Age, Growth and Otolith Microstructure of the Spotted Lanternfish *Myctophum punctatum* Rafinesque 1810

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Abstract: This study investigated, for the first time, the age and growth of the spotted lanternfish *Myctophum punctatum* through an analysis of otolith microstructure. A total of 377 individuals were collected from the Strait of Messina (central Mediterranean Sea), ranging between 20.3 and 73.7 mm of standard length. Their length–weight relationship was estimated, and these outputs indicated an isometric growth, for all specimens and when males and females were analysed separately. The sagittal otoliths were removed from 185 fish, although the microincrement readings were considered valid for only 173 otoliths. Microincrement counts ranged from 32 to 48 (average = 37.6) in the otolith external zone, 30 to 56 (average = 44.3) in the middle zone, and 36 to 384 (average = 165.5) in the central zone. Overall, total microincrements ranged between 106 and 469. Different growth models (Gompertz, von Bertalanffy and logistic models) were considered, to understand which one fit best in describing the growth patterns in *M. punctatum*. The Gompertz model was then selected as the best-fitting model and its parameters for all individuals were \( L_\infty = 74.79, k = 0.0084 \) and \( I = 139.60 \).

Keywords: sagittae; age determination; daily growth; growth model; length–weight relationship; Myctophidae; Mediterranean

1. Introduction

Lanternfishes (Myctophidae) are an important component of the mesopelagic fauna and include more than 250 small pelagic species [1]. Their key role in the pelagic trophic web is widely recognised thanks to their high biomass [2] and importance in the diet of several top predators [3,4]. Lanternfishes have different life strategies, resulting in various adaptations to deep-sea life and migration patterns. For instance, these species display different migratory behaviours, which can be resumed in three main categories [5–7]: (i) strong migrants: species that usually carry out large diel vertical excursions, reaching the epipelagic layer at night; (ii) weak migrants: species performing limited vertical movements in the water column; (iii) non-migrants: species occurring in the same water layers during both daylight and night. However, the extent of vertical movements in lanternfishes can be influenced by environmental factors, as demonstrated elsewhere [8].
with cyclic migrating patterns in *Hygophum* spp. from the north and central Atlantic, in relation to the different lunar cycle phases. These differences in migratory behaviour are reflected in the otolith microstructure [8]. For instance, sequences of clear growth increments represent a fast-growth period due to migration in the warmer upper layers; however, when limited vertical excursions occur, less distinguishable increments are laid down, associated with periods of slow growth in deeper and colder waters.

Several studies have investigated the depositional periodicity of the growth increments in the microstructure of lanternfish otoliths, and most of them agree that the ring formation occurs on a daily scale, although some fine increments can be laid down sub-daily [2,8–20]. According to the current knowledge, otolith microstructure analysis is useful in investigating lanternfish life history traits, since the formation of different otolith regions can be correlated with particular periods of the lifespan, such as the larval zone (LZ), the post-larval zone (PLZ) and the post-metamorphic zone (PMZ).

To date, information on the age and growth of lanternfish is still limited to few species, considering the high number of members belonging to the family Myctophidae. Age and growth studies provide useful outputs for the assessment of population dynamics and growth rates and can be applied to better understand fish biology and ecology. This information can also be used for fishery management purposes, given the recent attempts to exploit mesopelagic resources [21].

The aim of this paper is to investigate the age and growth of the spotted lanternfish *Myctophum punctatum*, Rafinesque 1810, examining the growth patterns in the otolith microstructure and analysing the length–weight relationship. Different growth models were taken into consideration to understand which one fits best when describing the growth patterns in *M. punctatum*. This species is considered a highly migrant lanternfish, able to perform wide vertical excursions, also reaching the surface at night [7,22–24]. Its population generally displays size stratification in the water column distribution, with a maximum abundance at 700,800 m and with smaller specimens in deeper waters [25]. *M. punctatum* is quite abundant in the central Mediterranean and plays an important role in the pelagic food web, being predated by several pelagic fish and cephalopods [4,7,22,26]. A better knowledge of the life traits of *M. punctatum* is essential for understanding the biology and ecology of this species, given that it has already been selected for biotechnological studies due to the interesting anticancer and antibacterial activities of its tissue [27].

