An Indo-Pacific coral spawning database

Andrew H. Baird
James Cook University

James R. Guest
Newcastle University

Alasdair J. Edwards
Newcastle University

Andrew G. Bauman
National University of Singapore

Jessica Bouwmeester
Smithsonian Institution, Hawai'i Institute of Marine Biology

See next page for additional authors

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Maria Dornelas  
*University of St Andrews*

Christopher Doropoulos  
*CSIRO*

Gal Eyal  
*The University of Queensland*

Lee Eyal-Shaham  
*Bar-Ilan University*

Nur Fadli  
*Syiah Kuala University*

Joana Figueiredo  
*Nova Southeastern University, jfigueiredo@nova.edu*

Jean-François Flot  
*Université libre de Bruxelles*

Sze-Hoon Gan  
*Universiti Malaysia Sabah*

Elizabeth Gomez  
*University of the Philippines*

Erin M. Graham  
*James Cook University*

Mila Grinblat  
*James Cook University*

Nataly Gutiérrez-Isaza  
*The University of Queensland*

Saki Harii  
*University of the Ryukyus*

Peter L. Harrison  
*Southern Cross University*

Masayuki Hatta  
*Ochanomizu University*

Nina Ann Jin Ho  
*Xiamen University Malaysia*

Gaetan Hoarau
Mia Hoogenboom  
*James Cook University*

Emily J. Howells  
*University of Wollongong*

Akira Iguchi  
*National Institute of Advanced Industrial Science and Technology*

Naoko Isomura  
*Okinawa College*

Emmeline A. Jamodiong  
*University of the Ryukyus*

Suppakarn Jandang  
*Chulalongkorn University*

Jude Keyse  
*Glenala State High School*

Seiya Kitanobo  
*University of the Ryukyus*

Narinratana Kongjandtre  
*Burapha University*

Chao-Yang Kuo  
*Academia Sinica*

Charlon Ligson  
*University of the Philippines*

Che-Hung Lin  
*Academia Sinica*

Jeffrey Low  
*National Biodiversity Centre, Singapore*

Yossi Loya  
*Tel-Aviv University*

Elizaldy A. Maboloc  
*Hong Kong University of Science and Technology*

Joshua S. Madin  
*University of Hawaii at Manoa*
Takuma Mezaki  
*Kuroshio Biological Research Foundation*

Choo Min  
*National University of Singapore*

Masaya Morita  
*University of the Ryukyus*

Aurelie Moya  
*James Cook University*

Su-Hwei Neo  
*National University of Singapore*

Matthew R. Nitschke  
*Victoria University of Wellington*

Satoshi Nojima

Yoko Nozawa  
*Academia Sinica*

Srisakul Piromvaragorn

Sakanan Plathong  
*Prince of Songkla University*

Eneour Puill-Stephan  
*Sustainable Research Vessel, Landéda*

Kate Quigley  
*Australian Institute of Marine Science*

Catalina Ramirez-Portilla  
*Université libre de Bruxelles*

Gerard Ricardo  
*Australian Institute of Marine Science*

Kazuhiko Sakai  
*University of the Ryukyus*

Eugenia Sampayo  
*The University of Queensland*

Tom Shlesinger  
*Florida Institute of Technology*
Leony Sikim  
*Reef Guardian Sdn. Bhd*

Chris Simpson

Carrie A. Sims  
*The University of Queensland*

Frederic Sinniger  
*University of the Ryukyus*

Davies A. Spiji  
*Reef Guardian Sdn. Bhd*

Tracy Tabalanza  
*University of the Philippines*

Chung-Hong Tan  
*Universiti Malaysia Terengganu*

Tullia I. Terraneo  
*King Abdullah University of Science and Technology*

Gergely Torda  
*James Cook University*

James True  
*King Mongkut’s Institute of Technology Ladkrabang*

Karenne Tun  
*National Biodiversity Centre, Singapore*

Kareen Vicentuan  
*National University of Singapore*

Voranop Viyakarn  
*Chulalongkorn University*

Zarinah Waheed  
*Universiti Malaysia Sabah*

Selina Ward  
*The University of Queensland*

Bette Willis  
*James Cook University*

Rachael M. Woods  
*Macquarie University*
The discovery of multi-species synchronous spawning of scleractinian corals on the Great Barrier Reef in the 1980s stimulated an extraordinary effort to document spawning times in other parts of the globe. Unfortunately, most of these data remain unpublished which limits our understanding of regional and global reproductive patterns. The Coral Spawning Database (CSD) collates much of these disparate data into a single place. The CSD includes 6178 observations (3085 of which were unpublished) of the time or day of spawning for over 300 scleractinian species in 61 genera from 101 sites in the Indo-Pacific. The goal of the CSD is to provide open access to coral spawning data to accelerate our understanding of coral reproductive biology and to provide a baseline against which to evaluate any future changes in reproductive phenology.

