Centre for Tropical Water and Aquatic Ecosystem Research

Conservation planning for cling gobies and short-steep-coastal-streams in the Australian Wet Tropics

Brendan C. Ebner, James A. Donaldson and Travis A. Sydes

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A Report to the Queensland Government in accordance with the Everyone's Environment Grants Program

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EXECUTIVE SUMMARY

This project served to define short-steep-coastal-streams (SSCS) and provide an appraisal of their spatial extent and distribution in the Australian Wet Tropics. It also served to initiate hydrological monitoring in some of these streams and to provide modelled distributions of associated fauna in the form of sicydiine gobies (including four threatened species). We used the opportunity to engage relevant interest groups and users of these catchments and to communicate the existence of the specialist fauna occupying these streams.

This report provides the first physical-geomorphology definition of SSCS for tropical Queensland, or for that matter globally. SSCS catchments are hot spots for recreation due to the rainforest lined terrain, availability of waterfalls and flowing freshwater and small sandy beaches. Short-steep-coastal-streams are also sites for resorts, caravan parks, national parks and Indigenous Protected Areas and popular swimming beaches. These ecosystems are known to support a unique aquatic fauna dominated by amphidromous species including fishes (especially cling gobies, subfamily Sicydiinae), crustaceans (prawns, shrimps) and molluscs. Amphidromous is a term used to describe species that live the majority of their life in freshwater where they grow and breed, but where their larva travel to sea for a period of time to develop and disperse.

Spatial decision rules were used to quantify and map SSCS. For brevity the main channel of SSCS are short in length (100’s to 10’s of kilometres), steep (average slope > 5% across the entire stream network) and coastal, in that they empty directly to the sea via no or at most a rudimentary estuary. The lack of a substantial estuary is characterized by no mangroves or minimal mangroves present along the creek or lagoon near the mouth. The overall steep gradient of SSCS means that riffle-run-pool sequences are maintained along the entire length of the stream, leaving few areas for the deposition of alluvium. To perform our assessment at a landscape scale, we used a threshold of <20% alluvium total intersected by each stream. We estimate that SSCS catchments comprise 709 km^2 equating to 3.6% of the total area of the Wet Tropics bioregion. Further, SSCS represent 4.7% of the total 52,695 km of stream network in the region. Of the 602 SSCS, the smallest had a catchment area of 0.2 km^2 and the largest was 36 km^2 (limited by definition).

This project provided an opportunity to commence stream gauging in a subset of SSCS. The method used for achieving relatively low cost estimates of stream flow and water temperature is described, and was based on installing portable pressure and temperature sensors in-stream in regulated and unregulated streams. Water depth calibrated pressure sensors were then correlated with spot measurements of cross sectional flow (discharge). Preliminary findings show that the method is effective, and it is intended that extended sensor deployment beyond the life of this project will provide an annual estimate of stream discharge and daily variability in discharge and temperature across catchments. One relatively dry (Ellis Beach) and two wet sub-

regions (Yarrabah, Cape Tribulation) formed the centre of this gauging work, with deployments and data retrieval forming a collaboration with indigenous ranger groups in the latter two sub-regions. Human water extraction is potentially impacting the stream flow in some SSCS, and warrants further investigation in terms of measuring discharge and ecosystem function, particularly in the late dry season and drier years.

Preliminary data were used in species distribution modelling (SDM) based on available records of cling goby species level presence/absence data. At least nine species of cling goby have been recorded from the Australian Wet Tropics, and this report provides the first published records from Australia for two of these, namely *Smilosicyopus leprurus* and *Sicyopterus cynocephalus*. Our hypotheses were that large SSCS (typically pools >10 m wide, depth > 1m) would contain greater numbers of cling goby species than smaller SSCS, and that wetter catchments containing SSCS would contain greater numbers of species than those in drier catchments (i.e. according to rainforest as opposed to schlerophyll forest dominated catchments). An objective of the project was to redress two major imbalances in available survey data representing cling goby distribution in the Wet Tropics. Specifically, we aimed to overcome a bias in surveys in lowland as opposed to upland sections of SSCS, and to overcome sub-regional bias. With regard to the latter, surveys had not been conducted in the southern and northern extremities of the Wet Tropics, nor at the relatively low elevation but high rainfall Mission Beach sub-region.

Targeted rapid field surveys for cling gobies along entire main channels (snorkeling from the upper tidal limit to essentially the source of the stream) were used to provide representative sampling from six sub-regions: Hinchinbrook Island/Goold Island, immediately north of Mission Beach, Russell Heads to Trinity Inlet, Ellis Beach to Turtle Creek, north of the Daintree River to Cape Tribulation, and Cedar Bay (these surveys were aimed at refining the SDM). Only a single large stream was surveyed at Cedar Bay, whereas, at least three streams representing a range of the available stream sizes, were surveyed in each sub-region. Where fish survey data was available from our previous work in three streams (Noah Creek, Pauls Pocket Creek, Turtle Creek) these streams were not resurveyed for fishes.

Generally, three functional groups of cling gobies were recognizable based on our findings in this study and from publications and our experience elsewhere (e.g. Solomon Islands, and wider tropical Pacific high islands). These were lowland specialists, upland specialists and altitudinal generalists. Lowland specialists and the altitude generalist, *Sicyopterus lagocephalus* usually exhibited an order of magnitude or greater abundance than upland specialists.

This project served to foster community appreciation of SSCS and cling gobies provided a means by which people could relate to the ecology of these streams. Four species of cling goby are currently under either national or state listing and all cling goby species have been listed as no-take species under the Queensland

Fisheries Act. Furthermore, 77% of SSCS are nested within some form of conservation estate (e.g. Indigenous Protected Area, National Park). However, alien species (e.g. pigs, cane toads including their tadpoles, a number of fishes, invasive macrophytes and alien molluscs), human water extraction, climate change and direct harvesting of species (for recreational aquaria) have the potential to threaten these small aquatic ecosystems.

The definition and processes used in defining SSCS, setting spatial decision rules for desktop mapping, undertaking rapid biodiversity assessment, and refining SDM, has potential to be applied elsewhere in Australia and the tropical Pacific islands. This would presumably enable refinement of the definition of SSCS ecosystems and could form a basis for appraising if there is a similar fauna in places with similar habitat attributes that remain to be ecologically surveyed. To this end, within Australia, there are candidate regions to the north and south of the Wet Tropics on the north Queensland coastline.

Key recommendations from the project are:

a) Short-steep-coastal-streams should be integrated into the existing Queensland Wetland mapping and conceptualization.
b) The conservation status of all nine recognized Australian cling goby species should be reassessed based on this newly acquired dataset which is far less spatially biased than was the previous knowledge base.
c) Investment in the ecology of sicydiine goby ecology including monitoring of threatened species abundance, growth, reproduction at key sites within an inter-annual schedule, is required to aid the conservation of this fauna. Management of water availability and temperature as well as alien species interactions should be a feature of this work. In this regard, consolidation and further development of collaborations between traditional owner groups and university researchers may provide the long-term platform for progress.
d) The degree of (genetic) connectivity and recruitment dynamics between Australian and overseas adult populations of cling gobies remains an urgent scientific priority to inform management of these relatively rare species in an Australian context (Ebner *et al.* 2011).
e) That cling gobies be integrated into existing promotional and educational initiatives relating to the biodiversity value of the Australian Wet Tropics. The elevational zonation of individual species as shown in Figure 3.7 may provide a starting point for advertising the existence of these fishes in the region.

CHAPTER 1 GENERAL INTRODUCTION

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The Australian Wet Tropics is a high biodiversity region of international significance as a World Heritage Area, adjacent the Great Barrier Reef. There is a diverse fauna associated with freshwater ecosystems of the region, however, an inventory of this fauna remains incomplete, and new scientific discoveries of species continue to be made in terms of even vertebrates (e.g. frogs, fishes) (Thuesen *et al.* 2011, WTMA 2013, Pearson *et al.* 2015). Regionally, a substantially higher level of research effort has been put into understanding the marine and terrestrial ecosystems than has been the case in the freshwater realm.

The freshwater streams of the region encompass some of the more permanently flowing streams found on the Australian continent (Kennard *et al.* 2010) and this translates into flow microhabitats which have ecological and evolutionary consequences for plants and animals (e.g. Pusey *et al.* 2008, Donaldson *et al.* 2013). For instance, a number of endemic fish species are associated with refuges of high flow habitat in the drier periods of the Pleistocene (Pusey *et al.* 2008). However, there has been very little detailed geomorphological research or classification of streams in the region, although, preliminary classification of river reaches in northern Australia is underway (Erskine *et al.* 2005).

Short-steep-coastal-streams (SSCS) are a stream ecosystem type that is common on many high islands throughout the Pacific. They typically occur in steep, high rainfall areas close to the coast, are short and seldom have an estuary. In the Australian context, SSCS can be found throughout the Wet Tropics. By virtue of their nature, SSCS provide a centrepiece for recreation in terms of the stream, swimming holes and waterfalls, and also by association in terms of the adjacent and picturesque rainforest and beaches. Outside of protected areas, SSCS have an additional range of associated interest groups including indigenous people, resorts, caravan parks, surf life-saving clubs, farmers, tourists and schools. This diversity of interests groups poses a challenge for scientists communicating relevant messages about SSCS and cling gobies.

The hydrology of SSCS is poorly understood but is thought to be unique. Occurring in high rainfall areas, with often sheltered rainforest catchments, SSCS in the Wet Tropics are generally perennial. Even low order catchments with relatively small catchment sizes can retain flowing water year round. In many of these catchments, water extraction infrastructure exists to supply water to the many and varied stakeholder groups associated with this ecosystem type. Previous studies have established the importance of the flow regime in streams of the Wet Tropics (e.g. Pusey *et al.* 2008, Donaldson *et al.*, 2013), however, few studies have sought to document the hydrology of these unique systems.

In recent years, the discovery that a number of fish species from a group known as cling gobies (subfamily Sicydiinae) occupy small coastal streams of the Australian Wet Tropics led to the realisation that something different was going on in certain small catchments relative to the large river systems of the region including their tributaries (Ebner and Thuesen 2010, Thuesen *et al.* 2011). Preliminary precautions were recommended for protecting some of the cling gobies in the small coastal streams (e.g. Ebner *et al.* 2011), however, there was little available data that was relevant since by far the majority of past freshwater fish surveys had been conducted in large river catchments (cf. Pusey *et al.* 2004, and references therein). In fact, the most valuable reference material were field guides from tropical Pacific islands (e.g. Keith *et al.* 2002, Marquet *et al.* 2003).

Cling gobies use a suction cap which is actually two fused pelvic fins, to cling to rocks. In this report we use the terms 'sicydiine' and 'cling goby' interchangeably (although, we recognise that there are also marine cling gobies that are not closely related to this group of fishes). Some ecological interest in these fishes led to documentation of the habitat use of some of them in the small coastal catchments. Perhaps most notably, Donaldson *et al.* (2013) demonstrated that benthic goby species partitioned spatially according to habitat and especially flow habitat as a function of swimming capability. Additionally, gradual accumulation of records of the elusive and unique Freshwater moray, *Gymnothorax polyuranodon* (an eel), revealed its refuge behaviour within the interstices under boulders, in three streams at Cape Tribulation (Ebner *et al.* 2016). The availability of these interstices are presumed to be a function of the discharge regime in these streams (Ebner *et al.* 2016).

A few field trips by researchers (Ebner and Thuesen) in tropical Pacific islands including the Solomon Islands combined with the slow process of opportunistically mapping out cling goby distribution in the Australian Wet Tropics, stimulated thinking about how to survey this fauna more systematically. Combined with funding of the current study, this resulted in synthesis of current knowledge including unpublished data on cling goby presence records and attempts to conceptualise the small streams which these fishes inhabit. These streams are termed here, short-steep-coastal-streams.

The primary objective in the current project is to produce and consolidate spatial information on the distribution of SSCS in the Wet Tropics in order to ascertain regional and national management priorities and to empower local communities to make planning decisions and enable local landholders to consider options for sustainable on-ground management. Cling gobies are a key faunal group occupying this ecosystem type, and four of these species are conservation listed species requiring consideration in developing relevant conservation plans.

In chapter 2 we define SSCS and deal with physical aspects of this ecosystem. In chapter 3, biotic aspects of the ecosystem, and the distribution and relative abundance of cling gobies are the focus. This includes the first attempts to model the distribution of each species. Chapter 4 explores the community engagement side of the project. This includes an outline of the field collaborations with landholders and environmental managers in the lead up to and during the project. It ends with discussion of future directions for regional sustainable SSCS and cling gobies. In chapter 5, a final discussion is used to bring different elements of the project together and to provide regional, state, national and international context for this project work.

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CHAPTER 2 SHORT-STEEP-COASTAL-STREAMS IN THE WET TROPICS

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INTRODUCTION

The ecosystem is a concept used to isolate and study a physical and/or biotic system (Tansley 1935, Gignoux *et al.* 2011). In this case we consider stream ecosystems. However, the classification of rivers and stream systems is not straightforward relative to terrestrial ecosystems or perhaps non-flowing waters, because flowing waters form directionally nested hierarchies whereby upper levels or units cannot be subdivided into finer scales in a meaningful way (Melles *et al.* 2012). Nevertheless, defining, classifying and quantifying aquatic ecosystems including flowing waters is important for their conservation (Mactaggart *et al.* 2008, Kennard *et al.* 2010, Gignoux *et al.* 2011, AETG 2012, DEHP 2016).

In Australia, advances in classifying wetlands and rivers have been made from geological and hydrological perspectives, however, these classifications are either of a preliminary nature or are comprehensive but limited to very specific habitats or regions (e.g. Erskine *et al.* 2005, Mactaggart *et al.* 2008, Moliere *et al.* 2009, AETG 2012). Kennard and colleagues (2010), delineated 12 distinct classes of annual flow regime type across the extent of Australia; and from a geomorphological perspective, nine types of river reach were recognised by Erskine *et al.* (2005) as being present in the tropical regions of the country.

In Queensland extensive effort has gone into defining and classifying wetlands in a systematic way, and this process has dealt with lentic (non-flowing) water bodies to date (DEHP 2016). Flowing waters are yet to receive similar detailed attention. The geomorphological and flow classifications, previously mentioned, among other works, provide some basis for classifying flowing waters in Queensland (Pusey *et al.* 2004, Erskine *et al.* 2005, Kennard *et al.* 2010). Intuitively the Wet Tropics streams are expected to be of special interest in this regard, as a function of regional characteristics of predominantly mountainous terrain and high rainfall (Pusey *et al.* 2004, Peel *et al.* 2007) combined with the phenomenon of rainforest cloud interception (McJannet *et al.* 2007).

