**Reef fish growth dataset: a dataset of annual otolith sagittal growth for 51 reef fish from French Polynesia**

Fabien Morat 1, 2\*, Jérémy Wicquart 1, 2\*, Guillemette de Sinéty 1, 2, Jean Bienvenu 1, 2, Simon J. Brandl 3, Jérémy Carlot 1, 2, Jordan M.Casey 1, 2, Alexandre Mercière1, 2, Pauline Fey 4, René Galzin 1, 2, Yves Letourneur 4,2, Pierre Sasal 1, 2, Nina M. D. Schiettekatte 1, 2, Jason Vii 1, 2, Valériano Parravicini 1, 2

Corresponding author e-mail: [fabien.morat@univ-perp.fr](mailto:fabien.morat@univ-perp.fr); [valeriano.parravicini@ephe.psl.eu](mailto:valeriano.parravicini@ephe.psl.eu)

Fabien Morat and Jérémy Wicquart equally contributed to the paper and share first authorship.

*1 PSL Université Paris: EPHE-UPVD-CNRS, USR 3278 CRIOBE, Université de Perpignan, 52 Avenue Paul Alduy, 66860 Perpignan Cedex, France*

*2 Laboratoire d’Excellence « CORAIL »*

*3 Department of Biological Sciences, Simon Fraser University, Burnaby, BC V5A 1S6, Canada*

*4 Université de la Nouvelle-Calédonie, Institut ISEA, Nouméa Cedex, New Caledonia*

*Orcid numbers :*

Fabien : <https://orcid.org/0000-0002-9925-1437>

J Wicquart : <https://orcid.org/0000-0003-3462-3188>

Simon : <https://orcid.org/0000-0002-6649-2496>

J Carlot : <https://orcid.org/0000-0003-0887-8005>

Jordan : <https://orcid.org/0000-0002-2434-7207>

Yves : <https://orcid.org/0000-0003-3157-1976>

Nina : <https://orcid.org/0000-0002-1925-3484>

Vale : <https://orcid.org/0000-0002-3408-1625>

Pierre : <https://orcid.org/0000-0002-2371-6912>

**Introduction**

The overexploitation of resources and climate change can both significantly alter the structure and functioning of marine ecosystems (Dulvy et al. 2000, Jackson et al. 2001, Hoegh-Guldberg and Bruno 2010). Understanding how species will respond to these major stressors may benefit from the assessment of their vulnerability (William et al. 2007, Graham et al. 2011). This requires high-resolution data on the life history and ecological traits of species (Dulvy et al. 2000, 2003, Cheung et al. 2005). Somatic growth, i.e. the increment in body mass across time is an important ecological trait, which is pivotal for the assessment of physiological as well as population to ecosystem-level processes. These traits and particularly the growth parameters of fish are important for the population dynamic understanding and for stock managements. However, somatic growth has been assessed for a small number of commercial species while this parameter remains unknown for the great majority of coral reef associated species that are targeted mainly by subsistence fishing.

Somatic growth is an essential parameters to quantify ecosystem processes such as the production of biomass (Depczynski et al. 2007, Morais and Bellwood 2019). Moreover, the rate of somatic growth is directly correlated to the energetic demand of organisms, their metabolism the influence they may have on important ecological processes such as the nutrients cycling. As such, the rate of somatic growth is one of the basic information that feeds bioenergetic models, one of the main tools to quantify fluxes at individual to the ecosystem level (e.g., Schreck and Moyle 1990, Schindler and Eby 1997, Frost et al. 2006).

Fish growth parameters can be estimate form several approaches but those linking age to body size are the main used. Hard structures such as scales, vertebrae, fin spines cleithra, opercula and otoliths presents growth increments used for age estimations (Campana 2001). For teleost fish, the age is traditionally estimated in most of case from otoliths. Otoliths are calcified structure of the inner ear growing with the deposition of successive calcium carbonate layers which respond to both circadian and seasonal rhythms (Pannella 1971, Panfili et al. 2002, Jolivet et al. 2008, 2013). Fish growth parameters can be obtained from various models such as Gompertz, Logistic, Power or Von Bertalanffy (the most used). Growth can be modelled from large sampling with number fish representative of the complete size range of studied species. However, this kind of analyses are extremely time consuming and data are generally unpublished or available only for commercial species. However, in most of case, sample size is small due to difficulties of catches, or to the rarity of fish by species in multi-species assemblage as observed in coral reef. In this context, another approach consist to applied a back-calculation model to estimate size at previous age prior to model the growth as suggested by Vigliola and Meekan (2009).