Background & Summary
Scleractinian corals are the ecosystem engineers of coral reefs, the most species-rich marine ecosystems. Scleractinian corals have a bipartite life history, with a sessile adult stage and a planktonic larval stage that allows dispersal among reefs. Corals produce larvae in one of two ways: gametes are broadcast-spawned for external fertilization or the eggs are retained for internal fertilization, followed by the release of planula larvae from the polyp. The discovery of multi-species synchronous spawning on the Great Barrier Reef\(^1\) stimulated a large effort to document coral spawning times in other regions of the world. Similar multi-species spawning events \(\text{sensu}^2\) have now been documented in over 25 locations throughout the Indo-Pacific\(^3\)–\(^5\). However, much additional data on coral sexual reproductive patterns remain unpublished. Even when spawning data are published, there is often insufficient detail, such as the precise time and duration of spawning, to address many important questions. Consequently, predicting the month of spawning has been the focus of many studies to date\(^6\).

Coral spawning times can be used to address many significant and fundamental questions in coral reef ecology. Most coral species are notoriously difficult to identify and spawning times have been used to infer pre-zygotic barriers to fertilization and thus assist decisions about species boundaries\(^7\)–\(^9\). While proximate cues associated with the month of spawning are reasonably well understood in some taxa\(^8\)–\(^9\), the relationship between cues for the date and time of spawning are poorly understood. Similarly, potential phylogenetic patterns and geographical variation in spawning times are only beginning to be explored\(^10\). Knowing when corals spawn is also important for managing coastal development. For example, in Western Australia, legislation requires dredging operations to cease during mass spawning events\(^11\)–\(^12\). Coral spawning is also an economic boon for tourist operators in many parts of the world, such as the Great Barrier Reef. Furthermore, population level records of spawning times provide a baseline against which to evaluate potential changes in spawning synchrony or seasonality associated with anthropogenic disruptions to environmental cues, in particular, sea surface temperature\(^13\). Knowledge of the timing of spawning is also essential for accurately estimating levels of connectivity among populations, given season differences in current flow\(^14\). The value of long-term species level data on coral spawning has recently been demonstrated in a test of the influence of temperature and wind on the night of coral spawning\(^15\).

In this data descriptor, we present the Coral Spawning Database (CSD). The CSD includes spawning observations for reef building coral species from the Indo-Pacific. The CSD includes 6178 observations (3085 of which were unpublished) of the time or day of spawning for 300+ scleractinian species in 61 genera (Online-only Table 1) from 101 sites (Fig. 1) in the Indo-Pacific. The goals of the CSD are: (i) to assemble the scattered and mostly unpublished observations of scleractinian coral spawning times and (ii) to make these data readily available to the research community. Our vision is to help advance many aspects of coral reef science and conservation at a time of unprecedented environmental and societal change.

\(^{#}\)A list of authors and their affiliations appears at the end of the paper.
Methods

The CSD includes spawning times for broadcast spawning scleractinian coral species in the Indo-Pacific. There are two sources for these data: the literature and unpublished observations. Published literature was selected based on the authors’ knowledge of the subject area and a literature search using the terms “coral AND spawn*”. Over 50 researchers known by the authors to have extensive data on coral spawning times were approached to contribute unpublished data. This initial invitation led to a subsequent round of invitations to additional contributors. Of course, we encourage any researchers with data we have missed to contribute their observations in the annual update of the database. The database focusses on spawning times. Many other biological variables related to coral reproduction, such as fecundity, are available in the Coral Traits Database16.

