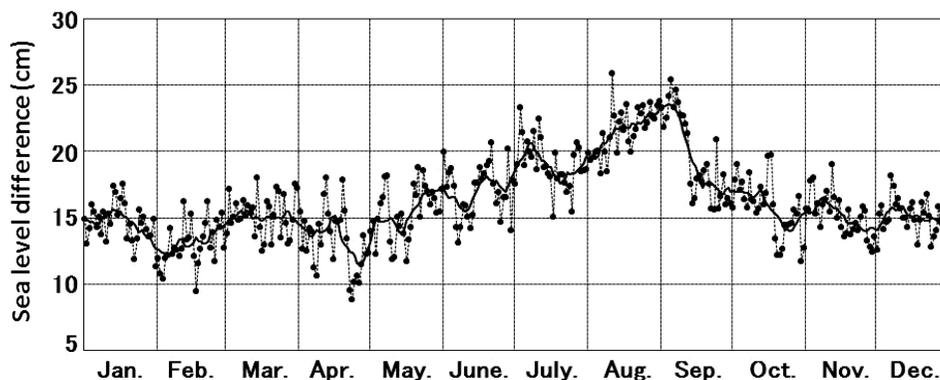


Fig. 9. Seasonal variation of sea level difference (thin curve) between Kushimoto and Uragami tide gauge stations averaged for the period from 1994 through 2010. The data are used only when the separation distance of the Kuroshio is less than 15 km off Cape Shionomisaki. The thick curve indicates 11 days running mean (NAKAMURA *et al.*, 2012).

日について平均を取った串本・浦神間の水位差の季節変化を求めた。この図を Fig. 9 に再録しておくが、Fig. 8 の階級 7 および階級 8 のカーブは、全体として Fig. 9 のカーブに非常によく似ている。ここで得られた結果は、中村ら (2012) の結果を支持しているものと考えられる。

直接、潮波観測に参加した和歌山水試の担当者は、「夏季には潮波が立ちやすい」という感触を持っている。Fig. 8 の階級 7 および階級 8 の出現頻度に、8 月下旬を中心として大きな鋭いピークが現れている。目視観測者の注目が典型的な強い潮波に注がれていると仮定すれば、このピークの存在が、上記のような観測者の感触が得られた理由を与えていると思われる。

## 6. おわりに

潮岬灯台直下の潮波の立ち方を観察することによって、潮岬近くの海況情報が得られるとされてきた。この論文では、潮波階級という形で潮波の立ち方を定量化し、それとやや沖合の ADCP 観測点で測られた流れの東西流成分とを比較することにより、相互の相関が高いことから、潮波階級の設定の合理性を明らかにした。また、潮波階級と串本・浦神の両検潮所間の水位差や、衛星画像から求めた潮岬南方の黒潮北縁の離岸距離との相関が高いことを示し、潮波観測が潮岬周辺の海況を理解する良い指標のなることを示した。

衛星画像から求められた水温フロントの位置を基にして黒潮の離岸距離を議論してきたが、水温フロントが黒潮北縁のどのような構造に対応しているかは、今後の研究課題である。しかし、潮岬

灯台直下の潮波の立ち方から見る限り、黒潮北縁を強い東向流域の北縁とし定義するならば、その離岸距離が完全に 0 となる場合が少なくない。沖合の黒潮の定常的な流れは、地衡流の特性を示し、その流れの構造は主温度躍層以深の水温・塩分構造に支配されていることは良く知られている。前川ら (2011) は潮岬周辺の海面高度分布を決定しているのは、高々 300 m 以浅の水温・塩分構造であることを示した。そうして、黒潮直進時に串本・浦神間の水位差を生み出す主要な原因は、紀伊半島南西海岸にもたらされた比較的高温・低密度の黒潮表層水によって、串本側の水位上昇させられることにあることを示した。中村ら (2008) は潮岬すぐ沖に時々現れる強い西向流を解析し、それを作り出す原因を、浦神側の水位が串本側の水位よりも著しく上昇することによって生じる潮岬沖の東西の水位勾配に求めた。この論文で対象としている潮波の立つ潮岬直下の流れを考える場合にも、潮岬を挟んでの東西の水位差 (串本側が高い) にその成因を求めるのが自然であろう。岸に接した浅海の流れについては、河川の流れのように水位勾配と岸あるいは海底による摩擦力が釣り合ったバランスで流れていることが考えられる。この岸近くに生じた流れが、沖合の地衡流バランスの基に流れる黒潮の強流帯の流れとどのようにつながるのか、その形態、メカニズムについては今後さらに研究する必要がある。

顕著な潮波 (階級 7 および 8) の生起頻度には、顕著な季節変動が見られた。その変動の形状は、中村ら (2012) が黒潮直進時のデータのみから得た串本・浦神間の水位差の季節変化の特性に類似

していることも1つの大きな結論である。

前川ら(2011, 2012)は、従来行われたことのない高密度の観測点分布を設定し、潮岬周辺の微細海況の観測研究を行っている。しかし、ここで論じたような岸近くの現象や、黒潮北縁の構造を明らかにするには、さらに密度の高い観測点分布を持った観測を実施する必要がある。また、岸沿いの水位差についても、潮岬を挟んだ水位差を直接測定する必要がある。現在の串本検潮所は潮岬の陸繋部の西側にあるが、細かい議論にはもう一方の浦神検潮所は潮岬から離れ過ぎている。黒潮の流路のモニターや、潮岬周辺の微細海況を議論するためには、例えば、潮岬陸繋部の東側、串本港側にも検潮所を設けることが必要である。

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# Occurrence patterns and ontogenetic intervals based on the development of swimming- and feeding-related characters in larval and juvenile Japanese sea bass (*Lateolabrax japonicus*) in Tokyo Bay

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**Abstract:** Occurrence patterns of the sea bass (*Lateolabrax japonicus*) larvae and juveniles were examined in Tokyo Bay by monthly samplings using the following two types of gear; a small seine net on tidal flats around the mouth of the Tama River from January 2007 to December 2008, and a ring net in offshore waters from December 2005 to March 2008. Their functional development was also observed by the osteological method on the basis of 47 cleared-and-stained specimens of 3.0–30.1 mm BL. The specimens collected from offshore waters were 391 in number,  $3.67 \pm 1.37$  (mean  $\pm$  SD) mm body length (BL) in ranging from 1.8 to 8.1 mm BL and yolk-sac and preflexion larvae in developmental stages, while those from tidal flats were 580 with  $21.9 \pm 11.0$  mm BL from 11.4 to 123.5 mm BL and varied from flexion larvae to juveniles. No specimens from 8 to 11 mm BL were collected in this study. The sea bass larvae spawned and hatched offshore waters near the mouth of Tokyo Bay are likely to migrate passively to inshore waters and then swim weakly with poorly developed swimming characters to inshore waters. In this study, few sea bass specimens smaller than 13.5 mm BL and larger than about 30 mm BL were collected in tidal flats, and thus the tidal flats of inner Tokyo Bay provide a nursery ground mainly for 13.5–30.0 mm BL juveniles. The 13.5–20.0 mm BL juveniles start acquiring functional, juvenile swimming and feeding abilities.

**Keywords:** Japanese sea bass, early life history, shoreward migration, functional development, Tokyo Bay

## 1. Introduction

The Japanese sea bass (*Lateolabrax japonicus*), distributed on the coast of Japan from Hokkaido south to Kyushu and the southern coast of the Korean Peninsula (HATOOKA, 2002), is known as a typical euryhaline fish, migrating from the sea to brackish/fresh waters, and as an important commercial fish, not only for fisheries but for angling in Japan (SHOJI *et al.*, 2002). Therefore, in Ariake Bay,

the gross biology of sea bass has been well studied, especially their early life histories; eggs are spawned and larvae hatch in offshore/open waters, remaining there up to about 8 mm in body length (BL), before moving to coastal surf zones, where the larvae are divided into two migratory groups, one remaining in the surf zone and the other swimming up rivers (MATSUMIYA *et al.*, 1985; HIBINO *et al.*, 2002, 2006). In Tokyo Bay, central Japan, many studies of the sea bass have been conducted to date, and their spawning ground has been identified as the mouth of Tokyo Bay (WATANABE, 1965; SUZUKI, 1982), with larvae collected by ring nets in offshore waters (KANOU *et al.*, 2002a; NAGAIWA *et al.*, 2005) and juveniles using seine nets in coastal tidal

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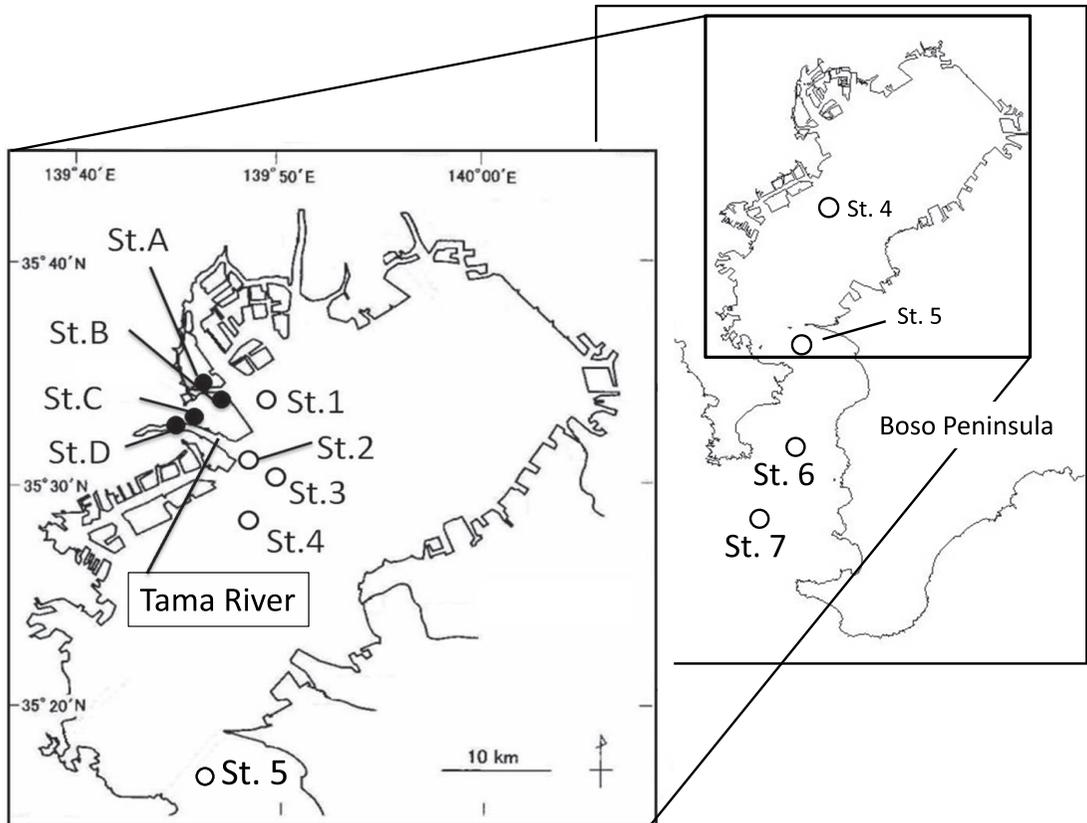


Fig. 1. Map of Tokyo Bay, central Japan, indicating the locations of sampling stations. A–D, stations for seine-net samplings; 1–7, those for ring-net samplings.

flats/surf zones (KANOU *et al.*, 2000; ARAYAMA *et al.*, 2002; KOHNO *et al.*, 2008; MOTEGI *et al.*, 2009).

As survival during the larval stage affects recruitment and population fluctuations in the sea bass, the early life history and ecology of the species were reviewed by ISLAM *et al.* (2011). However, no studies are available on the relationships between occurrence patterns and the functional development of larvae and juveniles of the sea bass. This study aimed to clarify the relationships between ontogenetic habitat shifts and the functional development of swimming and feeding abilities of the sea bass in Tokyo Bay. These relationships will indicate whether the larvae/juveniles move actively or passively, and represent important, basic information for elucidating the ways in which each area of Tokyo Bay provides habitats for the sea bass and for managing sea bass

resources in Tokyo Bay.

## 2. Materials and methods

The specimens used in this study originated from three sources and were collected using two types of sampling gear. A small seine net with 1-mm mesh size, as described by KANOU *et al.* (2002b), was deployed monthly at four sampling sites [stations (Stns.) A–D; Fig. 1] on tidal flats around the mouth of the Tama River located on the innermost, western coast of Tokyo Bay from January 2007 to December 2008 (except February 2008). A 1.3 m diameter ring net with 0.5-mm mesh size was towed for 15 minutes by 2 knots through surface waters during day time; two vessels, a 19-ton training ship (T/S) *Hiyodori* and a 277-ton T/S *Seiyomaru*, of the Tokyo University of Marine Science and Technology were operated. The *Hiyodori* samples were collected monthly from

four stations (Stns. 1–4; Fig. 1) located in the innermost offshore waters of Tokyo Bay from January 2006 to March 2008, while those of *Seiyo-maru* were collected from the inner Stn. 4 and three stations (Stns. 5–7) in outer Tokyo Bay in December 2005. The aim of the *Seiyo-maru* samples was to compare sizes and developmental stages between inner and outer Tokyo Bay. The collected specimens were fixed in 5% buffered seawater formalin and later preserved in 70% ethanol. The identification followed the method of KINOSHITA and FUJITA (1988) for the larvae larger than about 9 mm BL, and the series method of LEIS and TRNSKI (1989) was applied for those smaller than about 9 mm BL. The sizes of specimens collected were measured to the nearest 0.1 mm using a micrometer attached to a binocular dissecting microscope for specimens smaller than 10 mm BL and callipers for specimens 10 mm BL and larger; developmental stages were determined by the methods of KENDALL *et al.* (1984). Specimens collected by ring-nets were all measured, while those by seine nets were measured at most 30 individuals by each station/month.

Of the specimens sampled, 47 (19 of 3.0–8.1 mm BL collected by *Hiyodori* from the innermost waters and 28 of 11.4–30.1 mm BL collected by seine net from tidal flats) were selected for the morphological study to determine functional development. These specimens were cleared and stained by the method of POTTHOFF (1984), and the following characters were observed: fin supports and fin rays, the angle of notochord flexion, the vertebral centra, hemal and neural arches and spines and the greatest body depth and its position as swimming-related characters and the structure of the upper jaw (maxilla, premaxilla and supramaxilla), the structure of the lower jaw (Meckel's cartilage, dentary, angular and retroarticular), jaw teeth, mouth width, premaxilla/gape, pharyngeal teeth, suspensorium, hyoid arch, branchiostegal rays and opercular bones as feeding-related characters. Developmental phases were determined by the method of KOHNO and SOTA (1998), in which both the histogram method of developmental events by 0.5-mm BL fish size intervals employed by

SAKAI (1990) and the key character method were applied. In this study, the description was based on the body length in the state of ethanol preservation and on the smallest specimen when the developmental phenomena and events were observed.

### 3. Results

#### 3.1. Occurrence patterns

The total number of sea bass larvae collected offshore by ring nets towed by both *Hiyodori* and *Seiyo-maru* was 391 with size of  $3.67 \pm 1.37$  mm BL (mean  $\pm$  SD), ranging from 1.8 to 8.1 mm BL, with a mode of 3.00–3.49 mm BL (Fig. 2). In the innermost offshore waters of Stns. 1–4, without regard to sampling vessel, the number of specimens collected was 191 of  $4.44 \pm 1.39$  mm BL, ranging from 1.8 to 8.1 mm BL, and with a mode of 3.50–3.99 mm BL; water temperature and salinities varied from 7.8 to 15.1°C and from 26.0 to 32.3, respectively. The specimens collected from the outer Tokyo Bay of Stns. 5–7 numbered 200, with  $2.93 \pm 0.84$  mm BL ranging from 1.8 to 6.3 mm BL and with a mode of 3.00–3.49 mm BL; water temperature and salinities varied from 15.4 to 16.1°C and from 33.3 to 34.3, respectively. The months of occurrence were limited to the period from December to March.

The sizes of the 230 *Seiyo-maru* samples collected in December 2005 were as follows by sampling station (Fig. 3): Stn. 4,  $n=30$ , mean  $\pm$  SD =  $3.15 \pm 0.93$  mm BL, ranging from 1.8 to 6.1 mm BL; Stn. 5, 99,  $3.43 \pm 0.49$  mm BL, 1.8–5.6 mm BL; Stn. 6, 11,  $3.62 \pm 1.45$  mm BL, 1.8–6.3 mm BL; and Stn. 7, 90,  $2.29 \pm 0.57$  mm BL, 1.8–4.8 mm BL. The sizes of these specimens were significantly different among stations and between Stn. 7 and others (Tukey's test,  $P < 0.01$ ).

Of the 391 larvae collected offshore, 88 (22.2%) were yolk-sac larvae and the remainder of 303 were preflexion larvae. Of 200 larvae collected in outer Tokyo Bay, 83 (41.5%) were yolk-sac larvae and the remainder of 117 were preflexion larvae. Of 191 larvae collected in inner Tokyo Bay, 5 (2.6%) were yolk-sac larvae and the remainder of 186 were preflexion larvae.

All the specimens collected offshore in inner

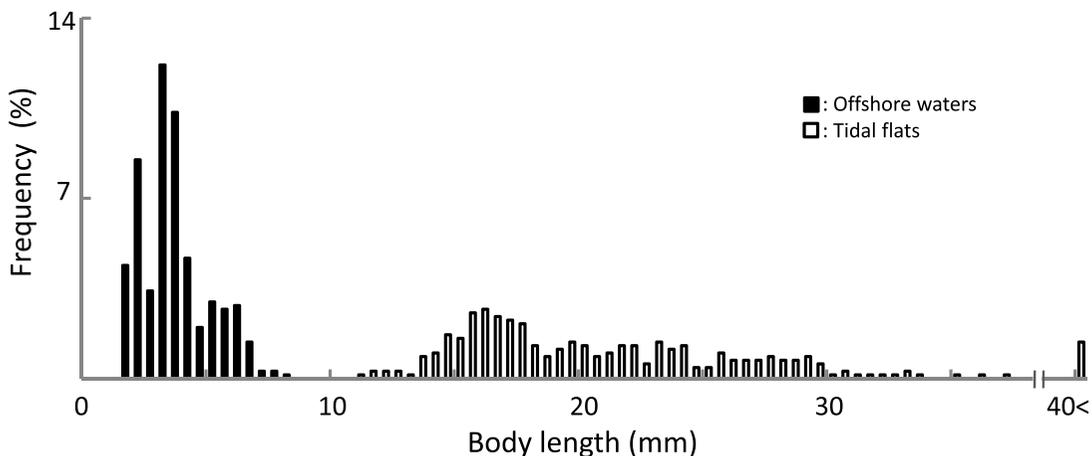


Fig. 2. Body length (BL) frequencies of larval and juvenile *Lateolabrax japonicus* collected from offshore waters ( $n=391$ ) and tidal flats ( $n=311$ ) in Tokyo Bay.