The stream gauging data available across tropical Australia are skewed toward large rivers and is spatially and temporally patchy (Moliere *et al.* 2009, Kennard *et al.* 2010). Within the Wet Tropics region, long-term gauging stations are not associated with the smaller streams and in particular SSCS, probably because these waterways are perceived to be of low value from an economic or at least agricultural vantage point. Human water harvest of SSCS in the Wet Tropics remains essentially unquantified. The biodiversity value of these streams and specifically how the temporal dimension of hydrographs effect aquatic biodiversity, remain to be investigated as do the potential biodiversity implications of human water extraction. Current ecological understanding is based primarily on overseas studies in comparable ecosystems (e.g. Keith 2003) with a lone local study demonstrating strong spatial partitioning of habitat use according to fish species preference for flow microhabitat (Donaldson *et al.* 2013).

The aims of this chapter are to: a) define SSCS from a physical perspective and to describe the distribution of this ecosystem type within the Australian Wet Tropics, b) to report on developing an inexpensive technique for obtaining some initial gauging estimates of daily stream discharge in a sample of these streams, and c) to provide an initial record of river regulation structures and water extraction related activities in a selection of these streams.

METHODS

An outline of our conceptual thinking regarding SSCS is provided below, followed by a description of the mapping of these streams at the extent of the Wet Tropics. This is followed by a brief description of the trial stream gauging method and catchments where water extraction was observed. A general definition of SSCS for regional purpose is then provided in the results section alongside of quantitative estimates of regional catchment contribution.

Conceptual basis for SSCS

It is commonplace to establish the conceptual basis for stream and ecosystem classification (Melles *et al.* 2012). While this chapter focuses on the physical aspects of SSCS, it is important to acknowledge that the conceptual basis for defining SSCS comes from the observation of a relatively distinct biotic composition of the resident fish fauna in these streams and its commonality with that from streams on high islands of the tropical Pacific and relative dissimilarity to the fauna in large catchments of the Australian Wet Tropics (Thuesen *et al.* 2011). The SSCS fishes are comprised of diadromous species that migrate between freshwater and sea, and amphidromous species (grow mostly in freshwater, spawn in freshwater, and have a marine larval phase) are especially common (Keith 2003, McDowall 2007, Thuesen *et al.* 2011).

Three main types of flowing water catchments can be recognised in the Australian Wet Tropics. First, the large floodplain river systems that contain substantial alluvium depositional areas and meandering lower channels with substantial estuaries. Second the smaller coastal catchments that contain substantial alluvium deposition and surface waters that include swamps and streams sourced from low elevation, and often with substantial estuaries along the lower course. The third, SSCS have limited alluvium or estuaries and the main channel is dominated by riffle-run-pool sequences that extend essentially down to the high tide mark.

It is well documented that estuaries play an important nursery and connectivity function for aquatic fauna (e.g. Nagelkerken *et al.* 2015). We deduce that the absence (or near absence) of an estuary from catchments is an important structuring force for SSCS biotic assemblages/communities. We also propose that this has current day ecological relevance and biogeographic implications for assemblages including levels of endemism as a function of extinction and recolonization events relating to sea level change (Weigelt *et al.* 2016). High rainfall is also likely an important characteristic of SSCS ecosystems. Rainfall ultimately represents the primary mechanisms for maintaining stream flow, and rainforests provide a means for intercepting cloud moisture (Mc Jannet *et al.* 2007). Additionally, the microclimate provided by closed canopy rainforests provides thermal, light and wind buffering of streams. Thus we propose SSCS are characteristically short and steep facilitating riffle-run-pool sequences effectively to the coast, are nested within rainforests, and have no or minimal estuary at the exit to the sea.

SSCS mapping

SSCS were defined based on expert opinion as outlined here. We assigned threshold values for the mean slope, catchment area and percentage of alluvium intersected by each stream in the Wet Tropics Bioregion. This process was conducted in ArcGIS (Version 10.0) with spatial data from the Queensland Spatial Catalogue (http://qldspatial.information.qld.gov.au/). A digital elevation model (25 metre) was used to derive values for slope relating to each stream in the stream network layer. The watershed tool in ArcGIS was used to build polygons around the catchment boundary of each stream and calculate catchment area. The land zone attribute in the Regional Ecosystem mapping (https://data.qld.gov.au/) was then used to derive values for the percentage of each stream network that intersecting alluvium. We then used ‘select by attributes’ in ArcGIS (version 10.0) to select streams within the Wet Tropics Bioregion that fit the criteria for SSCS derived from expert opinion.

SSCS hydrology

In total, 17 HOBO U20L loggers were deployed at 10 sites across four sub-regions in the Wet tropics Bioregion to measure temperature and water depth based (on atmospheric pressure) (Figure 2.1). Sites were selected partly to represent high rainfall and low rainfall areas and to obtain data from regulated and unregulated creeks. The locations for logger deployment were Emmagen, Myall and Noah creeks in the Cape Tribulation sub-region, Hartleys and Spring creeks in the Port Douglas/Cairns sub-region, Pauls Pocket Creek and two unnamed creeks in the Malbon-Thompson sub-region and Wylie and an unnamed creek in the Mission Beach sub-region. For logistical reasons, no loggers were deployed in the Cedar Bay or Hinchinbrook Island sub-regions during this pilot study. For each of the four relevant sub-regions, a single logger was deployed above water to measure atmospheric pressure to enable calibration for the water pressure/depth loggers (Figure 2.1). At streams with active water extraction, depth loggers were deployed upstream and downstream with a view to potentially quantifying rates of extraction, with a focus on the late dry season. The HOBO U20L loggers were set to record pressure and temperature at hourly intervals.

To calibrate the data from the depth loggers for discharge, we used a hand-held flow meter (model FLO-BTA; Vernier Corporation, Beaverton, OR, U.S.A.) to measure cross sections of flow under a range of different depth/discharge scenarios. Late in the dry season when streams were almost ceasing to flow, in order to accurately quantify discharge we recorded the time required for the stream to fill waterproof bags (5 or 20 litre) at locations where the entire stream was spilling at a confined location and was near to a logger (i.e. immediately above or below the relevant pool). Spot measurements of water quality were recorded in all of the focal streams in association with rapid assessments of fish assemblages. Discharge and temperature data are not analysed in this report, only the field testing of the method is discussed, briefly.

Figure 2.1 Stream gauging was achieved in a subset of short-steep-coastal-streams. Above water sensors were used to control for climatic shifts in barometric pressure; shown here a Djunbunji Ranger attaching a sensor to a tree. b) researchers took spot measurements of water quality in isolated pools during the dry season, and c) shows a combined pressure and temperature sensor submerged and fixed in boulders (submerged sensors were also attached to tree roots and large in-stream wood in a number of cases).

Freshwater-marine interface

We took basic qualitative notes on the presence of mangroves, and signs of tidal limits in SSCS and photographed the mouths of the streams that were surveyed for fishes. A subset of the more accessible stream mouths (e.g. streams at Ellis Beach, Cape Tribulation, Mission Beach) we have observed over a number of years giving us some experience with the dynamic nature of their connection to the sea and geomorphology.

Water extraction

During rapid assessments of the fish fauna in a sample of SSCS (see next chapter) we recorded the presence of any past or existing water extraction structures (mostly small dams and/or off-take pipes) that were encountered.

RESULTS

Defining short-steep-coastal streams

Short-steep-coastal streams are a feature of tropical high islands and some continental margins in the Pacific region. These streams are short in length (100's metres to 10's of kilometres main channel length), and can experience perennial discharge as a function of trade winds driving high rainfall in high elevation catchments (Mueller-Dombois and Fosberg 2013). The prevailing flow characteristics result in the lower reaches above the high-tide limit typically comprising riffle-run-pool sequences supporting some combination of bedrock, boulder, cobble, pebble or gravel as dominant substrates. The lower reaches of these streams do not have the classic depositional zone characterized by meandering channels dominated by in-stream fine sediment or sand substrates and there is a lack of extensive alluvium deposits in the lower catchment. Typically, an estuary is either absent (the stream flows through or over the beach when connected to the sea) or is rudimentary (e.g. a lagoon or relatively straight channel with some mangrove lined riparian zone).

Excluded from the definition of SSCS are steep streams that originate close to the coast but enter into the lower catchment of large rivers (of catchment size greater than 100 km^2) or the extensive estuaries remnant of past large rivers. By way of example, in the context of the Australian Wet Tropics, Hills Creek flows from the Murray-Prior Range immediately south of Cairns into the ocean just on the seaward side of an extensive estuary, Trinity Inlet (which is the remnant of a river capture event, Willmott and Stephenson 1989). Hills Creek is a SSCS whereas, it's westerly neighbouring stream Pine Creek is not since the latter flows directly into Trinity Inlet.

We assigned quantitative thresholds to reflect this qualitative description of SSCS. Firstly, a threshold of greater than 5 % mean slope across the entire length of a stream was used to reflect the steep nature of these streams. Secondly, an upper limit of 40 km^2 and a lower limit of 0.2 km^2 for catchment area of each stream were given. This is based on the catchment area of the largest stream in the Wet Tropics deemed by expert opinion to be a SSCS (Noah Creek). Finally, a threshold of less than 20 % alluvium was used to reflect the steep, high energy nature of SSCS which often lack depositional environments. We acknowledge that the thresholds used are somewhat arbitrary, however, we feel that they reflect the physical attributes of SSCS to a large extent.

SSCS mapping

Based on our definition, we estimate that SSCS catchments comprise 666 km^2 or 3.3% of the total area of the Wet Tropics bioregion (Figure 2.2). Furthermore, SSCS represent 4.7% of the total 52,695-km stream network in the region. Of the 602 SSCS, the smallest had a catchment area of 0.2 km^2 and the largest was 36 km^2 (both limited by definition). The major clusters of SSCS are in the northern (Cedar Bay and Cape Tribulation sub-regions) and central Australian Wet Tropics (Cairns-Port Douglas sub-region, Malbon-Thompson sub-region) and the far southern Australian Wet Tropics in association with Hinchinbrook Island and the Palm Island group. The Mission Beach area has very few SSCS (Figure 2.2).

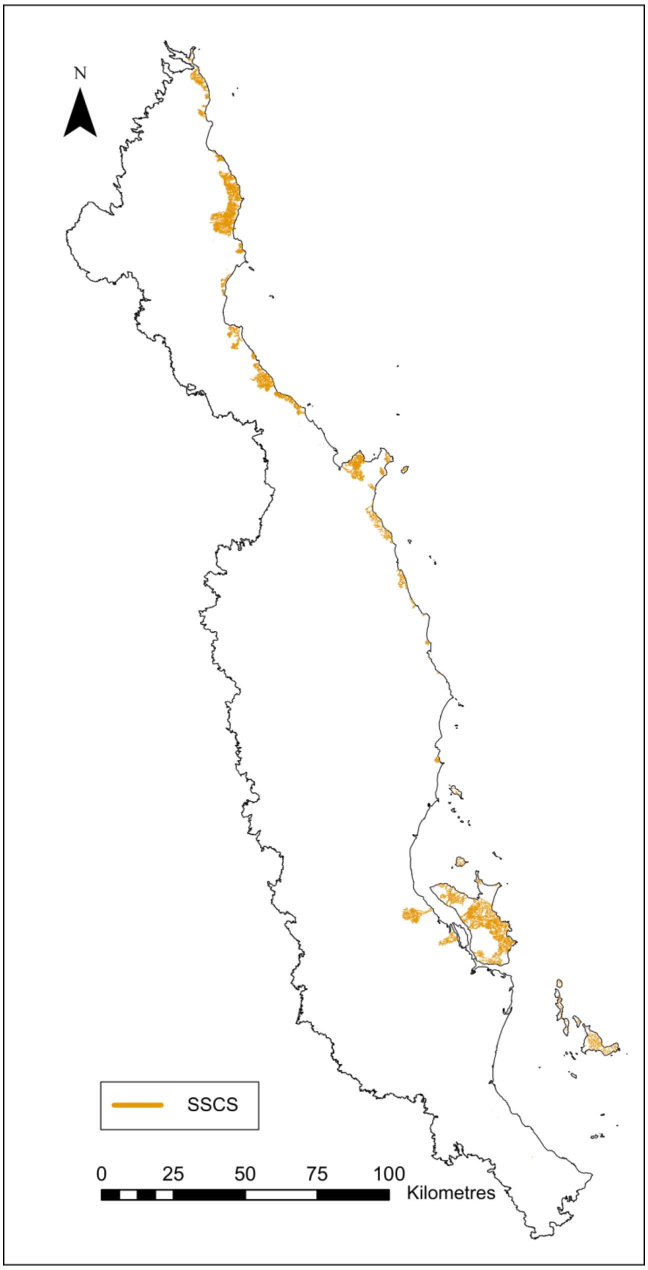

Figure 2.2 Map of short-steep-coastal streams in the Wet Tropics Bioregion.

SSCS hydrology

The temperature and depth sensor loggers remain in the field and most of these loggers have been periodically visited to ensure they are in place and down loaded. Calibrations of instantaneous discharge and stream depth have been achieved at a subset of locations under low flow. The intention is to summarise this information once one year of field data has been obtained and calibrations complete.

Freshwater-marine interface

SSCS mouths were not quantified systematically, however, a range of scenarios were commonly observed (Figure 2.3). A number of permanent streams (e.g. Emmagen Creek, Noah Creek) were always found to open directly to the sea via surface water, and these systems typically had straight lower estuaries with mangroves at the edges. These mangroves extended along the banks for hundreds of metres at most. Large and permanent or near permanently flowing streams in drier regions (e.g. Hinchinbrook Island, and Hartley Creek) and in wet regions (e.g. Pauls Pocket Creek), had sandy lagoon mouths that periodically opened to the sea (Figure 2.3 a, b). These lagoons had minimal mangrove stands (tens of metres along stream bank). The mouths of other streams clearly opened to the sea under periodic flow (e.g. two streams at Ellis Beach) or on high monthly tides (Figure 2.3 c-f). These sandy pools lacked mangroves and usually contained freshwater or mildly brackish water (occasionally with boulders visible or buried).

Water extraction infrastructure and activity

Of the 18 streams surveyed (in association with fish surveys), eight had water extraction infrastructure in the form of weirs, pumps and or pipes (Table 2.1). This included off take pipes from all four streams surveyed in the Port Douglas-Cairns sub-region, with dams or relic dams present in all of these streams except Turtle Creek. By way of detail, water offtake pipes were present in lower Hartleys Creek and relic concrete dams (with no extraction pipes) are present higher in the catchment on the main tributary and in one of the feeder creeks. In the Malbon-Thompson sub-region, two of three streams surveyed had small dams present (Bessie Creek at the base of Bessie Falls, and the offtake for the Russell Heads holiday home community). Water offtake pipes and a dam were present in one of three small streams surveyed immediately north of Mission Beach. Water offtake pipes were present in lower Mason Creek, Cape Tribulation.

Direct water offtake via pumping to trucks has also been observed at Emmagen Creek and Oliver Creek (Cape Tribulation) in association with road construction. Additionally, of note as potential instream barriers are the concrete footings to bridges associated with private and public roads in a number of the creeks. A number of these concrete structures present as vertical faces and therefore instream barriers to movement of a subset of stream fauna. Examples include the main road crossings of the small creeks at Ellis Beach, Turtle Creek, and the three creeks surveyed at Mission Beach. Bridge or roads directly crossings through stream beds at three streams in the Cape Tribulation area did not present with freefall concrete drops, and road crossings were not present or were non-problematic at the Malbon-Thompson, Hinchinbrook and Cedar Bay sites.