Our goal is to provide data of back-calculation of size at age for 51 species (848 individuals) of coral reef fish collected in different islands of French Polynesia. We provide only back-calculation data and not model data in order to give the model choice to user in function of their scientific questions. We emphasize that these data can also be used to estimate length weight relationships.

**Metadata**

**Class I. Data set descriptors**

1. **Data set identity**

**Title:** Reef fish growth dataset: a dataset of annual otolith sagittal growth for 51 reef fish from French Polynesia

1. **Data set identification code**

size\_at\_age\_coral\_reef\_fishes\_data.csv

1. **Data set description**
2. **Principal Investigators**

Dr. Valeriano Parravicini

*PSL Université Paris: EPHE-UPVD-CNRS, USR 3278 CRIOBE, Université de Perpignan, 52 Avenue Paul Alduy, 66860 Perpignan Cedex, France, Laboratoire d’Excellence « CORAIL »*

Dr. Fabien Morat

*PSL Université Paris: EPHE-UPVD-CNRS, USR 3278 CRIOBE, Université de Perpignan, 52 Avenue Paul Alduy, 66860 Perpignan Cedex, France, Laboratoire d’Excellence « CORAIL »*

1. **Abstract**

Somatic growth, i.e. the increment in body mass across time is an important ecological trait, which is pivotal for the assessment of physiological as well as population to ecosystem-level processes. Indeed, the rate of somatic growth is directly correlated to the energetic demand of organisms, their metabolism the influence they may have on important ecological processes such as the nutrients cycling. As such, the rate of somatic growth is one of the basic information that feeds bioenergetic models, one of the main tools to quantify fluxes at individual to the ecosystem level. However, for marine fishes this information is available mainly for those species targeted by commercial fisheries and aquaculture often limiting our capacity to perform analysis at community level, on a large number of species in coastal areas. This is partly due to the fact that somatic growth can hardly be estimated in aquaria due to a general loss of weight of individuals kept in captivity. The analysis of the sagittal growth of fish otolith, a calcium carbonate structure in the inner ear, has shown as a powerful tool to estimate individual growth. However, this type of data is rarely available because of the extremely time-consuming nature of the otolith processing. This is especially true for coral reef fishes whose commercial importance mainly relies on local subsistence fisheries and whose large diversity often discourage assessments over a large number of species. Here we report information on the sagittal otolith growth and back-calculation of fish size at age of 848 individuals belonging to 51 species of coral reef fishes. Individuals were caught in French Polynesia in different islands belonging to different archipelagoes and subjected to different temperatures (Moorea, Mataiva, Hao and Mangareva). No copyright or proprietary restrictions are associated with the use of this data set other than citation of this Data Paper.

1. **Key words**

French Polynesia, coral reef, fish, otolith, back-calculation

**Class II. Research origin descriptors**

1. **“Overall” project description**
2. **Identity**

Titre du projet: REEF SERVICES

1. **Originator(s)**

Valeriano Parravicini

*PSL Université Paris: EPHE-UPVD-CNRS, USR 3278 CRIOBE, Université de Perpignan, 52 Avenue Paul Alduy, 66860 Perpignan Cedex, France, Laboratoire d’Excellence « CORAIL »*

1. **Period of study**

The project started in March 2016 with the sampling for the incentive project NECTAR (Funding by the LABEX CORAIL) and continued by the REEF SERVICE project since 2017.

The research started in March 2016 and finished in November 2018.

1. **Objectives**

Reef services aims to collect important ecological data to understand how climate change is impacting ecosystem processes and key services (e.g. food provisioning, coastal protection) to humans.

1. **Abstract**

Climate change has already triggered profound impacts of ecosystems that go beyond its effect on biodiversity. Concerns are emerging about the potential for impacted systems to deliver key services to humans. In the marine realm, coral reefs host the highest marine biodiversity and provide crucial services (e.g. edible biomass) sustaining 500 million people worldwide. However, reefs are degrading due to increasing frequencies of climate-induced (e.g. due to El Niño) coral bleaching events. These acute disturbances occur against the backdrop of chronic stress (e.g. ocean acidification, human activities) and already produced devastating effects in 1998 and 2010. Since 1998 a significant body of literature has been produced. The mechanisms associating climatic extremes with coral die-off are now clear, but we still have no idea on the consequences for the services sustaining human populations even they are expected to be dramatic. Mathematical models suggest that reduced habitat complexity after bleaching impacts small-bodied fish and that this effect propagates through the food-web toward species of high commercial value. The gap of knowledge on the effects of climate change on services is due to a lack of assessments, on a large set of species, of their contribution to ecosystem services. This is a huge concern considering the millions of people depending on coral reefs. Here we aim at partially filling these gaps testing how extreme climatic event can impact the productivity of coral reef ecosystem.

