Protected coral reproduction
BCBC2020-01

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Presentation prepared for CSP Technical Working Group
26 August 2021

Climate, Freshwater & Ocean Science

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Introduction

- Reproductive strategy (alongside age, growth, mortality), determines the productivity of a coral species or population
- Pilot ecological risk assessment for deep-sea protected corals showed reproductive information is scarce for the region
- Protected coral reproduction project key tasks:

  Literature review, recommend study species, and describe spawning event for *Goniocorella dumosa*

- Addresses state of knowledge of reproductive strategies employed by deep-sea corals - information critical to manage and conserve protected corals in NZ region

Specific objectives

1) Summarise the literature on deep-sea coral reproduction studies included in and published after the review by Consalvey et al. (2010) and the State of Knowledge Report (Tracey & Hjorvarsdottir 2019).
2) Examine preserved coral specimens currently held in the NIWA Invertebrate Collection to assess what amount of reproductive information can be obtained from stored samples.
3) Select which of the key protected coral groups will be a focus of further reproduction studies.

4) Monitor progression of, record and provide a report of the 2020 *G. dumosa* spawning event in NIWA aquaria, including a written account and imagery of observed life history traits of larvae and polyps (e.g., fecundity, larval swimming and feeding behaviour, pelagic larval duration (PLD) settlement behaviours and cues, sequential developmental biology imaging) and a life-cycle graphic for DOC educational resources.

- Additional aim: liaise with international coral reproduction experts, in order to share expertise and collaborate, and be able to contextualise the results for New Zealand more broadly, e.g., potentially carry out regional comparisons.

Obj 1: Literature review

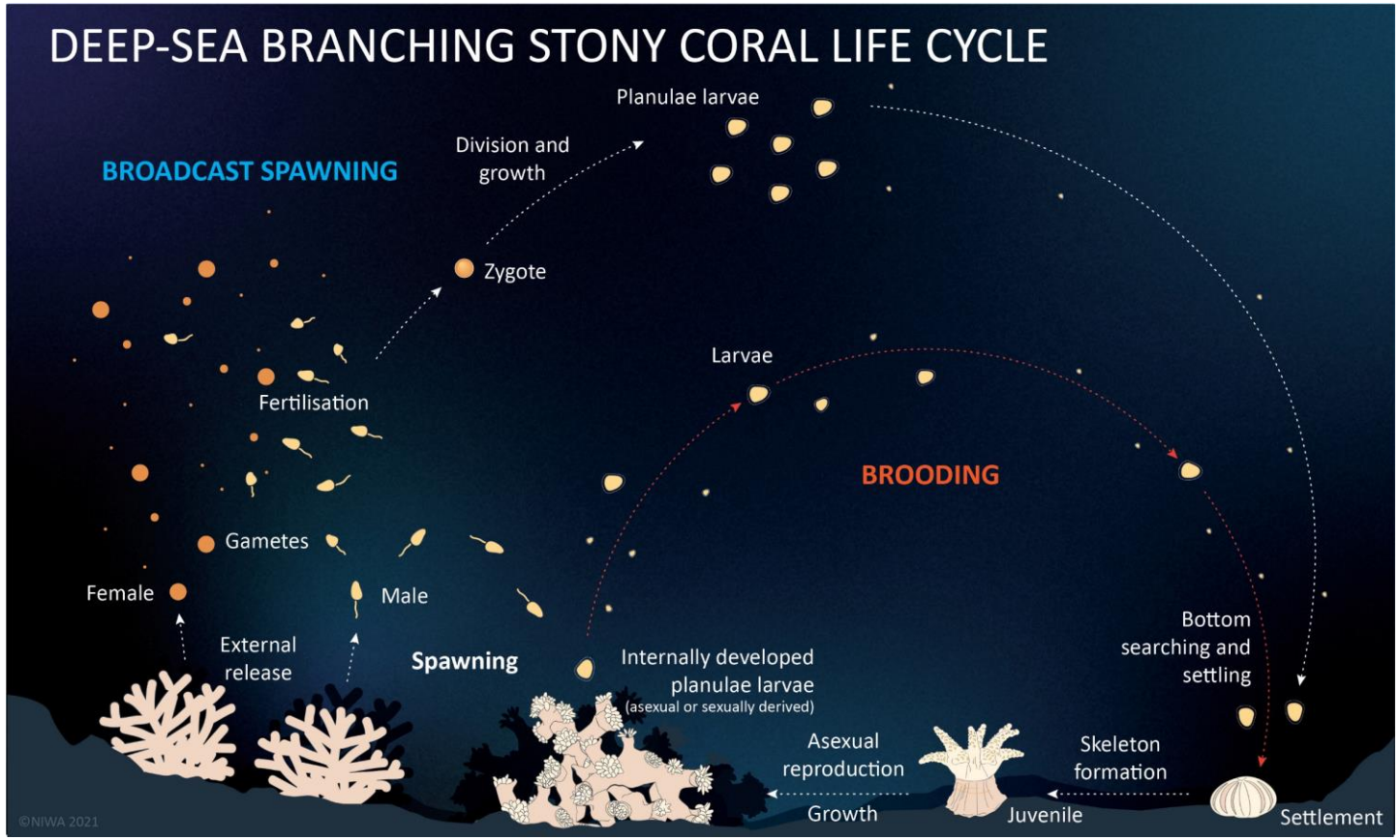
- Review describes key findings from 2 earlier reviews plus adds relevant more recent literature for protected coral groups
- **Client Report Table 4.1** presents a range of reproductive modes, larval behaviour, and fecundity estimates for deep-sea corals protected under the New Zealand Wildlife Act 2010 (amendment of Schedule 7A of the Wildlife Act 1953)
  - Orders Antipatharia (black corals)
  - Alcyonacea (gorgonian octocoral groups previously known as Gorgonacea
  - Scleractinia (stony corals)
  - Hydrocorals (lace corals) family Stylasteridae

Reproduction strategies

Scleractinia - reef-like branching forms

- Until recently, all NZ branching stony corals were thought to be **seasonal, gonochoric broadcast spawners**
  - 1 species, *G. dumosa,* now known as a **brooder** (larvae mature internally before being released)
- Hypothesised to produce **lecithotrophic** larvae = feed on yolk as opposed to **planktotrophic** larvae = feed on plankton in the surrounding waters
- Some species undergo both sexual and asexual reproduction
  - Evidence of **budding** observed from colonies of *G. dumosa* and *S. variabilis* on the Chatham Rise

Life-history modes of both broadcast spawning and brooding used by branching scleractinian stony corals



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Reproduction strategies

Scleractinia – cup coral form

- No existing NZ deep-sea cup coral reproductive studies
  - Genetic data shows *Desmophyllum dianthus* undergoes sexual reproduction & has widespread dispersal
- Global studies do not show any generality in **sexual systems**, **reproductive modes, periodicity**, or **larval development modes**
  - *Caryophyllia* spp. can be **gonochoric** or **hermaphroditic**
  - *Flabellum* spp. collected from West Antarctic Peninsula **brood**, while those in NE Atlantic **spawn** gametes
  - High **fecundity** compared to other coral groups

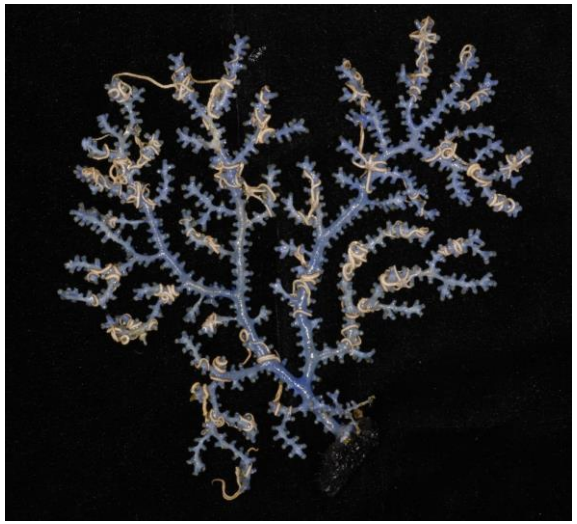
Reproduction strategies
Antipatharia

- NZ Fiordland black coral *Antipathella fiordensis* is a **gonochoric**, **broadcast spawner,** produces **lecithotrophic** larvae with limited dispersal
- Globally nearly all black coral species are thought to be gonochoric broadcast spawners
  - more deep-sea studies needed to confirm
- Black corals have reduced **fecundity** compared to stony corals

Reproduction strategies

Gorgonian octocorals

- Diverse group with broad range of reproductive strategies
- NZ morphological studies indicate several primnoids are **gonochoric brooders**
- Global studies also indicate most octocorals are **gonochoric** with varying **reproductive modes** and **periodicity**
  - Continuous, quasi-continuous, seasonal spawners, and brooders
  - *Fanyella* and *Thouarella* spp. are **brooders**
  - Isidids (bamboo corals) and plexaurids appear to be mostly **broadcast spawners**
- No clear relationship between oocyte size and larval development mode
- Low **polyp fecundity** but potentially high **colony fecundity**



Reproduction strategies
Stylasteridae

- Limited reproductive knowledge
- NZ morphological studies show stylasterids are typically **gonochoric brooders**
  - similar to Alaskan study
- Predicted to have short dispersal due to brooding mode & crawling behaviour of larvae

Obj 2. Examine preserved coral specimens in NIC

- NIWA Invertebrate Collection (NIC) *niwainvert* db interrogated
- Assessed amount of reproductive information that could be obtained from stored samples:
  - numerous samples in formalin
  - not specifically collected for reproduction studies
  - some fixed for a long period
  - some transferred from formalin to ethanol
- Suitable samples
  73 scleractinian stony corals
  94 alcyonacean corals (including gorgonian octocorals
- Sub-set priority species compiled

Obj. 3 Select species for reproduction study - scleractinia

Selection criteria:

- recent samples (2010 onwards)
- fixed in formalin then transferred reasonably quickly post collection into 80% ethanol
- samples size
- scores in the pilot risk assessment

Scleractinian stony corals - cup & branching forms	Count (sample jar)	Total number of organisms within the subset of jars
Desmophyllum dianthus	9	19 (2018)
Goniocorella dumosa	10	numerous (2019/2020)
Enallopsammia rostrata	3	numerous (2020)

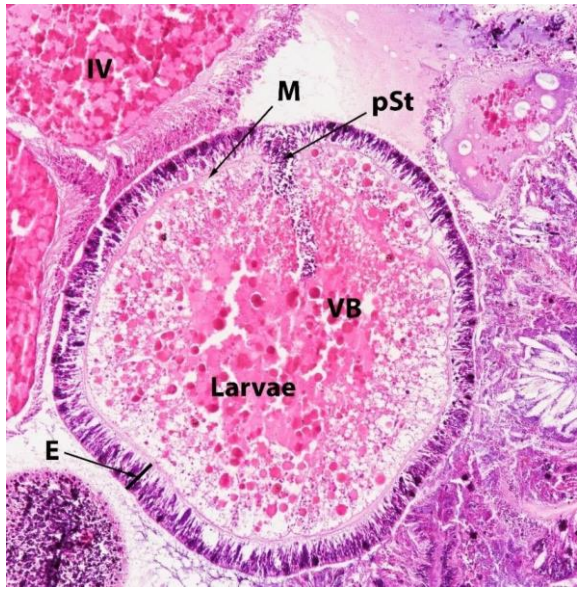
Obj. 3 Select species for reproduction study – gorgonian octocorals

Alcyonacea gorgonian octocorals plus one endemic soft coral	Count (sample jar)	Number of organisms = numerous per jar from 4 colonies (year collected post 2010)
P. arborea	**2**	**(2010)**
Primnoa notialis	**2**	**(2010)**

Selection criteria:

- recent samples (2010 onwards)
- fixed in formalin then transferred reasonably quickly post collection into 80% ethanol
- sample size
- scores in the pilot risk assessment

Obj 3. Recommendations summary



Scleractinian corals

- *Burgess & Babcock (2005) examined 24 polyps per stony branching coral species covered only one time period (April 2001)*
- *Expand for 2x branching & 1 cup coral species, over time*
- *G. dumosa – build on current histological study (2021 samples)*

Gorgonian octocorals

- *Waller et al approach of histology & gross morphometrics of colony*
  - *data on polyp density*
  - *changes in polyp density across the colony,*
  - *number of polyps per colony*

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Liaison international experts

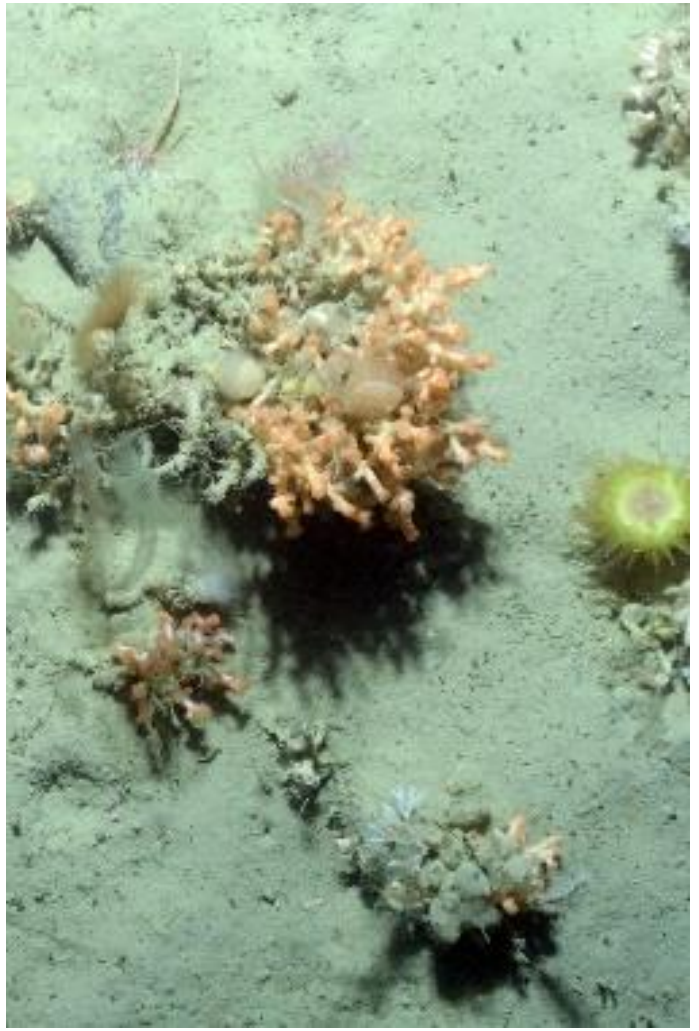
- **Rhian Waller**, University of Maine, US
  - co-collaboration propose 3 phase reproduction study
  - research approach would involve a student

- **Pål Buhl-Mortensen**, Institute of Marine Research, Norway
  - On-going advice on the larval settlement results & growth rates

Obj. 4 Spawning event

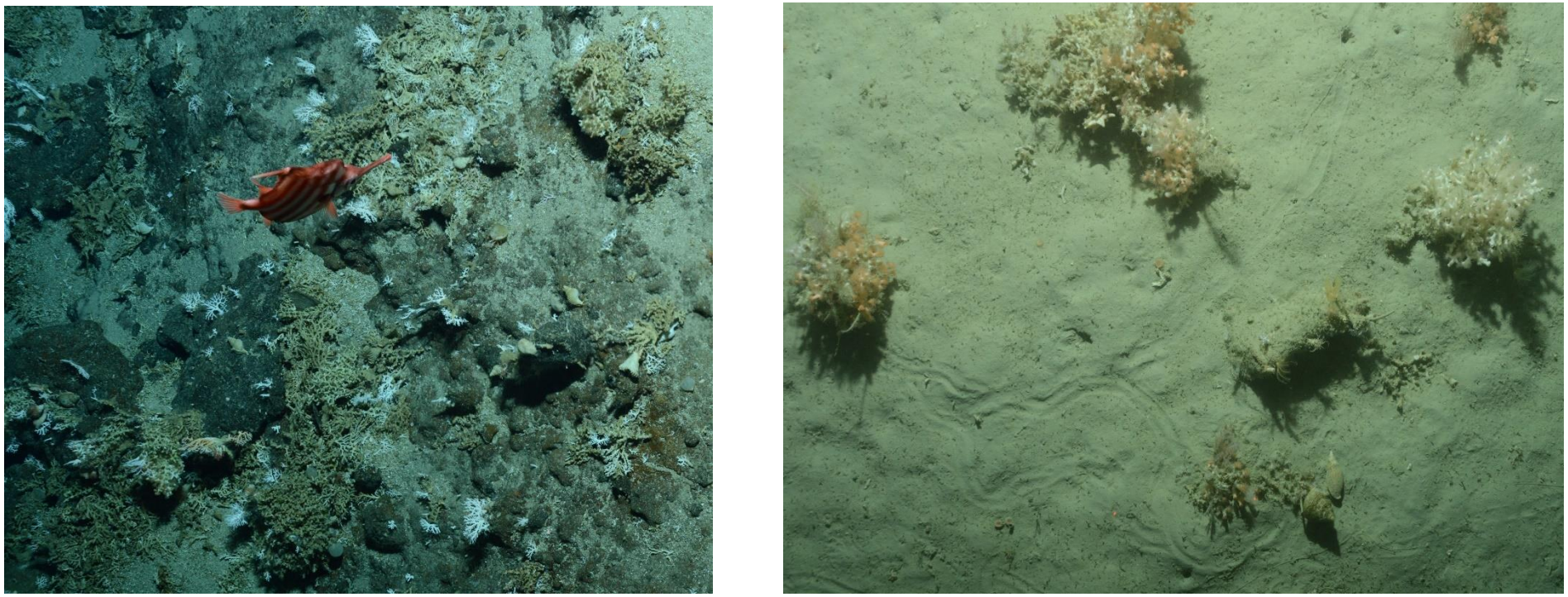
Describe the observed spawning event for NZ deep-sea scleractinian branching stony coral

G. dumosa

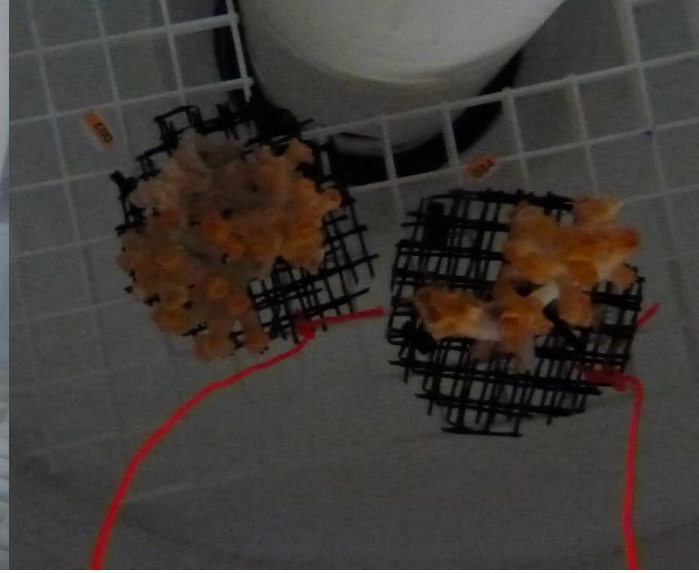


Sampling

- Coral colonies collected from the Chatham Rise (approx. 400 m water depth) in June 2020
  - Research programme on the *"Resilience of Deep sea Benthic Communities to the Effects of Sedimentation (ROBES)*
- Colonies held in an on-board flow-through aquarium system onboard *Tangaroa* for 2 days before being transferred to holding tanks in NIWA's Marine Environmental Manipulation Facility (MEMF), Wellington