Figure 2.3 Short-steep-coastal-streams exit permanently or intermittently into the sea without an estuary or via a rudimentary estuary. A selection of these stream mouths is shown here with a) a tidal lagoon at Bullimba Ck (Eastern Malbon-Thompson Range), b) a tidal lagoon that is essentially fresh at Warrawilla Ck, (eastern Hinchinbrook Island), c) Turtle Ck cutting through the beach (South of the Mowbray River), d) Wiley Ck emptying at low tide across the beach (north of Mission Beach, e) Spring Ck (Ellis Beach) with a small temporary lagoon, and f) the (often) closed mouth of Cascade Ck (Ellis Beach). Mangroves are sometimes present in the lowest reaches of these systems usually spanning tens to hundreds of metres at most.

Table 2.1 Presence and absence of water extraction infrastructure in 18 streams surveyed rapidly for cling gobies.

Sub-region	Stream	Extraction Infrastructure
Cedar Bay	Ashwell Ck.	No
Cape Tribulation	Mason Ck.	Yes
Cape Tribulation	Myall Ck.	No
Cape Tribulation	Noah Ck.	No
Port Douglas/Cairns	Turtle Ck.	Yes
Port Douglas/Cairns	Hartleys Ck.	Yes
Port Douglas/Cairns	Spring Ck.	Yes
Port Douglas/Cairns	Cascade Ck.	Yes
Malbon-Thompson	Bessie Ck.	Yes
Malbon-Thompson	Pauls Pocket Ck.	No
Malbon-Thompson	Russell Heads Ck.	Yes
Mission Beach	Unnamed Ck.	No
Mission Beach	Kingys Ck.	No
Mission Beach	Wylie Ck.	Yes
Hinchinbrook	Goold Island	No
Hinchinbrook	Warrawilla Ck.	No
Hinchinbrook	Banksia Ck.	No
Hinchinbrook	Zoe Ck.	No

DISCUSSION

The current chapter has served to define SSCS primarily from a physical perspective, albeit derived from ecological and biogeographic conceptual underpinnings. This should provide a starting point for incorporating this ecosystem type into classification of flowing waters for wetland mapping in Queensland. From this perspective it is interesting to consider the transferability of this definition to other parts of Queensland and still further afield. For instance, presumably parts of coastline in the Proserpine-Whitsunday region contain SSCS. High islands in the tropical Pacific are also undoubtedly comprised of SSCS.

This ecosystem type comprises just 3.3% of the Australian Wet Tropics (this study) but undoubtedly have much higher representation in other parts of the Pacific where there are steep volcanic outcrops rather than gradual continental margins (e.g. The Solomon Islands). These SSCS contrast the 13 adjacent large river catchments of the Australian Wet Tropics that are themselves relatively small relative to the larger river systems across the greater wet-dry tropics in Australia (Pearson *et al.* 2015). The large catchments of the Australian Wet Tropics region comprise predominantly sandy rivers and support floodplains (Pearson 2005, Conolly *et al.* 2007). In contrast, the SSCS by definition have limited alluvium, essentially no floodplains and an absence of substantial estuary habitat. Even the lowland components of these streams are dominated by coarse rock including cobble, boulder and bedrock (Donaldson *et al.* 2013, Ebner *et al.* 2016). However, in reality, there is little known of these physical environments and it should be informative to develop an understanding of temperature, flow, and nutrient cycling, among other aspects of these streams.

In this regard the current study has implemented a relatively low cost system for logging temperature and water depth with the latter to serve in reconstructing daily discharge. The pilot study has shown that the method has potential but requires more field time and effort than had been envisaged for implementing the low cost automated flow measure based on monitoring the movement of a tethered sphere (Marchant *et al.* 2014). Specifically the new approach requires further site based calibration before daily discharge can be interpreted from pressure sensor data (i.e. reconstructing flow profiles from cross sectional flow measurements based on field validations across a range of discharge scenarios). A future research priority should be to refine this approach and apply it to a number of SSCS in the tropical Pacific islands with regard to stream elevation, latitude and degree of topographic isolation or buffering (see Grubb 1971). The ultimate goal is to quantify daily discharge and understand trade-offs with in-stream biodiversity and human water resource needs. Ideally this should include an understanding of the extent and dynamic of the rithron (cf. Bayly and Williams 1973 modification of Illies 1961) in relation to the Massenerhebung Effect (Grubb 1971) in these small ecosystems, as it likely has major ecological implications for the elevational structuring of amphidromous fauna and managing potential climate change effects.

In terms of water resource extraction, the current project has at this stage not provided immediately usable discharge data. However, the project provides some preliminary step toward formally recognising and dealing with this issue. First, a method for obtaining some initial estimates of daily discharge across a representative set of streams is in place. Second, the documentation of basic water extraction infrastructure and practices is provided here in a semi quantitative way. Water quality late in the dry season in small creeks under human water extraction warrants investigation. We recommend local water authorities take some steps towards consolidating information on known and unknown regulated SSCS in the Australian Wet Tropics. This is not a straightforward nor necessarily affordable process in the short term, though given the implications for threatened species and likely other species yet known to local science (see next chapter) it may be advisable to convene a small working group involving water resource managers, councils and town planners and ecologists with some preliminary view to prioritising high biodiversity value SSCS, and assessing expanding areas of human development. This would effectively build on pioneering conservation planning work in the region, which was established principally from sampling fishes in the large river catchments of the Wet Tropics (i.e. Januchowski-Hartley *et al.* 2011a, b).

It is also worth briefly mentioning the freshwater-marine interface of SSCS observed in this study. In several streams there was clearly no estuary. This took the form of sandy beaches where streams intermittently cut a surface flow through sand and the ocean tides ebb and flow across a mere scale of tens of metres of beach. Presumably this has major implications for the faunal composition of the lowland sections of SSCS, for instance in terms of occupation by marine and estuarine species including predators. From the larger SSCS in particular (and a small number of smaller SSCS), a simple rudimentary estuary was observable. This took the form of either a permanently open narrow channel lined with some mangroves (spanning a maximum of a few hundreds of metres) or a small lagoon (tens of metres to approximately 100 m in maximum dimension) with narrow and intermittent openings to the sea. These habitats lacked seagrass beds, and were often comprised of sand and secondarily exposed or buried cobble-boulder. These systems did not comprise the complex mosaic of estuary habitats discussed in Nagelkerken *et al.* (2015). The short, shallow, sandy stream sections crossing beaches represented essentially simple structure-less habitats. These simple passage points likely have ramification for recruitment of amphidromous fauna. In the next chapter we focus on the most conspicuous amphidromous fauna in these streams, the cling gobies.

Summary points

This chapter provides the first definition and recognition of short-steep-coastal-streams as a freshwater ecosystem type occurring in the Australian Wet Tropics. These streams do not have the classic depositional zone characterized by meandering channels dominated by in-stream fine sediment or sand substrates and there is a lack of extensive alluvium deposits in the lower catchment. Typically, an estuary is either absent or is rudimentary.

Stream gauging stations are not commonly present in short-steep-coastal-streams, and the current study provided a preliminary trial of low-cost gauging in this stream type.

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CHAPTER 3 CLING GOBIES IN THE AUSTRALIAN WET TROPICS

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INTRODUCTION

Many of the freshwater fish species found in the Wet Tropics have an amphidromous life history, meaning that as adults they live in freshwater where they lay and guard eggs which then hatch and drift through the streams and rivers to the ocean (Pusey *et al.* 2004, McDowall 2007, Thuesen *et al.* 2011). The larvae spend time in marine waters where they develop into juveniles before migrating back into freshwater environments where they remain (McDowall, 2007). As a function of this unique life history, many of the freshwater fishes of the Wet Tropics are shared with other Pacific islands (Thuesen *et al.* 2011).

Gobies of the sub-family Sicydiinae, commonly known as 'cling gobies', are one such group of amphidromous fishes (Keith 2003, Keith *et al.* 2015). Cling gobies were first reported in Australia in 1996, by (Pusey and Kennard 1996)who conducted extensive freshwater fish surveys across the Wet Tropics, primarily using backpack electro-fishing. These surveys recorded a single cling goby species, *Sicyopterus lagocephalus*. The second species to be recorded in Australia was the opal cling goby, *Stiphodon semoni*, which was first observed in Harvey Creek, a tributary of the Russell River, 25 km south of Cairns and originally named *Stiphodon alleni* (Watson, 1996) (Allen *et al.*, 2002). Since 2009, a further seven species of sicydiines have been discovered in the Australian Wet Tropics (Ebner and Thuesen 2010; Ebner *et al.* 2011; Thuesen *et al.* 2011; This study). Increasing findings of sicydiine species locally is likely a result of increased detection by a shift in survey technique (from primarily electrofishing to snorkel-based surveys) and focus on relevant locations. Other potentially important factors are the fluctuating occurrence of these fishes as a function of changing climate and ocean currents affecting recruitment.

Despite an increase in the number of records of Sicydiine goby species, there are still relatively few records of most cling gobies from a small number of locations in Australia (Ebner *et al.* 2011). From a precautionary perspective, based on low apparent abundance and confined distributions (within Australia, at least) and owing to a number of potential threats (e.g. water extraction especially towards the end of the dry season, loss of stream habitat, sedimentation and direct collection by aquarists), a number of cling goby species have been recently listed under Queensland State legislation and in one case under Federal legislation (Appendix 3.1). Specially, the opal cling goby (*Stiphodon semoni*) is listed as Critically Endangered under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). More recently, three other *Stiphodon* species (*Stiphodon rutilaureus*, *Stiphodon atratus, Stiphodon birdsong*) have been listed as Vulnerable under the Queensland state legislation (Nature Conservation Act 1992). More recently, updated taxonomy, has *S. atratus* named as *S. pelewensis* and *S. birdsong* as *S. surrufus* (Keith *et al.* 2015). In the absence of extensive datasets on the distribution of these and other cling goby species, we used species distribution models (SDMs) to model their potential distribution and suitable habitat within the Australian Wet Tropics. Initially, this was done to inform areas for targeted field surveys but also used post-survey to refine a SDM.

Species distribution models (SDMs) combine species occurrence records with spatial layers of ecologically-relevant environmental data to predict suitable habitat across large areas. There is a wide range of SDMs which use a variety of different approaches and input data. MaxEnt models (Phillips *et al.*, 2006) use the principle of maximum entropy to build statistical relationships between presence-only records and potentially relevant environmental layers. For this reason, MaxEnt is suited to modelling the potential distribution and habitat suitability of rare or elusive species for which there is a paucity of data (e.g. Pearson *et al.*, 2007). Maxent has been shown to perform consistently well for determining habitat suitability compared to other techniques (Elith *et al.*, 2006). Typically, MaxEnt is applied to pixels in a gridded or raster domain over large continuous surfaces for terrestrial species, however here we have used euclidean distance in conjunction with a stream layer to focus the model at the extent of streams in the region. Our aim was to devise a model that combined occurrence records with a range of relevant environmental variables to identify the potential suitable habitat for each sicydiine species throughout the Wet Tropics.

METHODS

Species distribution modelling

We used MaxEnt (Phillips *et al.*, 2006) software to generate species distribution models (SDMs) for cling goby species (Sicydiinae) currently known from the Wet Tropics, Queensland, Australia. Occurrence records for sicydiine species were drawn from an existing database primarily comprised of survey data collected from 2009 until the beginning of this project in January 2015 (Figure 3.1). Many of these data were sourced from projects involving the authors of this report (BCE, JAD, PT), however there are a small number of records from previous projects in the Wet Tropics (Allen *et al.*, 2002; Russell *et al.*, 1998, 2000, 2003; Pusey *et al.*, 2004) which are also included in the database.

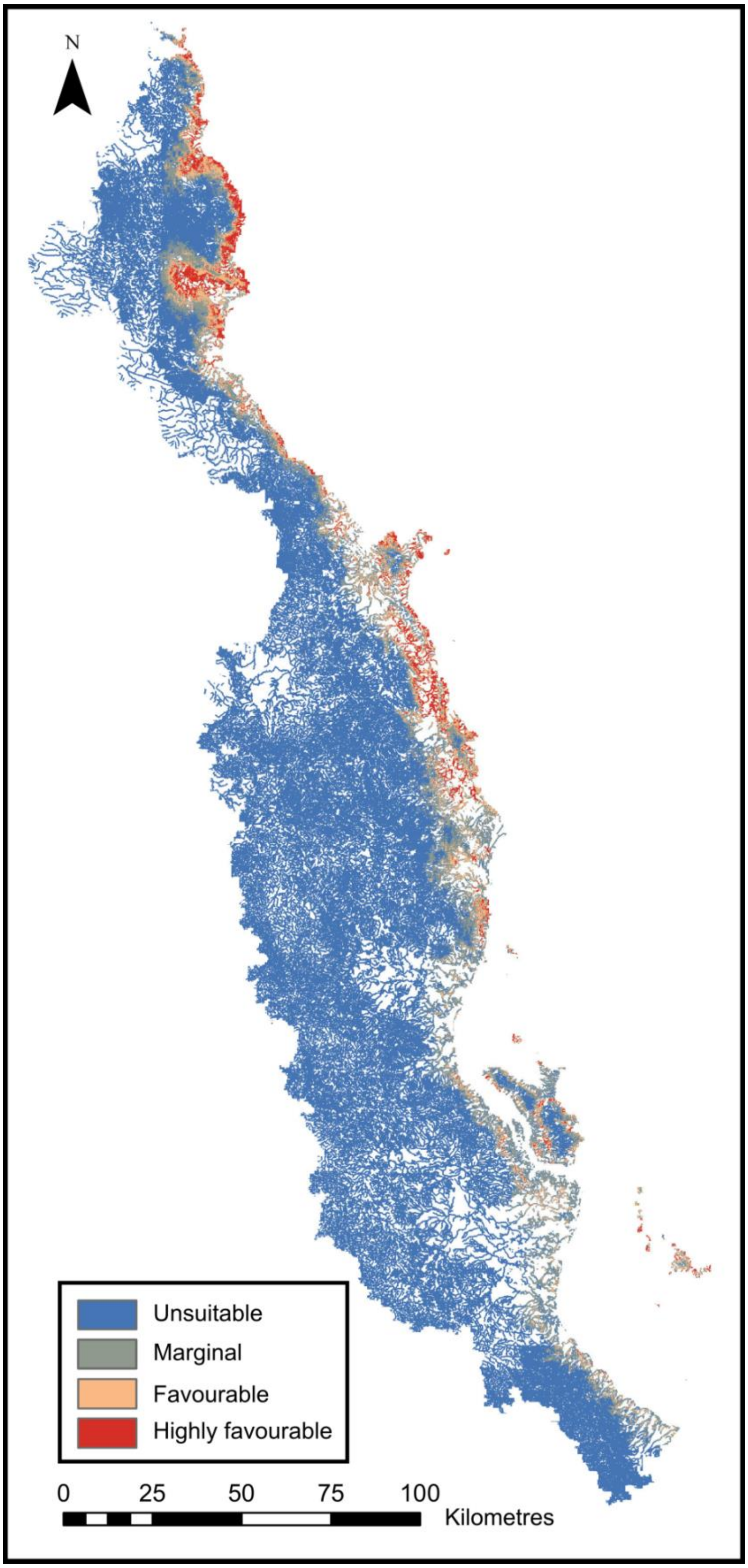

Figure 3.1 MaxEnt model combining all pre-January 2015 data for all sicydiine species (9 species total). The model categorises habitat suitability for sicydiine species into four categories; unsuitable, marginal, favourable, highly favourable.