Tokyo Bay by *Hiyodori* were preflexion larvae.

The total number of sea bass collected from tidal flats was 580, varying from 11.4 to 123.5 mm BL with  $21.9 \pm 11.0$  mm BL and a mode of 16.0–16.5 mm BL (Fig. 2); water temperature and salinities fluctuated from 12.3 to 30.5°C and from 0.1 to 29.9, respectively. These specimens were collected from January to August, and their developmental stages varied from flexion larvae to juveniles. Monthly changes in their body sizes are shown in Fig. 4. The sea bass grew in the tidal flats from January ( $12.3 \pm 0.9$  mm BL:  $n=2$ ) to April 2007 ( $19.2 \pm 3.6$  mm BL:  $n=54$ ) and from March ( $16.2 \pm 1.1$  mm BL:  $n=59$ ) to May 2008 ( $40.9 \pm 12.5$  mm BL:  $n=12$ ).

Specimens of 8.2–11.3 mm BL were not collected either from offshore waters or from tidal flats, and in the latter, few specimens were larger than about 30 mm BL (Fig. 2).

### 3.2. Functional development

#### 3.2.1. Swimming-related characters

*Flexion of the notochord end*: Flexion of the notochord end was not detected in the specimens collected from offshore waters, the largest of which was 8.1 mm BL (Fig. 5A). Notochord flexion was complete in the smallest specimen collected from the tidal flat, 11.4 mm BL, and the angle was stable at about 40°–47°.

*Caudal fin supports and fin rays*: No

elements of the caudal skeleton were detected until 5.5 mm BL, when two cartilaginous buds of hypurals 1–2 were observed. The cartilaginous buds of the parhypural and hypural 3 appeared at 6.9 mm BL and hypural 4 at 8.1 mm BL. In addition, the smallest specimen from the tidal flats (11.4 mm BL) possessed the cartilaginous bud of hypural 5 as well as those of the hemal and neural spines of the future pleural centra 2 and 3 and epurals 1–3. The bony urostyle and pleural centra 2 and 3 were observed in the 11.4-mm BL specimen. In a 13.8-mm BL specimen, ossification was perceived in the parhypural, hypurals 1–5 and the hemal and neural spines of future pleural centra 2 and 3. All cartilaginous elements, including epurals 1–3, started ossifying at 15.4 mm BL.

Principal caudal fin rays were first discerned at 5.5 mm BL, when four rays were counted (Fig. 5B). The adult complement of 8 + 7 principal caudal fin rays was attained at 11.4 mm BL.

*Dorsal fin supports and fin rays*: The smallest specimen with dorsal fin supports was 11.4 mm BL, in which an adult complement of 25 cartilaginous pterygiophores was observed. The ossification of three of these was first perceived at 14.2 mm BL. All pterygiophores started ossifying at 17.5 mm BL.

Dorsal fin rays were first discerned at 11.4 mm BL, when 12 soft fin rays were observed (Fig. 5C). Two spines were first perceived at

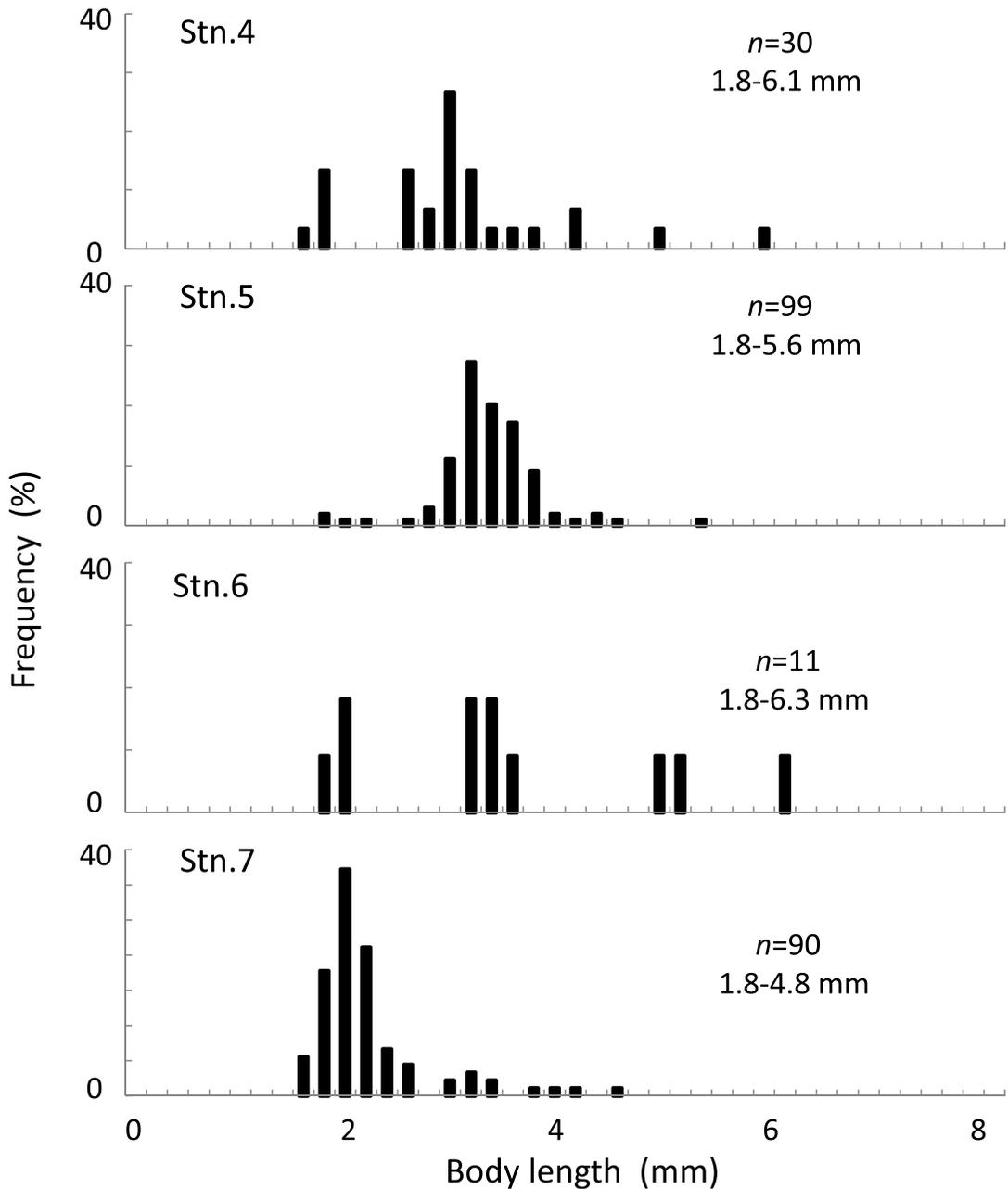


Fig. 3. Body length (BL) frequencies of larval *Lateolabrax japonicus* collected from Tokyo Bay offshore waters in December 2005 by the training ship *Seiyo-maru*, shown by ring-net sampling sites (Stns. 4–7). For sampling stations, see Figure 1.

11.7 mm BL, and the adult complement of 26–28 rays was attained at 13.0 mm BL.

*Anal fin supports and fin rays* : The adult complement in number of eight cartilaginous

pterygiophores was first discerned at 11.4 mm BL. Ossification of two pterygiophores was first observed at 14.2 mm BL, and all elements started ossifying at 17.5 mm BL.

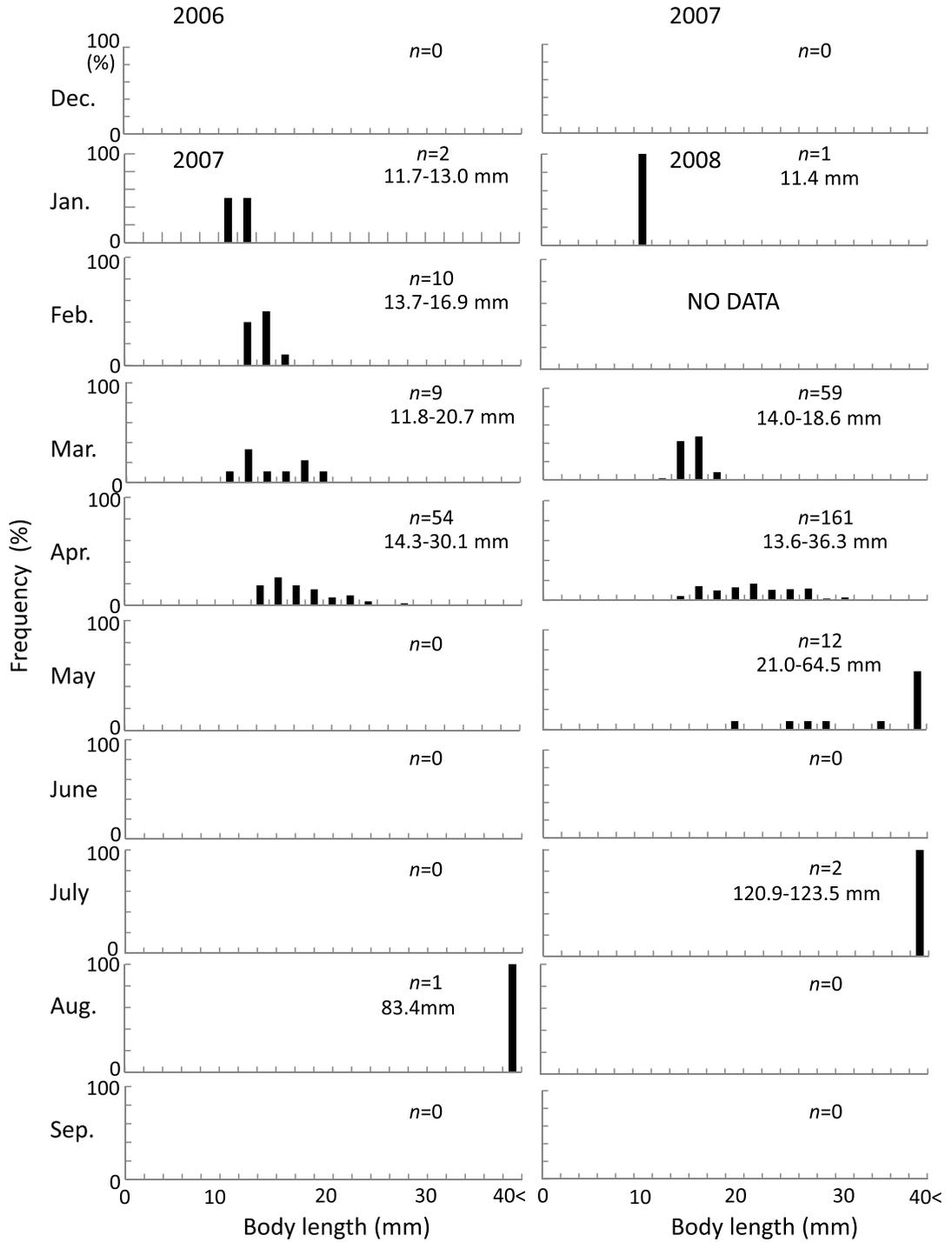


Fig. 4. Monthly changes in body length (BL) frequencies of larval and juvenile *Lateolabrax japonicus* collected from Tokyo Bay tidal flats.

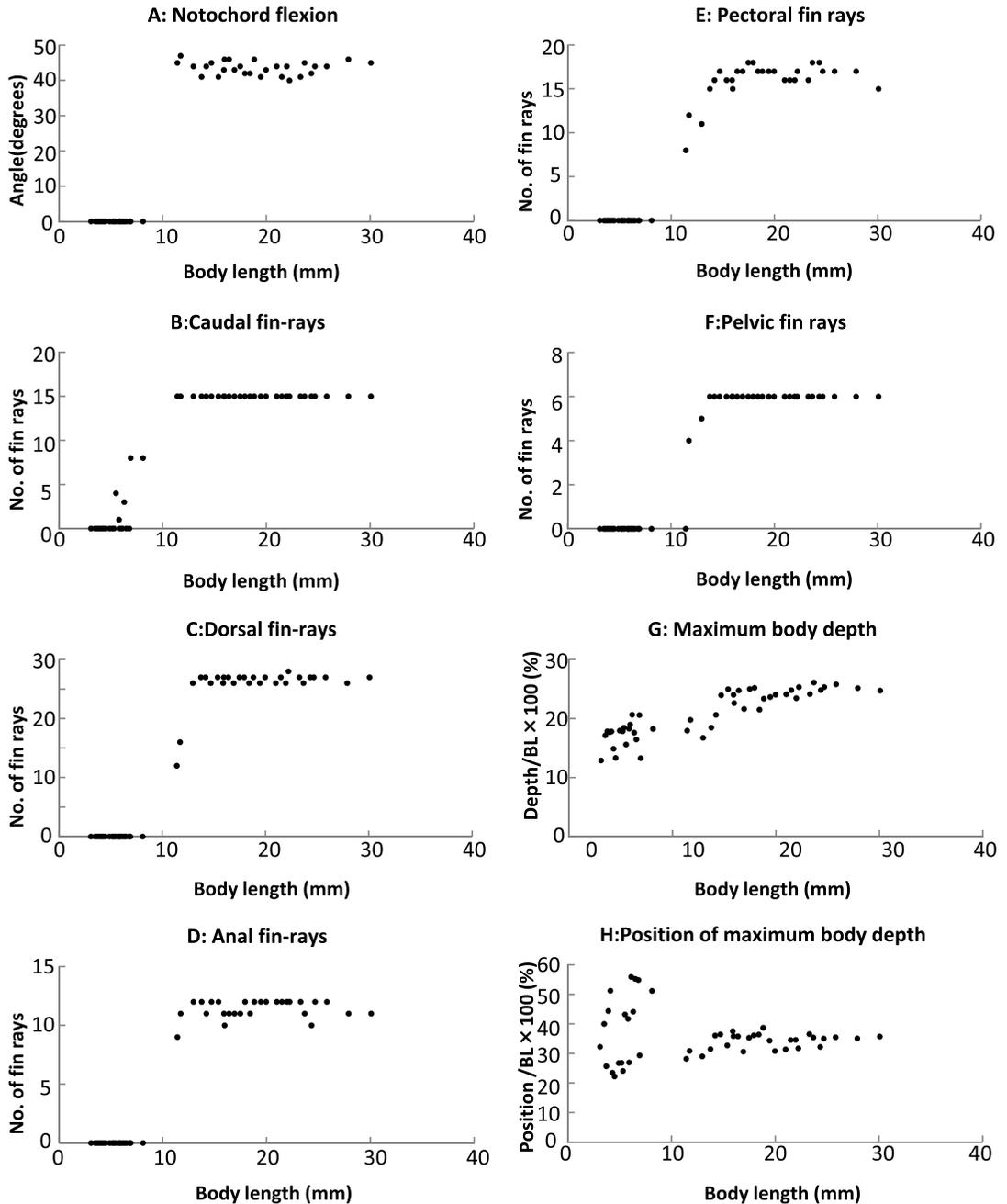


Fig. 5. Changes in swimming-related characters with growth in *Lateolabrax japonicus* collected from Tokyo Bay.

The anal fin rays were first discerned at 11.4 mm BL with one spine and eight soft rays (Fig. 5D). The adult complement of 10–12 rays was attained at 11.7 mm BL.

*Pectoral fin supports and fin rays*: The pectoral fin supports of a rod-shaped bony cleithrum, a coraco-scapular cartilage and a bladelike cartilage, which later grew into

actinosts, were observed in specimens of 3.1–8.1 mm BL collected from offshore waters. A supracleithrum and posttemporal were observed at 11.4 mm BL. Ossification of the coraco-scapular cartilage and actinosts was first perceived at 15.4 mm BL.

The pectoral fin rays were first discerned at 11.4 mm BL, when eight were noted (Fig. 5E). The adult complement of 15–18 rays was attained at 13.8 mm BL.

*Pelvic fin supports and fin rays* : The pelvic fin support, the basipterygium, was first discerned at 11.4 mm BL, and ossification started at 15.4 mm BL.

The pelvic fin rays were first discerned at 11.7 mm BL, with one spine and three soft rays (Fig. 5F). An adult complement of six rays was attained at 13.8 mm BL.

*Vertebra*: No vertebral elements were recognised in the specimens collected from offshore waters, up to 8.1 mm BL. In the smallest specimen collected from the tidal flat (11.4 mm BL) all hemal and neural arches and spines and centra were observed, with the ossification of the first three neural arches and spines. All arches and spines started ossifying at 14.2 mm BL.

*Maximum body depth and its position* : The ratio of the maximum body depth to BL was 13% in the smallest specimen examined of 3.1 mm BL, and varied from 13% to 20% in specimens up to 14.2 mm BL (Fig. 5G). Thereafter, the ratios were stable at about 22–26%.

The position of maximum body depth varied from 23% at 4.3 mm BL to 56% at 6.1 mm BL (Fig. 5H) and became stable from 28% to 39% thereafter.

### 3.2.2. Feeding-related characters

*Mouth width* : The mouth opened in all specimens examined. The mouth width was 0.3 mm in the smallest specimen of 3.1 mm BL and increased gradually in specimens from offshore waters (Fig. 6A). The growth rate became more or less rapid in specimens from 11.4 to about 20 mm BL and slowed thereafter, with the largest specimen examined (30.1 mm BL) possessing a 4.2-mm-wide mouth.