1. **Sources of founding**

The project was supported by the BNP PARIBAS foundation (REEF SERVICES Project); the French national Agency for research (ANR-17-CE32-006); the Fondation de France; Make our Planet Great Again (Grant/Award number: mopga-pdf-0000000144); “Direction des ressources marines” (convention number 09419); and the French Polynesia.

1. **“Specific subproject” description**
2. **Site description**
3. Site type
4. Geography

The sites sampled during this study covered different island in French Polynesia.

1. Habitat

Fish were collected in lagoon and/or in the outer slope of the reefs.

1. Climate

All the French Polynesia is in tropical climate. The see surface temperature varied from the East to West and from the North to South. The table xx show the sea surface temperature (SST) recorded around each island.

1. **Experimental or sampling design**
2. Design characteristics

Fish from Moorea (Society Island) and Nuku Hiva (Marquesas) were collected using spear gun or clove oil depending on size; those from Hao (Tuamotu) and Mangareva (Gambier) were collected by spearfishing; those from Tuamotu Archipelago were bought on the fish market of Tahiti.

1. Data collection period, frequency etc.

Fish were collected during several sampling missions. Fish from Moorea were collected in March 2016 and November 2018, fish from Marquesas in March 2017, those from Gambier in June 2018.

1. **Research methods**
2. Field/Laboratory

In the laboratory, total fish length (TL) were measured to the nearest millimeter and pairs of sagittae (largest otolith of the fish inner ear) were extracted, cleaned with distilled water, dried and stored in microtubes.

For each species, otolith were cut transversely, using a diamond disc saw (Presi Mecatome T210) to obtain a section of 500 µm. Sections were then fixed on a glass side with a thermoplastic glue (Crystalbond TM). Sections of small otolith were obtain by sanding both side. Otolith were sanded with abrasive disc of decreasing grain size (2 400, 1 200 grains cm-²) and polished with 0.25 µm diameter diamonds suspension in order to be closest to the nucleus. All sections were photographed under Leica DM750 light microscope with Leica ICC50 HD microscope camera and LAS software (Leia Microsystems). When section were too large, multiple photographs were taken and assembled in one with Photostitch software (Canon).

For each species, a reading transect was chosen and distances between annual growth increments were measured with Image J software. This procedure was done twice by two readers in order to limit observer bias on age estimation. When the coefficient of variation (Panfili et al. 2002) between observers was greater than 5 % a common reading was assessed. The measurements realized by the two readers were averaged for each section.

The back-calculation procedure, proposed by Vigliola and Meekan (2009), was used to estimate the fish length at previous ages. This method requires to examine the shape of the relationship (allometric or isometric) between the length at capture (Lcpt) and the radius of otolith at capture of all samples (Rcpt). In case of isometry (eq. 1) the fish size at otolith formation (a) was calculated from equation 2 although in case of allometry (eq. 3) it was calculated from equation 4. Back-calculation Modified Fry (MF) model (eq. 5), proposed by Vigliola et al. (2000) was carry out for each individual.

Isometry: (eq. 1) and (eq. 2)

Allometry: (eq. 3) and (eq. 4)

MF model: (eq. 5)

Where Li and Ri are the fish length and otolith radius at age *i,* and L0p and R0p are the fish size and radius of otolith at hatching. The L0p parameter was given in table I.