Single-pass snorkel surveys as outlined in detail in Ebner and Thuesen (2010) were used to gather the majority of these data. Prior to MaxEnt analysis, duplicate records for any species recorded more than once in any given stream were removed. This was done to ensure that habitat suitability models were not biased to locations with a high number of occurrence records as a consequence of sampling bias. In total, 71 unique occurrence records of nine sicydiine species from 21 streams were used to generate the pre rapid survey MaxEnt model.

A range of potentially ecologically-relevant biophysical variables were used in the model including; vegetation, geology, aspect, distance to the ocean, slope, land use, land zone and elevation. We also used two current climatic variables derived from BIOCLIM databases; annual mean temperature (BIO1) and annual precipitation (BIO12). The BIOCLIM layers were sourced at a 9-second (approximately 250 m) resolution and represented average values spanning 30 years from 1961 to 1990. Each of the biophysical layers were clipped to the extent of the Wet Tropics Bioregion in ArcGIS (Version 10.0) and converted to ASCII raster format with an 80 x 80 m grid size using Circuitscape (Version 4.0). These biophysical variables were chosen based on expert opinion, were subject to availability of spatial dataset available at the landscape scale, and were guided by field observations of likely relevant habitat parameters. We used the default settings in MaxEnt (Version 3.3.3k) with the exception of threshold and hinge features which were not selected to achieve predictions that are more 'ecologically rational' and to produce models of a more general nature (Austin 2007; James *et al.*, 2013). MaxEnt model outputs presented habitat suitability as a continuous logistic range which was then classified into natural breaks or 'jenks' in ArcGIS (Version 10.0) to form four categories; unsuitable, marginal, favourable and highly favourable. Models were generated for all sicydiine species combined and for the seven species for which we had a sample of five or greater observations from different locations.

Targeted rapid fish surveys

To identify SSCS where surveys for cling gobies were required, we used a combination of MaxEnt species distribution models and short-steep-coastal-streams (SSCS) mapping (outlined in Chapter 1) to firstly identify previously un-surveyed streams likely to have resident cling goby species. From this, we identified 6 sub-regions along the coastline of the Wet Tropics Bioregion that were likely cling goby habitat; Cedar Bay, Cape Tribulation, Port Douglas/Cairns, Malbon-Thompson, Mission Beach and Hinchinbrook (Figure 3.2). Streams targeted for surveys were not selected randomly. We targeted a large, medium and a small stream from each region where possible. Descriptive metrics regarding each stream are provided in Appendix 3.2.

We primarily used snorkel-based surveys, complimented by occasional dip-netting and above-water-observation, to survey 18 streams (shown in Figure 3.3) from the high tide mark continuously as far along the length of the stream as possible.

Rapid surveys in each creek involved single-pass snorkel surveys as outlined in Ebner and Thuesen (2010). However, a single observer on snorkel moved systematically through the stream in an upstream direction ensuring that all microhabitats were investigated including undercut banks and high velocity chutes (rather than multiple snorkelers as used previously). A dive torch was used to aid visibility in turbid or dark waters; a particularly useful tool for detecting eels in dark interstitial spaces. A second observer was present to inspect off-channel pools from above water and to record data as the snorkelling observer progressed through each stream reach. Snorkelling was also complimented by dip-netting and above water observation in situations where the water was too shallow to permit snorkelling.

On two occasions, small lengths of streams were not surveyed due to poor visibility and snorkeler safety requirements. Four lowland pools were not surveyed in Ashwell Creek since they were either stagnant (presumably as a function of an absence of flow and excessive leaf litter decomposition) or cloudy (due to pig damage) and this precluded safe checking of the pool for estuarine crocodiles. Similarly, two large pools in the mid-course of Hartleys Creek were not surveyed because they were blackened by woody debris, leaf litter and tannins under essentially no flow conditions late in the dry season. On both these occasions the length of stream not surveyed was minimal relative to the entirety of the main channel. In the case of Hartleys Creek, we included (small) opportunistic counts of sicydiines obtained on a previous trip (when deploying temperature and depth sensors) corresponding with this reach of stream. Once all rapid surveys had been completed and new data collated into a data base, MaxEnt models were re-run.

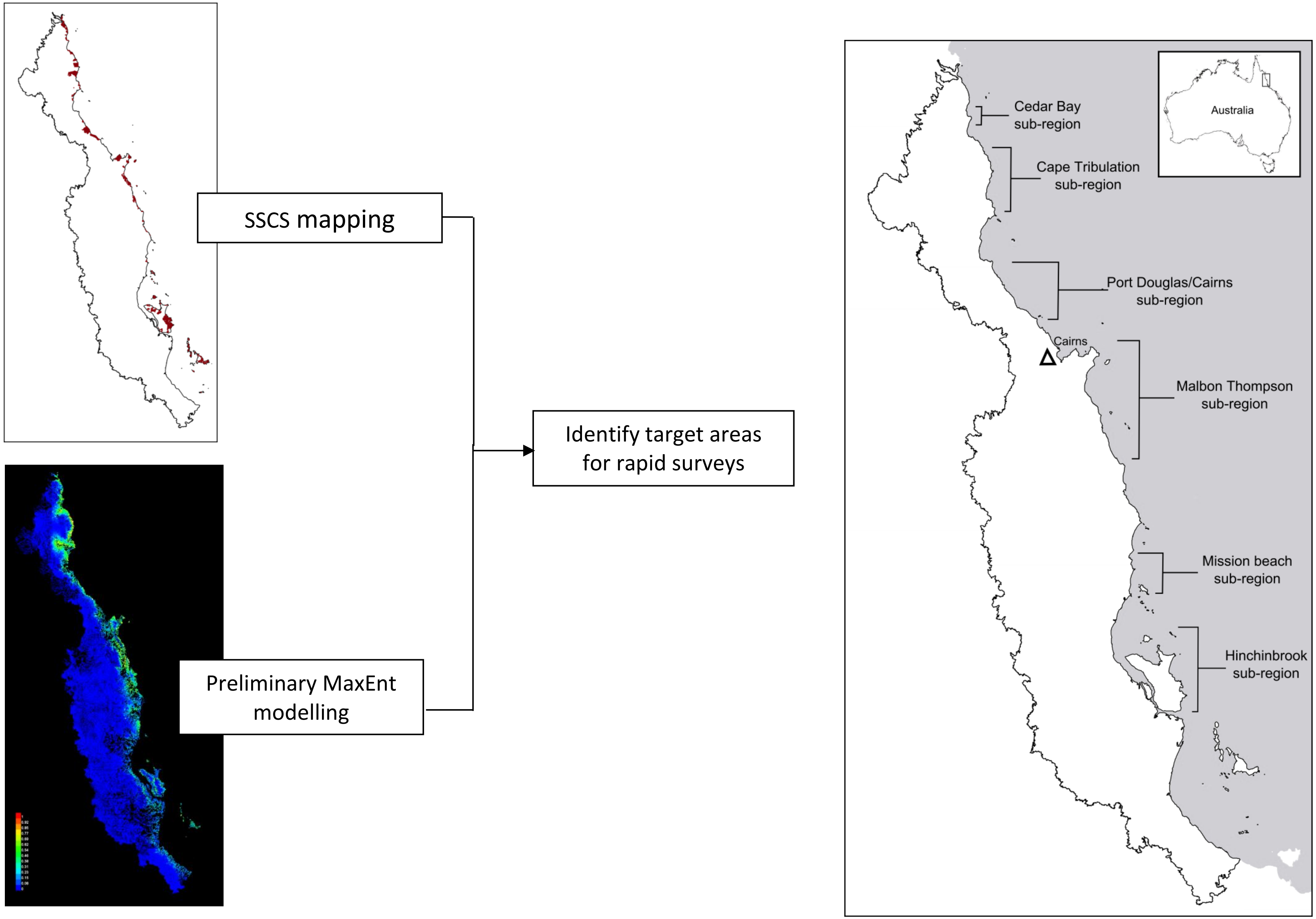

Figure 3.2 Illustration of the process involved in identifying target areas for rapid surveys

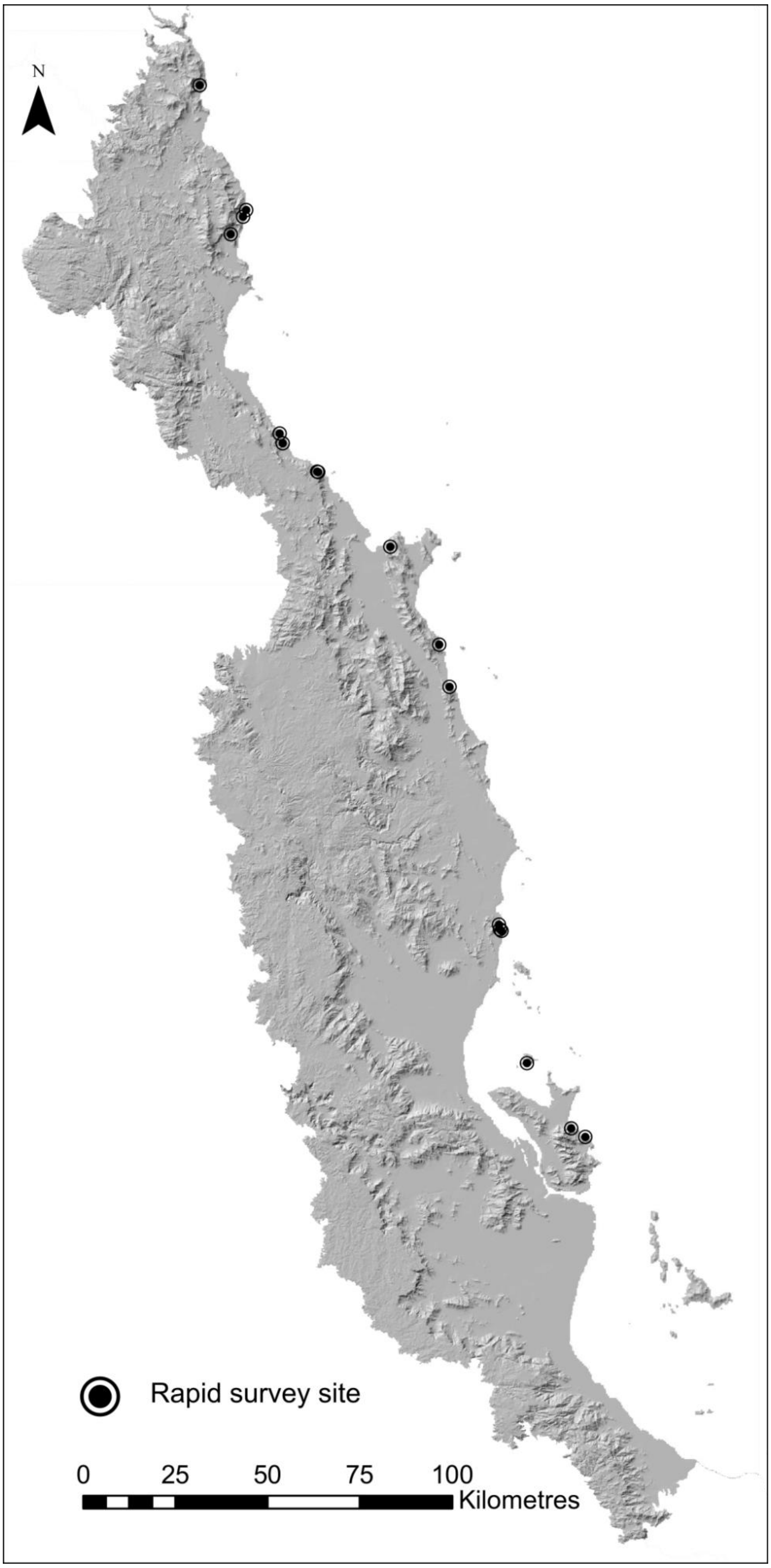

Figure 3.3 Location of eighteen whole-catchment rapid survey sites within Wet Tropics Bioregion.

Table 3.1 Analysis of variable contributions to the MaxEnt model for pre-rapid survey data. Percent contribution is a measure of the contribution made by each variable to the fitting of the model. Permutation importance is a measure of the relative contribution of each variable to the final model overall rather than the path that the MaxEnt code uses to generate the model.

Variable	Percent contribution	Permutation importance
Mean annual air temperature	42.5	8.1
Distance to coast	30	79.2
Euclidean distance	7.7	3.1
Geology	5.4	2.4
Mean annual precipitation	5	0.6
Vegetation type	3.8	2.7
Elevation	2.9	1.5
Land zone	2.3	1.5
Slope	0.4	0.2
Aspect	0.1	0.7

A total of 71 unique occurrence records of nine sicydiine species from 21 streams were used to generate the pre-rapid survey MaxEnt model. The predictive accuracy of the model was high, with an area under the curve (AUC) value of 0.97. For the pre rapid survey model, the variables with the greatest influence on the model in terms of percent contribution and permutational importance were mean annual air temperature and distance to the coast (Table 3.1).

RESULTS

Rapid surveys

The adult male of nine species of sicydiine species reported from the Australian Wet Tropics are shown in Figure 3.4. The males are shown because they are far more easily differentiated at the species level than females. The current study has produced 22 new location records (Figure 3.5) of eight of these species (*Sicyopterus lagocephalus, Sicyopus discordipinnis*, *Stiphodon pelewensis*, *Smilosicyopus fehlmanni*, *Stiphodon surrufus*, *Smilosicyopus leprurus*, *Stiphodon semoni*, *Stiphodon rutilaureus*) across the Wet Tropics Bioregion from Cedar Bay in the north to Mission Beach in the south (Figure 3.6). *Sicyopterus cynocephalus* was the only sicydiine species for which additional site records were not forthcoming (post-January 2015) (Figure 3.5).

Sicyopterus lagocephalus was found in lowland and upland reaches and is a true elevation generalist (Figure 3.7). *Sicyopterus cynocephalus* is considered an elevation generalist based largely on our observations in the Solomon Islands. *Stiphodon pelewensis*, *Stiphodon semoni* and *Stiphodon rutilaureus* were consistently observed at low elevation (typically less than 30 m ASL and often below the first major instream barrier)

(Figure 3.7). In contrast, *Smilosicyopus fehlmanni*, *Stiphodon surrufus*, *Smilosicyopus leprurus*, *Sicyopus discordipinnis* were found above at least the first major instream barrier (Figure 3.7). *Sicyopus discordipinnis* was more often than not found high up in the catchment when present, although, at times *Smilosicyopus* spp. were also well above major and multiple instream barriers (Figure 3.7). *Stiphodon surrufus* was mostly found at intermediate elevation (Figure 3.7).