The database is available as a Microsoft Access relational database or an Excel spreadsheet. To minimise repetition in data entry, spawning observation information is entered in three primary tables (Fig. 2). The first (“tblSitesForSpawningObservations”) is used to enter geographic information on each study site; the second
Data entry. Coral Spawning Database fields.

1) Site information (in tblSitesForSpawningObservations):

- **Ecoregion_ID** link to Ecoregions (150) as defined by 17
- **Country** the country, territory (e.g. Guam) or island group (e.g. Hawaiian Islands) where spawning observation was made
- **Site** accepted name for broad geographical location (e.g. archipelago, island, offshore reef, bay, etc.) of the observation
- **Subsite** more precise site name within location (where applicable; na entered where no subsite)
- **Latitude** in decimal degrees (-ve values for sites South of the Equator)
- **Longitude** in decimal degrees (-ve values for sites West of the Greenwich Meridian)

2) Spawning observations (in tblSpawningObservations):

- **Depth_m** the approximate depth at which the colony was collected (for ex situ observations) or observed (for in situ observations). If not recorded then −99 entered.
- **Genus** currently accepted genus name 19
- **O_n** open nomenclature qualifier: see explanation below under "Species identifications"
- **Species** the species name used by the observer
- **Date** date of spawning observation in the format day/month/year (e.g. 24/11/1983)
- **N** number of colonies or individuals observed spawning. Used −99 if not known. If exact number of colonies not counted but more than a specific number were observed to spawn (e.g. > 25), then minimum number counted was entered (e.g. 25).
- **Start_time** time of first observation of spawning for colony(ies) of species: time (hh:mm) on a 24 hour clock e.g. 18:30. See “recording the time of spawning” below for ways to use the time fields to capture the various ways spawning is usually observed. No threshold applied to the intensity of spawning.
- **No_start** no information on time that spawning started: True or False.
- **Quality_start** if No_start is False, Exact or Approx
- **End_time** time of last observation of spawning for colony(ies) of species (if later than start time, normally): time (hh:mm) on a 24 h clock e.g. 18:30
- **No_end** no information on time that spawning ended: True or False
- **Quality_end** if No_end is False, Exact or Approx
- **Gamete_release** (five character states as follows)
  - Bundles – eggs and sperm released together packaged in bundles
  - Eggs – only eggs released
  - Sperm – only sperm released
  - Both separately – eggs and sperm released separately from the same colony. Examples include Lobophyllia hemprichii and Goniatrea favusus
  - Not recorded – release of gametes not observed or not reported

- **Situation** In situ = spawning observed underwater or Ex situ = spawning observed in tanks of colony(ies) recently removed from the reef.
- **Timezone** local time zone on the date of the spawning observation. This allows local time of spawning to be related to local time of sunset (or occasionally sunrise, for daytime spawners). This field is not an integer to accommodate 30 minute time differences (e.g. India and Sri Lanka are on UTC + 5.5). Entering -ve values for sites west of the Greenwich Meridian: e.g. −11 for Hawaii. (Note: Daylight Saving Times mean that time zones at some sites vary with date, e.g. Fiji goes from UTC +12 to UTC +13 from early November to early January).

The next four fields contain benchmarks for comparing spawning among sites for different species or groups of species 23. The first is the date of the nearest full moon (DoNFM) to the date of spawning (with 75% of spawning recorded in the week after the full moon). This allows all spawning dates to be calculated in terms of days before or after the full moon (DoSRTNFM). Sunset provides a benchmark for comparing the times of spawning for most spawners (over 90% of spawning started within 4 hours of sunset) and sunrise for a few daytime spawners such as Pocillopora verrucosa. Dates of full moon and times of sunrise and sunset are available for given locations from the web (e.g. www.timeanddate.com) and can be entered manually. However, they can also be calculated automatically in the database based on the date, time zone and, for sunrise and sunset, the latitude and longitude. Excel spreadsheets are also available on request from the corresponding authors to calculate dates of full moon and times of sunrise and sunset in addition to a data entry template.
3) **Reference information** (in tblReferencesForSpawningObservations):

Each set of observations is referenced to its published or unpublished source in this table via a Ref_ID. The table contains two main fields: “Short_ref” (e.g. Baird *et al.* 2015) and “Full_reference” (e.g. Baird AH, Cumbo VR, Gudge S, Keith SA, Maynard JA, Tan C-H, Woolsey ES (2015) Coral reproduction on the world’s southernmost reef at Lord Howe Island, Australia. Aquatic Biology 23:275–284). These can be filled in before or after entering spawning observations. An email address is provided for all unpublished contributions.