Table I. Fish size at hatching (L0p) for each species studied in this study. Level referred to the taxonomic level where L0p was found. When it was possible L0p from different studies were averaged.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Species** | **Family** | **Lop (mm)** | **Level** | **Reference** |
| *Abudefduf sexfasciatus* (Lacepède, 1801) | Pomacentridae | 2.65 | Species | Shadrin and Emel’yanova (2007) |
| *Acanthurus achilles* Shaw, 1803 | Acanthuridae | 1.70 | Genus | McCormick (1999) |
| *Acanthurus lineatus* (Linnaeus, 1758) | Acanthuridae | 1.70 | Genus | McCormick (1999) |
| *Acanthurus nigricans* (Linnaeus, 1758) | Acanthuridae | 1.70 | Genus | McCormick (1999) |
| *Acanthurus pyroferus* Kittlitz, 1834 | Acanthuridae | 1.70 | Genus | McCormick (1999) |
| *Acanthurus triostegus* (Linnaeus, 1758) | Acanthuridae | 1.70 | Species | McCormick (1999) |
| *Balistapus undulatus* Tilesius, 1820 | Balistidae | 1.80 | Family | Leis and Carson-Ewart (2000) |
| *Caranx melampygus,* Cuvier, 1833 | Carangidae | 3.15 | Family | Leis and Carson-Ewart (2000) |
| *Centropyge bispinosa* (Günther, 1860) | Pomacanthidae | 1.95 | Family | Leis and Carson-Ewart (2000) |
| *Centropyge flavissima* (Cuvier, 1831) | Pomacanthidae | 1.95 | Family | Leis and Carson-Ewart (2000) |
| *Cephalopholis argus* Schneider, 1801 | Serranidae | 1.90 | Family | Leis and Carson-Ewart (2000) |
| *Cephalopholis urodeta* (Forster, 1801) | Serranidae | 1.90 | Family | Leis and Carson-Ewart (2000) |
| *Chaetodon citrinellus* Cuvier, 1831 | Chaetodontidae | 1.45 | Genus | Leis and Carson-Ewart (2000) |
| *Chaetodon ornatissimus* Cuvier, 1831 | Chaetodontidae | 1.45 | Genus | Leis and Carson-Ewart (2000) |
| *Cheilinus chlorourus* (Bloch, 1761) | Labridae | 1.97 | Genus | Hutapea and Slamet (2006) |
| *Chlorurus spilurus* (Valenciennes, 1840) | Scaridae | 1.65 | Family | Leis and Carson-Ewart (2000) |
| *Chromis iomelas* Jordan & Seale, 1906 | Pomacentridae | 3.05 | Family | Leis and Carson-Ewart (2000) |
| *Chromis viridis* (Cuvier, 1830) | Pomacentridae | 3.05 | Family | Leis and Carson-Ewart (2000) |
| *Ctenochaetus marginatus* (Valenciennes, 1835) | Acanthuridae | 1.70 | Family | Leis and Carson-Ewart (2000) |
| *Ctenochaetus striatus* (Quoy & Gaimard, 1825) | Acanthuridae | 1.70 | Family | Leis and Carson-Ewart (2000) |
| *Dascyllus aruanus* (Linnaeus, 1758) | Pomacentridae | 2.10 | Genus | Emel’yanova et al. (2009) |
| *Dascyllus flavicaudus* Randall & Allen, 1977 | Pomacentridae | 2.10 | Genus | Emel’yanova et al. (2009) |
| *Epibulus insidiator* (Pallas, 1770) | Labridae | 2.10 | Family | Leis and Carson-Ewart (2000) |
| *Epinephelus fasciatus* (Forsskål, 1775) | Serranidae | 1.50 | Species | Kawabe and Kohno (2009) |
| *Epinephelus hexagonatus* (Forster, 1801) | Serranidae | 1.70 | Genus | Ukawa et al. (1966), Hussain and Higuchi (1980), Lim (1993), Colin et al. (1996), Duray et al. (1996, 1997), James et al. (1997), Glamuzina et al. (1998), Glamuzina et al. (2000), Leu et al. (2005), Jagadis et al. (2006), Yoseda et al. (2006), Ma et al. (2013) |
| *Epinephelus merra* Bloch, 1793 | Serranidae | 1.50 | Species | Jagadis et al. (2006) |
| *Epinephelus polyphekadion* (Bleeker, 1849) | Serranidae | 1.65 | Species | James et al. (1997) |
| *Gnathodentex aureolineatus* (Lacepède, 1802) | Lethrinidae | 1.55 | Family | Leis and Carson-Ewart (2000) |
| *Gymnosarda unicolor* (Rüppell, 1836) | Scombridae | 2.75 | Family | Leis and Carson-Ewart (2000) |
| *Halichoeres trimaculatus* (Quoy & Gaimard, 1834) | Labridae | 1.58 | Genus | Kimura and Kiriyama (1993) |
| *Lutjanus fulvus* (Forster, 1801) | Lutjanidae | 1.83 | Genus | Suzuki and Hioki (1979) |
| *Lutjanus gibbus* (Forsskål, 1775) | Lutjanidae | 1.83 | Genus | Suzuki and Hioki (1979) |
| *Lutjanus kasmira* (Forsskål, 1775) | Lutjanidae | 1.83 | Species | Suzuki and Hioki (1979) |
| *Monotaxis grandoculis* (Forsskål, 1775) | Lethrinidae | 1.55 | Family | Leis and Carson-Ewart (2000) |
| *Mulloidichthys flavolineatus* (Lacepède, 1801) | Mullidae | 2.50 | Family | Leis and Carson-Ewart (2000) |
| *Myripristis berndti* Jordan & Evermann, 1903 | Holocentridae | 1.80 | Family | Leis and Carson-Ewart (2000) |
| *Naso lituratus* (Forster, 1801) | Acanthuridae | 1.70 | Family | Leis and Carson-Ewart (2000) |
| *Naso unicornis* (Forsskål, 1775) | Acanthuridae | 1.70 | Family | Leis and Carson-Ewart (2000) |
| *Odonus niger* (Rüppell, 1836) | Balistidae | 1.80 | Family | Leis and Carson-Ewart (2000) |
| *Ostorhinchus angustatus* (Smith & Radcliffe, 1911) | Apogonidae | 4.25 | Family | Leis and Carson-Ewart (2000) |
| *Ostorhinchus apogonoides* (Bleeker, 1856) | Apogonidae | 4.25 | Family | Leis and Carson-Ewart (2000) |
| *Parupeneus barberinus* (Lacepède, 1801) | Mullidae | 1.95 | Genus | Pavlov et al. (2011) |
| *Plectropomus laevis* (Lacepède, 1801) | Serranidae | 1.62 | Genus | Masuma et al. (1993) |
| *Pristiapogon taeniopterus* (Bennett, 1836) | Apogonidae | 4.25 | Family | Leis and Carson-Ewart (2000) |
| *Sargocentron microstoma* (Günther, 1860) | Holocentridae | 1.80 | Family | Leis and Carson-Ewart (2000) |
| *Scarus psittacus* Forsskål, 1775 | Scaridae | 1.65 | Family | Leis and Carson-Ewart (2000) |
| *Siganus argenteus* (Quoy & Gaimard, 1825) | Siganidae | 2.02 | Genus | May et al. (1974), Popper et al. (1976), Bryan and Madraisau (1977), Hara et al. (1986) |
| *Siganus spinus* (Linnaeus, 1758) | Siganidae | 2.02 | Genus | May et al. (1974), Popper et al. (1976), Bryan and Madraisau (1977), Hara et al. (1986) |
| *Stegastes albifasciatus* (Schlegel & Müller, 1839) | Pomacentridae | 3.05 | Family | Leis and Carson-Ewart (2000) |
| *Stegastes nigricans* (Lacepède, 1802) | Pomacentridae | 3.05 | Family | Leis and Carson-Ewart (2000) |
| *Zebrasoma scopas* (Cuvier, 1829) | Acanthuridae | 1.70 | Family | Leis and Carson-Ewart (2000) |

