
Predicting patterns of coral spawning at multiple scales: the closer you look the harder it gets

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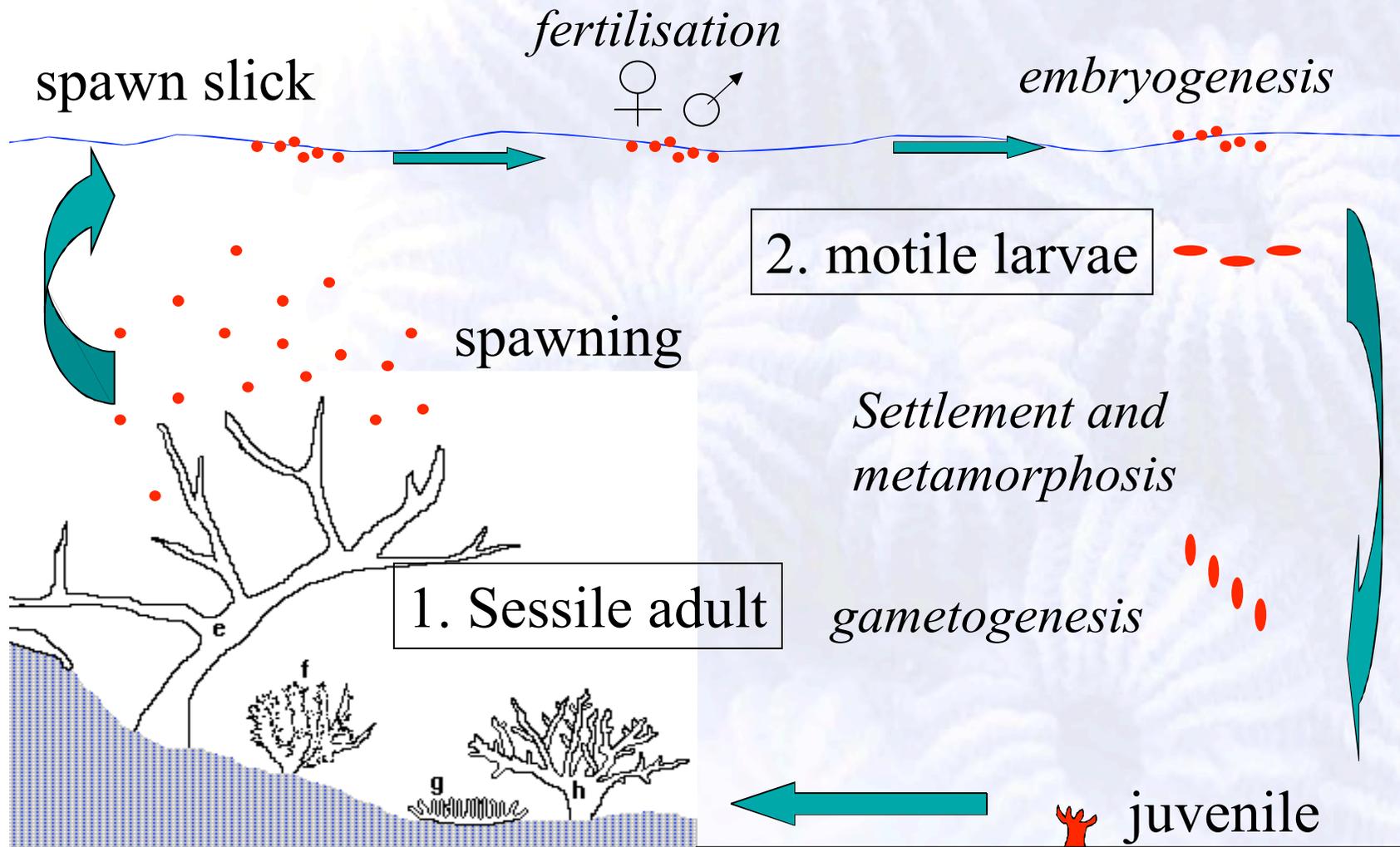
Abstract

Understanding the reproductive biology of organism is of fundamental interest to scientist and resource managers. Early theoretical studies predicted that the reproductive season of widespread organisms should be more extended near the equator than at high latitudes because conditions favourable for gametogenesis persist year round. Similarly, it was believed that synchrony among both populations and species would be lower because there are fewer good cues in the tropics where annual fluctuations in environmental variables are reduced. Subsequent work from numerous locations within the Indo-Pacific indicates that multi-specific synchronous spawning is a characteristic feature of all *Acropora* assemblages. At large spatial scales spawning periods are highly predictable. In the central Indo-Pacific, for example, the majority of reproductive output is concentrated in brief spawning periods following full moons at the beginning and end of the monsoon. The spawning peak in Western Australia, Manado, Singapore, northern New Guinea, southern Japan and Aceh is in Mar/Apr, whereas in Bali, Padang, Makassar, the Solomon Islands, New Caledonia and on the GBR the peak is in Oct/Nov. While the comparative intensity of these peaks varies between locations, it appears to be consistent among years. Above approximately 28-30 degrees latitude, and possibly at some sites in the central Pacific, such as Guam, this pattern breaks down and the spawning peak is progressively one month later in the season for every 2-400 km further from the equator. At smaller spatial scales the patterns are far less regular. For example, in the central GBR peak spawning on inshore reefs occurs one month before offshore reefs, however, *Acropora* spawning occurs following every full moon between Oct and Feb at most reefs. Some species spawn predominantly early in the season, such as the classic mass spawners *A. millepora* and *A. hyacinthus*, some spawn throughout the season, eg *A. humilis*, and some species spawn predominantly later in the season eg *A. verweyi*. Peak spawning within populations of a single species can vary dramatically over very small scales. For example, consider 4 mid-shelf reefs in the Central GBR separated by less than 20 km: on 2 reefs fecund colonies of *A. monticulosa* were observed only in Dec, at a 3rd reef, fecund colonies were only observed in Nov, while at the 4th reef, fecund coral were observed in both Nov & Dec. In conclusion, while large scale patterns in coral spawning may be relatively predictable, detailed studies at the local scale will rarely be avoidable.