*Jaw structure* : The smallest specimen of 3.1 mm BL possessed the maxilla and Meckel's

cartilage. Premaxilla, dentary and angular were discerned at 5.5 mm BL, the retroarticular at 13.0 mm BL and supramaxilla at 14.7 mm BL.

*Premaxilla length/Gape* : The ratio of premaxilla to gape was 66% at 5.5 mm BL (Fig. 6B). Although the ratio tended to increase in specimens collected from offshore waters, the ratio varied from 70% to 90% in the specimens from tidal flats.

*Jaw teeth* : The first upper jaw teeth observed were six in number at 5.5 mm BL (Fig. 6C). The number of upper jaw teeth increased exponentially up to about 20 mm BL, with a maximum of 198 at 19.5 mm BL and varying from 100 to 150 thereafter. The lower jaw teeth were first observed at 11.4 mm BL with four noted (Fig. 6D). The lower jaw teeth increased up to about 20 mm BL with a maximum number of 112 at 19.5 mm BL, and the number became stable thereafter.

*Suspensorium* : The palatoquadrate and hyomandibular-symplectic cartilages were first observed at 3.1 mm BL and the bony ectopterygoid and endopterygoid at 11.4 mm BL. The quadrate, hyomandibular and symplectic started ossifying at 13.0 mm BL and the palatine and metapterygoid began at 13.8 mm BL.

*Hyoid and branchiostegal rays* : The ceratohyal-epihyal and interhyal cartilages were first observed at 3.1 mm BL and the hypohyal cartilage was noted at 11.4 mm BL. The ceratohyal and epihyal started ossifying at 13.0 mm BL, the interhyal began at 13.8 mm BL and the hypohyal started at 15.4 mm BL.

A branchiostegal ray was first observed at 5.5 mm BL, and the adult complement of seven rays was attained at 11.4 mm BL (Fig. 6E).

*Pharyngeal teeth* : The first upper pharyngeal teeth, 10 in number, were observed at 5.5 mm BL (Fig. 6F). The number of teeth increased exponentially with the maximum number of 134 at 22.0 mm BL.

The first lower pharyngeal tooth, 1 in number, was observed at 8.1 mm BL (Fig. 6G). The number of teeth increased exponentially with the maximum number of 132 at 22.0 mm BL.

*Opercular bones* : The first opercular bones to appear were the preopercle and opercle at 5.5

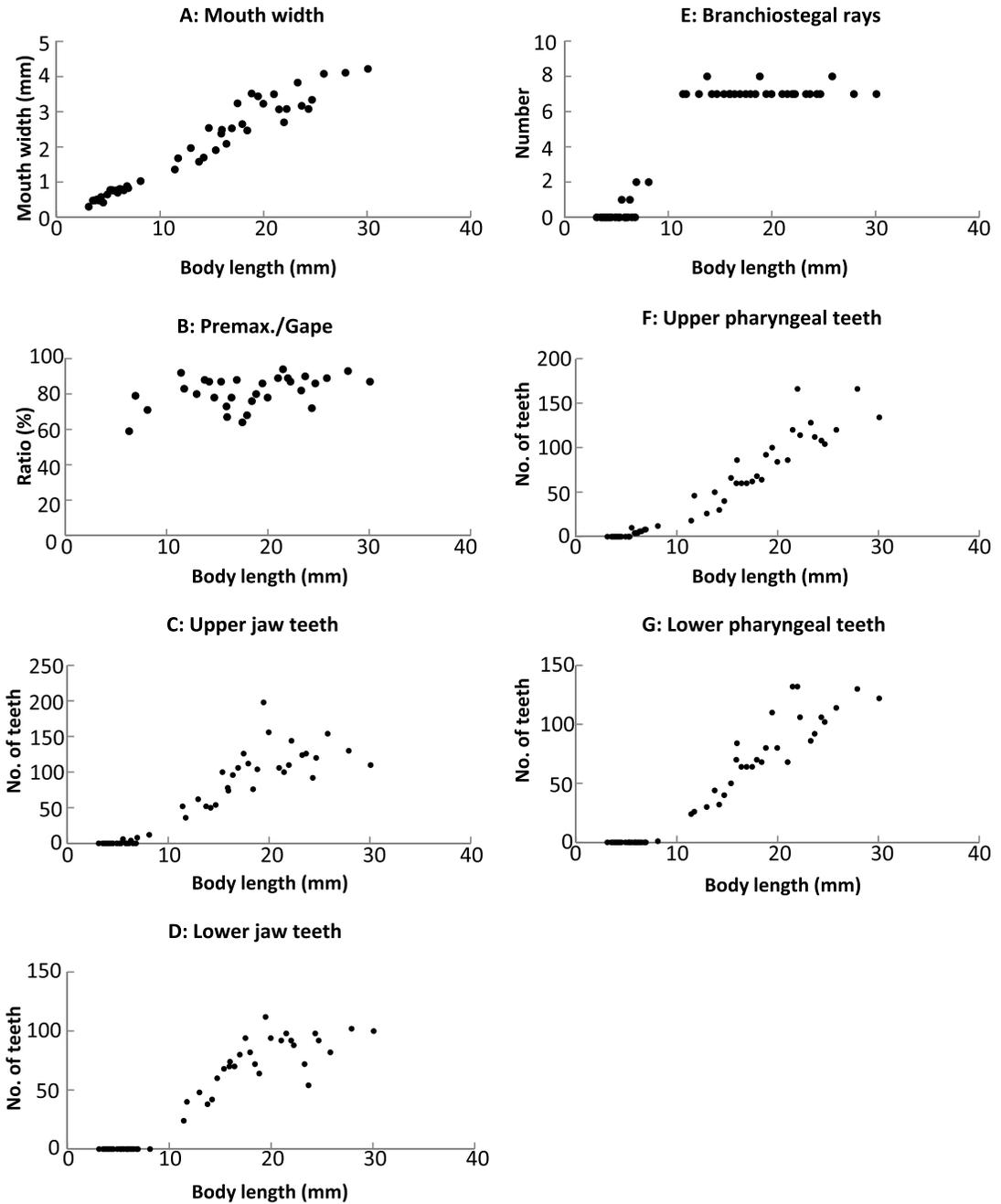


Fig. 6. Changes in feeding-related characters with growth in *Lateolabrax japonicus* collected from Tokyo Bay.

mm BL. The interopercle and subopercle were first observed at 11.4 mm BL.

#### 4. Discussion

##### 4.1. Developmental phases of Japanese sea bass larvae and juveniles

The development of characters concerning the swimming and feeding functions of the

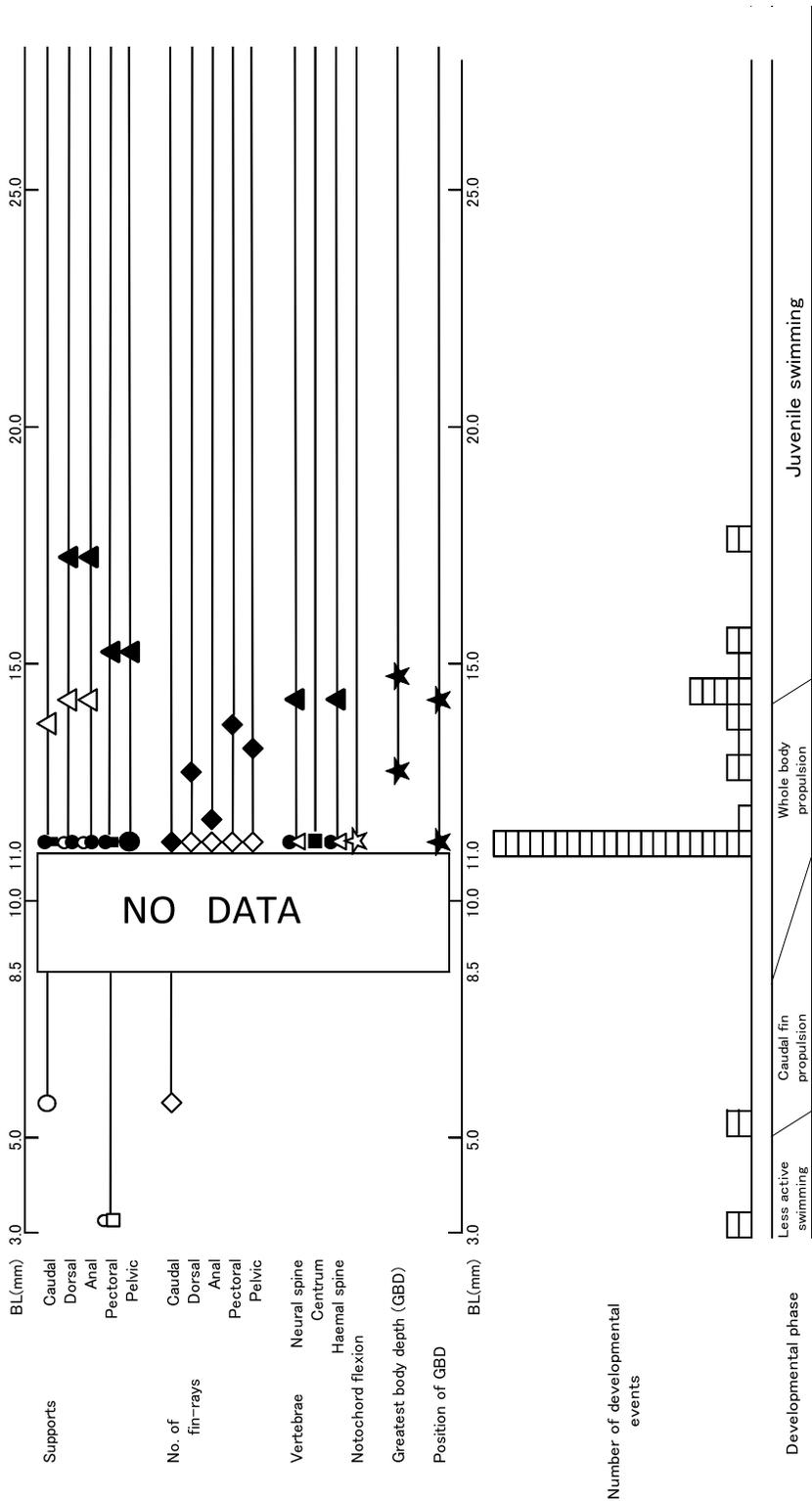


Fig. 7. Schematic representation of the development of swimming-related characters with growth (body length, BL) in *Lateolabrax japonicus* collected from Tokyo Bay. Open circles, cartilaginous elements start appearing; closed circles, all cartilaginous elements start appearing; open squares, bony elements start appearing; closed squares, all bony elements start appearing; open triangles, cartilaginous elements start ossifying; closed triangles, all cartilaginous elements start ossifying; open diamonds, fin rays start appearing; open diamonds, fin rays become complete in number; an open star, notochord flexion becomes complete; closed stars, flexion points of morphometric characters are observed.

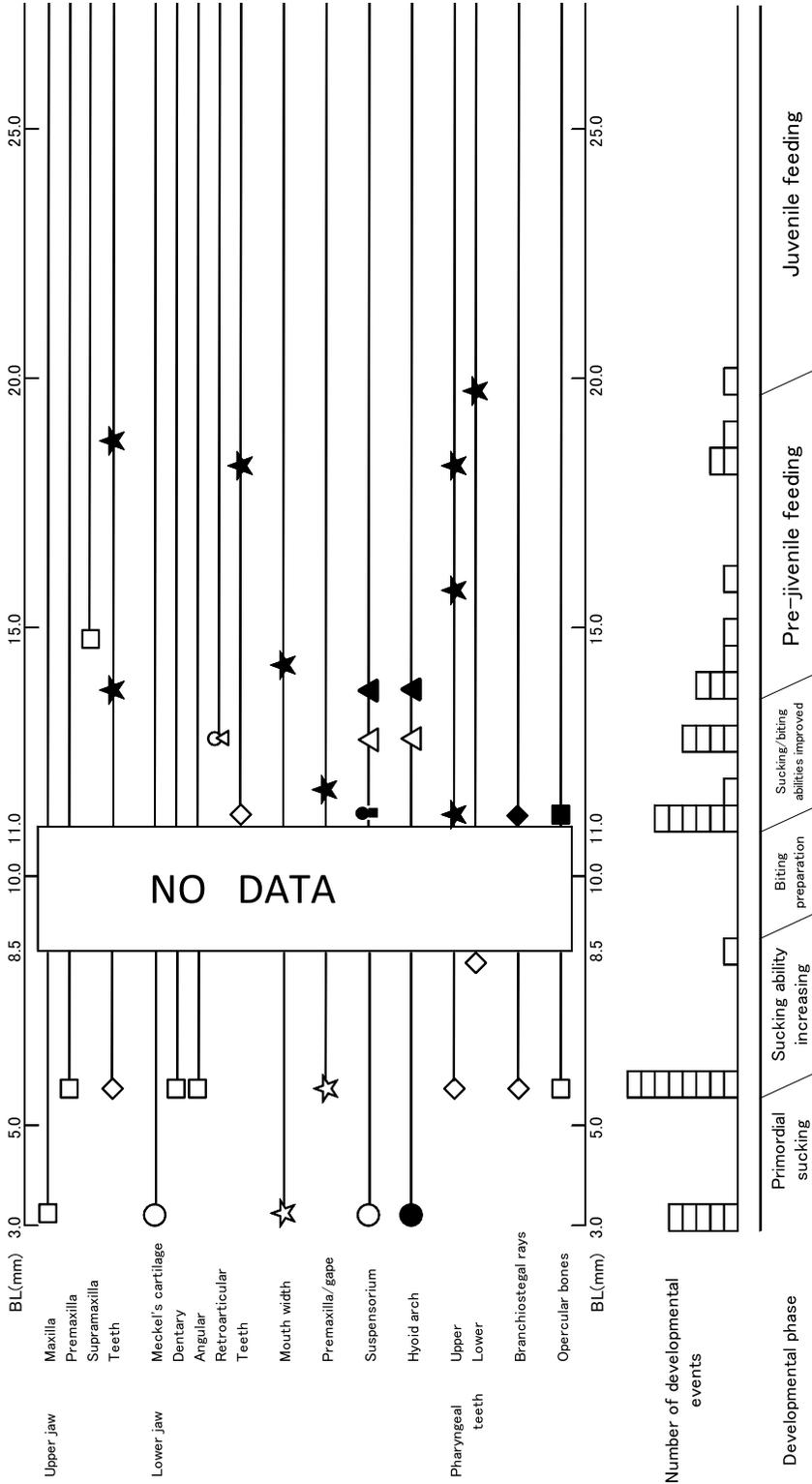


Fig. 8. Schematic representation of the development of feeding-related characters with growth (body length, BL) in *Lateolabrax japonicus* collected from Tokyo Bay. Open circles, cartilaginous elements start appearing; closed circles, all cartilaginous elements start appearing; open squares, bony elements start appearing; closed squares, all bony elements start appearing; open triangles, cartilaginous elements start ossifying; closed triangles, all cartilaginous elements start ossifying; open diamonds, teeth and branchial rays start appearing; a closed diamond, branchial rays become complete in number; open stars, mouth opens and premaxilla start appearing; closed stars, flexion points of teeth number and morphometric characters are observed.

Japanese sea bass larvae and juveniles obtained in this study are shown in Fig. 7 and 8.

#### 4.1.1. Developmental phases of swimming function

Based on the development of characters related to swimming function, sea bass larvae and juveniles were divided into the following four phases.

##### 1) The phase of less active swimming (3.0–5.5 mm BL)

No swimming-related characters appeared, other than the pectoral fin elements such as the cleithrum, coraco-scapular cartilage and fan-like cartilaginous plate, which developed later into actinosts. The larvae in this phase are therefore considered to drift passively rather than to swim actively.

##### 2) The phase of caudal fin propulsion (5.5–8.5/11.0 mm BL)

In this phase, the caudal fin supports and fin rays started appearing. However, no other characters related to swimming were detected; therefore, this phase was judged as the caudal fin propulsion phase, during which the beating of the caudal fin produces propulsion. Larvae of 8.5–11.0 mm BL were not examined in this study, and thus the end of this phase and the beginning of the next phase were not precisely determined.

##### 3) The phase of whole body propulsion (8.5/11.0–14.0 mm BL)

The neural and hemal arches and spines and the vertebral centra started appearing and were completed in number during this phase. These characters are considered to reinforce the body axis (KOHNO *et al.*, 2000). Notochord flexion was also completed, all the elements of caudal fin supports appeared and the number of caudal fin rays reached the adult complement during this phase, indicating that the beating ability of the caudal fin would increase (KOHNO and SOTA, 1998). The strong body axis and completed caudal fin allow larvae to swim powerfully by propagating the beat of the whole of the body posterior to generate propulsion (OMORI *et al.*, 1991). The dorsal and anal fin supports and fin rays were also completed during this phase; these characters prevent the larvae from rolling caused by whole-body

beating (GOSLINE, 1979). In addition, the pectoral and pelvic fin rays started appearing during this phase. The development of paired fin rays indicates the improvement of manoeuvrability (NARISAWA *et al.*, 1997).

##### 4) The phase of functional, juvenile swimming (over about 14.0 mm BL)

All characters concerning swimming function became complete in number, and ossification started in all related elements. Therefore, larvae/juveniles larger than about 14 mm BL were considered to have acquired the functional, juvenile swimming mode.

#### 4.1.2. Developmental phases of feeding function

Based on the development of characters related to feeding function, sea bass larvae and juveniles were divided into the following five phases.

##### 1) The phase of primordial sucking (3.0–5.5 mm BL)

The oral cavity was enclosed by the maxilla, Meckel's cartilage, a part of the suspensorium and hyoid arch, indicating that the feeding mode in this phase is sucking. However, these elements, other than the small bony maxilla, are cartilaginous, and thus negative pressure for sucking is considered to be low (see KOHNO *et al.*, 1997).