1. Taxonomy and systematics

Fish were identified using Bacchet et al. (2006) and Moore and Colas (2016). Families and validity of fish name were verified using the world register of marine species web site (<http://www.marinespecies.org/index.php>).

1. Permit history

Sampling collection is permit by the French Polynesia government (Authorization N°:681MCE/ENV)

1. **Project personnel**

This work was conducted by FM, JW and VP. Fish collection on the field was made by FM, SJB, JC, JMC, PF, RG, AM, YL, PS, NMDS, VP. Otoliths analysis were made by FM, JW, GdS, JB. Funds were get by VP, PS, JMC. Statistical analyses were conducted by JW, NMDS. Temperature data were compiled by JV from DATA SOURCES DE TEMPERATURE. Sampling maps were made by JV. All authors have contributed to the paper writing.

**Class III. Data set status and accessibility**

1. **Status**
2. **Latest update**

July 2019

1. **Latest archive date:**

July 2019

1. **Accessibility**
2. **Storage location and medium**

**Data where linked to this data paper and otolith slides were storage in the CRIOBE in Perpignan.**

1. **Contact person(s)**

Fabien Morat ([fabien.morat@univ-perp.fr](mailto:fabien.morat@univ-perp.fr)) and Valeriano Parravicini ([valeriano.parravicini@ephe.psl.eu](mailto:valeriano.parravicini@ephe.psl.eu))

1. **Copyright restrictions**

No copyright restriction

1. **Proprietary restrictions**

None. When using the dataset, we request the users to cite this data paper.