Questions to address

- How synchronised is coral spawning? One month or several?
- Is there geographic variation in the timing of spawning?
- Are there consistent inshore-offshore differences?
- Are there species which spawn more than once?
- Are there species which are not synchronous?
- What proportion of the population might typically spawn in a single event?

Coral life history



Mature eggs in an *Acropora* colony



Photo: James Guest

Photograph reproduced with kind permission of Springer Science and Business Media.
Guest JR, Chou LM, Baird AH, Goh BPL (2002) Multispecific, synchronous coral spawning in Singapore. *Coral Reefs* 21: 422-423

Acropora colony setting just prior to spawning

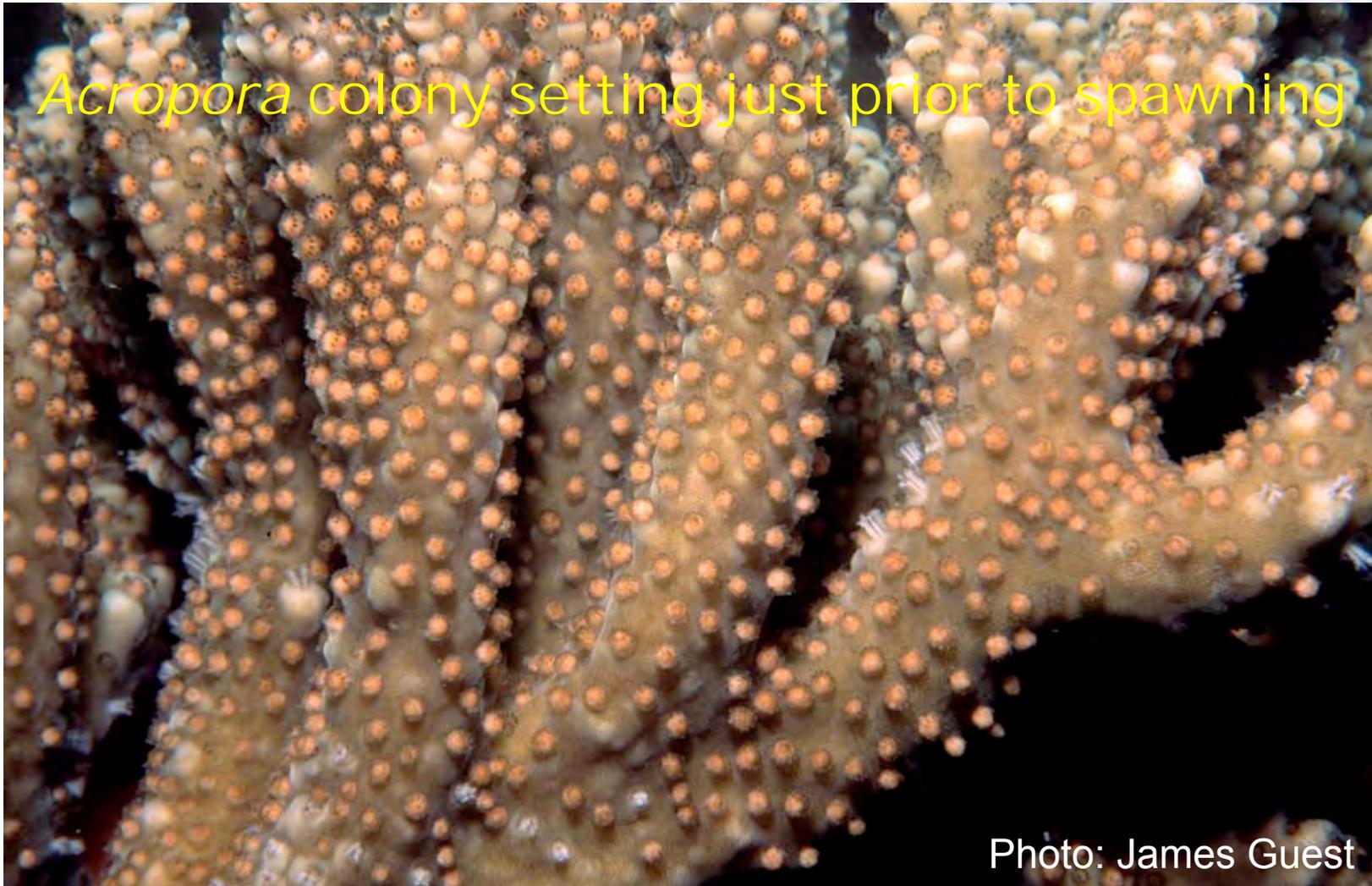


Photo: James Guest

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Guest JR, Chou LM, Baird AH, Goh BPL (2002) Multispecific, synchronous coral spawning in Singapore. Coral Reefs 21: 422-423

Close up of an egg-sperm bundle



Photo: Masanori Nonaka

Photograph reproduced with kind permission of Springer Science and Business Media.

Nonaka M, Yamamoto HH, Baird AH, Kamiki T (2003) Reseeding the reefs of Okinawa with the larvae of captive-bred corals. *Coral Reefs* 22: 34-34

Bundle release: *Platygyra* sp.