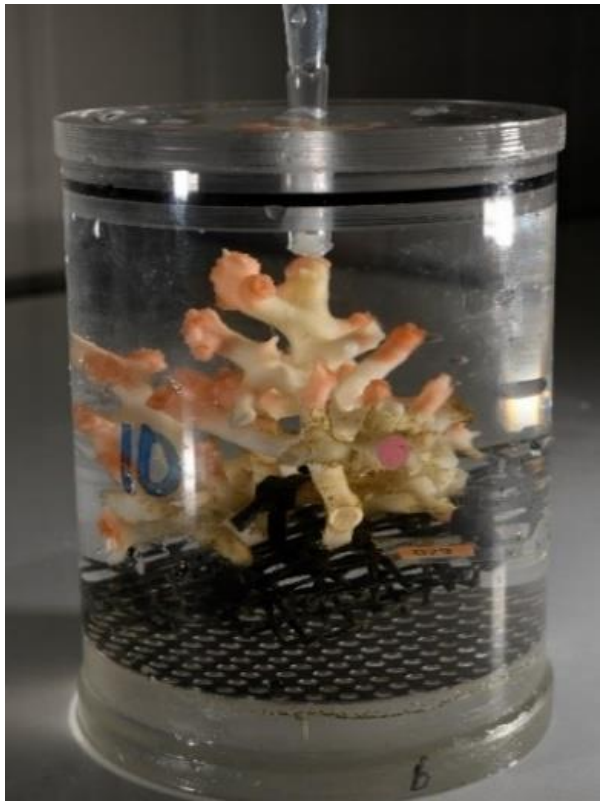
G. dumosa colonies *in-situ* on seamount feature (left); growing on hard substrates surrounded by soft sediments, Chatham rise (right)



ROBES sediment tolerance experiment on *G. dumosa*

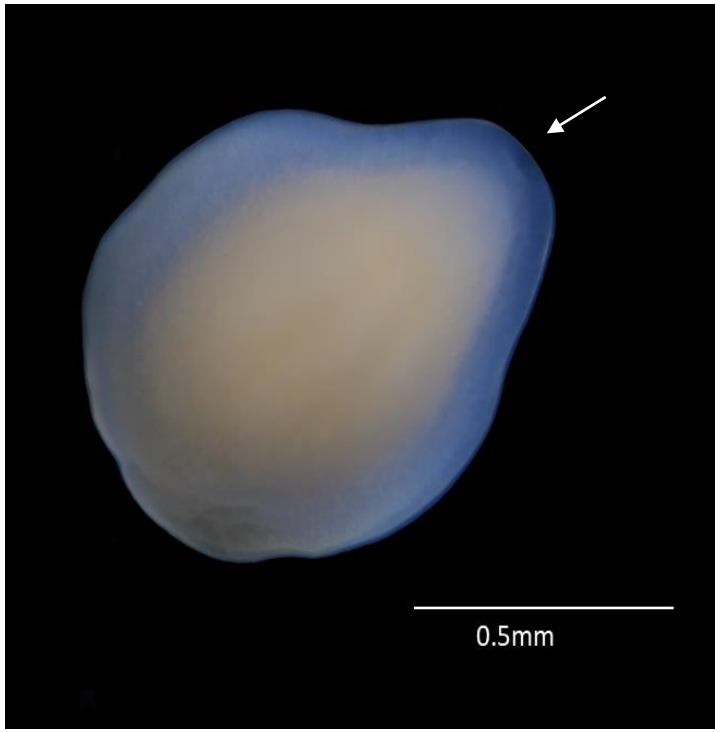
Last day of 4 week experiment (17th September 2020), coral larvae found swimming inside a respiration chamber (bottom right image)

Further investigation showed *G. dumosa* colonies had spawned in 8 sediment tolerance chambers as well as in a large tank with non-experimental animals

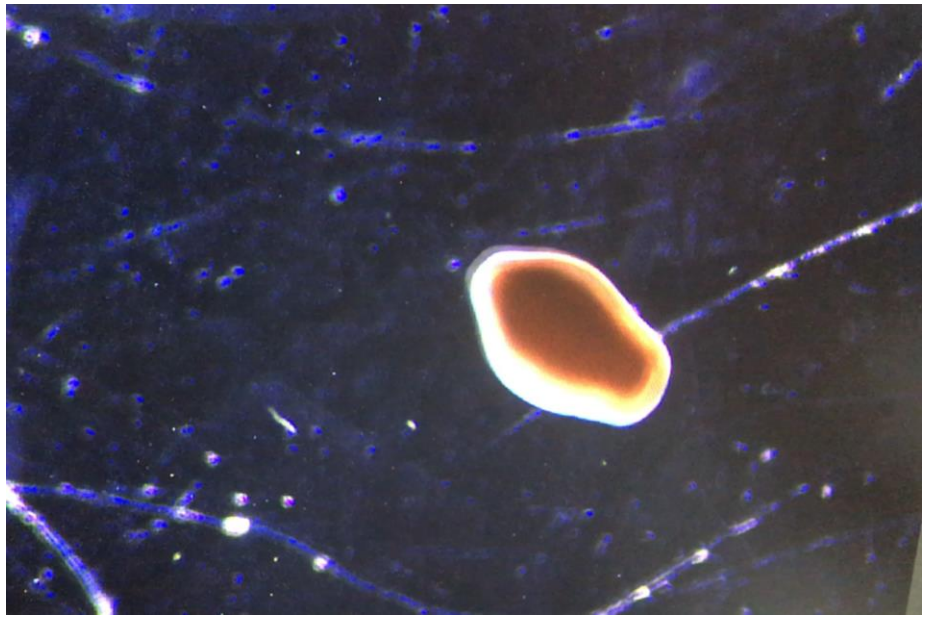


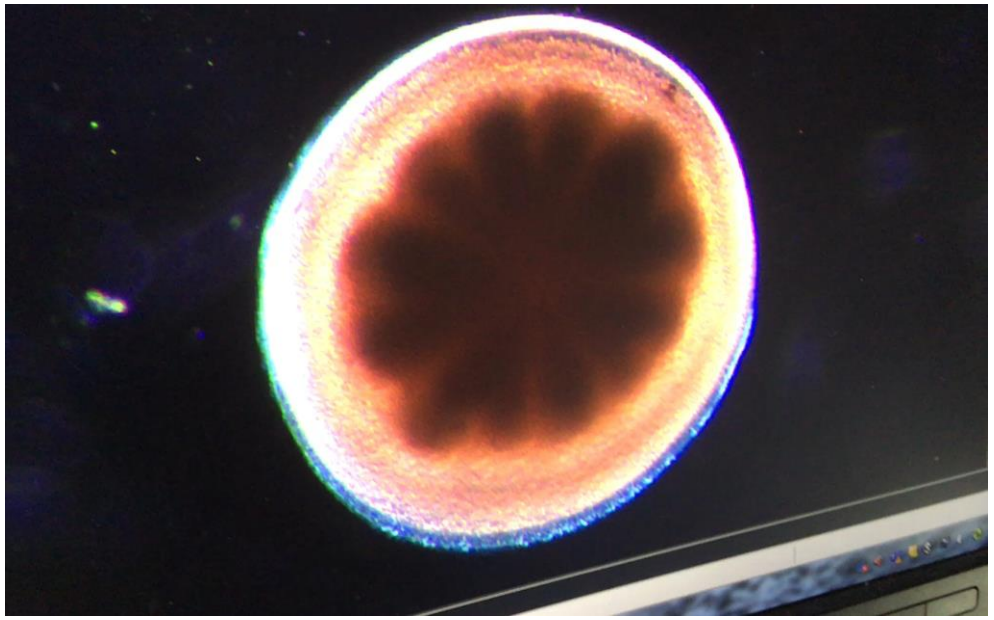
Larval Characteristics & Behaviour

- Large (approx. 1.1 x 0.8 mm in size)
- Free-swimming. Able to change speed and direction
- Covered in cilia
- Orange in colour
- Pear-shaped (though shape could change)



Swimming *G. dumosa* larvae. White arrow shows the formed mouth





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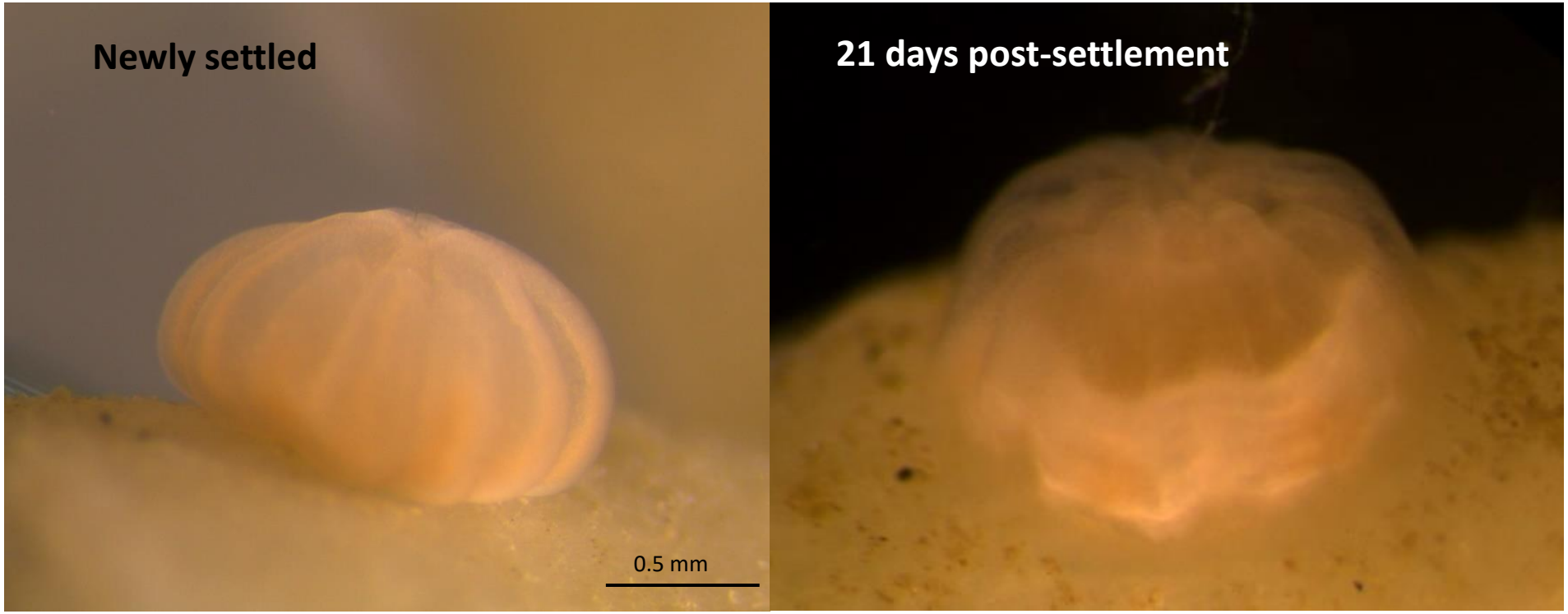
Settlement & Development