1. **Costs: None**

**Class IV. Data structural descriptors**

1. **Data set file**
2. **Identity**: size\_at\_age\_coral\_reef\_fishes\_data.csv
3. **Size**: 950 Kb
4. **Format and storage mode**: Comma-separated values, no compression
5. **Header information**: The header row indicates variable names as described in Table II (see part IV.B).
6. **Variable information**
   1. **Variable identity**: see Table II
   2. **Variable definition**: see Table II
   3. **Units of measurement**: see Table II
   4. **Data type**
      1. **Storage type**: see Table II
      2. **List and definition of variable codes**: None.
      3. **Range for numeric values**: see Table II
      4. **Missing values codes**:
      5. **Precision**:
   5. **Data format**

Table II. Description of the variables included in the dataset file

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Column** | **Variable identity** | **Variable definition** | **Unit** | **Storage type** | **Range** |
| 1 | Family | Family names according to Fishbase (https://www.fishbase.de/search.php) | - | Factor | - |
| 2 | Genus | Genus names according to Fishbase (https://www.fishbase.de/search.php) | - | Factor | - |
| 3 | Species | Species names according to Fishbase (https://www.fishbase.de/search.php) | - | Factor | - |
| 4 | ID | Unique code identifying each individual | - | Factor | - |
| 5 | Agei | Age *i* | years | Integer | 0 - 30 |
| 6 | Ri | Otolith radius at age *i* | mm | Numeric | 0 - 3.784 |
| 7 | Agecpt | Age at capture | years | Integer | 0 - 30 |
| 8 | Rcpt | Otolith radius at capture | mm | Numeric | 0.152 - 3.859 |
| 9 | Lcpt | Total length at capture | mm | Numeric | 28.11 - 984.69 |
| 10 | L0p | Total length at hatching | mm | Numeric | 1.45 - 4.25 |
| 11 | R0p | Otolith radius at hatching | mm | Numeric | 0.012 - 0.086 |
| 12 | Li | Total length at age *i* | mm | Numeric | 1.45 - 949.576 |
| 13 | Biomass | Wet body mass at capture | g | Numeric | 0.4 - 12950 |
| 14 | Location | Island or archipelago of the sampling | - | Factor | - |
| 15 | Observer | Name of the person who made the reading of the otolith | - | Factor | - |

1. **Data anomalies**

NA in the dataset indicates missing data. Missing values are present in the variables ‘Ri’ (366) and ‘Biomass’ (603). For variable ‘Ri’ missing values correspond to individuals for whom it has not been possible to estimate the radius at hatching on photographs. For variable ‘Biomass’ missing values are due to lack of measurement during sampling.

**References**

Bacchet, P., T. Zysman, and Y. Lefèvre. 2006. Guide des poissons de Tahiti et ses îles. Au vent des îles.

Bryan, P. G., and B. B. Madraisau. 1977. Larval rearing and development of Siganus lineatus (Pisces: Siganidae) from hatching through metamorphosis. Aquaculture **10**:243-252.

Campana, S. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. Journal of Fish Biology **59**:197-242.

Cheung, W. W., T. J. Pitcher, and D. Pauly. 2005. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. Biological conservation **124**:97-111.

Colin, P., C. Koenig, and W. Laroche. 1996. Development from egg to juvenile of the red grouper (Epinephelus morio)(Pisces: Serranidae) in the laboratory. Pages 399-414 *in* Biology, fisheries and culture of tropical groupers and snappers. ICLARM Conf. Proc.

Depczynski, M., C. J. Fulton, M. J. Marnane, and D. R. Bellwood. 2007. Life history patterns shape energy allocation among fishes on coral reefs. Oecologia **153**:111-120.

Dulvy, N. K., J. D. Metcalfe, J. Glanville, M. G. Pawson, and J. D. Reynolds. 2000. Fishery stability, local extinctions, and shifts in community structure in skates. Conservation Biology **14**:283-293.

Dulvy, N. K., Y. Sadovy, and J. D. Reynolds. 2003. Extinction vulnerability in marine populations. Fish and Fisheries **4**:25-64.

Duray, M. N., C. B. Estudillo, and L. G. Alpasan. 1996. The effect of background color and rotifer density on rotifer intake, growth and survival of the grouper (Epinephelus suillus) larvae. Aquaculture **146**:217-224.