Photo: James Guest

Coral spawn slick



Embryogenesis

12 to 36 hours
depending on the species

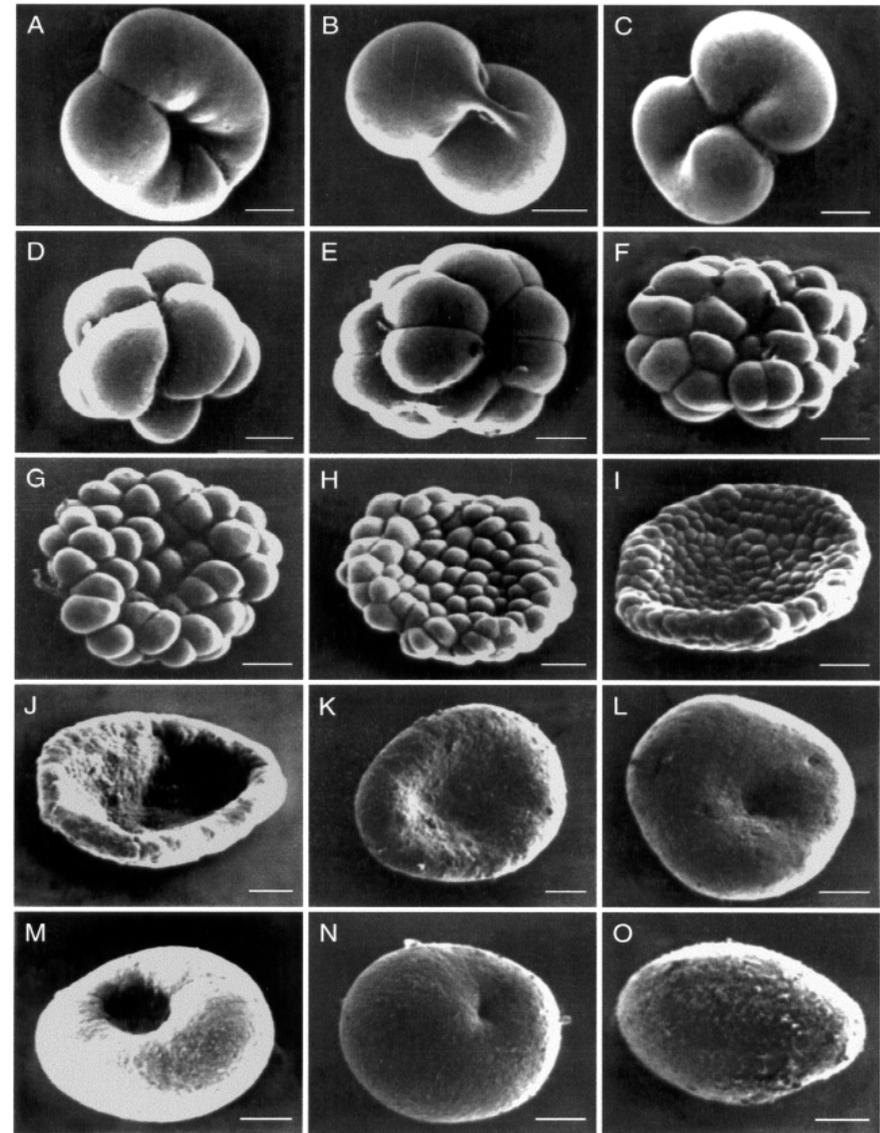


Photo: Andrew Heyward

Coral planula larva



Coral recruit: 2 months old



Coral sexuality

Hermaphrodites

- Individual colonies produce both eggs and sperm

Gonochores

- Individual colonies either male or female

Coral reproductive mode

Brooders

- Internal fertilisation
- Larvae are competent to settle on release
- Colonies breed more than once per year

Spawners

- External fertilisation
- Larvae not competent to settle on release
- Colonies breed once per year

Patterns in coral reproductive biology

Sexuality	Reproductive mode		Sum
	Brooding	Spawning	
Gonochorism	19 (5.8)	80 (24.3)	99 (30.1)
Hermaphroditism	23 (7.0)	207 (62.9)	230 (69.9)
Sum	42 (12.8)	287 (87.2)	349

Kerr & Baird unpublished data

Coral reproductive biology: a brief history

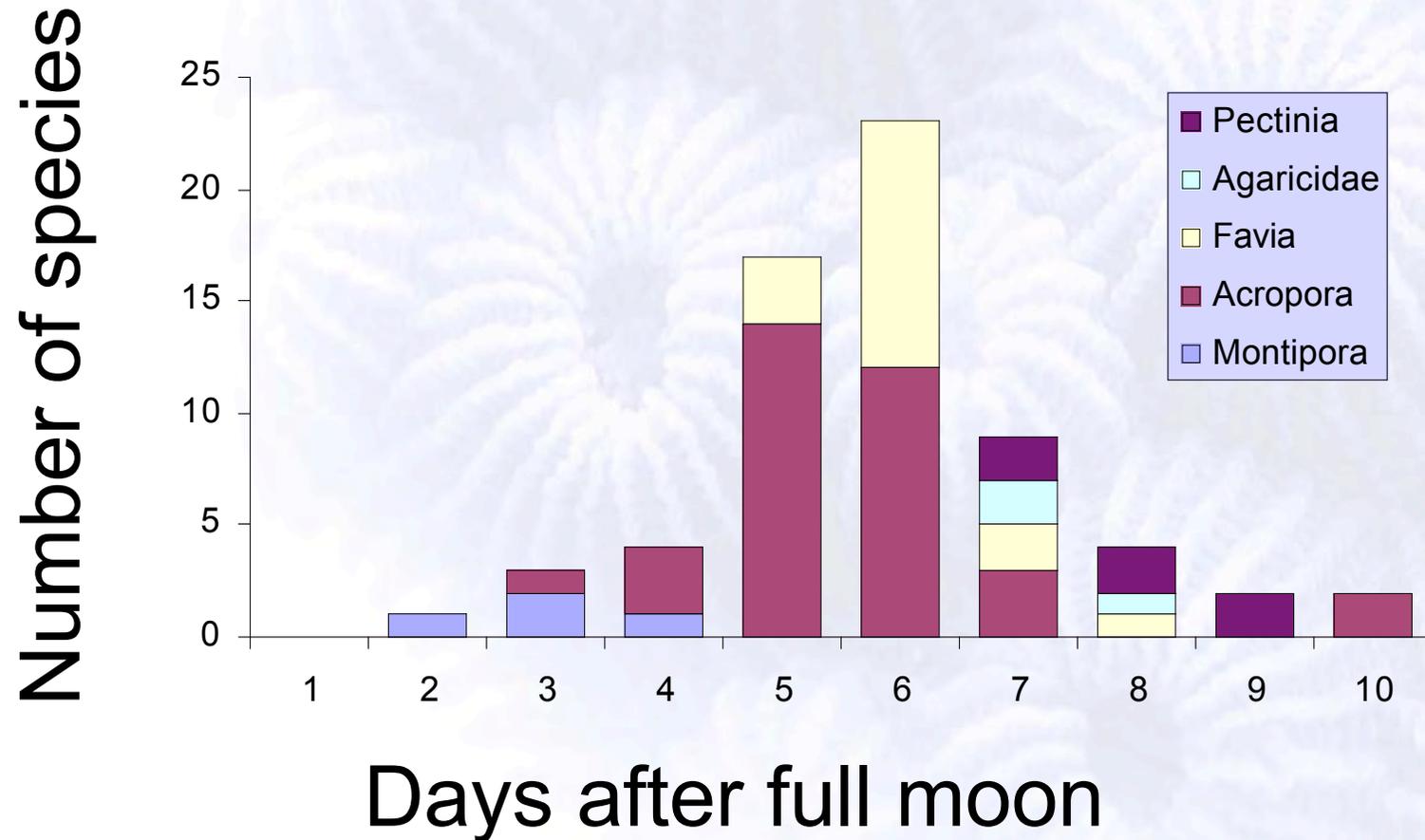
- Prior to 1984 most corals were believed to be brooders, reproductively active year all year resulting in:
 - a uniform pool of larvae;
 - and settlement through out the year