##### 2) The phase of increasing sucking ability and biting preparation (5.5–8.5/11.0 mm BL)

The gape elements of the premaxilla, dentary and angular started appearing in this phase, indicating that gape opening and closing abilities increase (SHINAGAWA *et al.*, 2002). The appearance of branchiostegal rays and opercular bones would increase the sucking ability during this phase.

Although the upper jaw and pharyngeal teeth started appearing during this phase, no lower jaw teeth were recognised until 11.4 mm BL. The functions of the jaw and pharyngeal teeth are to bite/capture and to propel acquired food organisms to the digestive tract, respectively (GOSLINE, 1971). No specimens were examined between 8.5 and 11.0 mm BL in this study, and thus the larval size when the feeding mode of biting started could not be determined;

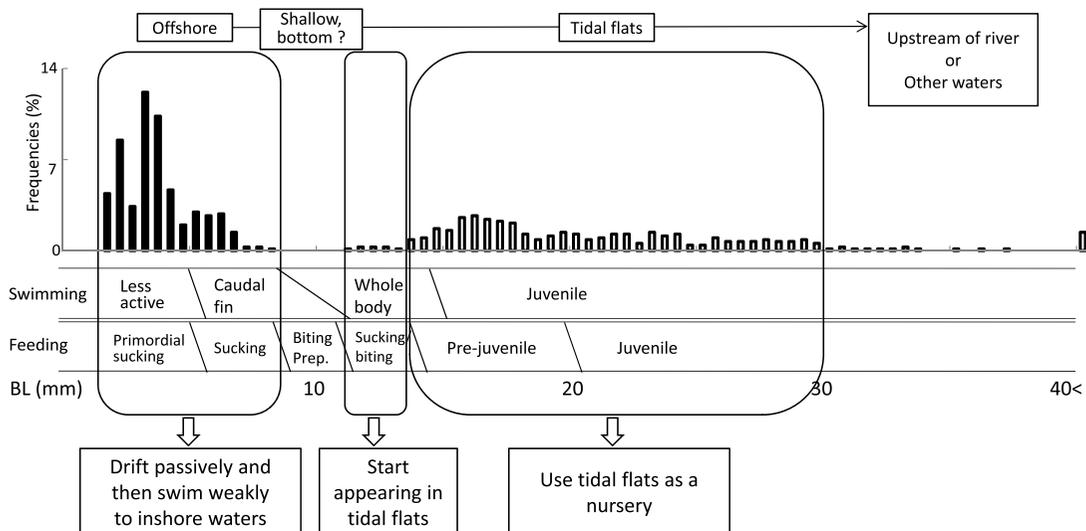


Fig. 9. Schematic representation summarizing the appearance patterns, habitat shifts, and functional development of swimming and feeding abilities, shown with growth (body length, BL), of the larval and juvenile *Lateolabrax japonicus* in Tokyo Bay.

therefore, this phase was tentatively recognised as biting preparation.

### 3) The phase in which sucking and biting abilities improved (8.5/11.0–13.5 mm BL)

In this phase, sucking ability was improved by the appearance of all the suspensorium and opercular bone elements. The numerical completion of the branchiostegal rays also helps to generate more or less strong negative pressure for sucking. In addition to sucking, the feeding mode of biting is gained by the appearance of lower jaw teeth. The stable ratio of premaxilla length to gape of 70–90% is considered to allow gape opening and closing to function well and thus to improve biting ability.

### 4) The phase of pre-functional, juvenile feeding (13.5–20.0 mm BL)

All the characters concerning feeding function except for the number of jaw and pharyngeal teeth became complete in number, and ossification began in all related elements. Therefore, larvae/juveniles of 13.5–20.0 mm BL are considered to have acquired a pre-functional, juvenile feeding mode.

### 5) The phase of functional, juvenile feeding (over about 20 mm BL)

The number of jaw and pharyngeal teeth became stable, and the functional, juvenile

feeding mode was considered to be acquired in juveniles of over 20 mm BL.

## 4.2. Relationships between developmental stages and distribution patterns

The relationships between the developmental phases obtained in this study and the appearances of Japanese sea bass larvae and juveniles in Tokyo Bay are schematically shown in Fig. 9.

### 4.2.1. Spawning and ontogenetic shoreward migration

In this study, yolk-sac larvae were mainly collected from outer Tokyo Bay, and the sizes of offshore specimens were significantly different among stations and between Stn. 7 and others. These results support the results of WATANABE (1965) and SUZUKI and ITOH (1984), according to whom the spawning ground of sea bass in Tokyo Bay was considered to be located in waters of the bay mouth, with hatching larvae moving to the inner waters of Tokyo Bay with growth. Also, in Ariake Bay, the spawning ground is located in the central region of the bay, and the eggs and larvae disperse toward the inner region (HIBINO, 2002; HIBINO *et al.*, 2002). These spawning grounds are located

in thermohaline frontal regions formed between the outer and inner bay waters, and eggs are densely distributed in these regions (WATANABE, 1965; NAKATA and IWATSUKI, 1991; HIBINO *et al.*, 2007).

This study revealed that nearly all the larvae collected offshore that were smaller than 5.5 mm BL would drift passively with primordial characters related to their swimming function, and even larger larvae up to about 8 mm BL would swim only weakly using caudal fin propulsion (Fig. 9). These results support the suggestion that the inshore ontogenetic migration of sea bass early larvae depends on shoreward currents. OHMI (2002) speculated that the gravitational circulation in Wakasa Bay in the Sea of Japan plays an important role in larval drift to the inshore region through the middle to bottom layer, and HIBINO *et al.* (2007) showed that in Ariake Bay, larvae temporally expand their distribution into the inner, shallow water regions via the middle layer. In this period of shoreward migration, the first feeding larvae prey on smaller zooplankton, based on the estimated mouth size (ISLAM and TANAKA, 2005). Sea bass larvae smaller than about 8 mm BL likely generate low negative pressure to suck food organisms with a poorly developed oral cavity.

#### 4.2.2. Habitat shifts with development

The largest larva collected from offshore waters in Tokyo Bay was 8.1 mm BL, and the smallest larva from the innermost tidal flats was 11.4 mm BL in this study. Dodging behaviour by sea bass larvae larger than 8 mm BL is very unlikely because KANOU *et al.* (2002a) collected larger, more active fish larvae such as a 39.4 mm BL juvenile of atherinid *Hypoatherina valenciennesis*, a 28.4 mm BL juvenile of carangid *Seriola quinqueradiata* and a 24.6 mm BL mugilid *Mugil cephalus cephalus* using the same gear and methods as those used in this study. OHMI (2002) reported that sea bass of 8–14 mm BL appeared in sandy bottom waters of 5–10 m depth off the Yura River mouth of Wakasa Bay. Therefore, sea bass larvae of 8–11 mm BL would be distributed in shallow, bottom waters of Tokyo Bay (Fig. 9).

The larvae and juveniles collected from the

tidal flats ranged from 11.4 to 123.5 mm BL in this study. However, few fish measuring 13.5 mm BL and smaller were collected, and numbers decreased suddenly at about 30 mm BL and larger, with a mean of 21.9 mm BL and mode of 16.0–16.5 mm BL. The juvenile stage was attained at 13.8 mm BL when the fin rays reached their adult complements in number. Therefore, the tidal flats of inner Tokyo Bay provide a nursery ground mainly for 13.5–30-mm BL juvenile sea bass (Fig. 9). This study showed also that sea bass early juveniles starting at 13.5 mm BL acquire functional, juvenile swimming and feeding abilities.

The early juveniles appearing in the tidal flats swim actively and select this area as a habitat. The complete juvenile feeding mode was acquired at 20 mm BL, with the stability of tooth numbers. NIP *et al.* (2003) reported that sea bass of 11–20 mm BL fed on copepods and cladocerans, shifting to decapods and amphipods at 20 mm BL in Tolo Harbour, Hong Kong. FUJITA *et al.* (2007) also indicated that sea bass larger than 20 mm BL fed exclusively on mysids in Ariake Bay. HIBINO *et al.* (2006) showed that in the sand flats of the eastern part of Ariake Bay, sea bass juveniles of 16.7 and 22.9 mm BL on an average at the spring and neap tides, respectively, migrate to shallow water after sunrise to feed on copepods before emigrating from there after sunset.

#### 4.2.3. Importance of larval and juvenile habitats for the Tokyo Bay sea bass

Tokyo Bay has been a leading location for the catch of sea bass, with the production from the bay accounting for about 30% of the total catch in the 2009 fiscal year (Fisheries AGENCY, 2011). As pointed out by SHOJI *et al.* (2002), the Tokyo Bay sea bass catch has been favourably retained since the 1990s, indicating that the recruitment of sea bass has been stable. A major factor affecting recruitment variability is the survival rate during the early life history (HOUDE, 1987). The Tokyo Bay sea bass, as a migratory fish, is considered to face two major challenges during the egg, larval and juvenile stages, one being the long-distance migration from the spawning to nursery grounds, and the being other the selection of a

nursery ground.

No serious environmental problems affect the sea bass spawning ground at the mouth of Tokyo Bay. However, the distance from the spawning ground at the mouth of Tokyo Bay to the innermost tidal flats is about 50 km, and the avenue to the nursery ground including the spawning ground is narrow and experiences heavy maritime traffic, with the giant ports of Yokohama, Tokyo and Chiba being located in the inner bay. Therefore, the challenging migration of the sea bass to the nursery ground could likely be disturbed by anthropogenic impacts, although the details of the mechanisms of transport for eggs and early larvae to the nursery grounds are unknown.

Many studies have pointed out that sea bass nursery grounds are diversified, including surf zones in open waters and tidal flats, shallow areas, seagrass beds and rivers in embayments (HIBINO, 2002; KINOSHITA, 2002; FUJITA *et al.*, 2007), and the adaptability of sea bass to these diversified environments would increase the stability of their population dynamics. However, these nursery grounds in innermost Tokyo Bay have been destroyed by factors such as reclamation, dredging and the construction of ports and estuarine dams.

To properly maintain the Tokyo Bay sea bass population, further studies are needed to demonstrate the mechanisms of shoreward migrations and the variety of embayment nurseries used, and the environments of the habitats required during the early life history of the sea bass should be protected from any sort of destruction.

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# Early life history of the rockfish *Sebastes inermis* inferred from otolith microstructure and nutritional condition assessment in two temperate bays, central Japan\*

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**Abstract:** In order to identify any factors regulating larval extrusion, growth rates, and settlement patterns of the rockfish *Sebastes inermis*, otolith microstructure analysis was conducted for two samples from two distinct but contiguous fishing sites in the southwest coast of Miura Peninsula in central Japan: Sajima Bay and Aburatsubo Bay. Condition indices (RNA : DNA ratio, total proteins, Fulton's K) were also examined for habitat quality assessment. Four monthly extrusion groups were identified by daily age backcalculation. Growth rate during the planktonic period was positively related with the duration of this life stage and with water temperature. Flexible settlement timings of each group suggested an adaptive strategy to variability in environmental conditions: larvae experiencing unfavourable temperature settle earlier at smaller lengths and grow faster after settlement. Clear differences in traits related to planktonic and post-settlement stages between sites imply the utilization of different habitats during early life stages, and suggest that offshore mixing of larvae might not be occurring. Juveniles in Sajima Bay had higher growth and condition indices, showing a higher habitat quality and importance as a nursery of this site.

**Keywords:** growth rate, nutritional condition, otolith, *Sebastes inermis*

## 1. Introduction

The rockfish *Sebastes inermis* inhabits rocky reefs and seagrass (*Zostera* and *Sargassum*) beds, preying upon small fishes and marine invertebrates (NAKABO, 2000). This species is important for both commercial and recreational fishing activities and is a major demersal fish

resource in coastal waters of Japan and southern Korea (KAMIMURA *et al.*, 2011). In *Sebastes* spp., eggs are fertilized, develop and hatch internally, and soon after larvae are extruded (released) at an advanced stage of development, in which organogenesis is essentially complete before starting a planktonic stage (MOSER and BOEHLERT, 1991, WOURMS, 1991, NAKAGAWA and HIROSE, 2004). Some young-of-the-year migrate into nearshore areas (e.g. seagrass beds) as larvae or very early juveniles, after completing their planktonic stage offshore. This ontogenetic movement has been described as an adaptive strategy to allow nearshore rockfishes to maximize settlement, 1–2 months after extrusion for *S. inermis* (PLAZA *et al.*, 2003), and avoiding offshore dispersal.

The survival success during the early life stages depends on both biotic (predation, food

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availability and prevalence of pathogens) and abiotic (temperature, tidal transportation or oxygen depletion) factors (JENKINS *et al.*, 1998, BORGES *et al.*, 2007). Fish larvae are highly vulnerable to mortality and larval cohorts tend to experience a rapid loss of individuals (BOEHLERT and YAMADA, 1991). The close relationship between daily growth rate and survival of larvae has been verified for some species and is known as the growth-selective mortality (ANDERSON, 1988, TAKASUKA *et al.*, 2007). Defining the timing and duration of the early life stages is crucial to understand the strategies adopted by the species during the transition to benthic habitat (CHAMBERS and LEGGETT, 1987, HOUDE, 1987, MOSER and BOEHLERT, 1991). Several studies have presented effective methods by analysing the sequence of daily growth increments of otoliths to describe life traits, in particular the extrusion date and growth rate (NELSON, 2001, TAKAHASHI *et al.*, 2001), and to determine the duration of pelagic larvae (PLAZA *et al.*, 2003). There is however a lack of information on the nutritional condition of early life of the rockfish *S. inermis*. Poor overall nutritional condition is frequently associated with poor feeding success and/or unstable environmental factors; therefore, fish with lower condition could have higher mortality rates (CHÍCHARO *et al.*, 1998, DUTIL and LAMBERT, 2000). The RNA : DNA ratio has been used as an index of nutritional condition (e.g. CLEMMENSEN and DOAN, 1996). RNA concentration fluctuates in response to food availability and demand for protein synthesis – higher in early life stages due to accelerated somatic growth – while DNA remains relatively constant throughout lifecycle (CALDARONE and BUCKLEY, 1991). Hence, in early life stages of fishes, RNA : DNA ratio can be used as a proxy of survival potential via nutritional condition and growth performance (CHÍCHARO *et al.*, 1998).

The aim of the present study was to examine the spatio-temporal variability of the settlement of *S. inermis* in two comparative bays in Miura Peninsula, central Japan, through otolith microstructure analysis. We also aimed to analyze physiological condition indices along with daily growth rates of juveniles to compare

habitat quality and suitability for juvenile recruitment. Three hypotheses are tested: H<sub>1</sub>- *S. inermis* larval duration, growth rate, and settlement timing along the Miura Peninsula show temporal variability and are temperature related; H<sub>2</sub>- Larval transport and settlement into inshore areas occur separately for each bay and in a small geographical range; H<sub>3</sub>- Nutritional condition of settled rockfish varies among the study sites and the growth rate is affected by their condition.

## 2. Materials and methods

### 2.1 Sampling

Surveys were carried out at two bays in Miura Peninsula, central Japan, separated by 13.5 km from each other, Sajima Bay (Saj) (35° 12'40.50"N-139°37'1.12"E) and Aburatsubo Bay (Abt) (35°9'23.38"N – 139°36'50.36"E) (Fig. 1). Boat seine net and set net were used for sampling in *Zostera marina* canopy areas in both bays twice per month from May to July of 2010. Juveniles of *Sebastes* spp. were collected and kept at –80 °C. Sea surface temperature (SST) data were obtained from Fisheries and Technology Centre of Kanagawa Prefecture database ([www.agri-kanagawa.jp/suisoken/kaikyozu](http://www.agri-kanagawa.jp/suisoken/kaikyozu)). Only juveniles that were correctly identified as *Sebastes inermis* as described by KAI and NAKABO (2008) were used for the study ( $N = 550$ ). Total length ( $L$ ) and wet weight were measured to the nearest 0.1 mm and 0.1 g, respectively. Both left and right sagittal otoliths were extracted, cleaned, and stored dry.