As a consequence of this study, substantial increases in records of the four high elevation specialist species (from 38–60% increase) and a 27% increase in the number of catchment records relating to the elevation generalist, *Sicyopterus lagocephalus* (Figure 3.5) were achieved.

Figure 3.4 A male of the cling goby species confirmed to occur in the Australian Wet Tropics: a) *Stiphodon surrufus,* b) *Stiphodon rutilaureus,* c) *Stiphodon pelewensis,* d) *Stiphodon semoni,* e) *Smilosicyopus fehlmanni,* f) *Smilosicyopus leprurus,* g) *Sicyopus discordipinnis,* h) *Sicyopterus lagocephalus,* i) *Sicyopterus cynocephalus.*

Sub-regional patterns

Field surveys demonstrate that *Sicyopterus lagocephalus* is likely the most widespread sicydiine in the SSCS of the Wet Tropics, being found in 12 of the 18 catchments surveyed (Figure 3.6). *Stiphodon* species (*S. semoni* 9, *S. pelewensis* 8, *S. rutilaureus* 7, *S. surrufus* 6) were among the other more widespread species (Figure 3.6). Three of the four upland specialists were relatively rare being found at five or less sites (*Smilosicyopus* *fehlmanni* 5, *Smilosicyopus leprurus* 2, *Sicyopus discordipinnis* 5) (Figure 3.6). *Sicyopus discordipinnis* was not found in the drier subregions.

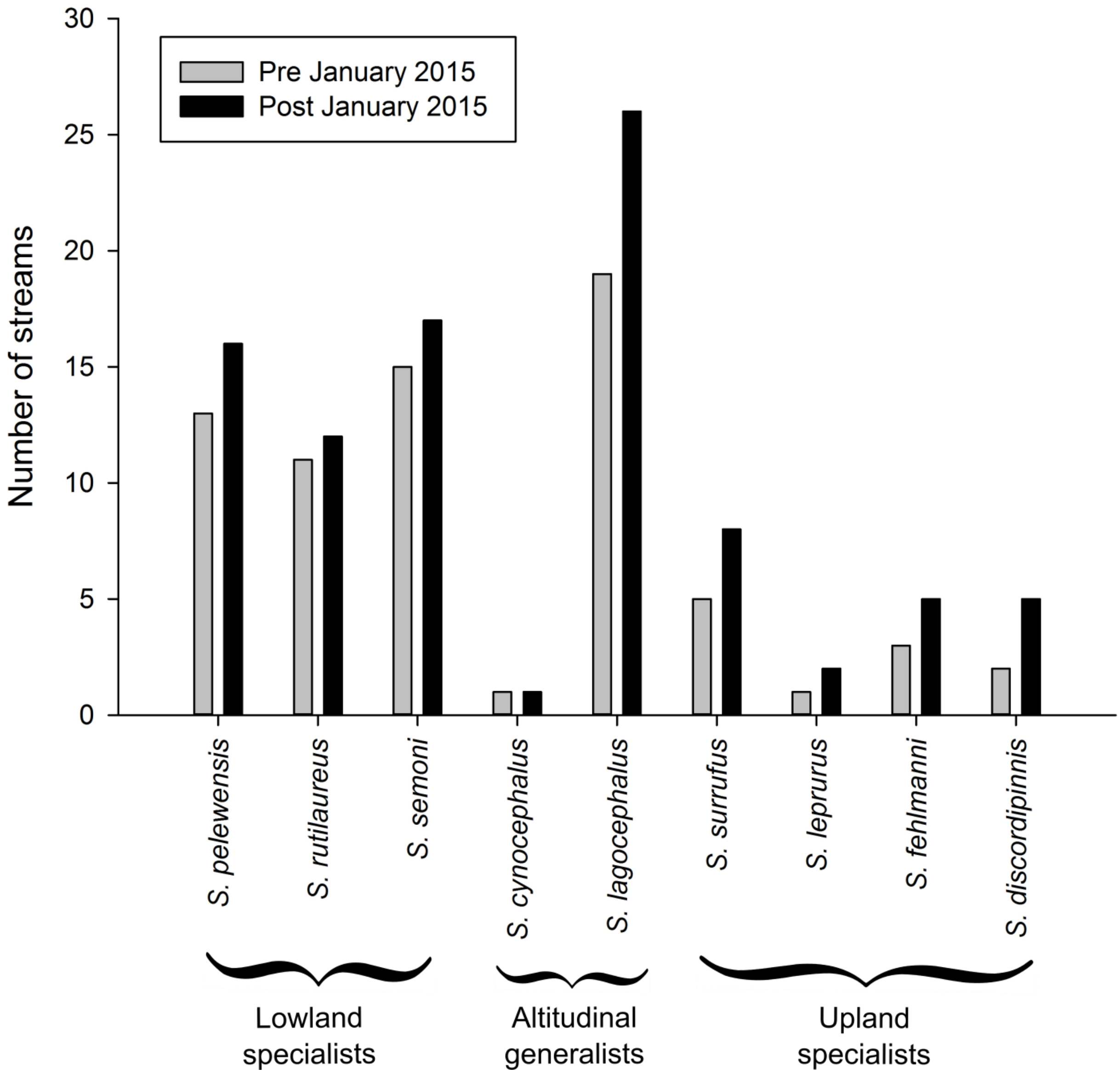

Figure 3.5 The number of streams each cling goby species has been recorded from in the Wet Tropics Bioregion before and after rapid survey of whole SSCS in this study.

In terms of sub-regions, it is premature to comment on the streams of Cedar Bay region given only a single stream was surveyed. However, this stream (Ashwell Creek) is known anecdotally at least, to provide freshwater all year round. It contained the most impressive assortment of upland specialist sicydiines, in terms of species richness and most notably abundance, recorded in Australia to date (Figure 3.6). Conversely, it lacked the lowland specialists despite being rainforest covered. At the time of survey, much of the stream had ceased to exhibit surface flow in the lower course.

The permanent streams of the Cape Tribulation sub-region represent an important area for sicydiine occupation in the Wet Tropics, based on our surveys (including unpublished visits to other lowland streams in that region) (Figure 3.6). Moderately large counts of *S. lagocephalus* and *S. pelewensis* were obtained in the two larger streams surveyed at Cape Tribulation. Furthermore, it is likely that the counts of *S. lagocephalus* in particular, represent an underestimate of true numbers as a function of the secrecy of this species and its association with complex and less accessible habitat (including riffles, runs, cascades and cobble-boulder interstices). Masons Creek was mostly dry at the time of survey potentially accounting for the absence of sicydiines.

Within the Port Douglas/Cairns sub-region streams (of the Ellis Beach area) yielded high species richness in two of four catchments, and all four streams generally returned low counts of species when they were detected. In this sense the streams were somewhat comparable to those at Mission Beach. Interestingly, only two species were found in Hartleys Creek, despite this being a large catchment with permanent water. Notably, the riparian zone along Hartleys Creek was dominated by drier sclerophyll forest rather than more complex notophyll vine forest along much of the mid and upper course, with pockets of rainforest immediately above the high tide mark and in upper tributaries.

Similarly, no species of sicydiine were encountered in Bessie Creek in the Malbon-Thompson sub-region, and that creek was a mixture of rainforest and drier sclerophyll forestlined tributaries. In contrast, to the immediate south Pauls Pocket Creek and Russell Heads Creek, which are both entirely rainforest catchments, yielded high species richness and relatively high relative abundance of particular species by Wet Tropics standards (Figure 3.6).

Very low individual species counts were achieved in the three streams within the Mission Beach sub-region. All of these creeks were small and dominated by rainforest canopy. *Sicyopterus lagocephalus* was recorded in all three streams. High species richness was recorded in the smallest of the three creeks (5 species – creek unnamed).

No sicydiines were recorded in the four streams surveyed in the Hinchinbrook sub-region. Each of these catchments contained a mixture of rainforest and sclerophyll coverage.

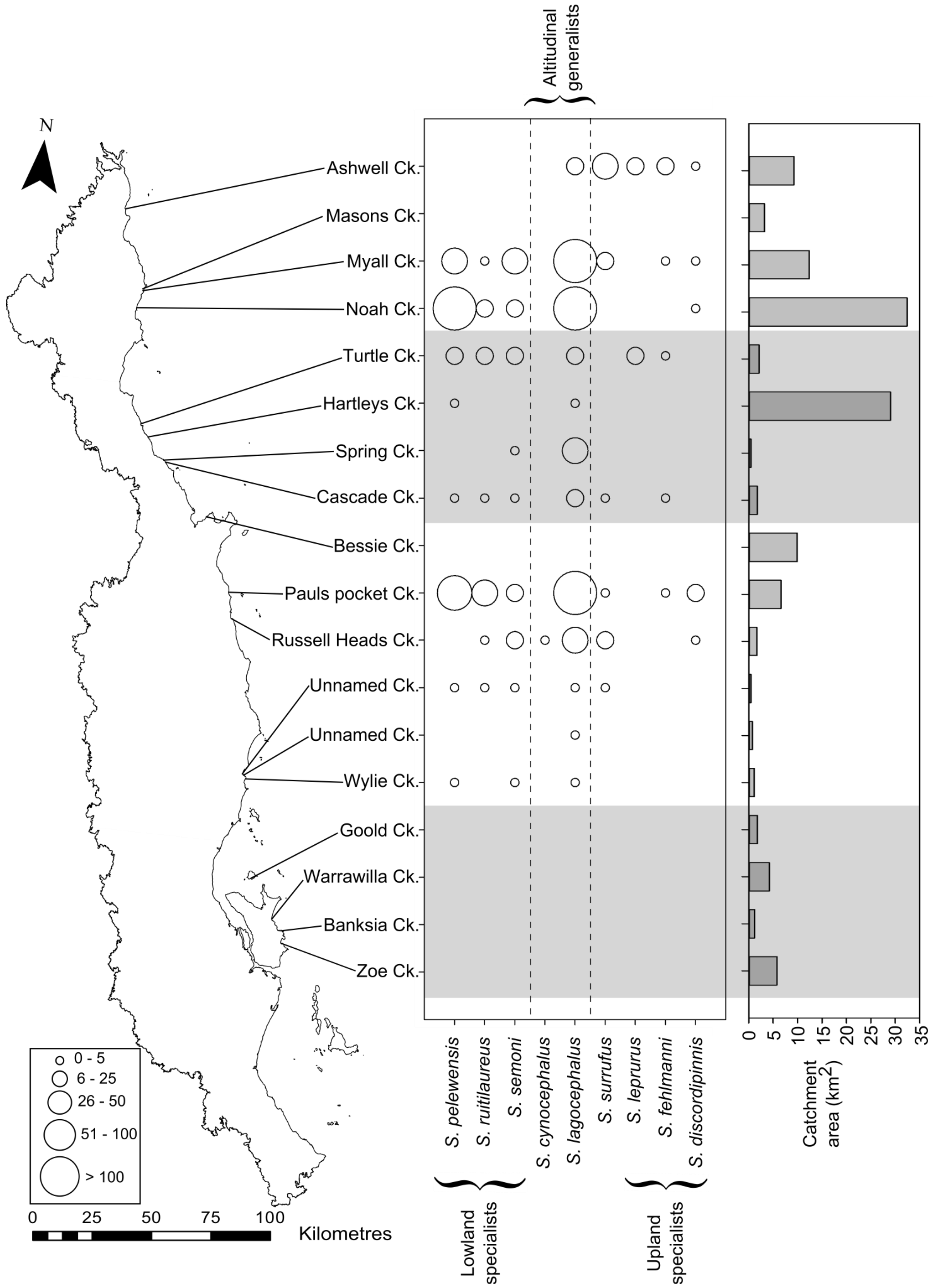

Figure 3.6 The relative distribution of sicydiine species in the 18 streams surveyed completely during this study. Circle diameters relate to the number of individuals each observed within catchments and upland and lowland specialists, as well as elevational generalists, are shown. Grey shading represents the two (relatively) dry sub-regions; Hinchinbrook and Port-Douglas/Cairns, and catchment area is provided in the graph to the right.

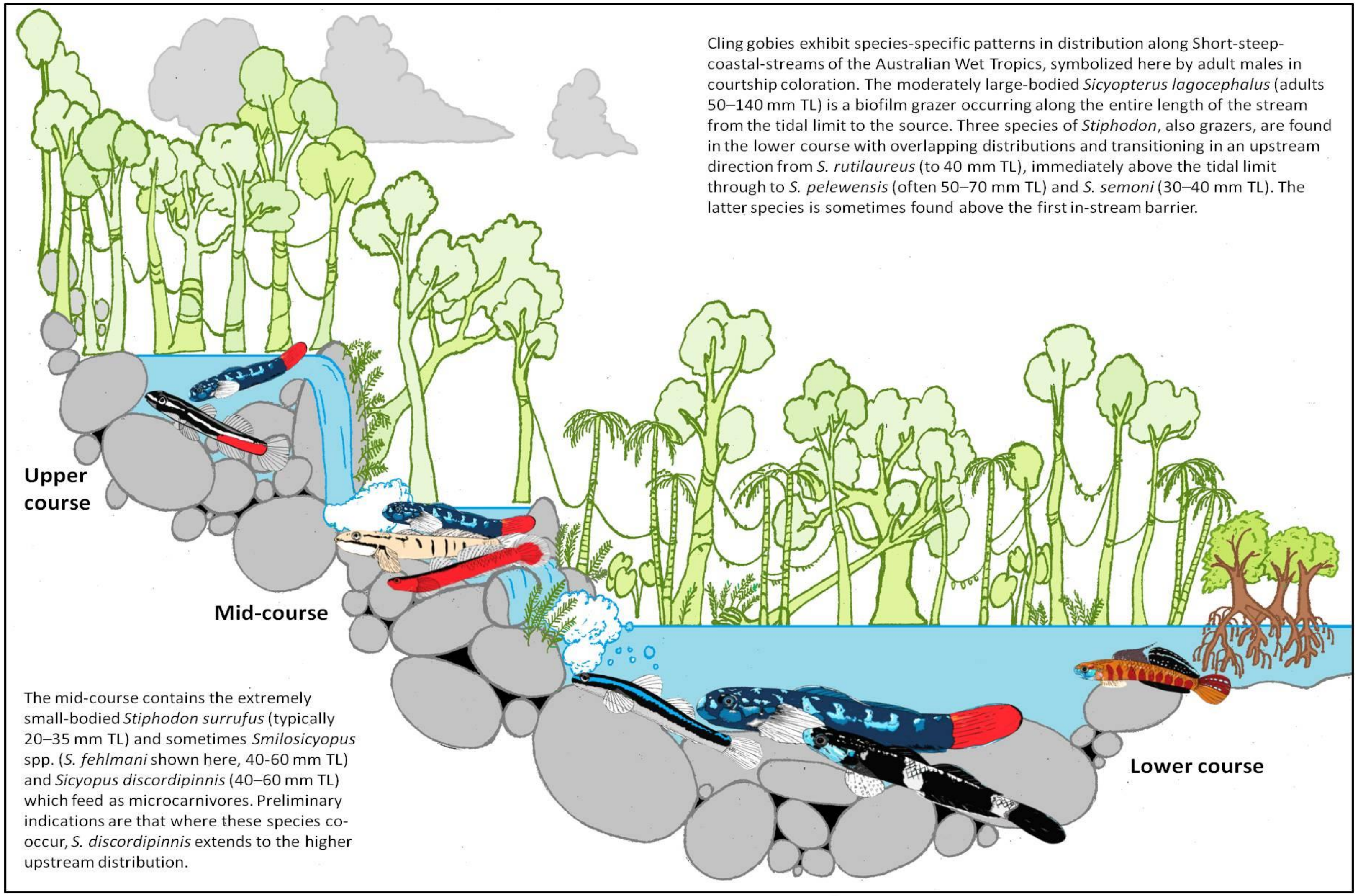

Figure 3.7 Elevational associations of the more commonly encountered sicydiine gobies in the SSCS of the Australian Wet Tropics.