Coral spawning on the Great Barrier Reef:

- in the central GBR over 130 species spawn in the week following a full moon in late spring (Harrison et al. 1984)
- > 30 species spawn within hours on the same night at a single location (Willis et al. 1985; Babcock et al. 1986)

The mass spawning period: GBR

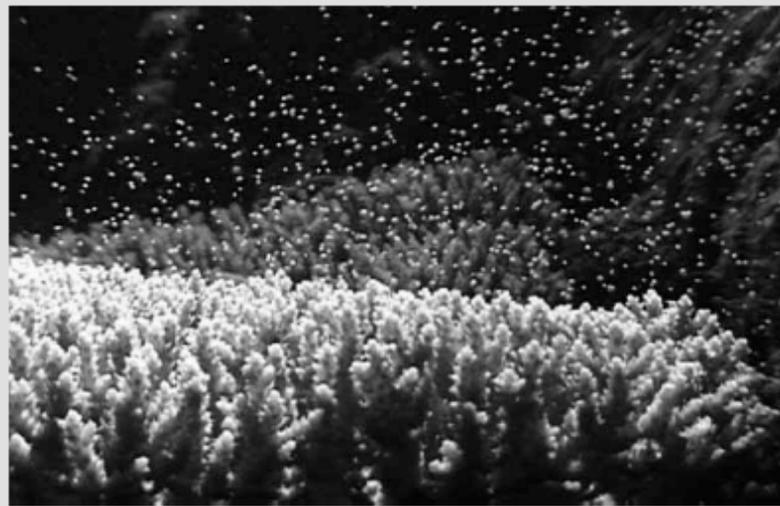
Orpheus Island, GBR November 1984 Willis et al. 1985



Coral spawning: global patterns 1990's view

“Synchronous spawning [occurs] on the Great Barrier Reef, while asynchrony among and within species has been observed in the Red Sea, Caribbean, Central Pacific, Hawaii, and southern Japan” (Richmond & Hunter 1990)