### 2.2 Otolith microstructure analysis

Daily growth increment (DGI) readings were carried out using the left otolith, after confirming statistical equality of increment number between each pair of otoliths. All otoliths were mounted in epoxy resin, fixed individually on a glass slide, and polished with waterproof abrasive grit 400. The otoliths on glass slides were observed under an optical microscope system coupled to a camera (Ratoc System Engineering, Japan). DGIs were counted and DGI widths were measured along the longest axis from the nucleus core to the outermost margin. Duplicate readings were conducted and mean age after extrusion was

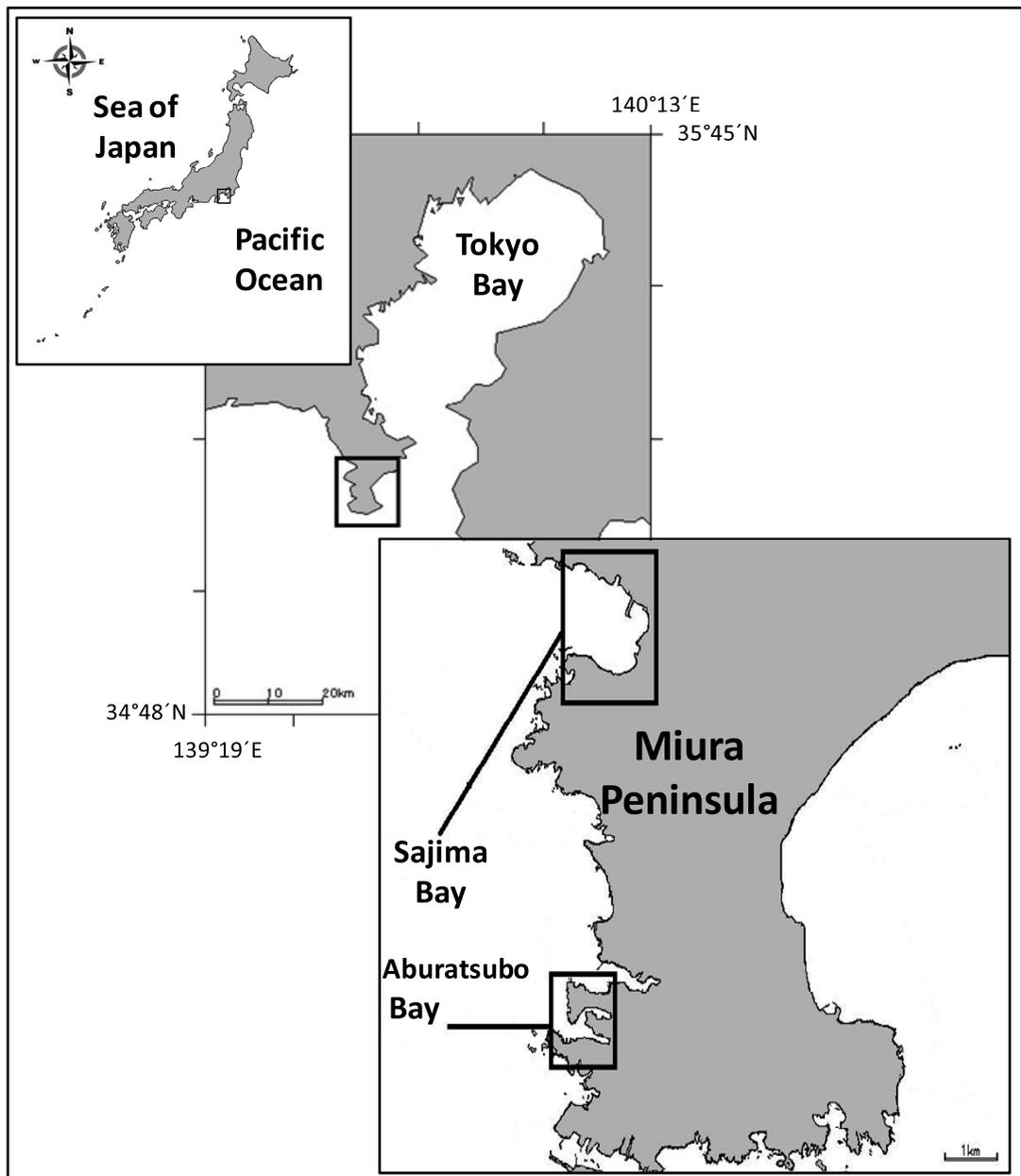


Fig. 1. Location of Aburatsubo Bay (Abt) and Sajima Bay (Saj) on the southwest coast of Miura Peninsula, Japan.

determined. The damaged otoliths without clear distinction of daily increments or clear signs of life stages were excluded from the analysis. Following the validation by PLAZA *et al.* (2001), daily periodicity of ring deposition

and extrusion check in newly extruded larvae ( $24.7 \pm 1.5 \mu\text{m}$  from the core, corresponding to 6–10 rings) were adopted in the present study. PLAZA *et al.* (2001) also indicated the length at extrusion as 6.68 mm.

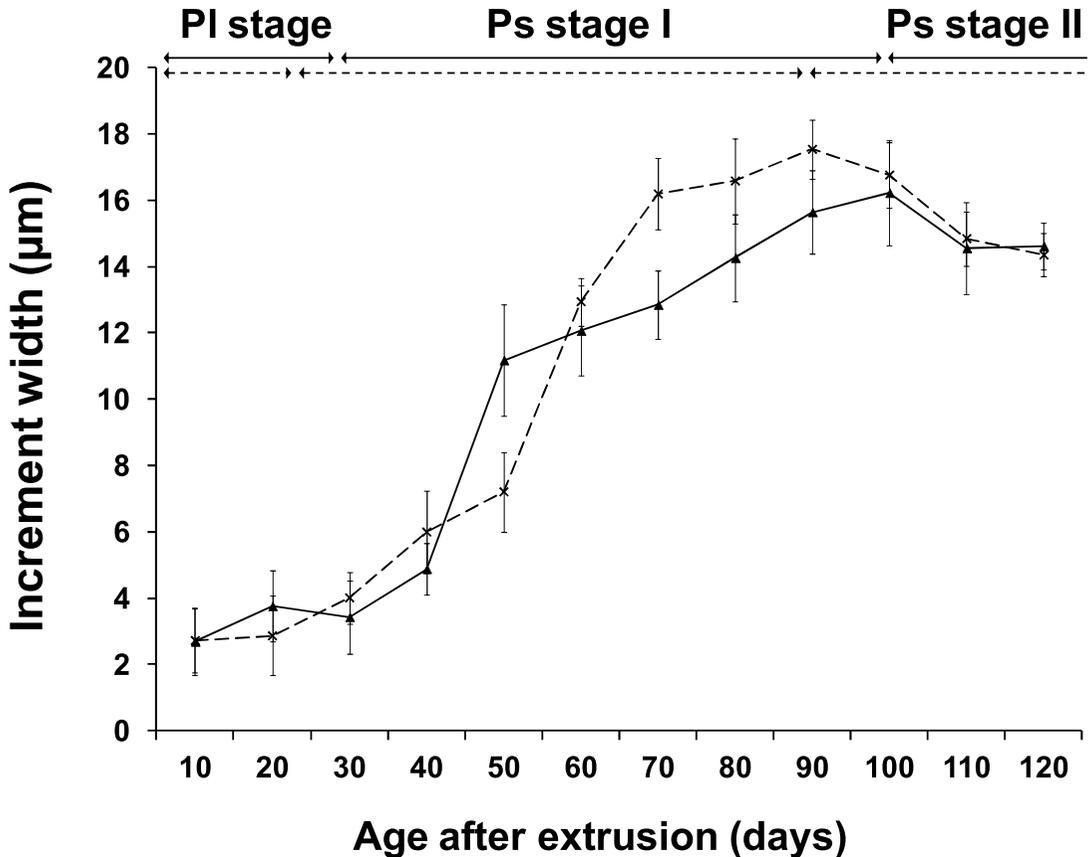


Fig. 2. Mean otolith increment width profile for early stages, planktonic (Pl), and post-settlement (Ps) I and II for Sajima (dashed line) and Aburatsubo (solid line).

Individual age and back-calculated total length of 219 specimens of *S. inermis* were estimated by the biological intercept method (CAMPANA, 1990). Daily growth rates were estimated based on back-calculated sizes using the following equation :

$$Gr_i = L_i - L_{i-1}$$

where  $Gr_i$  is the growth rate at daily age of  $i$ ,  $L_i$  is the total length at  $i$  and  $L_{i-1}$  is the total length at  $i-1$  (CAMPANA, 1990, CAMPANA and JONES, 1992). Regression line was fitted to the relationship between total length, otolith radius and age by using least squares method.

Planktonic (Pl) and post-settlement (Ps) stages were defined based on the daily ring width profile (Fig. 2) and observed settlement check formations (PLAZA *et al.*, 2001). Pl period

starts after extrusion and ends when the increment width shows a sudden increase rate with a settlement check. It was possible to distinguish two growth phases within the Ps period: Ps I showed an increasing trend of growth rate after the start of the Pl period, and Ps II showed a decreasing trend of the growth rate after the Ps I phase. The transition centered method (WILSON and MCCORMICK, 1999) was used to reduce the age effect on the analysis of growth rates before and after settlement in each group from each site. The parameters extracted from the increment profiles were analyzed and used for definition of each stage, originating several life trait variables (Table 1). Length at 120 days and growth rate until 120 days were assessed to provide average information on early life stages until early Ps II.

Table 1. Summary of the variables extracted from DGI analysis

|                                     |                             |
|-------------------------------------|-----------------------------|
| Otolith radius at extrusion         | Time duration of Pl stage   |
| Otolith radius at end of Pl stage   | Time duration of Ps I stage |
| Otolith radius at end of Ps I stage | Pl stage growth rate        |
| Ring number at start of Ps II       | Ps I stage growth rate      |
| Length at settlement                | Growth rate until 120 days  |
| Length at 120 days                  |                             |

Abbreviations: Pl – planktonic; Ps I – first period of post-settlement; Ps II – last period of post-settlement; 120 days after extrusion was found in 92% fish aged

Most (92%) of fish examined were aged older than 120 days.

### 2.3 Condition analysis

White muscle samples from the left dorsal anterior part of the body (100–200 mg) of fish representative of all sampling dates ranging from 65 to 77 mm in total length ( $n=96$ ) were used for RNA : DNA ratio assay. Nucleic acids were quantified using the method described by GONÇALVES *et al.* (2011). A fluorometer Shimadzu RF-1501 (Shimadzu, Kyoto, Japan) was used and its detection limits and linear range were tested by fluorescence of serial dilutions of DNA and RNA standards (DNA activated from calf thymus, RNA type IV from calf liver, Sigma, St. Louis, MO). The recovery rates of DNA and RNA standard spikes in the rockfish muscle homogenates were 105.4 and 99.0% respectively ( $n=5$ ). Method precision was tested by replicate muscle homogenate ( $n=5$ ) and found to be 97.1%. Sample autofluorescence and residual fluorescence were negligible. Muscle homogenates were used to estimate total proteins based on a modified Lowry method kit (Pierce, USA) using bovine serum albumin as standard. Fulton's K, a morphometric condition index was also applied to all individuals, using  $K=W/L^3$ ; where  $W$  is the fish eviscerated weight (g) and  $L$  is the fish total length (mm).

### 2.4 Data analysis

Data are shown as mean  $\pm$  standard deviation unless otherwise stated. All variables were screened for normality with Shapiro-Wilk's test and for inequality of variance with Levene's test. Variable of RNA : DNA ratio required a common log ( $1+x$ ) transformation.

DGI variables were tested for differences among extrusion months and sites, while condition variables were tested for differences amongst capture months and sites. The differences were assessed by two-way analysis of variance (ANOVA) followed by Student-Newman-Keuls (SNK) post hoc multiple comparisons test when applicable. Relationship between condition indices and growth rates of otolith marginal increments (10-day mean) for different age classes by 30 days (70–100, 100–130 and 130–160 days) was tested with Pearson's correlation coefficient test. The same analysis was also applied to examine the relationship between duration and growth rate during Pl period, and the relationship between early life variables (Table 1) and cumulative water temperature, represented by the thermal sum calculated for each life stage.

In order to further extend and enhance data comprehension, a multivariate approach was performed by means of canonical discriminant analysis (CDA), using DGI extracted data and also condition indices. By analysing these variables in an integrative perspective, CDA provides an estimate for the degree of separation of life history and nutritional traits among different extrusion groups (or different sampling months) and between distinct study sites.

The CDA output is presented in  $z-1$  discriminant functions (DF) scores, where  $z$  is the number of groups in the analysis and a DF is a linear combination of the original variables that best separate the groups. Variables loading the DF's were retained when their loading weights were  $\geq 0.5$  (HAIR *et al.*, 2000) and the efficiency of the discriminatory analysis was assessed with Wilk's lambda test ( $\lambda$ ). All analyses were performed with the statistical

Table 2. Sampling data of *Sebastes inermis* juveniles captured in Sajima and Aburatsubo in 2010

|            | Sampling month | N   | Total length (mm) | Range      | Weight (g) | Range     |
|------------|----------------|-----|-------------------|------------|------------|-----------|
| Aburatsubo | May            | 66  | 62.8±4.5          | 43.1–69.3  | 3.8±0.6    | 1.5–4.6   |
|            | June           | 50  | 72.5±8.6          | 51.4–87.2  | 6.4±2.2    | 2.1–11.7  |
|            | July           | 74  | 72.9±3.5          | 56.6–79.3  | 6.6±0.8    | 3.3–7.8   |
| Sajima     | May            | 92  | 65.0±4.2          | 44.0–83.5  | 4.3±2.0    | 1.4–9.4   |
|            | June           | 256 | 80.2±9.3          | 55.6–101.3 | 9.3±3.3    | 2.4–16.3  |
|            | July           | 12  | 87.9±2.8          | 83.4–92.2  | 11.5±1.9   | 10.2–13.2 |

Total length and weight are shown as mean±SD

software package STATISTICA 8.0 (Statsoft, Inc., OK, USA), and significance level was set to  $P < 0.05$ .

### 3. Results

#### 3.1 Sampling composition and temperature

Samples from Saj represented 65.2% of the total of captured juveniles ( $N=550$ ) and reached the maximum number (46.3%) during June (Table 2). In Abt, the capture was more homogeneously distributed among sampling months. Total length and weight of sampled *S. inermis* ranged from 43 to 101 mm and from 1.2 to 19.5 g, respectively, with juveniles in Saj presenting higher mean values than those in Abt. In both sites mean total length of samples increased with time (sampling months).

The lowest SST values (Fig. 3) were recorded in late January and early February (11.3 °C) for Saj, and in mid January and mid February (11.6 °C) for Abt. Mean monthly SST varied significantly (Two-way ANOVA; SNK test;  $P < 0.001$ ) but did not show any statistical differences between sites ( $P > 0.05$ ).

#### 3.2 Otolith microstructure

Otolith-based estimates of age indicated that rockfish juveniles ( $n=219$ ) ranged from 88 to 159 ( $123 \pm 18.7$ ) days old after extrusion. Linear regressions fitted to the relationships between total length and otolith radius ( $r^2 = 0.79$ ), between age and otolith radius ( $r^2 = 0.64$ ), and between age and fish length ( $r^2 = 0.63$ ).

From extrusion pattern (Fig. 3a), we observed several monthly extrusion peaks, starting in late December until early March. This

distribution was represented by a single peak for all extrusion groups with the exception of January group in Saj which showed three overlapping peaks. For Saj the higher frequency was observed in early groups (Dec and Jan), while for Abt in later groups (Feb and Mar). Although some extrusion peaks seem to be synchronous with new moon phases, this occurrence was not consistent among all extrusion groups: some peaks appeared before and other peaks did after the new moon phases.

Settlement pulses in both sites (Fig. 3b) extended from February to May and were not closely synchronous with the moon cycle. In Saj, the majority of individuals settled in late February and March. In Abt, as observed for the extrusion dates (Fig. 3a), the settlement showed distinct but more indiscernible pulses within time.

Transition centered method (Fig. 4) allowed the reduction of the age effect for each extrusion group regarding growth rates before and after settlement. All groups showed an abrupt increase in increment width during the transition from Pl to Ps stages.

Fish that extruded in January (Table 3) stayed for shorter periods and grew less in Pl stage achieving smaller sizes at settlement. They grew less in Ps I stage achieving smaller size at 120 days. Fish that extruded in March stayed longer and grew more in Pl stage thus achieved bigger sizes at settlement. Despite the shorter period, they grew more in Ps I stage. There was a decreasing trend in the variables (except Pl growth rate) from fish that extruded in December to January, followed by an increase, except in Ps I stage duration of March

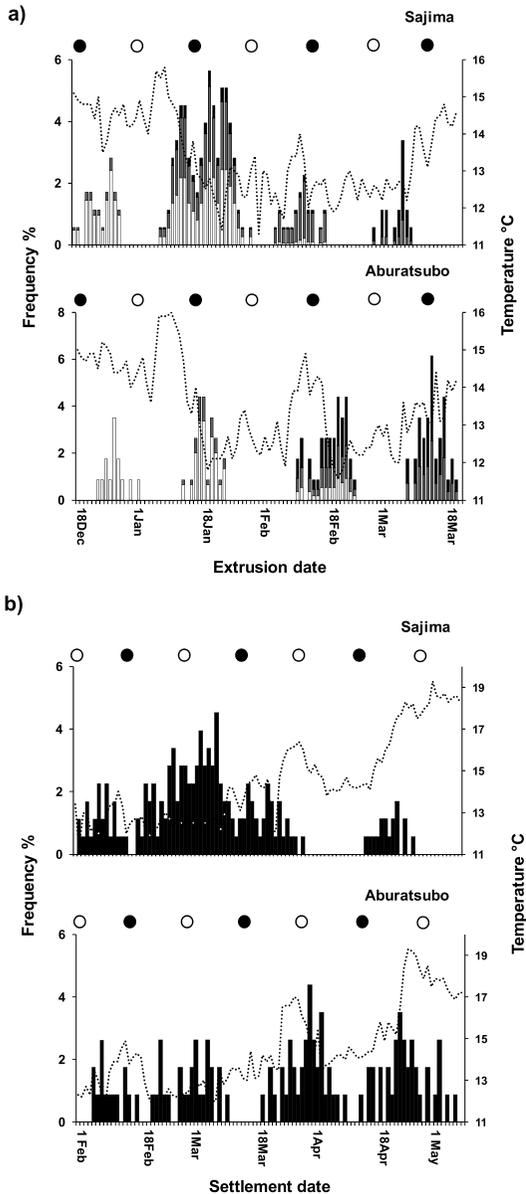


Fig. 3. Frequency of extrusion dates (a) and settlement dates (b) of *Sebastes inermis* in Sajima and Aburatsubo in 2010. Extrusion is shown for respective sampling months: May (open), June (grey), and July (closed). Dotted lines indicate sea surface temperature (SST). Lunar cycles are shown above with full moon (open circle) and new moon (closed circle).

extruded group, although significance was not always true. Individuals from Saj grew more during P1 stage and were bigger at settlement than those from Abt. Although there were no significant differences in P1 growth rate between the two sites, the individuals from Abt stayed longer period in P1 stage than those from Saj.

Longer P1 stage reflected higher growth rates (Fig. 5) in both sites (Pearson correlation test;  $r=0.24$ ,  $P=0.04$  for Saj;  $r=0.49$ ,  $P=0.002$  for Abt). The relationship was similar within each extrusion group of each site with the exception of February, showing a significant negative relationship in both sites ( $r=-0.60$ ;  $P=0.04$  for Saj;  $r=-0.11$ ;  $P=0.02$  for Abt). The DGI variables increased with cumulative temperature in each site with high significant correlations (Table 4).

### 3.3 Nutritional condition

Juveniles sampled in May had less proteins and lower condition index Fulton's K (Table 5), while in June we observed the opposite. Regardless of sites, the RNA : DNA ratios of individuals sampled in May were the highest ( $P < 0.0001$ ), thereafter it decreased in succeeding months. We found a significant difference in RNA : DNA ratio of juveniles sampled in July: the ratios in Saj were higher than that in Abt ( $P=0.013$ ). Individuals from Abt had lower RNA : DNA ratios, total proteins, and Fulton's K values than individuals from Saj.