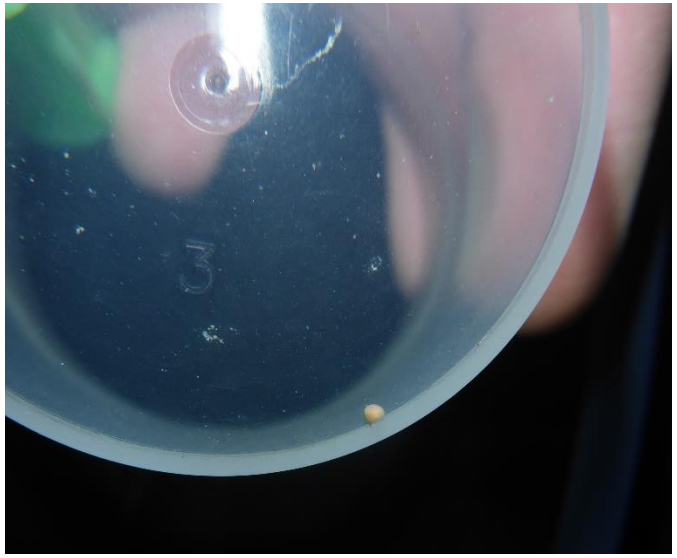
- Rapid settlement! First observed 2 days post-larval release
- Observed calcification and tentacle development



Goniocorella dumosa settlement and development on a coral fragment

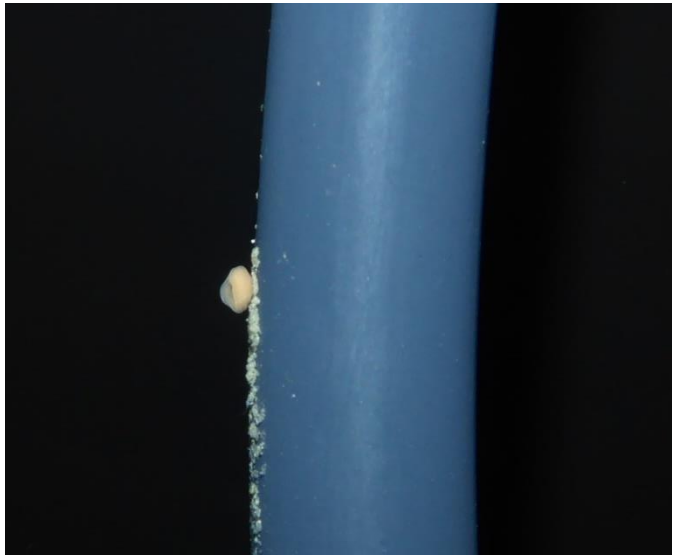
Settlement substrates

Clear plastic pottle



Pink pottle lid

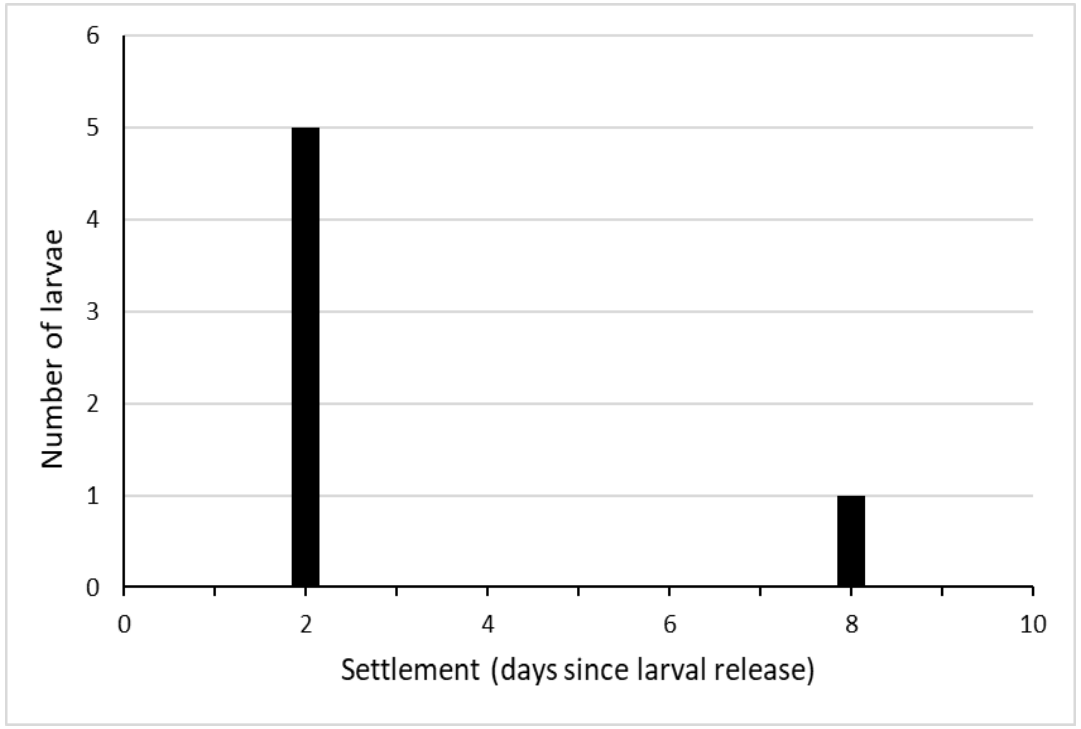
Silicone tubing



Coral substrate

Pelagic Larval Duration

- Successful settlement (where date of larval release date was known) occurred at 2 days (n = 5) and 8 days (n = 1)
- Metamorphosis of unsettled larvae observed approximately 40 – 72 days post-settlement
- One larvae remained alive and swimming after 88 days!
- Observed Pelagic Larval Duration was 2 - 8 days but maximum timeframe unknown



G. Dumosa are brooders!

- Observed up to 10 larvae inside a single polyp
- Several of these larvae were observed swimming upon release suggesting they were mature
- Spawning/larval release observed (in-aquaria) from September to November 2020