Modelled distributions

A total of 92 unique occurrence records of nine sicydiine species from 28 streams were used to generate the post-rapid survey MaxEnt model (Figure 3.8). The predictive accuracy of the model was high, with an area under the curve (AUC) value of 0.98. For the pre-rapid survey model, the variables with the greatest influence on the model in terms of percent contribution and permutational importance were mean annual air temperature and distance to the coast (Table 3.2).

The model of overall occurrence data based on all sicydiine species records combined led to an overall decrease in the predicted coverage of marginal, favourable and highly favourable habitat in the Wet Tropics, relative to that based on pre-rapid survey data (Figure 3.8). The updated estimate of unsuitable habitat for sicydiines is 94.4% of stream length in the region (Figure 3.8). Despite the absence of sicydiines from four streams in the Hinchinbrook sub-region, the MaxEnt model predicts there is some sparsely located favourable and marginal habitat and even very low levels of highly favourable habitat present on Hinchinbrook Island and to the south in the Orpheus-Palm Island Group (Figure 3.8). Subtle shifts in the estimated distribution of favourable and highly favourable habitat were observed in association with the Daintree River catchment and Bloomfield River catchments and nearby SSCS to the south and north of the major hotspot around Cape Tribulation (Figure 3.8).

Modelled distributions of each species (Figure 3.9) should be interpreted cautiously as a function of sample sizes. Specifically, there were too few records of *S. cynocephalus* and *S. leprurus* to model and the limited number of records for *S. surrufus*, *S. fehlmanni*, and *S. discordipinnis* is acknowledged. The latter three species have suitable habitat centred on the northern and central sections of the Wet Tropics, with a pronounced suitability in the Cape Tribulation sub-region (Figure 3.9). However, the estimated highly suitable habitat for *S. fehlmanni* is more extensive than that of either *S. surrufus* or *S. discordipinnis* (Figure 3.9). Note that *S. discordipinnis* has not been recorded from the Ellis Beach sub-region, whereas, the other two species have.

The models relating to the species for which there are more substantial presence records indicate a hot spot of highly favourable habitat in the northern section of the Wet Tropics centred on the Cape Tribulation region (Figure 3.9). In addition to the SSCS being suitable for *S. lagocephalus* and particularly those in the Cape Tribulation sub-region, there is extensive marginal and favourable habitat for this species including in areas within the river catchments that are larger than the SSCS. Of note is the prediction that extensive highly suitable habitat for *S. lagocephalus* occurs in the lower and mid catchment tributaries of the Daintree River (Figure 3.9). To a lesser extent the models predict that *Stiphodon semoni*, *S. pelewensis* and *S. rutilaureus*, have favourable habitat in the Daintree River catchment (Figure 3.9).

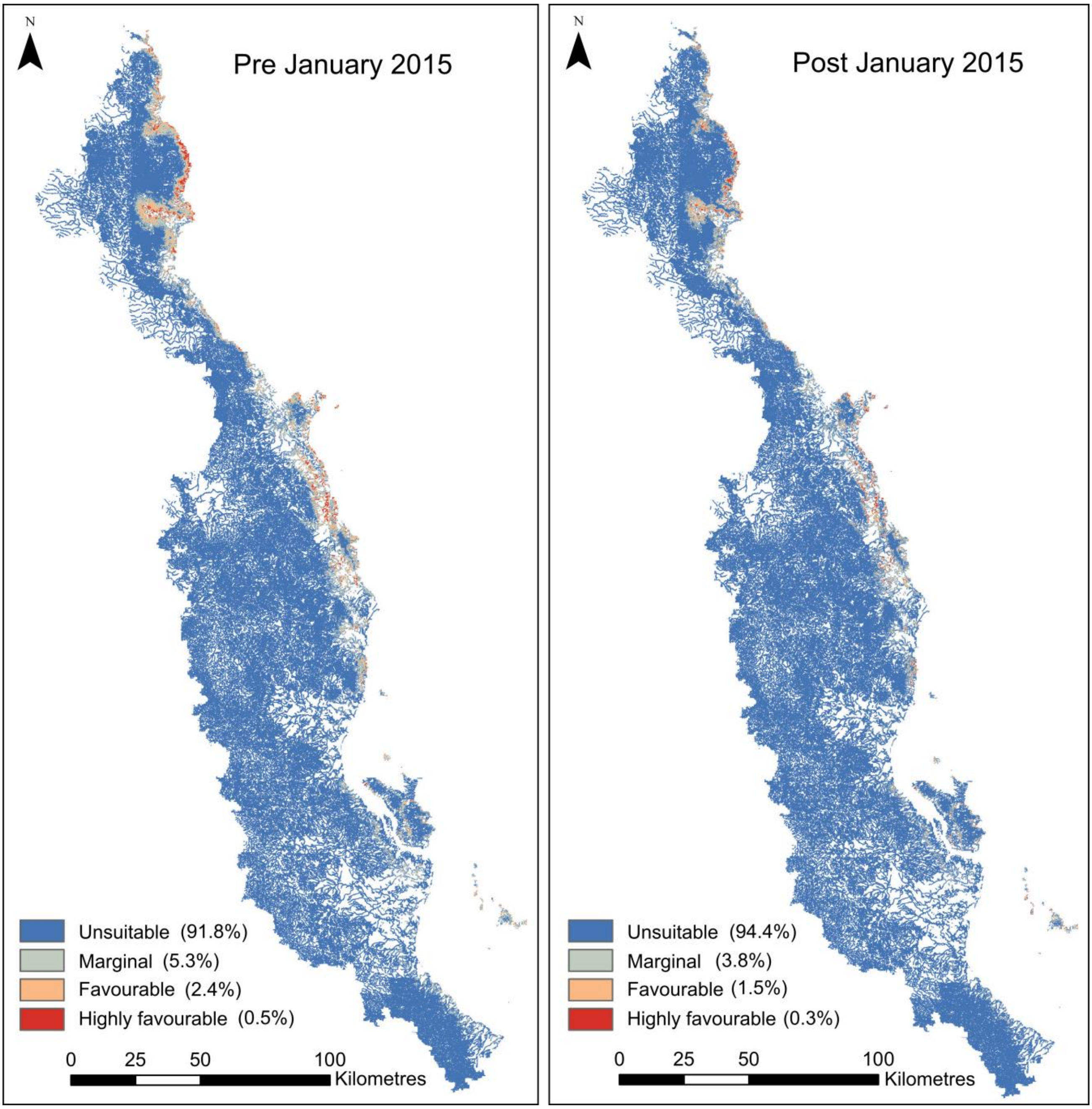

Figure 3.8 MaxEnt model outputs based on occurrence data for all nine sicydiine goby species pre and post January 2015. The model categorises habitat suitability for sicydiine species into four categories; unsuitable, marginal, favourable, highly favourable.

Table 3.2 Analysis of variable contributions to the MaxEnt model for post-rapid survey data (Pre-rapid survey values are shown in brackets). Percent contribution is a measure of the contribution made by each variable to the fitting of the model. Permutation importance is a measure of the relative contribution of each variable to the final model overall rather than the path that the MaxEnt code uses to generate the model.

Variable	Percent contribution	Permutation importance
Mean annual air temperature	39.4 (42.5)	4.3 (8.1)
Distance to coast	22.7 (30)	65.8 (79.2)
Euclidean distance	12.3 (7.7)	8.1 (3.1)
Elevation	8.3 (5.4)	14.6 (2.4)
Geology	5.5 (5)	1.2 (0.6)
Mean annual precipitation	4.3 (3.8)	0.9 (2.7)
Vegetation type	4 (2.9)	2.6 (1.5)
Land zone	2.4 (2.3)	1 (1.5)
Slope	1 (0.4)	1.4 (0.2)
Aspect	0.1 (0.1)	0.1 (0.7)

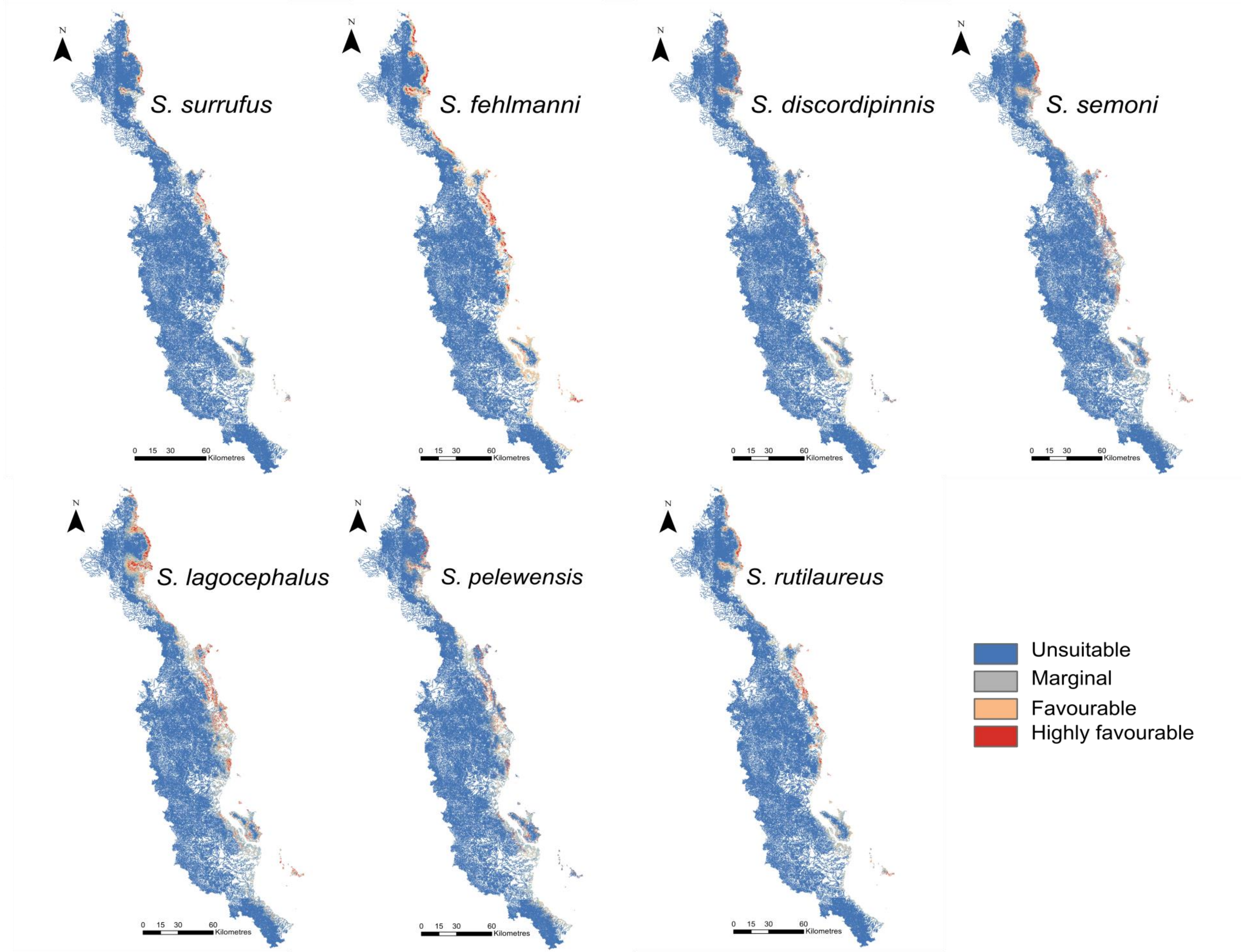

Figure 3.9 Species-specific distribution models (MaxEnt) for the seven sicydiine species for which there is data for five or more sites.

DISCUSSION

The primary goal of this chapter is reporting back on the modelling of cling goby distribution in the Australian Wet Tropics. This has been achieved through essentially a three step process of a) modelling available fish and habitat data, b) conducting targeted rapid field assessments to redress spatial gaps in fish data, and c) refining spatial models of fish distribution. The first of these steps provided a comprehensive map of likely suitable habitat for these species and reflected two main spatial bias in the cling goby distribution data — notably, a lack of fish survey effort across the full extent of the Wet Tropics, and a bias in survey within streams toward low elevation. In this project we restricted our effort to SSCS (other streams of the Wet Tropics are dealt with briefly in the General Discussion) where cling gobies appear to be more common relative to other freshwater ecosystems in the Wet Tropics (*cf.* Ebner *et al.* 2011, Thuesen *et al.* 2011).

The second step of conducting rapid field surveys for cling gobies proved highly informative with new location records achieved for eight of the nine relevant species. In terms of redressing the lack of full extent of cling goby surveys in the Wet Tropics, our rapid surveys produced first records of cling goby occurrence in the Cedar Bay and Mission Beach sub-regions and their apparent absence from the Hinchinbrook sub-region. The latter result should be interpreted cautiously, for a number of reasons. First, the Hinchinbrook streams were or had been relatively dry at time of the surveys (following extensive low rainfall periods and consecutive dry years in the Wet Tropics) and these streams may represent favourable habitat for cling gobies during wetter periods. Second, this does not negate the possible presence of cling gobies in other streams on Hinchinbrook Island with notably rainforest-lined streams particularly on the western side of the island warranting survey. Nevertheless, our study findings with regard to this southerly region of the Wet Tropics align with previous reports of an absence of cling gobies and low overall freshwater fish species richness on the seaward (eastern) side of the island (e.g. Malcolm and Graham 2000; Paul Thuesen, pers. obs.; James Donaldson, pers. obs.).