Geographic variation in spawning synchrony: global patterns

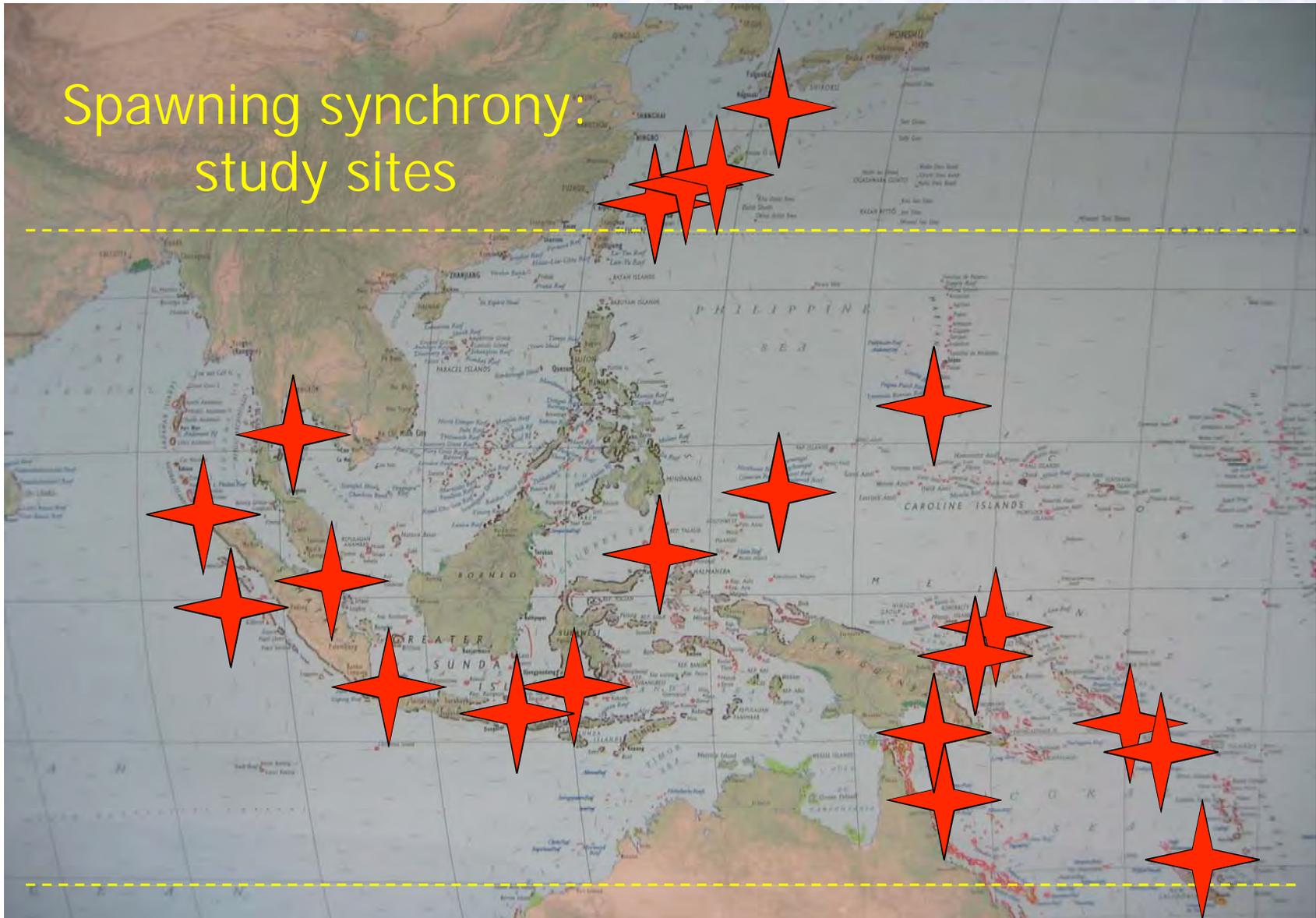


28 of 41 *Acropora* species sampled had mature colonies

A multi-specific spawning event close to the equator in contradiction to the dogma

Baird, A.H., & Sadler, C. (2001) Synchronous spawning of *Acropora* in the Solomon Islands. *Coral Reefs*. **19**: 286.

Spawning synchrony: study sites





Why the *Acropora*?

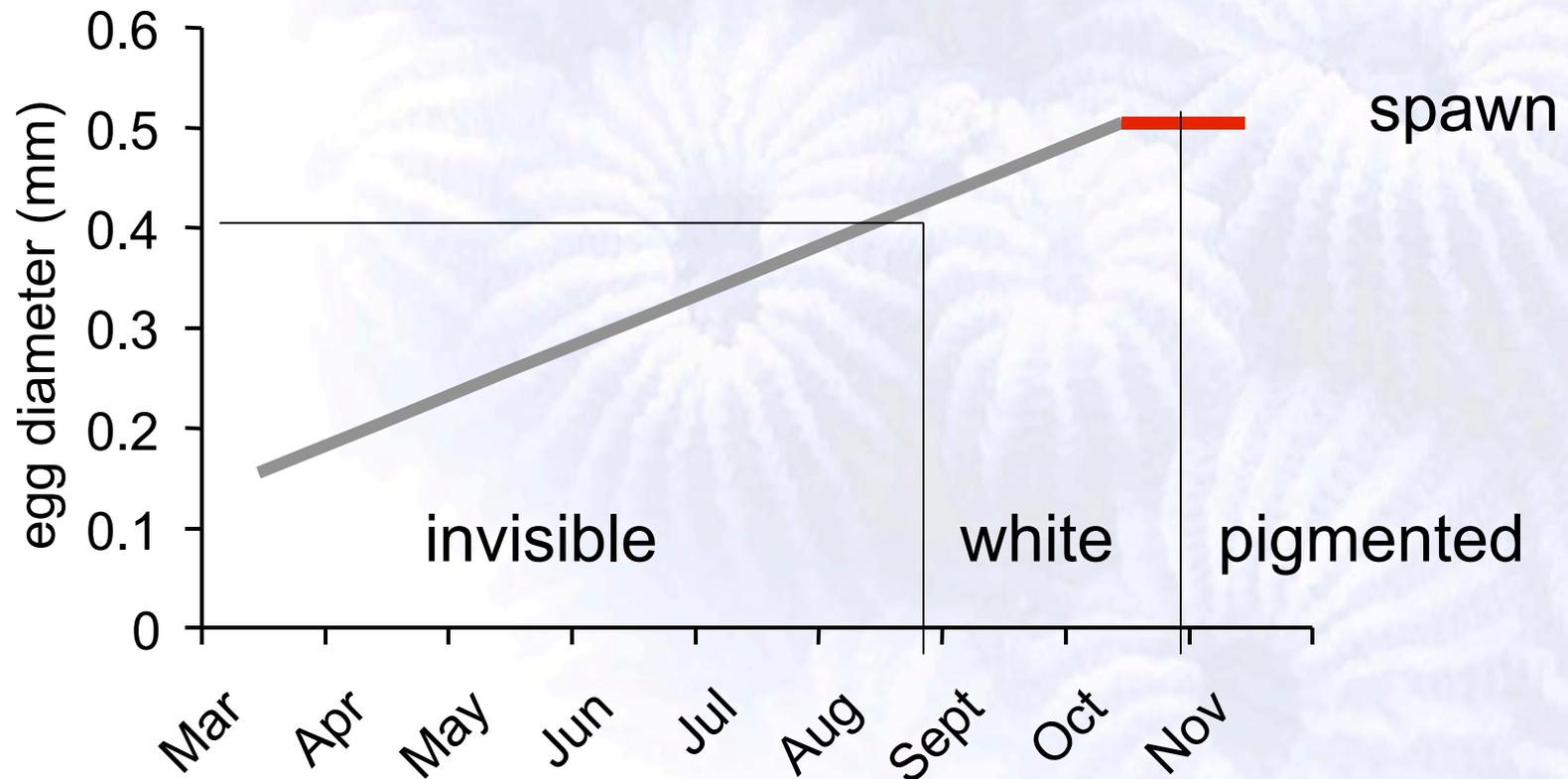
Abundant on most reefs

Ecologically significant

Easy to sample

Generally a good indicator of spawning
behaviour of other hermaphroditic species

Gametogenesis: the typical *Acropora* on the GBR



Reproductive condition of *Acropora* colonies



Photo: James Guest

Broken branch of *A. intermedia*

1. mature – pigmented eggs; spawning following next full moon
2. immature – white eggs; spawning in 2-3 months
3. empty - eggs too small to see or absent; recently spawned, or spawning unlikely to spawn in the near future.