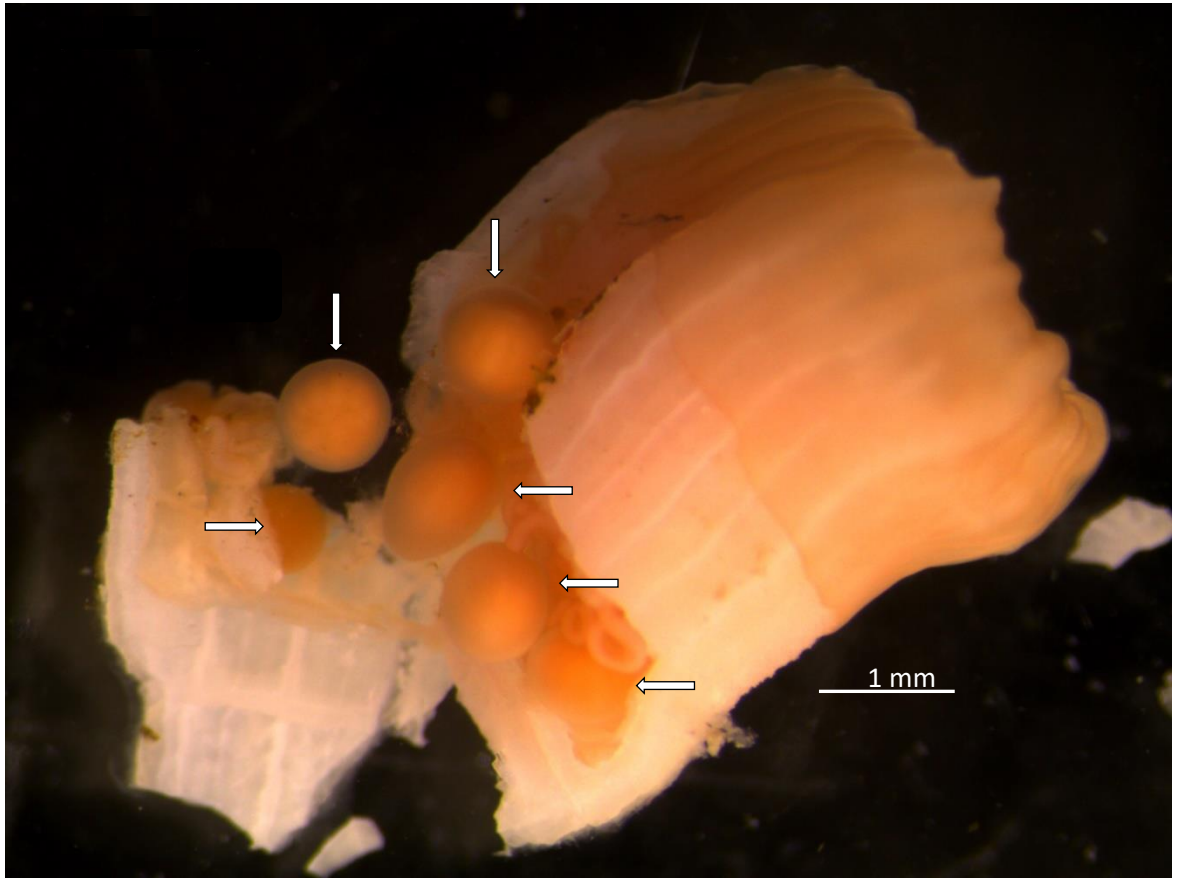
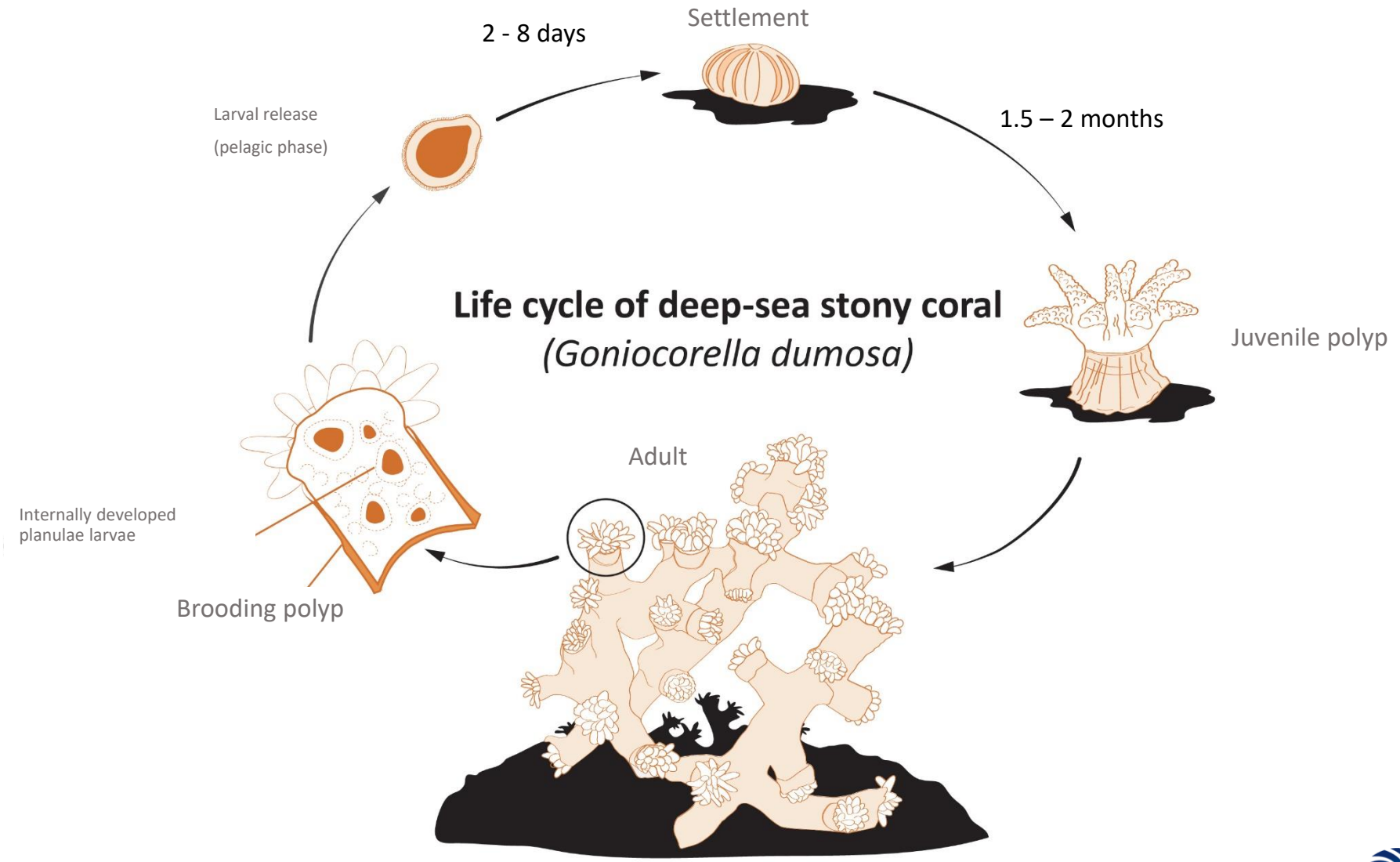


Image shows 6 of the 10 larvae in this single polyp



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Summary

- *G. dumosa* are brooders
- Release up to 10 larvae
- Larvae are approx. 1.1 x 0.8mm in size, free-swimming and have a formed mouth
- Settlement is relatively fast (2-8 days)
- Able to successfully settle to coral fragments/colonies, silicone and possibly plastic
- Previous work had suggested *G. dumosa* were broadcast spawners with spawning predicted in late April or May.
- We observed (*in-aquaria*) larval release from September to November 2020

Future work

This was opportunistic research and we have learnt a lot about *G. dumosa* reproduction. However, more work do be done on:

- Spawning cues (seasonality? food supply?)
- Settlement cues and substrate preferences
- Pelagic larval duration
- Dispersal potential

Obj. 4 Reproductive histology of *Goniocorella dumosa*

- Histology slides examined to collect data on
- male to female sex ratios
- oocyte stage and size distributions
- fecundity per polyp
- spermatocyst stage

- Sampled material - June to September

Developmental stages of oocytes and spermatocytes (adapted from Burgess 2002)

Stage	Oocytes/Larvae	Spermaries
I	Oogonia: Enlarged interstitial cells, with large nuclei in mesoglea of mesenteries	Small clusters of interstitial cells
II	Immature Oocytes (previtellogenic): Accumulation of small amount of cytoplasm around nuclei	Spermatocytes smaller with small nuclei, number of cells within spermatocyst much larger
III	Oocytes undergoing Vitellogenesis: variable size, main period of vitellogenesis	Spermatocytes with little cytoplasm, developed flagella not evident, lumen usually present
IV	Vitellogenic Oocytes: full sized with indented nucleus migrating to edge of oocyte, large vitellogenin bodies fill the cytoplasm, cortical granular layer may be seen	Spermatozoa with fully developed flagella, ready to spawn
V	Brooding larvae of various stages of development	

Observations - Females

- Few Type I oogonia or Type II immature oocytes
- Most were Type III - developing or Type IV – mature
- Type V - larvae at various stages of development

- Most advanced oocytes/larvae were more basal in polyp

Observations - Males

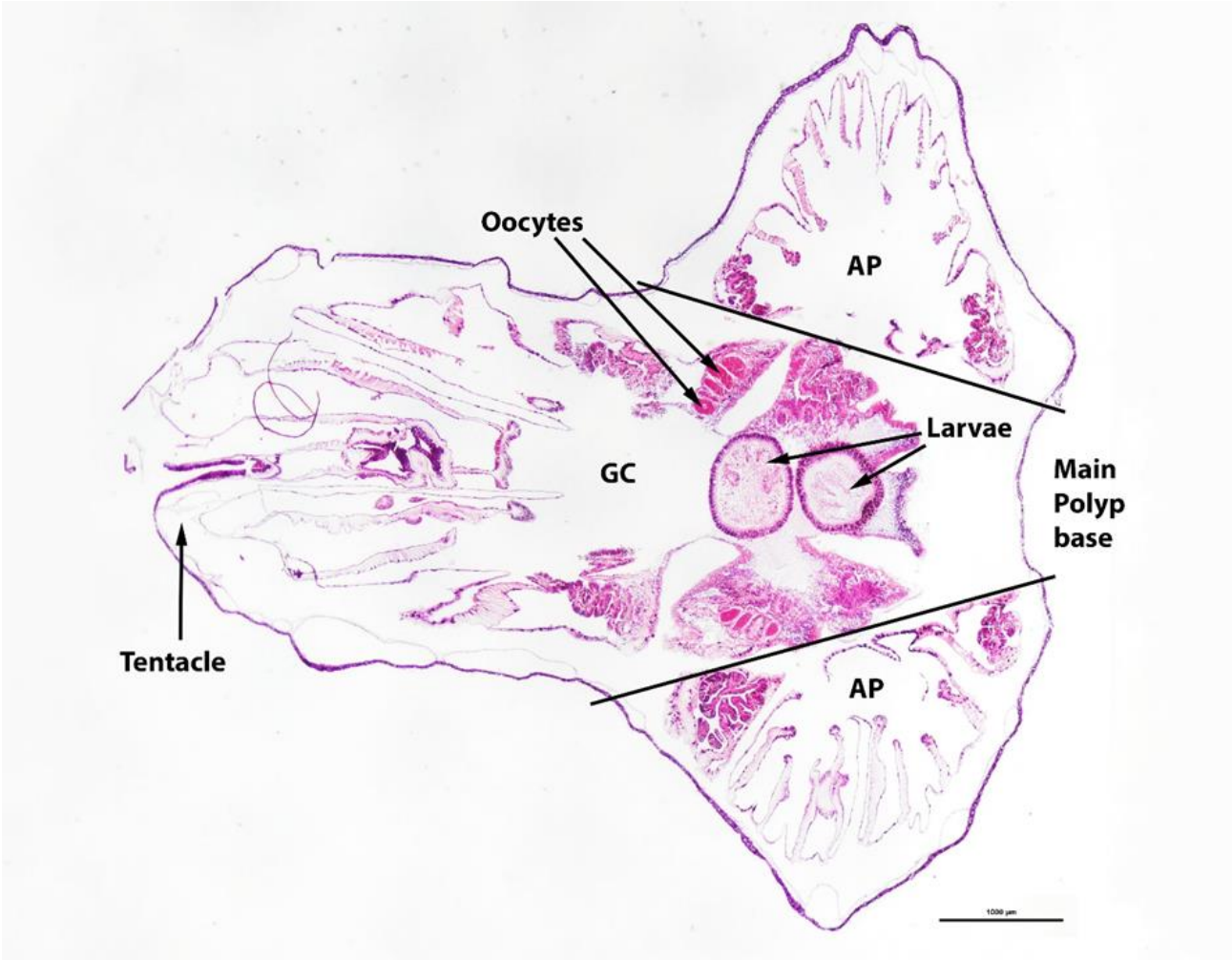
- Sperm were observed developing in spermatocysts
- No Type I clusters of interstitial cells were observed
- Spermatocyte forms Type II – IV were common.