### 2. Materials and Methods

#### 2.1. Sample Collection

The specimens examined in this study were found stranded and in good condition (fresh and often alive) along the Sicilian coast of the Strait of Messina (central Mediterranean Sea) (Figure 1), a location well known for the stranding of mesopelagic and deep fauna mainly due to the peculiar hydrodynamic features of this region [22]. Overall, 377 individual fresh-stranded specimens of *M. punctatum* were collected before sunrise to avoid weight loss due to dehydration (following [22]), and only undamaged individuals were used for this study.

#### 2.2. Length-Weight Relationship

Each individual was measured to the nearest 0.1 mm (standard length, SL) and weighed to the nearest 0.01 g (W). The gender was assessed through the macroscopic observation of gonads and by checking the secondary sexual characteristics (presence of supracaudal gland in males or infracaudal gland in females). The M-SL relationships were assessed for all individuals and for each gender (female and male), using the following equation:

\[ W = a (SL)^b \]

where \( W \) is the body weight, \( SL \) is the standard length of the fish and \( a \) is the value of the intercept of the regression line when the function is log-transformed and \( b \) is the regression coefficient, i.e., the slope of the log-transformed relation [28–30]. Fish growth
is isometric when \( b = 3 \); otherwise, it is negative or positive allometric when \( b < 3 \) and \( b > 3 \), respectively [30]. For each curve (male, female and general), the obtained regression coefficient \( b \) and the respective 95\% confident intervals were compared to the theoretical isometric growth coefficient \( b = 3 \) [31] through Student’s \( t \)-test (One Sample \( t \)-test; \( \alpha = 0.05 \)). In addition, the Welch Two Sample \( t \)-test was used to identify differences between male and female \( M-SL \) relationships, comparing the regression coefficients \( b_F \) and \( b_M \). The \( H_0 \) hypothesis \( (b_F = b_M) \) was accepted when no significant differences \( (p\text{-value} > 0.05) \) were found [32].

![Figure 1. Study area located in the Strait of Messina.](image)

2.3. Otolith Extraction and Preparation

The sagittal otoliths were removed from 185 fish, cleaned with water and a small brush and successively stored dry; each sample was assigned an identification code number.

Prior to otolith preparation, each sagitta was measured to the nearest 0.01 mm, recording the maximum distance from the anterior tip to the posterior edge (maximum length, OL) as well as the maximum distance between the dorsal and ventral margins (maximum height, OH), as described elsewhere [33,34]. Measurements were performed using a stereomicroscope (Carl Zeiss, model Discovery V.8, Milano, Italy) coupled with a camera (Axiocam 208 color, ZEISS) and the ZEN 3.1 blue edition (ZEISS) digital image processing software.

Otoliths were mounted on slides using Eukitt® mounting medium, and thin sagittal sections were obtained by a grinding/polishing machine (Remet LS2).

2.4. Otolith Readings, Increments’ Interpretation and Analysis

Otolith sections were examined using a light microscope ZEISS Axioscop2 coupled with a camera (Axiocam 208 color, ZEISS) and the ZEN 3.1 blue edition (ZEISS) digital image processing software using different magnifications to count the microincrements.

Microincrements were counted from the core to the otolith edge, according to [10,35], starting from the first distinguishable increment after the central primordium and annotating the number of increments for each otolith region: central (CZ), middle (MZ), and external zones (EZ). According to previous studies [10,11,36], this nomenclature is based on the particular features of the different regions in otolith sections and avoids
linking the otolith microstructure to life history traits. Indeed, according to other authors (e.g., [12,14,17], these otolith regions correspond to the larval zone (LZ), post-larval zone (PLZ) and post-metamorphic zone (PMZ), respectively.

Several papers (e.g., [14,16,18–20,37]) demonstrate that the microincrements in the otolith structure of lanternfish (Myctophidae) are formed daily; for this reason, we also assumed that the increments observed in the otoliths of *M. punctatum* are laid down daily.