Otolith marginal increment widths of individuals aged 100–130 days after extrusion was positively related with both RNA : DNA ratio ( $r=0.41$ ,  $P=0.013$ ) and total proteins ( $r=0.38$ ,  $P=0.022$ ), while Fulton's K, although not significant, was negatively related with the otolith growth rate ( $r=-0.12$ ,  $P=0.21$ ). The relationship between otolith marginal growth rate and condition indices of other age classes followed the same tendency, although not presenting significant coefficients (age class of 70–100 days:  $r=0.33$ ,  $0.31$  and  $-0.04$ ; age class of 130–160 days:  $r=0.67$ ,  $0.25$  and  $-0.82$  for RNA : DNA ratio, total proteins, and Fulton's K, respectively;  $P > 0.05$ ).

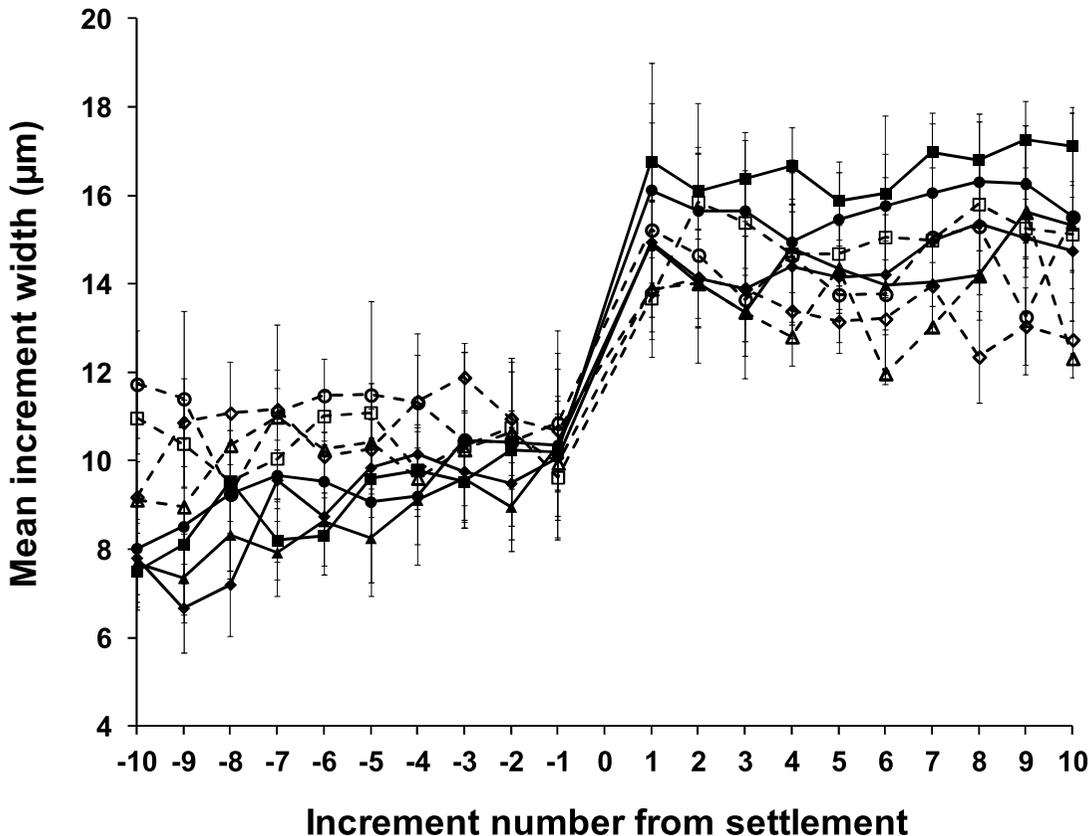


Fig. 4. Otolith increment width before and after settlement based on the transition centered method applied to each extrusion group in Sajima and Aburatsubo. Groups represented using: December ( $\diamond$ ), January ( $\triangle$ ), February ( $\square$ ), and March ( $\circ$ ) with open symbols for Sajima (dashed line) and filled symbols for Aburatsubo (solid line).

### 3.4 Multivariate approach

Based on the canonical correlation patterns of the 11 different DGI variables (Table 1), Saj and Abt were well separated (Table 6). The variables related to P1 and Ps stage, supported this discrimination, which was shown by the great difference between the group centroid scores, and 82% of the individuals were correctly classified. The extrusion groups were highly discriminated (Fig. 6a) with a clear distinction between the early groups (Dec and Jan) and the late (Feb and Mar) groups mostly based on P1 stage related variables (Table 6). This classification was successful in 78% of the cases and the first two discriminant functions explained 90% of the total variance among the extrusion groups.

The CDA based on condition variables showed a strong discrimination between the sites, mainly owing to RNA : DNA ratio, with 84% of correct classification (Table 6). The higher centroid score for Saj showed a higher mean RNA : DNA ratio when compared with Abt. Sampling months separation based on nutritional condition data (Fig. 6b) was also observed (77% of correct classification) and RNA : DNA ratios and total proteins were the variables with higher effects (loads) in the analysis. Hence, when compared with the morphometric condition index (Fulton's K), the biochemical condition indices (RNA : DNA ratio and total proteins) were more relevant to the temporal discrimination.

Table 3. Mean values of DGI variables for the different extrusion groups for Sajima and Aburatsubo extracted from otoliths of the rockfish *Sebastes inermis*

|                                |              | Extrusion groups              |                              |                                |                              | Total                  |
|--------------------------------|--------------|-------------------------------|------------------------------|--------------------------------|------------------------------|------------------------|
|                                |              | December<br>(n=50)            | January<br>(n=67)            | February<br>(n=44)             | March<br>(n=58)              |                        |
| Pl period duration<br>(days)   | Abt          | 47±3 <sup>ab</sup>            | 41±3 <sup>a</sup>            | 49±4 <sup>ab</sup>             | 54±4 <sup>b</sup>            | 47±4                   |
|                                | Saj          | 50±4 <sup>b</sup>             | 49±3 <sup>ab</sup>           | 47±2 <sup>ab</sup>             | 51±3 <sup>b</sup>            | 49±3                   |
|                                | <b>Total</b> | <b>49±3<sup>† §</sup></b>     | <b>45±3<sup>†</sup></b>      | <b>48±3<sup>† §</sup></b>      | <b>53±4<sup>§</sup></b>      |                        |
| Ps I period duration<br>(days) | Abt          | 65±4 <sup>a</sup>             | 57±4 <sup>ab</sup>           | 66±4 <sup>a</sup>              | 57±3 <sup>ab</sup>           | 62±4 <sup>*</sup>      |
|                                | Saj          | 60±6 <sup>ab</sup>            | 55±4 <sup>b</sup>            | 60±4 <sup>ab</sup>             | 52±5 <sup>b</sup>            | 56±5                   |
|                                | <b>Total</b> | <b>62±5<sup>†</sup></b>       | <b>56±4<sup>§</sup></b>      | <b>63±4<sup>†</sup></b>        | <b>55±4<sup>§</sup></b>      |                        |
| Pl growth rate<br>(mm/day)     | Abt          | 0.33±0.04 <sup>a</sup>        | 0.35±0.04 <sup>a</sup>       | 0.38±0.04 <sup>ab</sup>        | 0.41±0.03 <sup>ab</sup>      | 0.36±0.04 <sup>*</sup> |
|                                | Saj          | 0.41±0.04 <sup>ab</sup>       | 0.38±0.05 <sup>ab</sup>      | 0.42±0.04 <sup>ab</sup>        | 0.47±0.07 <sup>b</sup>       | 0.43±0.05              |
|                                | <b>Total</b> | <b>0.37±0.04<sup>†</sup></b>  | <b>0.37±0.04<sup>†</sup></b> | <b>0.41±0.07<sup>† §</sup></b> | <b>0.44±0.08<sup>§</sup></b> |                        |
| Ps I growth rate<br>(mm/day)   | Abt          | 0.50±0.05 <sup>b</sup>        | 0.50±0.05 <sup>b</sup>       | 0.54±0.04 <sup>b</sup>         | 0.55±0.02 <sup>ab</sup>      | 0.52±0.04              |
|                                | Saj          | 0.55±0.05 <sup>ab</sup>       | 0.53±0.07 <sup>b</sup>       | 0.54±0.09 <sup>b</sup>         | 0.57±0.06 <sup>a</sup>       | 0.55±0.07              |
|                                | <b>Total</b> | <b>0.53±0.05</b>              | <b>0.52±0.06</b>             | <b>0.54±0.07</b>               | <b>0.56±0.04</b>             |                        |
| Length at settlement<br>(mm)   | Abt          | 22.0±3.4 <sup>b</sup>         | 20.4±4.0 <sup>b</sup>        | 23.4±4.1 <sup>b</sup>          | 27.5±3.3 <sup>b</sup>        | 23.4±4.0 <sup>*</sup>  |
|                                | Saj          | 24.5±5.2 <sup>b</sup>         | 23.0±3.7 <sup>b</sup>        | 25.8±2.5 <sup>ab</sup>         | 30.1±4.7 <sup>a</sup>        | 25.9±4.1               |
|                                | <b>Total</b> | <b>23.4±4.3<sup>† §</sup></b> | <b>21.7±3.8<sup>†</sup></b>  | <b>24.6±3.3<sup>† §</sup></b>  | <b>28.7±4.0<sup>§</sup></b>  |                        |
| Length at 120 days<br>(mm)     | Abt          | 61.8±4.5 <sup>a</sup>         | 59.6±4.0 <sup>a</sup>        | 61.3±3.2 <sup>a</sup>          | 63.4±1.8 <sup>ab</sup>       | 61.5±3.5               |
|                                | Saj          | 62.2±4.9 <sup>a</sup>         | 61.4±3.1 <sup>a</sup>        | 65.4±4.8 <sup>b</sup>          | 63.3±1.6 <sup>ab</sup>       | 62.4±3.6               |
|                                | <b>Total</b> | <b>62.0±4.7</b>               | <b>61.0±3.4</b>              | <b>63.4±3.8</b>                | <b>63.3±1.7</b>              |                        |

Abbreviations: Pl—planktonic; Ps I—first period of post-settlement; Abt—Aburatsubo; Saj—Sajima; 120 days after extrusion was found in 92% fish aged

<sup>a,b</sup> represents significant differences among extrusion groups in each study area, <sup>†, §</sup> indicates significant differences among extrusion groups with both areas combined, and asterisk (\*) represents significant differences between study sites. Data are shown as mean±SD; two-way ANOVA; SNK;  $P < 0.05$

#### 4. Discussion

The settlement patterns and the nutritional status exhibited by *S. inermis* juveniles in the two bays from Miura Peninsula in central Japan were investigated in the present study. The larvae from the early extrusion groups (Dec and Jan) experienced lower temperatures during the Pl period than the later groups (Feb and Mar), and the larvae from the early groups remained in planktonic habitat for shorter periods with lower growth rates. This phenomenon was confirmed by the correlation between the cumulative SST and DGI data (Table 4) and by a clear seasonal discrimination of early (winter) and late (spring) extrusion groups (Fig. 6a, Table 6). Settlement timings seemed to depend on environmental conditions: the larvae settled earlier at smaller sizes when

they experienced unfavorable conditions (e.g. lower temperature) during the Pl period and grew more after settlement (Fig. 4). This pattern could be interpreted as one adaptive strategy of this species to maximize the growth rate and enhance survival during the early life stages in different environmental conditions, and here it was found to be related with temperature as found in other species (LOCKETT and SUTHERS, 1998, ÁLVAREZ *et al.*, 2012). HURST *et al.* (2005) refers to the increasing growth rate in juveniles as a “compensatory growth” mechanism, in response to temperature reduction and growth history of the individuals. The same mechanism might help to explain the early settlement and respective higher growth rates after settlement found in early groups (Dec and Jan).

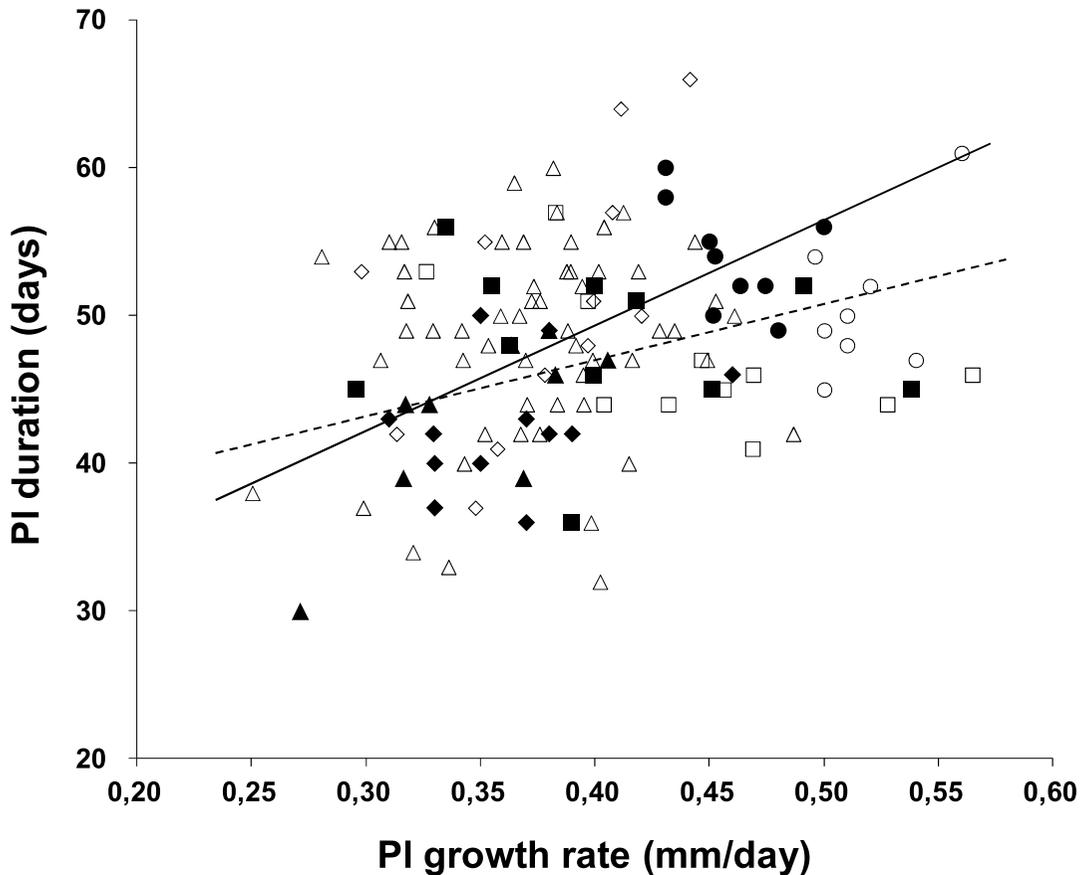


Fig. 5. Relationship between planktonic (PI) duration and growth rate for distinct extrusion groups of *S. inermis*: December ( $\diamond$ ), January ( $\triangle$ ), February ( $\square$ ), and March ( $\circ$ ) with open symbols for Sajima and filled symbols for Aburatsubo. Regression line is shown for Sajima, dashed line ( $y=23.0x+38.9$ ), and Aburatsubo, solid line ( $y=51.5x+25.9$ ).

PLAZA *et al.* (2003) found that settlement pulses in *S. inermis* into seagrass areas were induced by selective tidal currents, with governance by semi-lunar cycles crucial for the active migration of these larvae into nearshore areas. However, our results indicated a weak synchronism of extrusion dates and spring tides, and a much weaker relation between tidal variation and the settlement pattern of larvae in both sites (Fig. 3). Although the cause of such differences is not clear, tidal variation does not seem to be the main determinant of habitat shift from planktonic to benthic life in *S. inermis* larvae in our case study. Therefore, further studies will need to examine the effects of abiotic factors in the future.