- Development within a spermatocyst was synchronous
- Development within a mesentery or polyp was less so

- Most advanced spermatocytes were more basal in polyp

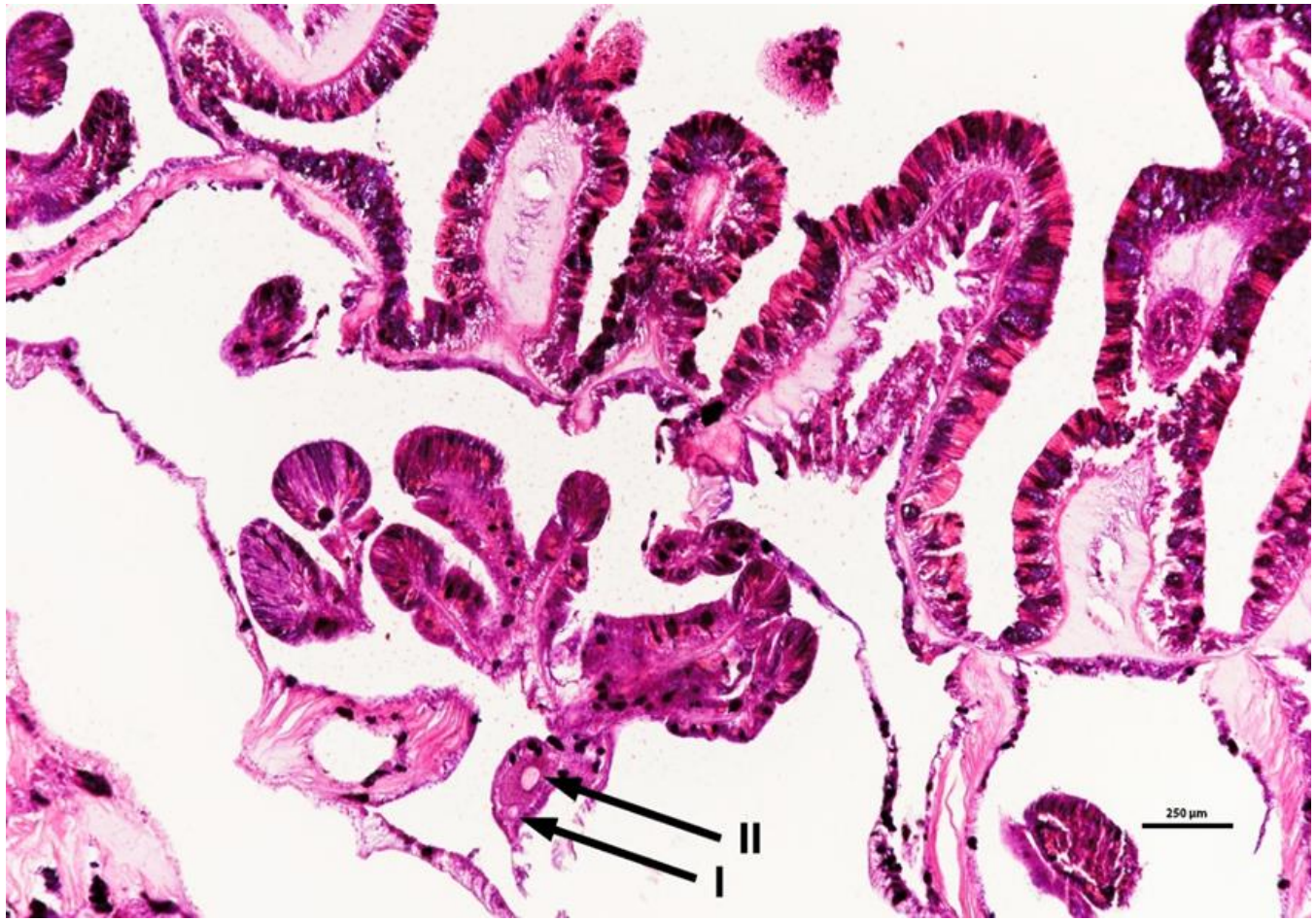
Polyp morphology

- Two mature larvae in the basal gut mesenteries
- Clusters of Stage III oocytes
- Accessory polyps



Stage I and II - Oocytes

- Stage I - an enlarged interstitial cell with a large nucleus
- Stage II - accumulating cytoplasm

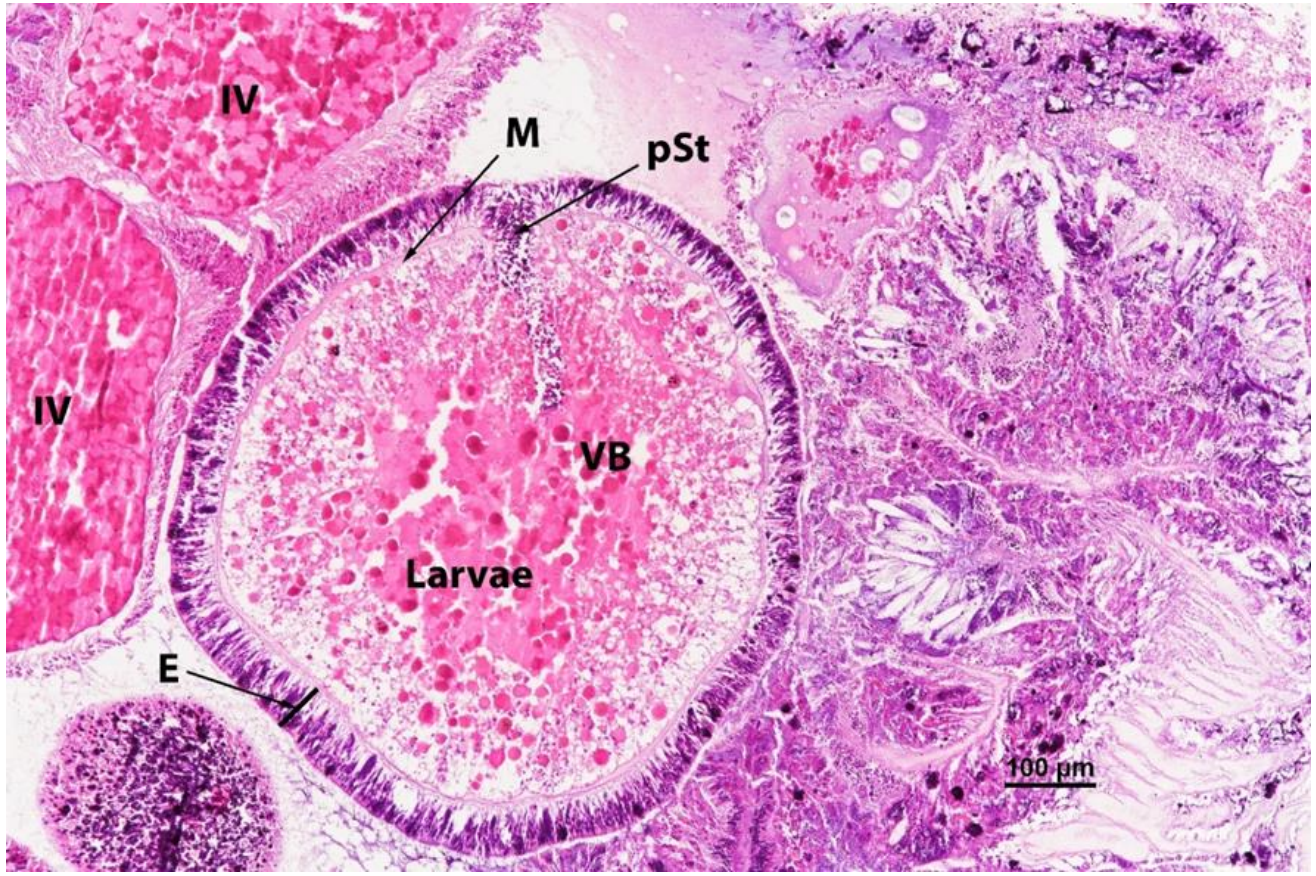


Stages III & IV- Oocytes

- Stage III - bright pink vitellogenic bodies
- Stage IV - mature globular vitellogenic bodies