Duray, M. N., C. B. Estudillo, and L. G. Alpasan. 1997. Larval rearing of the grouper Epinephelus suillus under laboratory conditions. Aquaculture **150**:63-76.

Emel’yanova, N., D. Pavlov, and L. Thuan. 2009. Hormonal stimulation of maturation and ovulation, gamete morphology, and raising of larvae in Dascyllus trimaculatus (Pomacentridae). Journal of ichthyology **49**:249-263.

Frost, P. C., J. P. Benstead, W. F. Cross, H. Hillebrand, J. H. Larson, M. A. Xenopoulos, and T. Yoshida. 2006. Threshold elemental ratios of carbon and phosphorus in aquatic consumers. Ecology Letters **9**:774-779.

Glamuzina, B., N. Glavic, P. Tutman, V. Kozul, and B. Skaramuca. 2000. Egg and early larval development of laboratory reared goldblotch grouper, Epinephelus costae (Steindachner, 1878)(Pisces, Serranidae). Scientia Marina **64**:341-345.

Glamuzina, B., B. Skaramuca, N. Glavic, V. Kozvul, J. Dulcic, and M. Kraljevic. 1998. Egg and early larval development of laboratory reared dusky grouper, Epinephelus marginatus (Lowe, 1834)(Picies, Serranidae). Scientia Marina **62**:373-378.

Graham, N. A. J., P. Chabanet, R. D. Evans, S. Jennings, Y. Letourneur, M. Aaron MacNeil, T. R. McClanahan, M. C. Öhman, N. V. C. Polunin, and S. K. Wilson. 2011. Extinction vulnerability of coral reef fishes. Ecology Letters **14**:341-348.

Hara, S., M. N. Duray, M. Parazo, and Y. Taki. 1986. Year-round spawning and seed production of the rabbitfish, Siganus guttatus. Aquaculture **59**:259-272.

Hoegh-Guldberg, O., and J. F. Bruno. 2010. The Impact of Climate Change on the World’s Marine Ecosystems. Science **328**:1523-1528.

Hussain, N. A., and M. Higuchi. 1980. Larval rearing and development of the brown spotted grouper, Epinephelus tauvina (Forskål). Aquaculture **19**:339-350.

Hutapea, J. H., and B. Slamet. 2006. MORPHOLOGICAL DEVELOPMENT OF Napoleon WRASSE, Cheilinus undulatus LARVAE. Indonesian Aquaculture Journal **1**:145-151.

Jackson, J. B. C., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. J. Bourque, R. H. Bradbury, R. Cooke, J. Erlandson, J. A. Estes, T. P. Hughes, S. Kidwell, C. B. Lange, H. S. Lenihan, J. M. Pandolfi, C. H. Peterson, R. S. Steneck, M. J. Tegner, and R. R. Warner. 2001. Historical Overfishing and the Recent Collapse of Coastal Ecosystems. Science **293**:629-637.

Jagadis, I., B. Ignatius, D. Kandasami, and M. A. Khan. 2006. Embryonic and larval development of honeycomb grouper Epinephelus merra Bloch. Aquaculture Research **37**:1140-1145.

James, C., S. Al‐Thobaiti, B. Rasem, and M. Carlos. 1997. Breeding and larval rearing of the camouflage grouper Epinephelus polyphekadion (Bleeker) in the hypersaline waters of the Red Sea coast of Saudi Arabia. Aquaculture Research **28**:671-681.

Jolivet, A., J.-F. Bardeau, R. Fablet, Y.-M. Paulet, and H. de Pontual. 2013. How do the organic and mineral fractions drive the opacity of fish otoliths? Insights using Raman microspectrometry. Canadian Journal of Fisheries and Aquatic Sciences **70**:711-719.

Jolivet, A., J. Bardeau, R. Fablet, Y. Paulet, and H. d. Pontual. 2008. Understanding otolith biomineralization processes: new insights into mircoscale spatial distribution of organic and mineral fractions from Raman microspectrometry. Anal Bioanal Chem **392**:551-560.

Kawabe, K., and H. Kohno. 2009. Morphological development of larval and juvenile blacktip grouper, Epinephelus fasciatus. Fisheries Science **75**:1239-1251.

Kimura, S., and T. Kiriyama. 1993. Development of eggs, larvae and juveniles of the labrid fish, Halichoeres poecilopterus, reared in the laboratory. Japanese Journal of Ichthyology **39**:371-377.