Duration and growth rate of PI stage correlated positively in both sites (Fig. 5) in all extrusion groups except in February where this relation was negative. MIZUSAWA *et al.* (2004) also found a negative relationship between these variables for individuals from two sites in similar geographic area, but those authors examined a shorter extrusion period. We believe that temperature is the main factor responsible for the positive relationship of these variables, as a cue to the reaction norm in their adaptive strategy as discussed above. Nevertheless, we also believe the negative trend found in February group could be explained by the presence of an ontogenetic stabilizing effect. Because size is related to the product of growth rates and

Table 4. Pearson correlation coefficients between DGI variables and the respective cumulative SST (°C) for Sajima and Aburatsubo

|                                 |  | <i>DGI variable</i>  | <i>Correlation coefficient</i> | <i>P-value</i> |
|---------------------------------|--|----------------------|--------------------------------|----------------|
| Sajima<br>( <i>n</i> = 121)     |  | Pl growth rate       | 0.82                           | <0.0001        |
|                                 |  | Pl duration          | 0.92                           | <0.0001        |
|                                 |  | Ps I growth rate     | 0.43                           | 0.015          |
|                                 |  | Ps I duration        | 0.97                           | 0.001          |
|                                 |  | Length at settlement | 0.67                           | <0.0001        |
|                                 |  | Length at 120 days   | 0.51                           | 0.003          |
| Aburatsubo<br>( <i>n</i> = 108) |  | Pl growth rate       | 0.86                           | <0.0001        |
|                                 |  | Pl duration          | 0.91                           | <0.0001        |
|                                 |  | Ps I growth rate     | 0.58                           | 0.0003         |
|                                 |  | Ps I duration        | 0.96                           | 0.041          |
|                                 |  | Length at settlement | 0.79                           | <0.0001        |
|                                 |  | Length at 120 days   | 0.45                           | 0.004          |

Abbreviations: Pl—planktonic; Ps I—first period of post-settlement; 120 days after extrusion was found in 92% fish aged; Pearson correlation significant for  $P < 0.05$

Table 5. Condition indices for the rockfish *Sebastes inermis* in Sajima and Aburatsubo at different sampling dates

|  |              | <i>Sampling month</i>           |                                 |                                 | <i>Total</i>                    |
|--|--------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
|  |              | May ( <i>n</i> = 31)            | June ( <i>n</i> = 33)           | July ( <i>n</i> = 32)           |                                 |
| RNA : DNA ratio                        | Abt          | 1.92 ± 0.54 <sup>a</sup>        | 1.43 ± 0.27 <sup>ab</sup>       | 1.05 ± 0.19 <sup>b</sup>        | <b>1.32 ± 0.47<sup>*</sup></b>  |
|  | Saj          | 1.97 ± 0.42 <sup>a</sup>        | 1.76 ± 0.51 <sup>ab</sup>       | 1.99 ± 0.37 <sup>a</sup>        | <b>1.88 ± 0.33</b>              |
|  | <b>Total</b> | <b>1.95 ± 0.68<sup>†</sup></b>  | <b>1.59 ± 0.41<sup>§</sup></b>  | <b>1.31 ± 0.28<sup>§</sup></b>  |                                 |
| Total proteins<br>( $\mu$ g/mg tissue) | Abt          | 37.65 ± 3.81 <sup>a</sup>       | 50.2 ± 2.21 <sup>c</sup>        | 47.37 ± 7.83 <sup>bc</sup>      | <b>44.00 ± 4.13<sup>*</sup></b> |
|  | Saj          | 43.45 ± 4.86 <sup>b</sup>       | 63.4 ± 5.68 <sup>d</sup>        | 51.65 ± 5.72 <sup>cd</sup>      | <b>47.76 ± 6.28</b>             |
|  | <b>Total</b> | <b>41.73 ± 5.62<sup>†</sup></b> | <b>52.90 ± 3.39<sup>§</sup></b> | <b>48.44 ± 6.74<sup>‡</sup></b> |                                 |
| Fulton's K                             | Abt          | 1.55 ± 0.20 <sup>a</sup>        | 1.68 ± 0.16 <sup>ab</sup>       | 1.72 ± 0.11 <sup>b</sup>        | <b>1.66 ± 0.16</b>              |
|  | Saj          | 1.68 ± 0.22 <sup>ab</sup>       | 1.86 ± 0.20 <sup>b</sup>        | 1.75 ± 0.17 <sup>b</sup>        | <b>1.70 ± 0.21</b>              |
|  | <b>Total</b> | <b>1.64 ± 0.22</b>              | <b>1.75 ± 0.17</b>              | <b>1.71 ± 0.12</b>              |                                 |

Abbreviations: Abt—Aburatsubo; Saj—Sajima

<sup>a,b,c,d</sup> represent significant differences among sampling months from each study site, <sup>†</sup>, <sup>§</sup>, <sup>‡</sup> indicate significant differences among sampling months with both sites combined, and asterisk (\*) represent significant differences between study sites. Data are shown as mean ± SD; two-way ANOVA; SNK;  $P < 0.05$

period duration, respective settlement sizes will be stabilized if there is a negative relationship between the growth rates and duration of the Pl stage, even if individual variability in growth rates is present within a group. This suggested scenario is schematized in Fig. 7.

Regarding the planktonic stage duration, CHAMBERS and LEGGETT (1987) suggested that a negative relationship between growth rate and duration of larval period is favorable to

larval survival: larvae that grow faster stays shorter period in vulnerable stage and enhances survival probabilities (i.e. “stage duration” mechanism). The results for the reaction norm to different temperature observed in the present study were not conformable to such hypothesis so other growth-related mechanism might be occurring in this case. TAKASUKA *et al.* (2004) refers that longer planktonic periods can be advantageous for a successful recruit-

Table 6. Summary of the discriminant analysis (CDA) performed on overall dataset regarding *Sebastes inermis* juveniles in order to identify: sites and extrusion groups based on DGI variables; sites and sampling months based on nutritional condition indices

| <i>Discriminant parameters</i>                         | <i>DGI</i>   |   |  | <i>Nutritional condition indices</i> |  |   |
|--|--|---|--|--------------------------------------|--|---|
|  | Site   | Extrusion group   |  | Site                                 | Sampling month                             |   |
| Wilk's Lambda ( $\lambda$ )                            | 0.89   | 0.67  |  | 0.67                                 | 0.54                                       |   |
| <i>F</i> value   | 2.56*  | 2.88**  |  | 15.01**                              | 11.04**                                    |   |
| Variability explained(%)                               | <i>DF1</i>   | <i>DF1</i>  | <i>DF2</i>   | <i>DF1</i>                           | <i>DF1</i>                                 | <i>DF2</i>                                |
|  | 100  | 59.1  | 31.4   | 100                                  | 86.3                                       | 13.7                                      |
| Variables loading                                      | Length at settlement<br>Otolith radius at end of Ps I<br>Ps I duration | Pl growth rate<br>Length at settlement<br>Otolith radius at end of Pl | Otolith radius at end of Ps I<br>Ps I duration<br>Ps I growth rate (-) | RNA : DNA ratio                      | Total proteins (-)                         | RNA : DNA ratio                           |
| Centroids of the groups ( <i>discriminant scores</i> ) | Saj (-0.19)<br>Abt (0.62)  | December (-0.39)<br>January (-0.22)<br>February (0.4)<br>March (1.62) | December (0.45)<br>January (-0.21)<br>February (0.56)<br>March (-0.52) | Saj (0.55)<br>Abt (-0.87)            | May (0.88)<br>June (-0.78)<br>July (-0.72) | May (0.01)<br>June (0.55)<br>July (-0.35) |
| Classification success (%)                             | 82.0   | 78.3  |  | 83.9                                 | 77.2                                       |   |

\*  $P < 0.05$ , \*\*  $P < 0.001$ ; (-) indicates variable loading the discriminant function negatively  
Abbreviations: DF1,2-discriminant functions 1,2

ment since the probability of larvae to be transported to favorable nursery grounds is higher. It seems that the individuals here studied might be adopting such strategy (i.e. December and January groups in Sajima), yet further investigation should be conducted to clarify this issue.

Regarding the first hypothesis of our study ( $H_1$ ), settlement of *S. inermis* along Miura Peninsula coast presented temporal differentiation. The larval adaptive strategy as a reaction to different water temperature was the main determinant of the settlement.

Several aspects help to interpret the geographical range of the larval transport and settlement: the clear differences in the pattern of

daily extrusion and settlement between the study sites with earlier extrusion in Saj (Fig. 3a), the significant differences of Pl growth rate and Ps I duration between the sites (Table 3, Fig. 5), and the clear differentiation of sites using DGI data, concerning variables related with the Pl and Ps stages (Table 6). We suggest that the groups in both bays are highly separated and larval distribution offshore is unlikely. The differences between the sites as stated above would be eliminated if this offshore mixing had occurred. Concerning the second tested hypothesis ( $H_2$ ), larval transport and settlement occurred separately for each bay, and migration if it occurs, seems to be confined to a small geographical range around

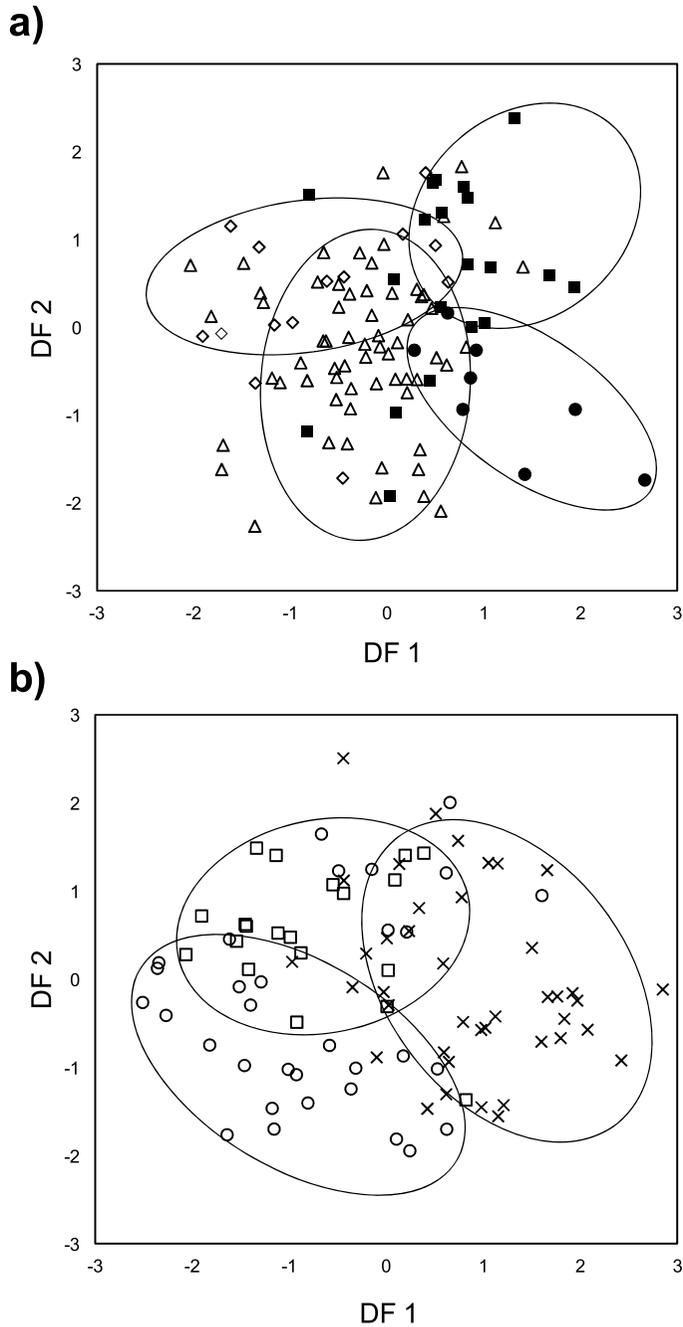


Fig. 6. Canonical discriminant analysis (CDA) based on DGI variables (a) and on nutritional condition indices (b) for rockfish juveniles: a) Canonical discriminant scores of the four extrusion groups from both sites combined, based on the first two discriminant functions (DF1&2) with 78% of individuals successfully classified. Groups represented using: December ( $\diamond$ ), January ( $\triangle$ ), February ( $\blacksquare$ ), and March ( $\bullet$ ), b) Canonical discriminant scores of the three sampling months from both sites combined, based on the first two discriminant functions (DF1&2) with 77% of individuals successfully classified. Months represented as: May (X), June ( $\square$ ) and July ( $\circ$ ).

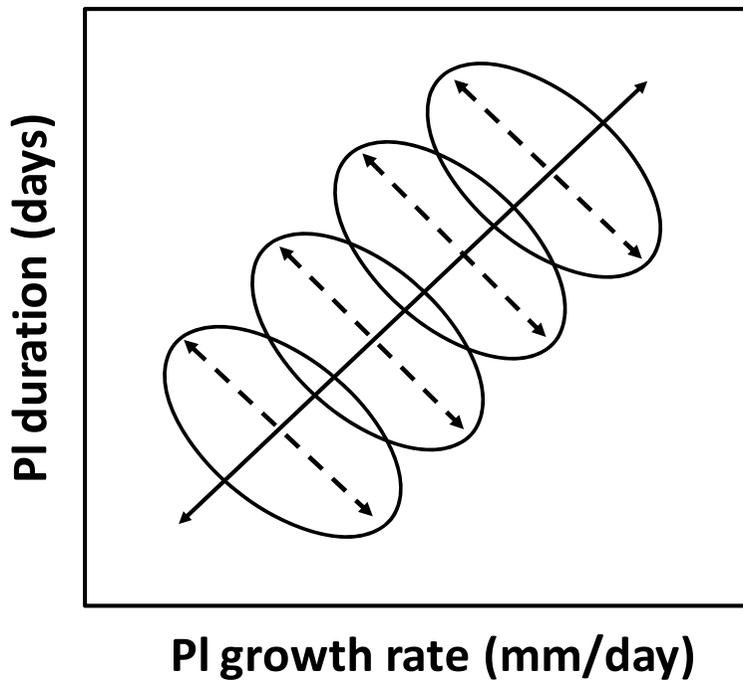


Fig. 7. Diagram of the relationship between Pl duration and Pl growth rate. Ellipses show the range of variability in each extrusion group. Solid arrow shows the direction of reaction norm to different temperature for different extrusion groups. Dashed arrows show the direction of individual's variability within each extrusion group caused by an ontogenic stabilizing effect.

each bay.

Average total length of settled juveniles increased amongst sampling dates in both sites (Table 2). The fact that individuals from early groups (Dec and Jan) were scarce or absent from the later sampling months (Fig. 3a) suggests a possible ontogenic movement of juveniles to adjacent nearshore areas in each site after several months after settlement. Gear selectivity effect was considered negligible partly because adults were also captured and partly because HARADA (1962) also described a short distance movement of post-juveniles to adjacent areas in this species. Such movement could be happening in a possible response to a change in resource requirements and vulnerability to predation (LOVE *et al.*, 1991). From the results of the present study, it is not possible to determine the geographic scale of such movement, therefore, a broader study on the sub adult and adult population is recommended to fully assess this issue.

Differences found in condition indices (Table 5) indicated that juveniles from Saj are in overall better physiological status. This conclusion was supported by CDA (Table 6), where RNA : DNA ratio was determinant. This index is correlated with food availability and is a good indicator of the nutritional condition (GARCIA *et al.*, 1998, GEIGER *et al.*, 2000, ISLAM and TANAKA, 2005). Based on this relationship, the higher values of RNA : DNA ratio found in juveniles from Saj reflect higher energetic reserves after settlement as observed in other species (VASCONCELOS *et al.*, 2009). On the other hand, the lowest indices found in juveniles from Abt might reflect a lower survival potential, as also found in other species (BLACK and LOVE, 1986, PASTOUREAUD, 1991).

Based mainly on the biochemical condition indices rather than the morphometric condition index, *S. inermis* juveniles at the settlement ground were clearly discriminated among sampling months (Fig. 6b). In addition, RNA :

DNA ratio and total proteins correlated positively with the increment widths of the otolith margin. It suggests that there is a positive relationship between fish condition and growth rates as found in other species (MALLOY and TARGETT, 1994, BUCKLEY *et al.*, 1999, RAMIREZ *et al.* 2004). The use of all condition indices (to our knowledge, this is the first time assessment for this species) allows an ecological evaluation of fish habitat (LLORET *et al.*, 2001, ISLAM *et al.*, 2006, VASCONCELOS *et al.*, 2009). Our case showed that Sajima Bay is a higher-quality nursery ground with more suitable characteristics for *S. inermis* early stage development, which supports the third hypothesis (H<sub>3</sub>). Saj has larger canopy areas which provide higher protection to the settled juveniles. In addition, the water in this bay may present higher nutrient enrichment since there is an influence of a stream in this area, and this may bring ecological benefits (e.g. LLORET *et al.*, 2001).

The present study provided basic biological information on the early life of *S. inermis*. The results enabled the differentiation of two geographical groups using an integrative analysis of life traits and nutritional condition. Further studies will need to focus on a larger temporal range and on adult populations to enhance the comprehension of inshore/offshore connectivity of populations, for this commercially important species in Japan.

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資 料

## 第 51 巻第 1・2 号掲載欧文論文の和文要旨

田村 康・茂木正人・横尾俊博・河野 博\*：東京湾におけるスズキ仔稚魚の出現様式と遊泳・摂餌形質の発達

東京湾のスズキの仔稚魚を内湾から外湾にかけての沖合での稚魚ネット（2005年12月から2008年3月）と湾奥の多摩川河口干潟域での小型地曳網（2007年1月から2008年12月）で採集し、成長にともなう出現様式を明らかにした。さらに、透明骨格標本を作製し、遊泳と摂餌に関する形質の発達にもとづいて、機能的発育と出現様式との関係を考察した。沖合で採集された個体は391個体で、平均体長±標準偏差は $3.67 \pm 1.37$  mm、体長範囲は1.8~8.1 mm、発育段階は卵黄仔魚と屈曲前仔魚であった。干潟では580個体が採集され、平均体長±標準偏差は $21.9 \pm 11.0$  mm、体長範囲は11.4~123.5 mm、発育段階は屈曲仔魚から稚魚であった。東京湾の湾口部で産卵され、ふ化した仔魚は、最初は受動的に、体長5 mm くらいからはごく弱い遊泳力をつけて接岸回遊をされると考えられた。体長8~11 mmの仔魚は本研究では採集されなかった。干潟域は、体長13.5 mm から約30 mmの稚魚に対して、成育場を提供していることが判明した。体長13.5 mm というのは鰭条数が定数に達して稚魚になる大きさであり、さらに体長13~15 mm にかけては遊泳機能も摂餌機能も稚魚として十分な能力を獲得する大きさである。

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Miguel RUANO<sup>1</sup>、Ana Teresa GONÇALVES<sup>2</sup>、山川 卓<sup>1</sup>、青木一郎<sup>1</sup>：耳石微細輪紋および栄養状態分析により推定したアカメバル *Sebastes inermis* の初期生活史\*

アカメバル *Sebastes inermis* の仔魚の孵出、成長速度、着底パターンに影響を与える要因を特定するため、三浦半島の2つの湾（佐島湾、油壺湾）で採集した稚魚・幼魚サンプルの耳石微細輪紋の解析を行った。また、生息場所の質を評価するために、魚体栄養状態の指標（RNA：DNA比、総タンパク質、Fultonの肥満度指数K）の分析も行った。日齢を用いた逆算推定により、月ごとの4つの孵出群が認められた。浮遊仔魚期の成長速度は水温および浮遊期の期間の長さとの正の相関があった。各群の着底時期が可変的であったことから、好適でない水温を経験した仔魚は小さな体長で早期に着底を行って着底後に速く成長するという、環境変動に対する適応戦略の存在が示唆された。浮遊期および着底後の種々の形質に関する湾間の明瞭な違いにより、浮遊期仔魚の沖合での混合は生じていないことが示唆された。佐島湾の稚魚は速い成長速度と高い栄養指標値を示したことから、当湾は生息場所としての質が高く、稚魚の生育場として重要であると考えられた。