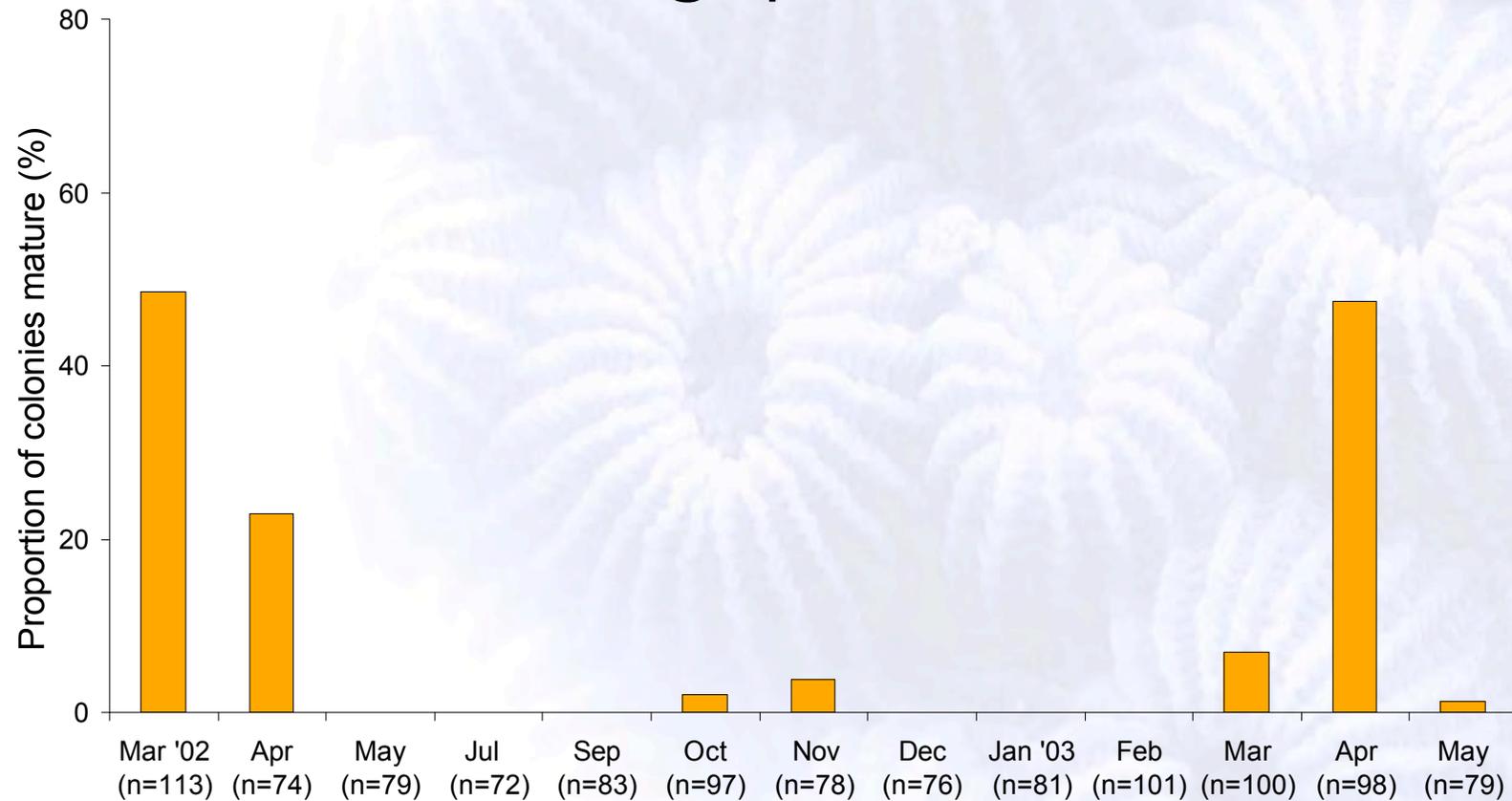
Spawning synchrony: Central Indo-Pacific



The proportion of *Acropora* colonies breeding

- In the central Indo-Pacific, for example, the majority of reproductive output is concentrated in brief spawning periods following full moons at the beginning and end of the monsoon.
- The spawning peak in Manado, Singapore, northern New Guinea, southern Japan and Aceh is in Mar/Apr, whereas in Bali, Padang, Makassar, the Solomon Islands, New Caledonia and on the GBR the peak is in Oct/Nov.
- While the comparative intensity of these peaks varies between locations, the timing appears to be consistent among years.