Efforts to redress the lack of survey effort for detecting cling gobies at high elevation also yielded rewards. We achieved pronounced relative increases in records of the four high elevation specialist species (from 38–60% increase) and a 27% increase in the number of catchment records relating to the elevation generalist, *Sicyopterus lagocephalus*. The moderately large increase in newly recorded catchments containing *S. lagocephalus* continues to support the idea that it is a widespread and common species in the Australian Wet Tropics relative to other cling gobies (Ebner *et al.* 2011). Conversely, the number of known sites containing some of the high elevation specialist species remains reason for concern. Our survey data indicate that given their sparseness (and apparently small population sizes, Ebner and Donaldson, unpubl. data), all of the upland specialist sicydiines in the Australian Wet Tropics warrant some form of protective status. Fortunately, just prior to the commencement of the current project the Queensland Government instated all sicydiine gobies as 'no take' species under fisheries legislation (https://www.daf.qld.gov.au/fisheries/consultations-and-legislation/legislation/upcoming-legislation-changes). More recently, one of these high elevation specialist species, *Stiphodon surrufus* (previously *Stiphodon birdsong*) was listed as Vulnerable under the Queensland Nature Conservation ACT, 1992.

The current study has increased the known distribution of the three lowland specialist cling gobies (*Stiphodon pelewensis*, *S. rutilaureus*, *S. semoni*). However, these increases have been modest relative to that of the upland specialists. Noteworthy, is the findings of these species in small creeks immediately north of Mission Beach. These records and previous records from the Liverpool Creek catchment represent the known southerly limits of the cling gobies in Australia, to date. Housing developments in association with two small catchments in this Mission Beach area represent opportunities for public engagement and stewardship of valuable stream ecosystems, considering all three of these species are conservation listed under state (*S. pelewensis:* Vulnerable; *S. rutilaureus*: Vulnerable) or national acts (*S. semoni*: Critically Endangered).

By way of completeness it is also worth mentioning that rapid surveys were on occasions challenging and time consuming. For instance, we completely underestimated how long it would take to survey Myall Creek, Cape Tribulation (estimated 2 days, actual 4 days). Nevertheless, other creeks were largely dry late in the dry season and simply required sampling refuge pools or upland surface water when lowland areas were dry (Mason Creek; unnamed Creek, Mission Beach; stream on Goold Island). Overall, the rapid survey approach provided a cost effective means of whole catchment scale survey and warrants application in more SSCS.

The third step of refining spatial models of cling goby distribution has provided a clear advance in our knowledge base for dealing with these rare fishes as a group and in most cases at the species level. In this study we have generated SDMs based on a fairly limited number of presence-only records to identify areas within a stream network that have similar environmental variables to those sites where species have been recorded previously. Of course, it must be emphasised that the SDMs presented here are not representations of actual distribution, but rather predicted distributions. In the present study we were not able to account for certain factors that may affect the distribution of cling goby species such as barriers to migration, perenniality of the streams or biotic interactions (see Frederico *et al.*, 2014). For instance, the streams on Fitzroy Island just south east of Cairns are modelled as highly suitable habitat even though they are largely ephemeral. However, these and other factors may be used to further refine these models in future as greater resolution in spatial data and funding permit.

One assumption common to all SDMs including MaxEnt is that occurrence records are derived from random sampling across the entire area of interest (Phillips *et al.*, 2009; Kramer-Schadt *et al.*, 2013). Contrarily, data used to generate these species distribution models are generally concentrated around areas that are easily accessible and may not be evenly distributed spatially and/or temporally (Phillips *et al.*, 2009; Kramer-Schadt *et al.*, 2013). The implications of this spatial bias can result in inaccuracies in the model (see Phillips *et al.*, 2009) and have flow-on effects for policy and management decisions. However, as discussed earlier, we have gone to considerable length to overcome spatial bias in input data. A major knowledge gap remains large river catchments and their tributaries, within the Wet Tropics. Until now, our focus has been on SSCS which by definition, exclude large river catchments and their tributaries. Opportunistic surveys have revealed a handful of locations in larger rivers where cling gobies are present and numerous absences from within habitats that seem suitable at least in terms of physical-chemical attributes (e.g. water temperature, substrate)(Ebner *et al.* 2011, Ebner and Donaldson, unpubl. data).

Summary points

Mapping of likely suitable habitat for cling gobies in the Australian Wet Tropics reflected two main spatial bias in the cling goby distribution data — notably, a lack of fish survey effort across the full extent of the Wet Tropics, and a bias in survey within streams toward low elevation.

Rapid field surveys for cling gobies proved highly informative with new location records achieved for eight of the nine relevant species. In terms of redressing the lack of full extent of cling goby surveys in the Wet Tropics, our rapid surveys produced first records of cling goby occurrence in the Cedar Bay and Mission Beach sub-regions and their apparent absence from the Hinchinbrook sub-region.

This study indicates that all of the upland specialist sicydiines in the Australian Wet Tropics warrant some form of protective status.

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CHAPTER 4 STAKEHOLDERS AND MANAGEMENT OF SHORT-STEEP-COASTAL-STREAMS AND CLING GOBIES

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INTRODUCTION

This chapter serves to provide a preliminary conceptualisation of the relevant interest groups or stakeholders associated or likely to be associated with short-steep-coastal-streams (SSCS) and cling gobies in the Australian Wet Tropics. We acknowledge that this chapter is not a comprehensive appraisal of the relevant societal networks, rather it is intended to stimulate awareness of this newly described ecosystem type and the discovery of some of its faunal inhabitants (mostly fish). Perhaps most importantly, the intention is to inform the societal groups and stakeholders of opportunities for celebrating and protecting these small catchment ecosystems.

Metcalfe and Lawson (2015) outline the precarious situation for lowland rainforests in the Australian Wet Tropics as a consequence of land clearing and other threats. Included in that appraisal was a list of threatened species associated with coastal lowland rainforest communities. Since that publication, three additional cling goby species have been recognised as Vulnerable in Queensland. Additionally, the current study has generally revealed a higher abundance and species richness in catchments that are rainforest dominated rather than dominated by sclerophyll forest (chapter 3). Further research and management attention is required to understand if there is a link between rainforest shading, water temperature and cling goby assemblage function.

The specific aims of this chapter are:

a) Provide preliminary appraisal of the diversity of potential stakeholders and relevant research and management agencies associated with SSCS and cling gobies in the Australian Wet Tropics.

b) Outline potential and realised threats to SSCS and cling gobies in the region.

c) Discuss opportunities for ecological sustainability in the context of SSCS and cling gobies.

d) Report on media and communications of the current project.

METHODS

We had made note of catchment user groups during opportunistic field visits to SSCS since 2009 and during rapid surveys and deployment of stream gauging sensors in the current study. We also developed networks with council representatives, state agency staff, natural resource managers and fellow researchers. Collectively these experiences and observations facilitated our preliminary list of societal interest groups and managers relevant to SSCS and sicydiine gobies in the Australian Wet Tropics.

A list of threatening processes to sicydiine gobies and SSCS was modified from a list relating to freshwater fishes of North-eastern Australia in Pusey *et al.* (2004). Where relevant observations had been made in the field we also compiled a semi-quantitative account of threats. This included information on presence and absence of alien/pest species, the presence of human-made instream barriers, water extraction infrastructure (e.g. offtake pipes) and activity (e.g. water trucks pumping from streams).

We also made note of opportunities for advancing the sustainability of SSCS catchments and for protecting cling gobies based on our thinking and informal discussions with others since 2009. This included accessing the expertise of aquatic ecologists working in Pacific Island streams, and capitalising on a postdoctoral fellowship to BCE specifically researching flagship species in freshwater ecosystems.

The project and project findings were communicated to the public and specifically to land managers in several instances. We documented media outputs to meet basic reporting requirements.

RESULTS AND DISCUSSION

Landholders, managers and user groups (and protected areas)

During this project and through our experience of conducting ecological research in SSCS over a period since 2009, we have observed numerous relevant societal groups. Short-steep-coastal-streams provide a centrepiece for recreation, immediately in terms of the stream, swimming holes and waterfalls, and by association in terms of the adjacent and picturesque rainforest and beaches. The lack of an estuary at the mouths of the small to medium sized streams also represents largely unsuitable habitat for estuarine crocodiles which in turn is clearly ideal for human swimming and water based recreation. Recreational angling for estuarine and freshwater species occurs at the mouths of some of the larger streams, and angling (primarily for jungle perch) occurs further upstream. However, our observations have been that angling pressure is far less pronounced than that which occurs in nearby large river catchments or in coastal marine waters. This likely reflects the overall low standing crop of large angling species present in SSCS, combined with a general lack of interest by many Australian anglers in targeting eels, and to some extent the fact that many SSCS exist in National Parks or Indigenous Protected Areas.

Agriculture is a major feature of large river catchments throughout much of the Wet Tropics and indeed throughout large tracts of coastal Northern Australia (Januchowski-Hartley *et al.* 2011, Dale *et al.* 2014). By virtue of having limited or no available lowland area and typically steep upland areas, SSCS are of relatively little value for agricultural purpose. Societal interest in SSCS ranges from limited interest in remote and inaccessible catchments, to extraordinarily diverse interest and a variety of user groups.

The owners and managers of SSCS catchments and adjacent areas in the Wet Tropics include:

a) Indigenous people, Indigenous corporations and Indigenous ranger groups
b) National Parks and conservation reserves
c) State forests and forestry reserves
d) Tourism resort operators
e) Ecotourism providers
f) Other local businesses (e.g. coffee shops and restaurants, petrol stations)
g) Local councils (reserves or esplanades managed in trust)
h) Private dwellings and suburban households
i) Surf life-saving clubs
j) Farmers
k) Schools
l) Wet Tropics Management Authority (WTMA)
m) Queensland Department of Agriculture and Forestry (Fisheries)
n) Threatened Species Branch, Environment and Heritage Protection (Queensland Government)
o) Environment Land and Water (Queensland Government)
p) National Parks and Wildlife (Queensland Government)
q) Water use and monitoring (Queensland Government)
r) Department of the Environment (Australian Government)
s) Great Barrier Reef Marine Park Authority
t) Terrain Natural Resource Management

User groups include:

a) Indigenous people
b) Bushwalkers
c) On-road motorists, motorbike riders and cyclists
d) Off-road motorists including four-wheel drive enthusiasts, motorbike riders and mountain bike riders
e) Swimmers (in stream/associated with waterfalls and rainforests)
f) Life-saving clubs and beach swimmers
g) Nature photographers
h) Wedding photographers
i) Local recreational users
j) Australian and international tourists
k) Road construction and maintenance crews
l) Fire brigades
m) Households (e.g. water supply, recreation)
n) Farmers (e.g. water supply, recreation)
o) Scientists (e.g. ecologists)
p) Recreational anglers

Perhaps not surprisingly given that much of the Wet Tropics World Heritage Area Protected Area encapsulates upland rainforests, that SSCS catchments are largely or partly nested within National Park (e.g. Cape Tribulation, Hinchinbrook Island) (Figure 4.1). Forestry reserves tend to occur on tablelands or on large lowland expanses and are generally not relevant to SSCS catchments in the region.

Januchowski-Hartley *et al.* (2011) assessed the suitability of terrestrial protected areas to incidentally provide a level of protection for freshwater ecosystems in the Australian Wet Tropics, with a focus on freshwater fishes. They concluded that protection was generally poor. Specifically they estimated that '83% of stream types defined by order, 75% of wetland types, and 89% of fish species have less than 20% of their total Wet Tropics length, area or distribution completely within IUCN category II protected areas' (Januchowski-Hartley *et al.* 2011). The situation is not as dire for SSCS.

By way of specifics, based on our mapping of SSCS in the Wet Tropics Bioregion (using criteria of < 20 % alluvium, > 5% slope and an upper limit of 40 km^2 and a lower limit of 0.2 km^2 for catchment area), there is a total of 2,461 km stream network classified as SSCS. Of this, 1,890 km, or 76.8 %, is within protected area tenure in the form of either Conservation Park, Forestry Reserve, National Park, Timber Reserve, Regional Reserve or State Forest (Figure 4.1). In comparison, there is a total of 52,695 km of stream network length (all stream types) in the Wet Tropics Bioregion, of which 31,074 km, or 58.97 % is within protected area. Based on our mapping of SSCS in the Wet Tropics Bioregion (using criteria of < 20 % alluvium, > 5% slope and < 40 km^2 catchment area), there is a total of 666 km^2 classified as SSCS catchment area. Of this, 507 km^2, or 76.1%, is within protected area tenure in the form of either Conservation Park, Forestry Reserve, National Park, Timber Reserve, Regional Reserve or State Forest (Figure 4.1). In comparison, the entire Wet Tropics Bioregion is approximately 19,884 km^2 of which 10,485 km^2 or 52.7 % is within protected area tenure.

Nevertheless maps prepared at a large extent such as that shown in Figure 4.1 tend to obscure small scale human occupation and activity at lowland edges including roads and highways. Because streams are often a focal point for human activity the potential impacts are more discrete and site specific than broader threats on freshwater ecosystems captured in most planning processes at a catchment scale. This activity has the potential to disrupt stream ecosystems (March *et al.* 2003, Smith *et al.* 2003) but also represents locations for positive human-nature experiences, including opportunities for individuals and user groups to appreciate the biodiversity and human benefits of these ecosystems.

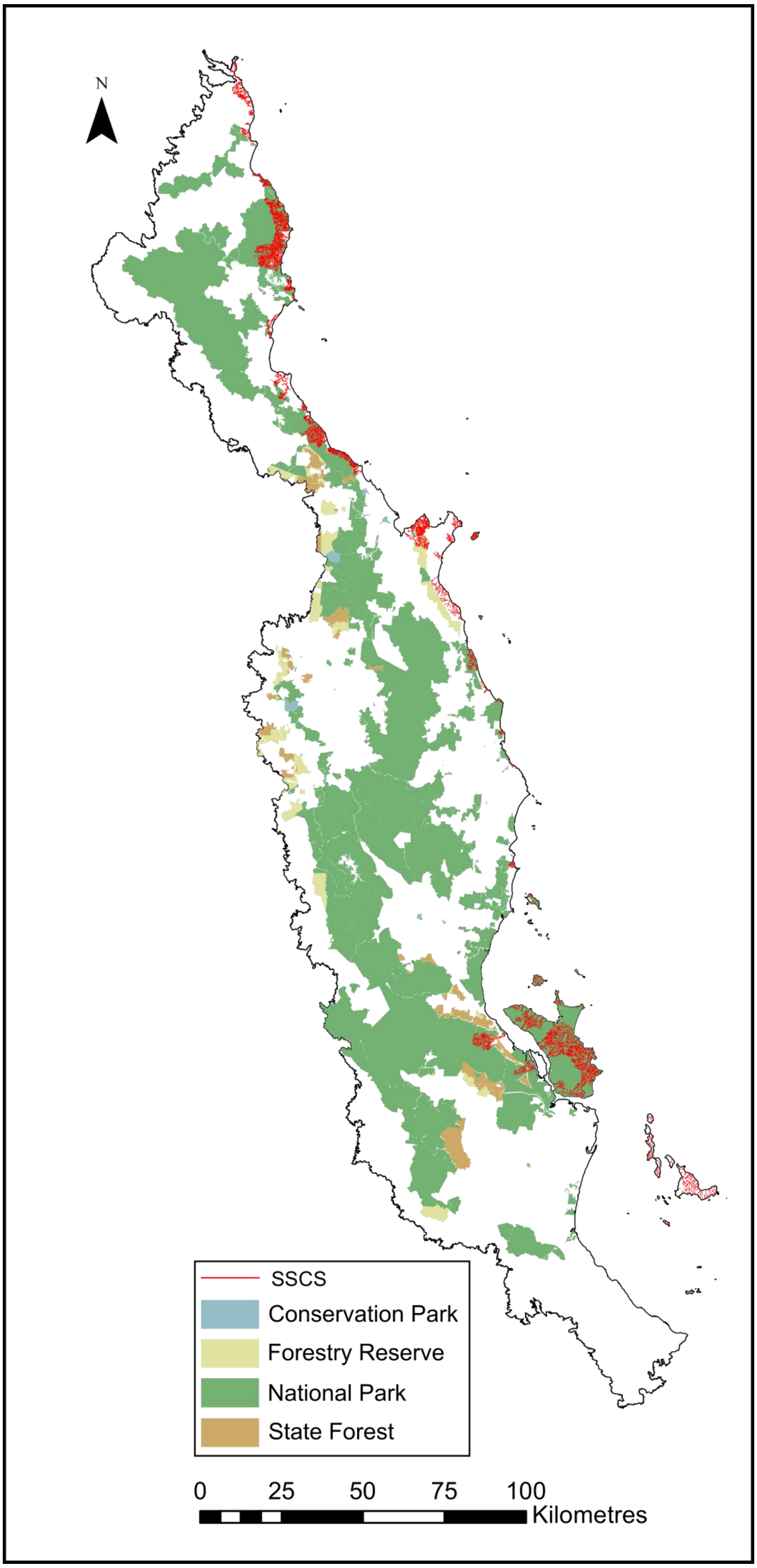

Figure 4.1 Spatial mapping of SSCS in relation to land tenure within the Wet Tropics Bioregion.