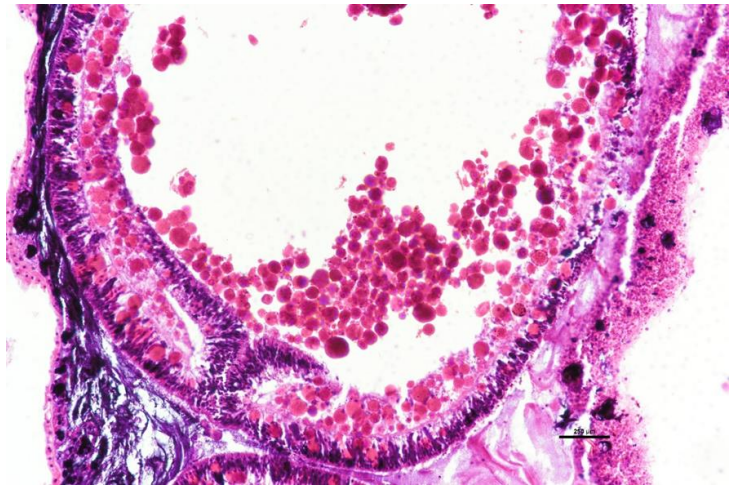
Stages IV – Oocytes & V - Larva

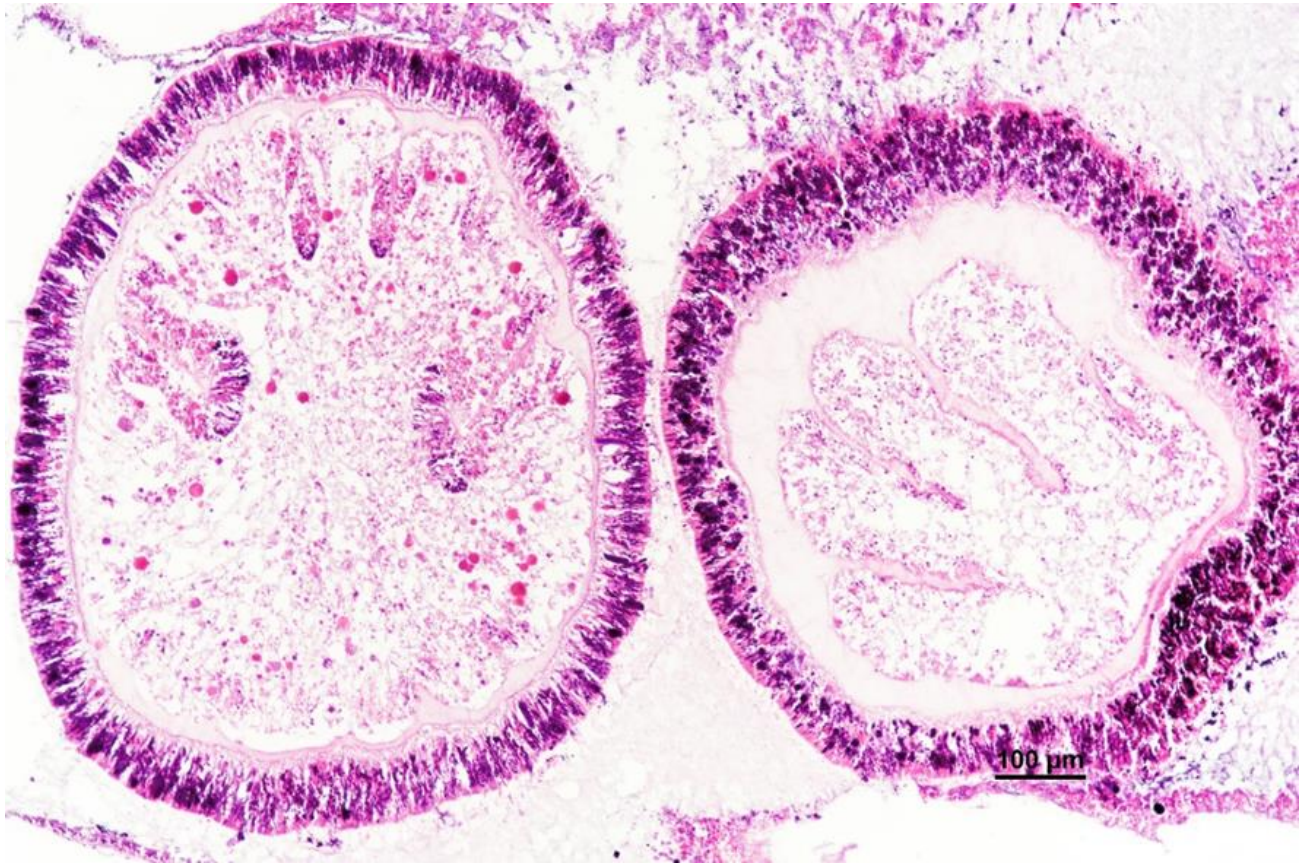
- Stage IV Oocytes - mature globular vitellogenic bodies
- Stage V Planula larva - high degree of cellular differentiation



Stage V - maturing larvae

- Developing stomodaeum
- Larvae showing increased development of internal tissue



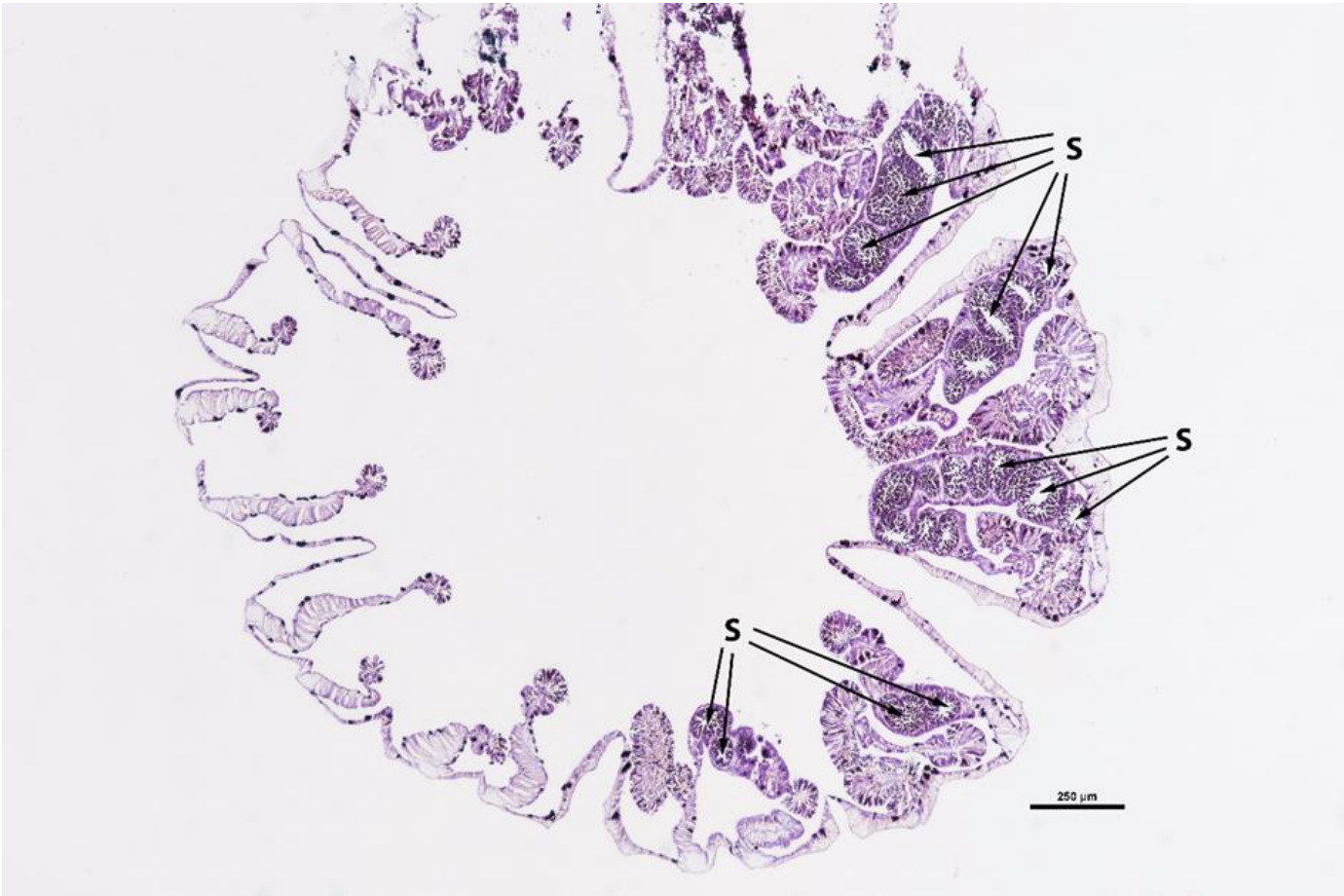


Stage V - mature larvae

- Development of feeding tentacles
- High degree of development prior to liberation