Furthermore, following the methodology of [10], microincrements in each otolith zone (CZ, MZ, EZ) were counted three times. When the differences among these three counts exceeded 5% (i.e., standard error > 5, calculated on the three readings in each otolith zone), the otolith was discarded. Furthermore, seven otoliths were excluded because of unreadable patterns in the middle zone. When the standard error was <5, the readings were considered valid, and the mean value, calculated over the three counts in each otolith zone was considered.

To validate the microincrement readings, some polished sections (*n* = 10) of otoliths of *M. puctatum* were etched using a solution of 5% ethylene di-amine tetra acetate (EDTA), pH 7.5, buffered with KOH, for 120 s [38]. After etching, the sections were washed in water (for 3 min), dried and coated with gold. Subsequently, they were examined using a scanning electron microscope (SEM Zeiss EVO MA 10). This control analysis was performed to validate and verify the existence of growth patterns throughout the section and to avoid errors in microstructure interpretation and overestimation in ring counts because of the presence of visual artefacts [38,39].

### 2.5. Growth Models

Length-at-age data of *M. puctatum* were fitted into three of the most used growth models (von Bertalanffy, Gompertz and logistic models):

- Gompertz growth model [40]: $SL = L_\infty e^{(-e^{-k(t-t_0)})}$
- von Bertalanffy growth model [41]: $SL = L_\infty \left(1 - e^{(-k(t-t_0))}\right)$
- Logistic growth model [42,43]: $SL = L_\infty \left(1 + e^{(-k(t-t_0))}\right)^{-1}$

where *SL* is the standard length at age *t*, *L_\infty* is the theoretical asymptotic length, *t_0* is theoretical age when the body length is equal to 0, *k* is the growth rate at which *SL* approaches *L_\infty*, whereas *I* is the age at inflection point.

The multi model inference (MMI) approach [12,44–46] was used to compare these different growth models, with the aim of selecting the best one for this species. Comparison was carried out on all data, as well as for both sexes.

In this procedure, the definition of starting values is necessary to avoid convergence issues. Therefore, starting values for all model coefficients (*L_\infty*, *K*, *t_0* or *I*) were obtained using the “vbStarts” function in the FSA package v.0.8.24 [47], whereas the bootstrapping method, with 999 iterations, was used to calculate standard errors (“nlstools” package v. 1.02; [48]). The best performing model was selected on the basis of the small-sample bias-corrected form of Akaike’s information criterion (AICc), an estimator of prediction error, which assesses the quality of each model, comparing them and representing a tool for model selection [49,50]. The AICc value, delta AICc (ΔAICc) and AICc weight [47,49–53] were calculated through the “aictab” function (AICmodavg package v. 2.2-2; [54]). Generally, the model with lowest AICc value was considered the best. However, when the ΔAICc (difference between AICc of two models) was <2, the model with the highest AICc weight was selected. Finally, residual plots and visual model fit were investigated to validate the selected model.

To detect any differences among all best fitting models, the Welch Two Sample t-test ($\alpha = 0.05$) was used to compare the growth curves’ coefficients (*L_\infty*, *K*, *t_0* or *I*). The software packages R (v. 3.6.2) and R-studio (v.1.1.463; [55,56]) were used to perform statistical analysis and to generate models and graphs.
3. Results

The length frequency distribution of individuals of *M. punctatum* is given in Figure 2. Males (\(n = 165\)) were slightly more numerous than females (\(n = 155\)), and 57 were not assessed.

![Length frequency distribution by sex of the studied sample of Myctophum punctatum.](image)

The size of the individuals ranged between 20.3 and 73.7 mm SL (mean \(\pm\) standard deviation = 53.2 \(\pm\) 10.8), whereas the size ranges of males and females were 31.0–69.4 mm SL (mean \(\pm\) standard deviation = 51.7 \(\pm\) 7.9) and 31.6–73.7 mm SL (mean \(\pm\) standard deviation = 53.2 \(\pm\) 9.5), respectively. Individuals were more abundant within the size classes 45–60 mm SL (Figure 2).