**Notes to recording the time of spawning.** For the quality of a start or end time to be ‘Exact’, a colony must be under continuous observation and the time of onset or end of spawning be observed and recorded. Most *in situ* observations would be expected to be approximate (‘Approx’).

The Quality_start, Quality_end, No_start and No_end fields are designed to accommodate the most common ways spawning is observed. A series of examples are given below.

1. A colony is observed spawning but it is not known exactly when it started. No end time is recorded. Here enter the time the colony was first observed spawning as the Start_time and the Quality_start as ‘Approx’. Leave the End_time blank and set No_end to True.
2. A colony is followed closely until spawning is observed to begin but the precise time when spawning ends is not recorded. However, the colony is observed to be still dribbling spawn 30 minutes after spawning started. Here enter the Quality_start as ‘Exact’ with the End_time set to 30 minutes after the Start_time and the Quality_end set to ‘Approx’.
3. A colony is followed closely from the beginning until the end of spawning. Here enter the times and note Quality_start and Quality_end as ‘Exact’.
4. A colony is placed in a bucket and checked every 30 minutes. At the first observation there is no evidence of spawning, 30 min later the surface of the water is covered in bundles and the colony is no longer spawning. Here enter the time of the first observation as the start time and the Quality_start as ‘Exact’ with the End_time set to 30 minutes after the Start_time and the Quality_end as ‘Approx’.
5. Only the night of spawning is known, for example, gametes are no longer apparent in a tagged and sequentially sampled colony. Here don’t enter either a start time or an end time and leave Quality_start and Quality_end blank. Set No_start and No_end to True.

**Species identifications.** Species were generally identified following 18,24 by comparing skeletons to the type material or the original descriptions of nominal species. Specimens identified following 18,24 were updated to the currently accepted names at the World Register of Marine Species 19. The database also allows for uncertainties in species identifications to be indicated with the use of a series of open nomenclature qualifiers 25,26 that allow the assignment of specimens to a nominal species with varying degrees of certainty. Specimens that closely resemble the type of a nominal species are given the qualifier *cf.* (e.g. *Acropora cf. nasuta*). Specimens that have morphological affinities to a nominal species but appear distinct are given the qualifier *aff.* (e.g. *Acropora aff. pulchra*): these specimens are either geographical variants of species with high morphological plasticity or potentially undescribed species. Species that could not be matched with the type material of any nominal species were labelled as *sp._* in addition to the location where they were collected (e.g. *Acropora sp._*1*Fiji*). These specimens are most probably undescribed species. For 1% of records spawning colonies were only identified to genus (e.g. *Montipora* *sp._*). Contact the sources of these data for further information on the species identity.

**Data Records**

A snapshot of the data contained in this descriptor can be downloaded from figshare 27. The data includes 6178 observations, 3085 of which were unpublished with the remainder gleaned from the literature 28–128. These data have been through a rigorous quality control and editorial process. Annual updates of the dataset will be uploaded to figshare as new version and also made available at any time on request from the Editor (JRG). Contributions to the CSD are welcome at any time and should be sent to the Editor (JRG).
Technical Validation

The database is governed on a voluntary basis, by an Editor (JRG), Assistant Editors (JB & AGB), a Taxonomy Advisor (AHB) and a Database Administrator (AJE). Quality control of data and editorial procedures include:

1. **Contributor approval.** Database users must request permission to become a database contributor.
2. **Editorial approval.** Once a contributor sends data to the Editor, the data will be checked and if correctly formatted will be forwarded to the Database Administrator.
3. **User feedback.** Data issues can be reported for any observation by email to the Editor.

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A.H.B. and J.R.G. conceived the idea. A.H.B., J.R.G., A.J.E., J.B., A.G.B., S.-H.N. & H.M. compiled the data and jointly wrote the data descriptor. A.J.E. designed the database. All other authors contributed unpublished data and commented on the text.

Competing interests
The authors declare no competing financial interest.

Additional information
Correspondence and requests for materials should be addressed to A.H.B., J.R.G. or A.J.E.

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