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## 学 会 記 事

### 1. 「津波で被災した三陸の養殖漁業復興のための活動」 報告

小池康之

うみ第 50 巻 1・2 号学会記事で経過を報告したこの活動は、その後も義援金募集を継続したが、2012 年のカキ採苗時期が終了した 9 月に被災地の状況を調査した結果、宮城・岩手両県の復興予算により研究備品の整備も進んでいることを確認したため、セッカルジ仏日海洋学会会長と相談の結果、9 月末に届いたエール・リキード基金からの 2 度目の送金で募金活動を終了することにした。義援金募集開始後の 1 年間に寄せられた義援金総額、協力支援団体名、寄贈機材は下記の通りである。

- ・義援金総額：3,302,606 円
- ・支援団体：フランス水産養殖振興会 (Association pour le Développement de l'Aquaculture), エール・リキード基金 (Fondation Air Liquide), ロータリークラブ, マルセイユ・サンジャン (Rotary Club Marseille Saint-Jean), 仏日海洋学会, 日仏海洋学会

註：オリンパス・メデイカル・サイエンス販売株式会社および株式会社離合社：  
機材の寄付と値引きによる協力

- ・寄贈機材：宮城県（水産技術総合センターおよび県漁業協同組合）：顕微鏡 9 台（生物顕微鏡：1, 実体顕微鏡：8), 定量式プランクトンネット 5 本, 岩手県（水産技術センターおよび県水産振興センター）：顕微鏡 8 台（生物顕微鏡：1, 実体顕微鏡：7), 定量式プランクトンネット 5 本

これらの寄付と支援活動に対し、両県知事および水産技術センター所長より寄付受領書と礼状が届けられた。また、現地の両センターで行われた数回に亘る寄贈式には地方テレビ局（岩手放送, NHK 盛岡放送局）や岩手日報・釜石新聞・河北新報・朝日新聞など新聞社数社からの取材があり、地方版ニュースおよび新聞記事として報道された。また、両県技術センターのホームページにニュースとして記載された。

寄贈機材は両県技術センターで管理され、必要に応じて県内各地の漁業協同組合事業所および水産振興センターに貸し出され、現場においてカキ、ホタテ貝、アサリ、ホヤ、ワカメ、ノリなどの養殖事業に幅広く利用されている。

### 2. 日仏共同研究プロジェクト「沿岸域の持続可能な開発に関する日仏共同研究：被災した三陸沿岸の復興を目指して」報告

小松輝久

日仏海洋学会の東日本大震災復興支援活動の一環として、財団法人日仏会館の 2012 年度日仏共同研究プロジェクトに応募し、採択された。平成 24 年 4 月に 140 万円の助成金を得て、プロジェクト「沿岸域の持続可能な開発に関する日仏共同研究：被災した三陸沿岸の復興を目指して」を実施することにした。このプロジェクトを実施する背景と目的は、次の通りである。フランスの養殖カキが大量に斃死し、カキ養殖漁業が壊滅しかけた 1960 年代後半に日本の三陸の種ガキがフランスに輸出され、カキ養殖が復活した。そのとき以来、日本の三陸とフランスのカキ養殖の産地の間には強い絆ができた。今回、三陸を襲った津波により、三陸のカキ養殖を含む沿岸漁業が崩壊した。現在、復旧の取り組みが始まっているが、三陸の沿岸漁業をさらに持続的に発展させることが重要である。そこで、2012 年の適切な時期に 1 週間程度、フランス人の沿岸域管理の専門家とステークホルダーを日本に招き、セミナーと現地視察（三陸沿岸）を行い、被災した三陸の復興のための沿岸域の持続的な開発についての議論を多角的に行うことを目的とした。なお、申請にあたっては、ブルターニュオキシデンタル大学大学院学生西村文英氏の協力を得た。

平成 24 年 9 月 29 日から 10 月 7 日まで、仏日海洋学会のメンバーで沿岸域管理について社会的な面から取り組んでいる、ブルターニュオキシデンタル大学教授 Denis Bailly 博士と水産経済学者で養殖の専門家のアグロバリテク大学教授 Catherine Mariojous 博士、沿岸域管理の研究をしているフランス海洋開発研究所トランブラード研究所所長 Jean Prou 博士、フランスでアキテンヌ・アルカッション地域貝類養殖委員会代表 Olivier Leban 氏の 4 名を招聘した。Denis Bailly 氏はブルターニュ州で、岩手県の漁業者に養殖用の機材を送る運動を行なっている団体のメンバーでもある。また、Catherine Mariojous 氏は、カキ養殖などの種苗検鏡用の顕微鏡を岩手県および宮城県の水産研究施設へ寄贈した団体であるフランス養殖振興協会会長でもある。また、この代表団と一緒に、ブルターニュオキシデン



平成 24 年 10 月 4 日東北水研におけるシンポジウムでの小池康之会員の講演



顕微鏡を寄贈するマリオジュウルス教授（於・岩手県水産技術センター）

タル大学の研究者とフランス政府の援助によりフランス人カキ養殖業者 8 名が来日した。

10 月 1 日から 10 月 3 日に三陸被災地の視察を行い、10 月 4 日に塩竈の水産総合研究センター東北区水産研究所において日仏合同セミナー「三陸の沿岸漁業の復興を目指す日仏シンポジウム—特に津波被害からのカキ養殖の復興に向けて」を、10 月 5 日に東京の日仏会館において公開講演会「日仏カキ文化：三陸の復興を目指して」を開催した。視察旅行において、岩手県では NPO 水産業・漁村活性化推進機構の内田 明氏に、宮城県では県漁業協同組合顧問の佐々木良氏にそれぞれ準備と現地案内の労をとっていただいた。

招待者以外の視察参加者名と行程は次の通りである。

招待者以外の視察参加者

ブルターニュオキシデンタル大学派遣：Ekaterini Frangoudes（エカテリニ フランゴウデス）、Bunei Nishimura（西村文英）、Manuelle Philippe（マヌエ フィリップ）

フランス政府派遣：Philippe Le Gal（フィリップ ルガル）南ブルターニュ地域貝類養殖委員会副会長、Isabelle Crénéguy（イザベル クレネギ）南ブルターニュ地域カキ養殖業者、Olivier Mahé（オリヴィエ マエ）南ブルターニュ地域カキ養殖業者、André Berthou（アンドレ ベルトゥ）南ブルターニュ地域カキ・海藻類養殖業者、Annie Castaldo（アニー カスタルド）マルセイユ地域ムール貝・カキ養殖業者

行程

- ・10 月 1 日：午後：岩手県宮古市田老町漁業協同組合（コンブ、ワカメ養殖および加工技術）
- ・10 月 2 日：午前：岩手県山田町大沢漁協と漁港

（カキ、アワビ、ワカメ養殖、漁港と組合施設の復興状況）、午後：釜石市、岩手県水産技術センター（岩手県水産業全般の被災状況と復興状態）、施設視察後に 9 月末に届けられたエール・リキード基金により、顕微鏡 2 台の寄贈式を行い、マリオジュウルス養殖振興協会会長自らセンター代表者に顕微鏡が手渡された。

- ・10 月 3 日：視察訪問は 2 組に分かれて行われた。
  - 1) 研究者グループ 午前：宮城県漁業協同組合志津川支所（漁港施設復興状況、養殖カキ生育状況）、午後：漁業協同組合石巻支所（万石浦湾内カキ養殖場および処理場施設など復興状況）、渡波の県水産技術総合センター（県内水産業全般の被災と復興状況、寄贈品の利用状況）
  - 2) 漁業者グループ 宮城県漁協気仙沼支所（被災後のカキ養殖の現状と復興の技術交換）
- ・10 月 4 日 東北水研において終日、日仏カキセミナー開催
- ・10 月 5 日 研究者グループ：東北大学水産学関連研究室および東北マリンサイエンス拠点事務室訪問後、野村正名誉教授等と交換会、漁業者グループ：仙台市内の水産加工工場視察、東京帰着
- ・10 月 6 日 研究者グループ：午前中、日仏会館において公開講演会、午後、学会関係者と交換会、漁業者グループ：魚市場他視察

10 月 4 日に東北水研（東北水研）において「三陸の沿岸漁業の復興を目指す日仏シンポジウム」および 10 月 6 日に日仏会館において講演会「日仏カキ文化：三陸の復興を目指して」を開催した。両会とも多数の参加者がおり、特に 10 月 4 日のシンポジウムでは、議論があり、予定時間を超過する盛会であった。シンポジウムでは中野俊樹会員（東北大）、奥村裕会員（東北水研）には、準備と進行をお

世話いただいた。プログラムは次の通りであった。

なお、東北水研におけるシンポジウムで小池康之会員による「フランスからの援助について」という題での報告した40年前に日本からの稚貝輸送でフランスのカキ大量斃死を救済した経緯および津波被災後フランスから受けた支援活動に関する講演内容がフランス側から高く評価された。そして、同会員は、平成24年11月下旬から4日間、フランス第一のカキ生産地アルカッションで開催された第一回「世界カキ会議、Congrès Mondial de l'Huitre」に招待され、基調講演「カキ養殖に伴う日仏両国間の歴史と絆」を世界27カ国から200名を超える参加者の前で発表した。また、同会議にはカキ研究の代表者として財団法人カキ研究所研究員、東北水研所長を歴任した關哲夫会員が参加し、日本におけるカキの疾病およびその対策について講演と意見交換を行った。

10月4日のシンポジウムおよび10月6日の市民向け講演会のプログラムは次の通りである。

10月4日 9:00-18:30 東北水産研究所会議室  
「三陸の沿岸漁業の復興を目指す日仏シンポジウム」  
講演は14題、参加者は45名。

開会の挨拶：

小松輝久 日仏海洋学会会長 東京大学大気海洋研究所准教授

挨拶：平井光行 東北水産研究所所長

(1)津波被害から復興へ

(座長 今脇資郎 日仏海洋学会前会長 独) 海洋開発機構地球情報研究センターセンター長)

沿岸漁業に及ぼした津波被害

岩手県について：

高橋正 岩手県水産技術センター副所長  
宮城県について：

山岡茂人 宮城県水産技術総合センター副所長

(2)津波被害からのカキ養殖の回復とフランスからの支援物資の利用

フランスからの援助について：

小池康之 日仏海洋学会幹事  
岩手県：高橋正 岩手県水産技術センター副所長  
宮城県について：

佐々木良 宮城県漁協養殖技術指導員  
松島湾におけるカキ養殖業者間の協同の試み：

渡辺茂 宮城県漁協鳴瀬支部カキ部会会長

(3)復興と沿岸域管理

(座長 中野俊樹 日仏海洋学会幹事 東北大学大学院農学研究所准教授)

フランスにおける海洋環境とその利用の生態系に基づく管理：

Denis Bailly ブルターニュオキシデンタル大学教授

フランスにおける貝類養殖の持続的発展へ向けた生態系アプローチ：

Jean Prou フランス国立海洋開発研究所ラトランブラード研究所所長

宮古市における沿岸域総合管理への取り組み：

財) 海洋政策研究財団特任研究員 大塚万紗子

(4)日仏のカキ養殖の問題

日本におけるカキの病気：

伊藤直樹 東北大学大学院農学研究所助教  
フランスにおけるカキの病気：

Olivier Laban アキテンヌ・アルカッション貝類養殖地委員長

(5)カキ養殖生産物の価値の向上に向けて一現状と将来

(座長 荒川久幸 日仏海洋学会幹事 東京海洋大学教授)

日本におけるカキの価値向上 伝統と将来のチャンス：關哲夫 農林漁業情報技術協会職員

フランスにおけるカキの価値向上 生産物とマークとラベル：

Catherine Mariojouis アグロパリテク大学教授

アマモ場の修復によるカキ身入の向上：

柳哲夫 九州大学応用力学研究所教授

(6)討論 三陸の沿岸漁業・カキ養殖の復興を目指す日仏協力と将来への提言

モデレータ：

小松輝久 日仏海洋学会会長 東京大学大気海洋研究所准教授

開会の挨拶：

木島明博 東北マリンサイエンス拠点形成事業代表機関代表研究者・東北大学副理事

10月6日 10:00-12:00 東京日仏会館

講演会「日仏カキ文化：三陸の復興を目指して」

(1)開会の挨拶：

小松輝久 日仏海洋学会会長 東京大学大気海洋研究所准教授

(2)フランスからの支援：

小池康之 日仏海洋学会幹事

(3)フランスにおけるカキ養殖の現状：

Olivier Laban アキテンヌ・アルカッション地域貝類養殖委員会委員長

(4)フランスにおける生態系に基づいたカキ養殖の管理：

Jean Prou フランス海洋開発研究所 ラトランブラード研究所所長

(5)三陸セミナーレポート：

Denis Bailly ブルターニュオキシデンタル大学教授

## (6)閉会の挨拶：

Catherine Mariojouis アグロパリテク教授  
日仏海洋学会幹事

## 3. 幹事会議事録（第4回）

日時：12月14日（金）10時00分～12時00分

場所：東京海洋大学9号館203会議室

参加：小松，今脇，森永，小池，荒川，長井

## 議題

1) 東北カキシンポジウムについて、小松会長から報告があった。フランス訪日団は9月30日に12名来日し（内4名が日仏海洋学会の招待）、以下の日程で行動した。

10月1-3日 三陸の被災地や養殖場を視察。

10月4日 東北カキシンポジウム開催（東北区水産研究所；参加者約50名）。

10月5日 東北マリンサイエンス（東北大）との懇談会

10月6日 日仏カキ文化に関するセミナー（日仏会館）

つづいて、世界カキ会議に招待された小池幹事から同会議の報告があった。

東北カキシンポジウムおよび世界カキ会議について、会長および小池幹事が記録を作成し、La merに掲載することとした。原稿の締切りとボリュームについて編集委員長に確認することとした。

2) La mer 出版の予定（吉田編集委員長 代荒川）：今年度の発行は終了している。次号は新年度。

3) 学会賞の委員半数改選および2013年度受賞者選考について、情報を事務局から会長へ連絡することとした。

4) 学会HPについて：記事を更新するとともに、フランス語版の作成も検討することとした。

## 5) その他：

- ・会長より日仏関連学会協議会報告がなされた。2013年度の日仏研究助成は募集があるのか未定。学者交換に関しては応募しないこととした。
- ・2013年10月に第15回日仏海洋学シンポジウムがフランスで開催される。テーマについて検討した。開催の情報をLa merへ掲載することとした。日仏双方のメンバーからなる委員会を作って今後対応することとした。組織委員および科学委員を確定することとした。
- ・エアリキッド報告（小池幹事）。顕微鏡の寄贈事業は終了する。お礼状の発送と報告を行う。

4. 学会賞選考委員会半数改選が行われ、2013-2014年度委員として、神田稷太，田中祐志，今脇資郎，磯田豊，柳哲雄の5名が選出された。2013年度非改選委員は、荒川久幸，石坂丞二，河野博，小松輝久の

4名。

## 5. 新入会員

## 【一般会員】

| 氏名    | 所属                         | 紹介者  |
|-------|----------------------------|------|
| 關 哲夫  | 一般社団法人 全国水産技術者協会           | 小池康之 |
| 進士 淳平 | 東京大学大学院農学生命科学研究科<br>農学国際専攻 |      |
| 西野 康人 | 東京農業大学生産業学部                | 谷口 旭 |
| 村山 利幸 | 東京海洋大学海洋工学系                | 荒川久幸 |
| 鹿島 基彦 | 神戸学院大学人文学部                 | 市川 香 |
| 山川 卓  | 東京大学大学院農学生命科学研究科           | 小松輝久 |
| 青木 一郎 |                            | 小松輝久 |

## 【賛助会員】

| 氏名       | 紹介者  |
|----------|------|
| 信幸建設株式会社 | 森永 勤 |

## 6. 退会

津久井文夫，井上りえこ，守安実己郎，長岩理央，長谷川直子，長谷川英一，佐川龍之，GIRAULT M ATHIAS，Tran Van Viet

## 7. 所属および住所変更

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omura@lasc.co.jp

## 8. 寄贈図書および資料

農工研ニュース（農村工学研究所）；No.80-83

農村工学研究所研究成果情報；平成23年度

FRAN NEWS（水産総合研究センター）；No.31-33

年報（水産総合研究センター）；平成22-23年度

広島観光コンベンション；Vol.87-89S

hip & Ocean Newsletter（海洋政策研究財団）；No.286-301

なつしま（JAMSTEC）；316-322

水産技術（水産総合研究センター）；第5巻1

CIC NEWSLETTER（東京大学）；No.9-10

J-STAGE NEWS（独立行政法人科学技術振興機構）；No.30-31

「海-自然と文化」（東海大学海洋学部）；第10巻1-2

Techno-ocean News（テクノオーシャンネットワーク）；No.47-48

- Niigata Convention Topics 2010 (新潟県産業労働  
観光部環境局交流企画課コンベンション推進グルー  
プ); Vol.1
- 東海大学海洋研究所研究報告; 第33号
- RESTEC News (一般財団法人リモート・センシ  
ング技術センター); 第1号
- Ocean Breeze (東京大学大気海洋研究所); 第9-11号
- 神戸海洋気象台情報; 第226号 (CD-R)
- 独立行政法人産業技術総合研究所 地質調査情報セ  
ンター; No.71-78 (CD-R)
- 日仏生物学会誌 (日仏生物学会); 第52卷
- ABSCJF (科学部門フランス政府給費留学生の会);  
No.44
- 先進陸水海洋学会 (ASLO)2012年日本大会 (琵琶湖)  
報告書
- 日仏薬学会創立40周年記念 (日仏薬学会)
- MEMOIRS OF THE NATIONAL MUSEUM OF  
NATURE AND SCIENCE (国立科学博物館専報);  
第43号, 第47-48号
- A類 (動物学) (国立科学博物館研究報告); 第37卷  
1-4, 第38卷1-4, 増補6
- 中国海洋大学学报; 204-214
- PROGRESS IN FISHERY SCIENCES (中国水産学  
会); 第33卷3-6
- Oceanologia et Limnologia Sinica (中国海洋湖沼学  
会・中国科学院海洋研究所); 第42卷5-6, 第43  
卷1-4
- Meereswissenschaftliche Berichte Marine Science  
Repoorts (Leibniz-Institut für Ostseeforschung  
Warnemünde (IOW)); No.88

## 賛 助 会 員

|                   |  |
|-------------------|--|
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日 仏 海 洋 学 会

郵便振替番号：00150-7-96503

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2013年3月

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