Leis, J. M., and B. M. Carson-Ewart. 2000. The larvae of Indo-Pacific coastal fishes: an identification guide to marine fish larvae. Brill.

Leu, M.-Y., C.-H. Liou, and L.-S. Fang. 2005. Embryonic and larval development of the malabar grouper, Epinephelus malabaricus (Pisces: Serranidae). Marine Biological Association of the United Kingdom. Journal of the Marine Biological Association of the United Kingdom **85**:1249.

Lim, L. 1993. Larviculture of the greasy grouper Epinephelus tauvina F. and the brown‐marbled grouper E. fuscoguttatus F. in Singapore. Journal of the World Aquaculture Society **24**:262-274.

Ma, Z., H. Guo, N. Zhang, and Z. Bai. 2013. State of art for larval rearing of grouper. International Journal of Aquaculture **3**.

Masuma, S., N. Tezuka, and K. Teruya. 1993. Embryonic and morphological development of larval and juvenile coral trout, Plectropomus leopardus. Japanese Journal of Ichthyology **40**:333-342.

May, R. C., D. Popper, and J. P. McVEY. 1974. Rearing and larval development of Siganus canaliculatus (Park)(Pisces: Siganidae). Micronesica **10**:285-298.

McCormick, M. I. 1999. Delayed metamorphosis of a tropical reef fish (Acanthurus triostegus): a field experiment. Marine Ecology Progress Series **176**:25-38.

Moore, B., and B. Colas. 2016. Identification guide to the common coastal food fishes of the Pacific Islands region.

Morais, R. A., and D. R. Bellwood. 2019. Pelagic Subsidies Underpin Fish Productivity on a Degraded Coral Reef. Current biology **29**:1521-1527. e1526.

Panfili, J., H. de Pontual, H. Troadec, and P. J. Wright. 2002. Manuel de sclérochronologie des poissons., Coédition Ifremer-IRD, Panfili J, de Pontual H, Troadec H, Wright PJ (eds), France, 464 pp.

Pannella, G. 1971. Fish otolith: daily growth layers and periodical patterns. Science **173**:1124-1126.

Pavlov, D., N. Emel’yanova, L. T. B. Thuan, and V. T. Ha. 2011. Reproduction and initial development of manybar goatfish Parupeneus multifasciatus (Mullidae). Journal of ichthyology **51**:604.

Popper, D., R. May, and T. Lichatowich. 1976. An experiment in rearing larval Siganus vermiculatus (Valenciennes) and some observations on its spawning cycle. Aquaculture **7**:281-290.

Schindler, D. E., and L. A. Eby. 1997. Stoichiometry of fishes and their prey: implications for nutrient recycling. Ecology **78**:1816-1831.

Schreck, C. B., and P. B. Moyle. 1990. Methods for fish biology.

Shadrin, A., and N. Emel’yanova. 2007. Embryonic-larval development and some data on the reproductive biology of Abudefduf sexfasciatus (Pomacentridae: Perciformes). Journal of ichthyology **47**:67-80.

Suzuki, K., and S. Hioki. 1979. Spawning behavior, eggs, and larvae of the lutjanid fish, Lutjanus kasmira, in an aquarium. Japanese Journal of Ichthyology **26**:161-166.

UKAWA, M., M. HIGUCHI, and S. MITO. 1966. Spawning habits and early life history of a serranid fish, Epinephelus akaara (Temminck et Schlegel). Japanese Journal of Ichthyology **13**:156-161.

Vigliola, L., M. Harmelin-Vivien, and M. G. Meekan. 2000. Comparison of techniques of back-calculation of growth and settlement marks from the otoliths of three species of Diplodus from the Mediterranean Sea. Canadian Journal of Fisheries and Aquatic Sciences **57**:1291-1299.

Vigliola, L., and M. G. Meekan. 2009. The back-calculation of fish growth from otoliths. Tropical fish otoliths: information for assessment, management and ecology:174-211.

William, W. L. C., W. Reg, M. Telmo, J. P. Tony, and P. Daniel. 2007. Intrinsic vulnerability in the global fish catch. Marine Ecology Progress Series **333**:1-12.

Yoseda, K., S. Dan, T. Sugaya, K. Yokogi, M. Tanaka, and S. Tawada. 2006. Effects of temperature and delayed initial feeding on the growth of Malabar grouper (Epinephelus malabaricus) larvae. Aquaculture **256**:192-200.