Analysis of the length–weight relationship (Figure 3) showed that the growth of *M. punctatum* is also isometric (\(p\)-value > 0.05) when males and females were analysed separately, as demonstrated by the results of Student’s *t*-test (\(t_{\text{all samples}} = 1.9186, \text{df} = 2; t_{\text{males}} = -0.1456, \text{df} = 2; t_{\text{females}} = 1.9361, \text{df} = 2\)). Moreover, comparison between the regression coefficients calculated for *M*-SL relationships of females and males (\(b_F = 3.1211\) and \(b_M = 2.9888\), respectively) did not show significant differences, and the \(H_0\) hypothesis (\(b_F = b_M\)) was accepted (\(t = -1.336, \text{df} = 3.8427\)), supporting the hypothesis of absence of body shape dissimilarity between sexes.

The observation of microincrements under a light microscope (Figure 4) and scanning electron microscope (Figure 5) showed that otoliths of *M. punctatum* had the same features and structure compared to those of other species belonging to Myctophidae. The central zone (CZ) was made up of thin increments laid down around a central primordium (Figures 4a and 5a). Accessory primordia were sometimes observed after the metamorphic check. The MZ appeared to be darker than the other otolith zones, and its growth increments were larger and organised in thick bands (Figure 4a). The growth pattern of EZ was regular, and microincrements were more easily readable Figures 4b,c and 5b.

The microincrement readings were considered valid for 173 otoliths. Microincrement counts ranged from 32 to 48 (mean number of increments = 37.6; mean standard error = 1.69) in the CZ, 30 to 56 (mean number of increments = 44.3; mean standard error = 2.41) in the MZ, 36 to 384 (mean number of increments = 165.5; mean standard error = 2.91) in the EZ. Overall, total microincrements ranged between 106 and 469 (mean number of increments = 247.4; mean standard error = 3.09).
Figure 3. Length-weight relationship for total individuals (a), males and females (b) of *Myctophum punctatum*.

Using the starting values reported in Table 1, the results of length-at-age analysis suggest that the Gompertz model supported the data (lowest AICc and Delta AICc values in Table 2).

Table 1. Starting values of the growth models for all datasets and for each gender. $L_\infty$ = the theoretical asymptotic length, $t_0$ = theoretical age when the body length is equal to 0, $k$ = the growth rate at which SL approaches $L_\infty$ whereas I = the age at inflection point.

|         | $L_\infty$ | $k$     | $t_0/I$ |
|---------|------------|---------|---------|
| All     | 75         | 0.0644  | 120     |
| Females | 70         | 0.0872  | 160     |
| Males   | 75         | 0.1070  | 150     |
Table 2. Model selection based on AICc results for the general (all data) and gender data relative to the Gompertz, Von Bertalanffy (VBGM) and logistic models.

|     | K | AICc  | Delta_AICc | AICcWt | Cum. Wt |
|-----|---|-------|------------|--------|---------|
| All |   |       |            |        |         |
| Gompertz | 4 | 912.00 | 0          | 0.59   | 0.59    |
| VBGM   | 4 | 913.07 | 1.07       | 0.35   | 0.94    |
| Logistic | 4 | 916.45 | 4.45       | 0.06   | 1.00    |
| Female |   |       |            |        |         |
| Gompertz | 4 | 419.06 | 0.00       | 0.36   | 0.36    |
| VBGM   | 4 | 419.23 | 0.16       | 0.34   | 0.70    |
| Logistic | 4 | 419.45 | 0.38       | 0.30   | 1.00    |
| Male   |   |       |            |        |         |
| Logistic | 4 | 348.60 | 1.17       | 0.36   | 1.00    |
| VBGM   | 4 | 377.70 | 30.27      | 0.00   | 1.00    |

Figure 4. Sagittal section of an otolith of *Myctophum punctatum* observed by light microscope, showing the growth pattern and otolith zones; (a) otolith zones: CZ = central zone; MZ = middle zone; EZ = external zone; (b,c) microincrement pattern in two different areas of the EZ.
Figure 5. Sagittal section of an otolith of *Myctophum punctatum* observed by scanning electron microscope, showing the growth pattern in the central zone (CZ) and the particular of growth increments in the external zone (EZ) ((a,b), respectively).