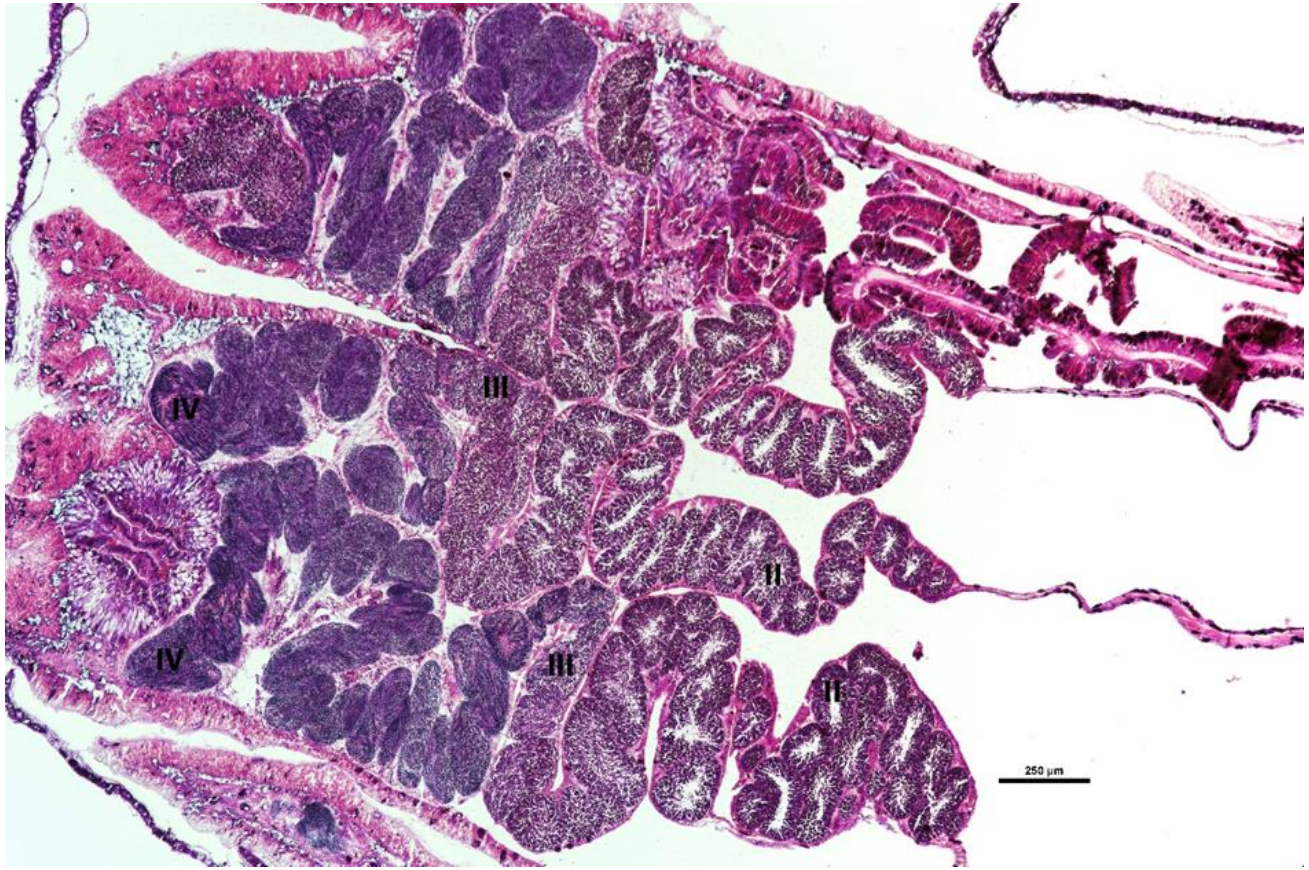
Male spermatocysts

- Spermatocysts in adjacent mesenteries
- likely all complete mesenteries contain gametogenic tissue



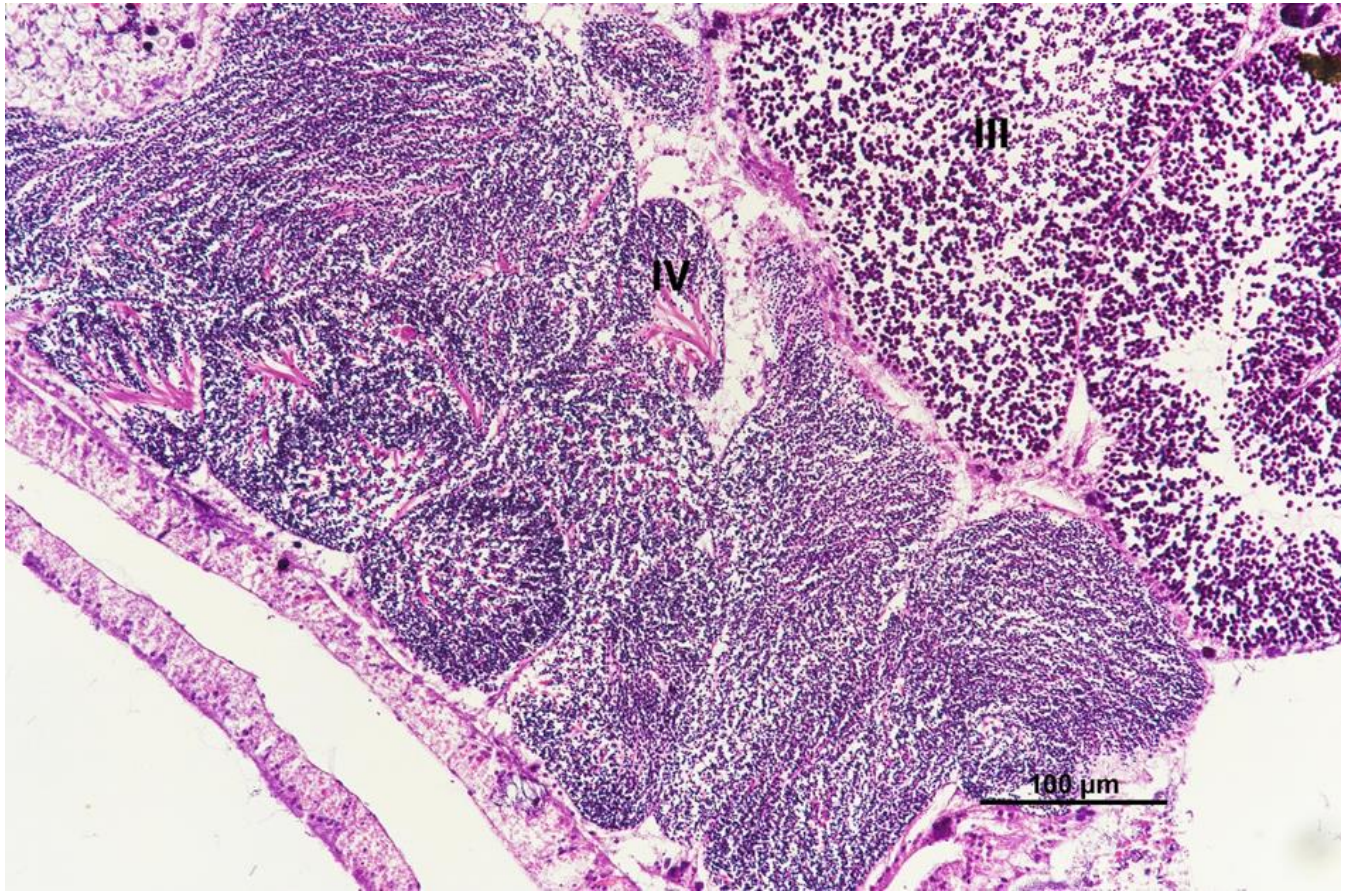
Male spermatocysts

- Types II, III, IV present
- Most advanced are most basal



Mature spermatozoa

- Type III maturing spermatocytes
- Type IV mature flagellated spermatozoa



Oocyte, larvae and spermatocyst sizes by stage

Sex	Stage	Count of oocytes / spermatocysts by stage	Minimum size µm	Maximum size µm	mean size µm	Standard deviation
Female	I	2	45	94	69	35.0
Female	II	11	63	211	117	46.9
Female	III	43	139	538	269	87.1
Female	IV	25	428	931	668	139.5
Female	V	19	596	1220	904	157.8
Male	II	42	88	380	235	84.3
Male	III	137	116	545	234	97.8
Male	IV	33	131	488	274	75.9

Counts and fecundity estimates

- Minimum fecundity estimates
- Twenty female polyps were observed
- 2-84 oocytes and larvae per section

Observed reproductive strategy for *G. dumosa*

- Gonochoric viviparous brooders
- Single sexed with internal fertilisation of gametes

- Population sex ratio relatively heterogeneous

- Serial spawner to continuous spawner
- Maturation occurs Austral autumn/winter
- Spawning late winter to early spring

Summing up

Literature review summarised understanding of reproductive & dispersal capacity of deep-sea corals

Collection *db* interrogated to select study species

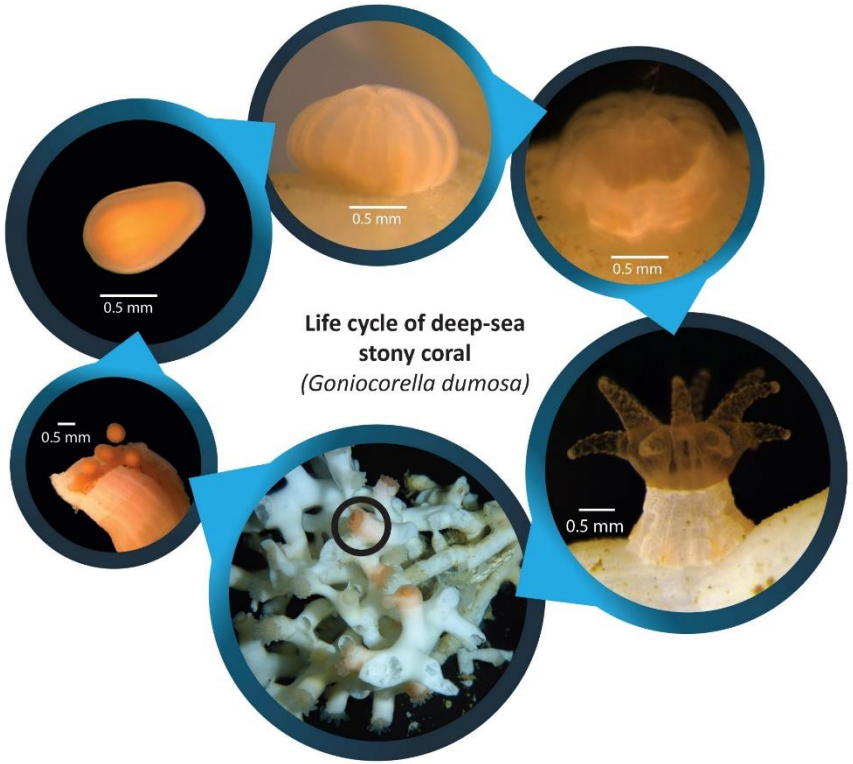
Future research proposed to improve understanding of reproductive & dispersal capacity

2020 *G. dumosa* spawning event reported on - observation & histology, analyses confirm brooding (Beaumont *et a*l. in prep)

Graphics produced

Liaised with international coral reproduction experts to contextualise the results for NZ more broadly

Research contributes to addressing the state of knowledge of reproductive strategies employed by deep-sea corals - information critical to manage & conserve protected corals in NZ region



Acknowledgements

We thank the Department of Conservation — Te Papa Atawhai for their support of this research particularly Ian Angus, Manager, Lyndsey Holland, Katie Clemens-Seely, & Shannon Weaver.

Special thanks to NIWA staff Sadie Mills (database extracts); Erika Mackay (Graphic artist); Malcolm Clark (Programme Leader ROBES), for enabling the in-aquaria sampling & supporting our use of the histology slides.

Ngā mihi nui ki a koe