Spawning synchrony: *Acropora* in Singapore

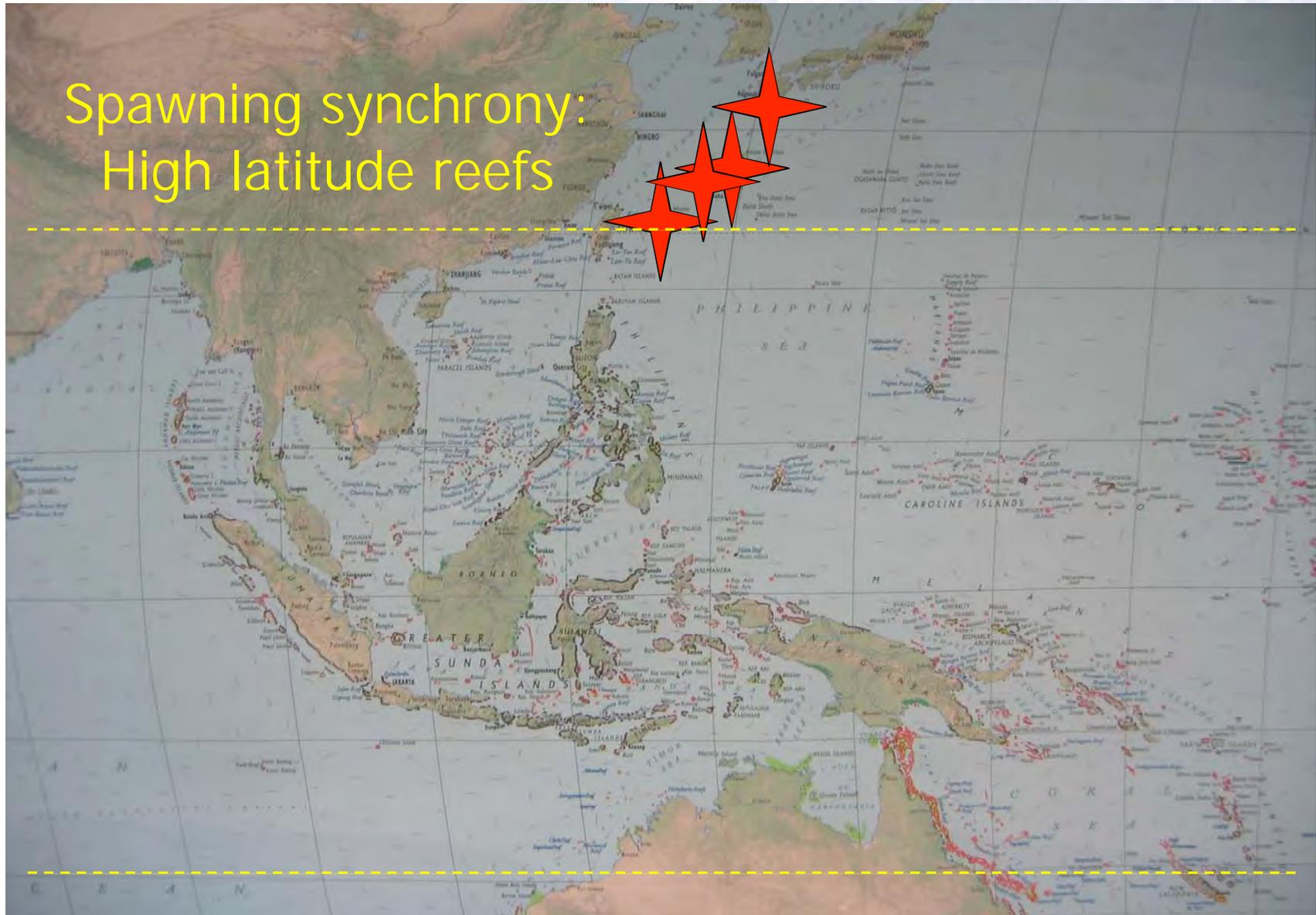


Guest JR, Baird AH, Goh BPL & Chou LM (2004) Coral Reefs in press

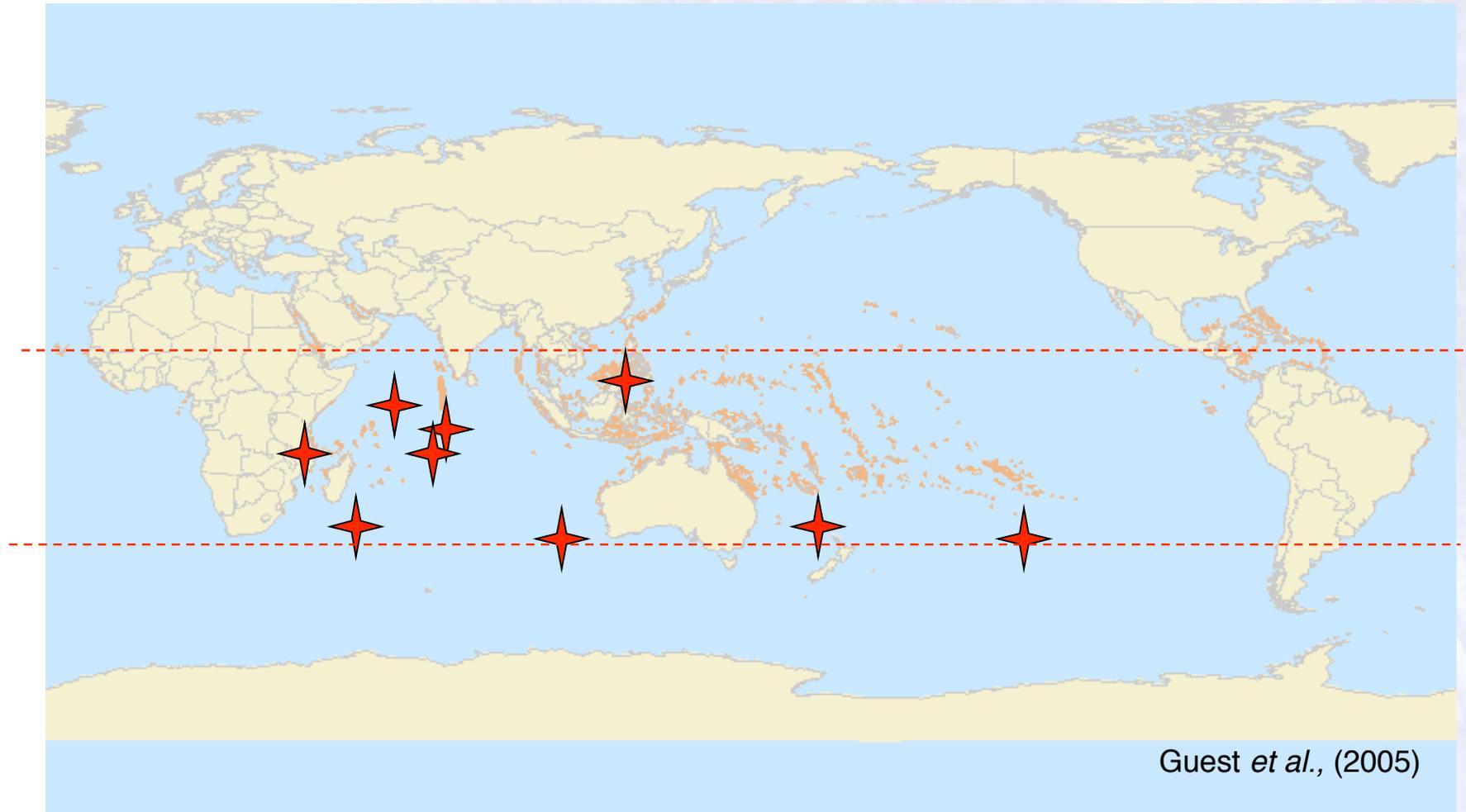
Geographic variation in the time of spawning: central Indo-Pacific