The Gompertz parameters and their lower and upper confident intervals (LCI and UCI, respectively) are reported in Table 3, whereas the growth curves are shown in Figure 6. The parameters calculated using the entire dataset (all data) were as follows: $L_\infty = 74.79$, $k = 0.0084$ and $I = 139.60$, whereas the parameters estimated by sex were $L_\infty = 81.45$, $k = 0.0068$, $I = 143.90$ for females and $L_\infty = 75.03$, $k = 0.0077$, $I = 132.00$ for males. No significant differences among the three growth curves were observed (Table 4), indicating that the growth of *M. punctatum* was similar for both sexes.
Table 3. Results of the parameters of the best fitting models of all individual, females and males. Information includes $L_\infty$, $k$ and $I$ estimates, lower and upper 95% confidential interval (C.I.) and standard errors.

| Best Model Parameters | Parameters | Estimate | Lower 95% C.I. | Upper 95% C.I. | Std. Error |
|-----------------------|------------|----------|----------------|----------------|------------|
| All individuals       | $L_\infty$ | 74.79    | 70.86          | 79.71          | 2.28       |
|                       | $k$        | 0.0084   | 0.0073         | 0.0096         | 0.0006     |
| (Residual standard error: 3.326 on 70 degrees of freedom) | $I$ | 139.60 | 133.59 | 147.48 | 3.52 |
| Females               | $L_\infty$ | 81.45    | 72.71          | 99.00          | 6.31       |
| (Residual standard error: 3.676 on 73 degrees of freedom) | $k$ | 0.0068 | 0.0047 | 0.0091 | 0.0012 |
| Males                 | $L_\infty$ | 75.03    | 68.49          | 87.23          | 4.56       |
| (Residual standard error: 2.688 on 68 degrees of freedom) | $I$ | 143.90 | 130.77 | 175.08 | 9.00 |

Figure 6. Gompertz best-fitting growth curves of *Myctophum punctatum* for all individuals and separated by sex.

Table 4. t-test results of the growth curves’ coefficients ($L_\infty$, $K$, $t_0$ or $I$) of the age-at-length data between females, males and all individuals.

| Comparison          | Compared Parameters of Growth Curves |
|---------------------|--------------------------------------|
|                     | $L_\infty$ | $k$ | $I$ |
| Females vs. Males   | $t = 0.7877$ | $t = -0.4781$ | $t = 1.0343$ |
| df = 3.6094         | df = 3.9573 | df = 3.0716 |
| $p$-value = 0.4794  | $p$-value = 0.6578 | $p$-value = 0.3755 |
| $t = -0.2965$       | $t = 0.4055$ | $t = 0.7052$ |
| All vs. Males       | $t = -0.7929$ | df = 2.7942 | df = 3.1690 |
| df = 2.8298         | df = 3.7142 | $p$-value = 0.5290 |
| $t = 1.1380$        | $t = -1.0791$ | $t = 0.7055$ |
| Females vs. All     | $t = 2.4335$ | df = 2.9559 | df = 2.3717 |
| df = 2.4335         | df = 3.606 | $p$-value = 0.5434 |
| $p$-value = 0.3547  | $p$-value = 0.3606 | $p$-value = 0.6578 |

4. Discussion

This study investigated, for the first time, the age and growth of the myctophid *M. punctatum* through the analysis of the otolith microstructure and assessment of daily increments.

According to the results of the length–weight relationship, the growth of *M. punctatum* is isometric for both sexes. These findings confirmed the observations made in two previous
studies [33,57], where the isometric relationship between weight and length was observed in 82 and 35 individuals of *M. punctatum*, respectively, although no differences between sexes were tested. Although other authors have reported a positive or allometric growth in myctophids [33,34,57–60], isometric growth has also been observed in other lanternfish species from the same study area, such as *Benthosema glaciale*, *Ceratoscopelus madreensis*, *Diaphus holti*, *Diaphus rafinesquei*, *Electrona risso*, *Gonychthys coco*, *Lampanyctus pusillus*, *Notopterus elongatus* [33,34]. Similar results have been reported for other myctophids by [57] in the western Mediterranean, [11] in the Oman Sea, [60] and in the Atlantic Ocean, although several cases of positive or negative allometric growth have also been observed [12,33,34,57,58,60].

Analysis of otolith microstructure confirmed the general growth pattern observed in other lanternfishes, consisting of three main zones of increment deposition. The first one is a central zone (CZ), characterised by thin increments surrounding a primordium and usually associated with a larval period [14,17]. A metamorphic check, a dark discontinuity around the nucleus, marks the transition between the CZ and the middle zone (MZ), probably indicating the transition from larva to post-larva [14,17]. Otolith MZ has different features: darker growth increments, larger than the ones laid down in other otolith regions, usually associated with a post-larval period [14,17]. These features have been observed by several authors [9–11,14–17,19,59,61], who agreed that it is usually more difficult to read growth increments in MZ than in other otolith regions. The modification in the otolith microstructure in MZ may be related to an environmental shift due to larval migration towards deep waters [10,59,61,62], to perform transformation, a process which also involves changes in the fish physiology [63,64]. According to [61], the drastic environmental change (from warm upper water layers to cold mesopelagic waters) may contribute to alterations in the regular deposition of growth increments, causing the formation of MZ. Moreover, Reference [10] suggested that otolith microstructure in MZ reflects a period of somatic growth suppression during the non-migratory behaviour of transforming larvae and early juveniles.

The last region (external zone, EZ) is characterised by a regular growth pattern with readable microincrements, which became thinner towards the otolith margin. According to previous studies (e.g., [14,17,59]), the deposition of these increments in the otolith structure occurs after the metamorphosis of post-larvae.

In general, the growth pattern in the otolith microstructure of *M. punctatum* is quite regular, which might be related to its particular life traits, since *M. punctatum* is considered as a highly migrant species, performing wide vertical excursions [7,22,24]. Indeed, Reference [65] observed clearer daily increments in otoliths belonging to species characterised by a well-defined migration pattern.

Our reading values for CZ were slightly higher than counts made for otoliths of *Benthosema pterotum* [11,13,66], *Ceratoscopelus warmingii* [9] and *Lepidophanes guentheri* [14]. The average number of microincrements in otolith CZ of *M. punctatum* was also higher than the values reported by [12,13] for the congeneric species *Mycophum asperum* and *Mycophum spinosum*, respectively. Our data are similar to estimations provided for *Benthosema suborbitale* [14], *Diaphus kapalae* [16] and *Electrona antarctica* [17] (Table 5).

Available data on MZ counts in lanternfish otoliths suggest that the post-larval period has different durations depending on the species and on the geographical area, in relation to different life history traits, migratory behaviour, changes in habitat and diet or environmental parameters (e.g., temperature). Microincrements laid down within this otolith region are few in some species (*B. pterotum*, *D. kalapae*, *M. asperum*), and numerous in *Tarletonbeania crenularis* [10] (Table 5). According to our assessment, the complete transformation from larva to early juvenile in *M. punctatum* lasts 44.3 days on average.
Table 5. Number of increments in the otolith zones in studies regarding age, growth and microstructure of lanternfish species. When information on the increments’ range was lacking, the mean value was provided (*).