- In the central Indo-Pacific the majority of spawning is concentrated in brief periods following full moons at the beginning and end of the monsoon

Spawning synchrony: High latitude reefs



Geographic variation in the timing of spawning: other studies



Geographic variation in the timing of spawning: high latitude reefs

- Above approximately 28-30 degrees latitude, the spawning peak is progressively one month later in the season for every 2-400 km from the equator

Spawning synchrony: cross shelf patterns GBR



Spawning synchrony in *Acropora* assemblages: Cross shelf patterns in the central GBR

- At smaller spatial scales the patterns are far less regular.
- For example, in the Central GBR peak spawning on inshore reefs occurs one month before offshore reefs.
- However, *Acropora* spawning occurs following every full moon between October and February at most reefs.

Inshore-offshore differences

- Peak spawning is typically one month earlier on inshore reefs at least on the GBR; almost certainly driven by temperature
- Similar pattern in the Gulf of Thailand, with inshore northern reefs spawning a month earlier than open ocean reefs in the south

Spawning synchrony: species which spawn more than once per year

- Some species spawn predominantly early in the season, such as the classic mass spawners, *A. millepora* and *A. hyacinthus*.
- Some spawn throughout the season eg. *A. humilis*.
- Some species spawn predominantly later in the season eg. *A. verweyi*.

Spawning synchrony: reef scale spatial variation in *Acropora valida*

- Peak spawning within populations of a single species can vary dramatically over very small scales.
- For example, consider 4 mid-shelf reefs in the Central GBR separated by less than 20 km:
- On 2 reefs fecund colonies of *A. monticulosa* were observed only in December, at a 3rd reef, fecund colonies were only observed in November, while at the 4th reef, fecund coral were observed in both November and December.

Are there species which spawn more than once per year?

- Most colonies of most spawning species have only one gametogenic cycle per year i.e. each colony spawns only once
- Very high synchrony within populations is the exception rather than the rule. Spawning is typically split over 2-3 months in most species at most locations

Are there species which are not synchronous?

- Brooders are less synchronous than spawners, particularly on low latitude reefs
- A small number of spawning species release gametes outside the main mass spawning periods eg *A. veryweyi*; *A. longicyathus*

What proportion of the population might typically spawn in a single event?

- Generally between 20-80 %
- Very rarely 100 %

How synchronised is coral spawning?

- Multi-specific synchronous spawning is a feature of all specious coral assemblages
- Discrete mass spawning periods, similar to that on the GBR, concentrated at changes of season within 28 degrees of the equator
- Highly predictable at large scale; less so a smaller scales eg. reefs with region

How synchronised is coral spawning?

Caveats

- Always exceptions eg Gulf of Thailand the northern reefs spawn in February; Guam in May/June
- Some sites remain a mystery despite intensive sampling eg. Sth PNG
- Exact day of spawning often varies between years
- How will spawning synchrony be affected by climate change
- Detailed studies at local scale are necessary

How synchronised is coral spawning?

Knowledge gaps

- Environmental cues for coral spawning remain unknown: temperature, solar irradiance or other cues?
- Data on reproductive biology is available for less than 50% of scleractinian species
- In particular, gonochoric species poorly known

Question time

Question	Responses
<p>Simpson- A previous explanation of why corals spawn in Spring on the East Australian Coast and Autumn on the Western Australian coast proposed that this was a genetic polymorphism with larvae distributed either way by prevailing currents.</p>	<p>Baird – there may be a genetic basis to the Spring-Autumn split in some species but we are not sure.</p>
<p>Kabay- What is the significance of the full moon in predicting spawning?</p>	<p>Baird- Corals can detect moonlight and may focus in on the moon phase – or it may be other factors associated with moon phase Simpson- the tide is critically associated with the moon and the 7d post full moon periodicity may be aligning with neap tides.</p>
<p>Ward- How local is the scale of variation in the percentages of coral populations that are reproductively synchronised? Could this patchiness be used for management?</p>	<p>Baird – Differences in fecundity are associated spatially within reefs or between reef patches. Some patches of <i>Acropora</i> individuals may be almost all gravid while others a few km away may be all non-gravid. It is not clear what environmental differences cause this patchiness. Simpson- This may relate to specific individuals – we have seen corals which will spawn at the same time year after year.</p>
<p>Metaxis – Is some of the apparent variation in the timing of spawning within a species due to taxonomic confusion?</p>	<p>Baird – With some groups the differences have been identified as relating to cryptic species – but others seem to vary within a single readily identified species.</p>
<p>Stoddart – You show sites which have a major and a minor spawning peak in Spring or Autumn. Are the site-specific differences constant between years?</p>	<p>Baird – We only have multi-year data for a few sites, but the ratio is constant over those years at those sites.</p>
<p>Forde – <i>Acropora</i> species are fast growing. Might your variation in fecundity be related to immature individuals?</p>	<p>Baird – Unlikely as we target individuals which are generally of a reproductive size.</p>