| Species                        | Number of Individuals | SL Range (mm) | Central Zone (CZ) or Larval Zone (LZ) | Middle Zone (MZ) or Post-Larval Zone (PLZ) | Maximum Number of Increments in the Whole Otolith | References |
|-------------------------------|-----------------------|---------------|--------------------------------------|---------------------------------------------|-------------------------------------------------|------------|
| Benthosema fibulatum          | 47                    | 15–80         | 30.8 *–38.4 *                         | -                                           | ~410                                             | [13]       |
| Benthosema pterotum           | 98                    | 14–48         | 28.0 *–31.6 *                         | -                                           | ~330                                             | [13]       |
| Benthosema pterotum           | 139                   | 2.6–30.0      | 11–26                                | 4–11                                         | -                                                | [66]       |
| Benthosema suborbitale        | 35                    | 16.60–39.49   | 22–32                                | 8–22                                         | 315                                              | [11]       |
| Ceratoscopelus warmingii      | 178                   | 11–33         | 30–50                                | 13–34                                         | 325                                              | [14]       |
| Diaphus diademophilus         | 2                     | 36–40         | 29.3 *                                | -                                            | 421                                              | [13]       |
| Diaphus dumeridi              | 210                   | 12–63         | 20–40                                | -                                            | 362                                              | [14]       |
| Diaphus kapalae               | 95                    | 11–15         | 31–48                                | 10–12                                         | 77                                               | [16]       |
| Electrona antarctica          | 117                   | 40–103        | 27–48                                | 38–60                                         | 1355                                             | [17]       |
| Lampanyctus sp.               | 7                     | 17–67         | 26.0 *                                | -                                            | 250                                              | [13]       |
| Lepidophanes guentheri        | 280                   | 14–65         | 20–34                                | 15–40                                         | 439                                              | [14]       |
| Myctophum asperum             | 52                    | 58–82         | 30.4 *                                | 10.3 *                                        | 440                                              | [12]       |
| Myctophum nitidulum           | 45                    | 30–79         | 33–43                                | 20–35                                         | -                                                | [36]       |
| Myctophum punctatum           | 176                   | 20.3–73.7     | 32–48                                | 30–56                                         | 384                                              | Present paper |
| Myctophum spinosum            | 15                    | 67–81         | 34.0 *                                | -                                            | 302                                              | [13]       |
| Notoscopelus resplendens      | 20                    | -             | 35 *                                  | 23 *                                          | -                                                | [58]       |
| Symblophorus californiensis   | 93                    | 23.0–107.3    | 30–64                                | 23–61                                         | 541                                              | [9]        |
| Symbolophorus evermanni       | 16                    | 36–86         | 36.3 *                                | -                                            | 249                                              | [13]       |
| Tarletonbeania crenularis      | 102                   | 4.6–78.0      | 51–102                               | 80–139                                         | 504                                              | [10]       |

Analysis of daily growth by the examination of the sagittal otolith showed that *M. punctatum* can live more than one year (about 13 months); the maximum number of increments counted in otoliths was equal to 384, within the considered SL range (20.3–73.7 mm). This estimate is coherent with results provided by most studies that focused on the age and growth of lanternfish species through the analysis of the daily deposition of otolith microincrements (Table 5).

The use of the multi-model inference (MMI) approach [44–46,59] allowed for the selection of the Gompertz model as the best-fitting growth equation to describe the growth of *M. punctatum*. A similar study on the congeneric species *M. asperum* from the South China Sea indicated that the von Bertalanffy model was more suitable to define the growth of this lanternfish. However, some authors [18,37] found that the growth in *M. asperum* best fitted the Gompertz model. The Gompertz model is a sigmoid-shaped growth function which better fits fish with a lower initial growth rate than the von Bertalanffy model. In the case of *M. punctatum*, this may be related to the fact that juvenile individuals of this species seem to exhibit a different migratory behaviour than adults. Indeed, they usually occur in deeper waters, whereas larger specimens migrate up to the surface [25]. The different environmental conditions at deeper water layers (e.g., lower temperature) may determine a slower growth rate in juveniles/postlarvae. Indeed, transforming larvae and early juvenile stages of many lanternfish species display a non-migratory behaviour, remaining in the mesopelagic environment [10,67].

In our study, the estimated value of the asymptotic maximum body length in females was slightly higher than that in males. In many fish species, males mature earlier, attaining a smaller asymptotic size and having higher adult mortality rates than females [68]. Consequently, it is possible that this difference is for this reason, although this explanation needs the support of further studies on the relationship between the somatic growth and
reproductive biology of *M. punctatum*. Moreover, *L*∞ values for all specimens and sexes were slightly lower than the estimations provided by [12,18,37] for the congeneric species *M. asperum*.

In conclusion, this study analysed the age and growth of *M. punctatum* through the observation of otolith microstructure, providing data on its lifespan and on the best fitting growth model for this species. These results improve the poor knowledge of this species, although more data should be collected to better understand the influences of environmental parameters on the daily deposition of otolith microincrements and on the duration of larval and postlarval stages. In addition, more information is needed on other aspects of the life history of this lanternfish (maturity, reproduction cycle, vertical migrations, etc.) to fill the knowledge gaps in its biology and ecology.

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