Potential threatening processes

In the book 'Freshwater Fishes of North-eastern Australia', Pusey *et al.* (2004) present a list of seven major threats facing freshwater fishes of Australia: 1. hydrological alteration, 2. loss of longitudinal and lateral connectivity, 3. changes in habitat structure, quality and chemical composition, 4. impacts of introduced species, 5. overexploitation, 6. global climate change, 7. inadequate knowledge and understanding. Each of these is potentially relevant to sicydiines in Australian Wet Tropics streams, and relevant information derived from this study is included and brief comment provided below.

1. **Hydrological alteration**

Reduced flow in streams as a function of direct water extraction or global climate change represent a threat to cling gobies and the function of SSCS ecosystems. Gobies, including cling gobies (Sicydiinae), preferentially use particular flow microhabitats within SSCS and disruption, particularly reductions in flow have the potential to disadvantage high flow specialists such as *S. lagocephalus* (Donaldson *et al.* 2013). In the current project a subset of SSCS have been equipped with sensors to quantify daily discharge and water temperature over a 1 year period. The year of monitoring and discharge calibrations are not complete as yet. Future applied studies should seek to determine if there is a relationship between an aspect of the biology or ecology of high flow specialists in SSCS and stream discharge.

There is also a need to refine local water management strategies in consultation with water resource users, council and town planners, state agency and specific service industries (e.g. road construction, rural fire brigade) with aquatic ecologists. Current knowledge of ground water dependent ecosystems and their interaction with rainfall driven flows within the Wet Tropics is in its early days. Greater knowledge of the potential impacts of increased seasonality under climate change and potential links to flows in SSCS warrant further investigation.

Hydrological alteration can also occur as the result of instream or off-stream drainage or construction works in the vicinity of SSCS (Figure 4.2). This is most likely at stream crossings which is detailed in the threatening process 2 but may also be brought about by diversion into, or away from SSCS. Although these activities may potentially present significant risk to the flow regimes and dynamics of SSCS, these may be mitigated largely by designs considerations which take both the hydrological and human functions of the landscape and the stream ecology and connectivity requirements into account.

2. **Loss of longitudinal and lateral connectivity**

Human-made in-stream barriers including road culverts and small dams, are present in a number of SSCS (Figure 4.2). The impacts of these structures on fish passage has not been assessed in the context of SSCS of the Wet Tropics but studies in neighbouring regions with other suites of freshwater species (Vietch and Burrows 2007) recommend mitigation of both physical and chemical barriers may be required to restore connectivity. Small vertical faces of dams may not be problematic for the movement of some cling goby species given they can ascend and descend waterfalls. However, it would be useful to understand species-specific capabilities to develop practical guidelines for road culvert and dam construction and modifications. For instance, the roughness of the vertical surfaces may be important and narrow spill over points may serve to promote connectivity under low flow scenarios, at minimal expense (certainly relative to fishways at dams on large rivers). Dams fitted with a spill over pipe (e.g. both creeks surveyed at Ellis Beach) and there modification warrant investigation as a priority since the horizontal nature of the underside of the spill over pipes may prove especially challenging for climbing juvenile cling gobies.

From a connectivity perspective, opening of stream mouths is an important issue for sicydiines in completing their life cycle (Keith 2003, Ebner *et al.* 2013). This was not a focus of the current study and warrants investigation in the future. Of specific interest is understanding recruitment of cling gobies into streams which are permanently as opposed to intermittently open to the sea. This has relevance to the selection of reference catchments (see Final Discussion).

3. **Changes in habitat structure, quality and chemical composition**

Intact riparian zones are likely important for sicydiine gobies (Keith 2003, Jenkins *et al.* 2010, Ebner *et al.* 2013). In this regard the current study found that cling gobies are typically associated with rainforest dominated SSCS rather than sclerophyll dominated systems. Arguably, this lends support to the idea that rainforest riparian zones warrant protection, although the relevant ecological mechanisms remain to be understood. A full year of monitoring the thermal behaviour of a subset of SSCS under a range of discharges and forest scenarios, remains to be completed, but should prove informative in time. Given the below average rainfall in the region in recent years, it would be useful to find a way to continue monitoring stream temperature across multiple years, and to relate this to counts and size structure of sicydiine gobies.

Figure 4.2 Water extraction and associated infrastructure

In the Wet Tropics, water infrastructure such as weirs, dams and culverts are common not only in our larger river systems such as the Barron (e.g. Tinaroo) or the Tully (e.g. Koombooloomba) but also in the short-steep-coastal streams (SSCS). In the 18 streams surveyed entirely in this study, eight had water extraction infrastructure.

These structures have associated effects (WTMA, 2013) that can include;

- Impeding upstream and downstream movement of fish, crustaceans and molluscs.
- Changing natural flow regimes
- Reducing the amount and quality of water in the system
- Modify the natural environment to favour alien species colonisation

The steep nature of SSCS is such that waterfalls commonly form natural barriers to fish movement along their length. For this reason, many fish species are only found below the first waterfall in the system. However, not all species follow this general pattern. Some species of cling goby, crustaceans and eels often possess remarkable ability to climb large natural or artificial barriers. Therefore the presence of weirs or dams in SSCS are potentially less detrimental for fish passage (dependant on their size, design and position in the catchment) than in lower gradient systems. However, water extraction associated with this infrastructure may have a more profound effect on the hydrology and ecology of SSCS.

As mentioned above, these structures are often used to maintain deep water areas that function as water off-take points. In addition to permanent water extraction infrastructure, there are also other forms of water extraction such as water pumping trucks that extract water for dust control during road works. Extracting water from SSCS, particularly during the dry season is likely to alter the natural flow regime of the system, reduce the amount of available habitat and affect the quality of the water. Previous studies have shown that water flow is a critical force in structuring the fish communities in streams of the Wet Tropics (Donaldson *et al.*, 2013). Reducing or altering discharge in SSCS may have flow-on effects for the composition and structure of the stream fauna. In the present study we have chosen to focus on this component of the threat posed by water infrastructure (hydrology is covered in chapter 2).

4. Impacts of introduced species

Alien and translocated species have serious potential to negatively impact cling gobies in streams (Jenkins *et al.* 2010, Ebner *et al.* 2011). Fortunately, no alien fishes were detected in the SSCS in the current study, and this is despite widespread pest fish populations including cichlids occupying nearby and adjacent large river catchments (Figure 4.3) (Burrows 2009, Kroon *et al.* 2015). Conversely, we observed individuals or at least found signs of two vertebrate pests, the cane toad (*Rhinella marina*) and pig (*Sus domesticus*) during field exercises (Figure 4.3).

The tadpole phase of cane toads were present in a number of SSCS (Figure 4.3) most notably in all of the streams surveyed in the Ellis Beach sub-region, and were common in one of the streams on Hinchinbrook Island at the time of survey. The tadpoles of cane toads are not nearly as common in SSCS of the other sub-regions and at Cape Tribulation this is confirmed from numerous visits (at least to the permanently flowing streams) by us since 2009. Nevertheless, the species is present and does persist in that region, so it may be insightful to expand surveys to the smaller, more ephemeral streams of the Cape Tribulation region during dry periods. Theoretically, herbivorous cling goby species may compete directly with cane toad tadpoles as biofilm grazers. Cane toad tadpoles also have a competitive advantage in being toxic or not consumed by many aquatic predators including native fishes (Shine 2010 and references therein).

Pigs and pig damage to streams was observed in all sub-regions including the one stream surveyed at Cedar Bay. In fact the latter stream exhibited substantial pig damage and occupation. This included excavation of stream beds and riparian zones along small tributaries, and a number of highly turbid deep (>1 m) waterholes in the main channel associated with bankside pig wallows, despite having cobble-boulder benthos, and contrasting nearby high clarity pools of similar dimension. Multiple pigs were sighted during a two day visit to Cedar Bay, contrasting our overall experience with SSCS in recent years where damage is present but the pigs are rarely encountered.

5. Overexploitation

Sicydiine gobies are collected from streams for food and for private aquaria across their global range (Iwata, 1997; Amarasinghe *et al.* 2006, Yamasaki and Tachihara 2006, Castellanos-Galindo *et al.* 2011, Ebner *et al.* 2011). However, only the latter purpose is relevant to Australia as these fishes do not occur in sufficient local abundance to warrant harvesting for food. Ebner *et al.* (2011) recommended that all species with the exception of *S. lagocephalus* receive some form of precautionary protection from over-collection in addition to other potential threats. The current study continues to provide mounting evidence that *S. lagocephalus* is more widespread (Chapter 3) and abundant (Ebner and Donaldson, unpubl. data) than other sicydiines in the Australian Wet Tropics. Furthermore, counts of *S. lagocephalus* are likely underestimates of true abundance due to this species having cryptic behaviour and inhabiting fast flowing and complex stream beds in riffles, runs and cascades; and the evasive nature of this species renders them more robust to over-collection than most of the remaining sicydiine species in Australia. Over-collection for the aquarium trade has not been demonstrated in Australia, nevertheless, the recent precautionary stance taken by the Queensland government to ban the collection of all sicydiines in the wild within the state is strengthened by the current study which has shown reductions in the projected suitable habitat for this group relative to previous estimates (chapter 3). The only exception being that the issue of lifting the ban on collection of *S. lagocephalus* may require conducting some supporting research to provide an absolute abundance estimation.

Figure 4.3 Alien species have the potential to threaten the condition of short-steep-coastal-streams. We observed a) cane toads (*Rhinella marina*), and specifically their b) tadpole phase grazing on biofilms, and occurring in high density in the lower pools of a number of streams in this study. c) Pigs, and pig damage to waterholes, was observed in a small subset of streams (most notably at Cedar Bay). Alien fishes were not detected in any of the SSCS in the current study, though several of these species are found in nearby catchments, shown here is d) spotted tilapia (*Pelmatilapia mariae*).

6. Global climate change

Global climate change poses myriad of challenges for ecosystems and for fishes such as cling gobies. Changes to stream discharge and thermal shifts are among the more easily recognisable drivers that are likely to effect sicydiine gobies. Riparian shading is considered important for sicydiines (Keith 2003, Jenkins *et al.* 2010) and Ebner *et al.* (2011) called for research attention toward high elevation specialist species including *Sicyopus* and *Smilosicyopus* in regard to climate change. The current study has found sicydiines generally occupy rainforest dominated rather than sclerophyll dominated catchments. In the current century, the Australian Wet Tropics are predicted to encounter shifts in extent and spatial distribution of these forest types as a consequence of climate change (Hilbert *et al.* 2001). This is likely to lead to intra-regional shifts in the distribution of the adult phase of cling gobies. However, the amphidromous life cycle of these species at least theoretically affords some level of resilience for them relative to potadramous fishes (which migrate purely within freshwater) since the former life history strategy enables for movement between catchments and even islands. At a local scale, the protection of riparian zones to provide shading and buffer against extreme temperatures, is one practical consideration for land managers and town planners.

Ocean acidification and warming have implications for the physiology, behaviour and ultimately the fate of marine species (Kroeker *et al.* 2013). This is potentially of relevance to larval sicydiines and indeed the marine larval phase of the migratory (diadromous) fauna found in SSCS.

7. Inadequate knowledge and understanding

Inadequate ecological and societal information can inhibit the protection of sustainable ecosystems (Pusey *et al.* 2004, Pahl-Wostl 2007). Ignorance of the existence of particular species or ecosystems, forms a basic part of this reasoning. From an ecological perspective, a lack of understanding of the requirements of species (Pusey *et al.* 2004) and ecological community structure and function, represent important knowledge gaps (for example 1-3 identify key threats which be in the large part mitigated or avoided though appropriate design or practice). That less than a decade ago the scientific community was essentially unaware of SSCS or sicydiine assemblages in the Australian Wet Tropics is a situation mirrored elsewhere at continental margins of the tropical Pacific (Nip 2010, Thuesen *et al.* 2011, Maeda *et al.* 2015). These streams are akin to those on tropical Pacific Islands being characteristically short, steep and straight and subject to flash floods from torrential rainfall (Smith *et al.* 2003; chapter 2). From a societal perspective, while tropical Pacific island communities are intimately familiar with these conditions and streams, the operating systems of continental society have in many cases evolved with sectors (e.g. agriculture, water supply and fisheries) that are dominated by large floodplain river catchments. This means that in continental societies there has been negligible opportunity to safeguard against human related disturbance of SSCS assemblages and ecosystems, and in this case in Australia, despite being part of a developed country. The current level of protection and representation of SSCS in Australias Wet Tropics is more of an artefact of their lack of utility for agriculture, development or extraction alongside the more dominant major freshwater systems which are highly exploited.

The relatively small size of the catchments in which these species lives also render such ecosystems vulnerable to human impacts which may appear minor but actually represent potentially large-scale disturbances in the context of these catchments. For instance, water extraction from small SSCS may actually alter flow and discharge cycles, and this may be especially relevant in the Australian Wet Tropics late in the dry season. Road culverts and small dams may effect faunal passage and have the potential to alter the structure and function of these ecosystems (March *et al.* 2003, Keith *et al.* 2015). The small extent of these catchments also precludes cost effective monitoring (e.g. stream gauging data) or management that is typical of larger catchments from which water is harvested.

Opportunities

Identifying threatening process to fauna and ecosystems is an important step in maintaining sustainable ecosystems. It is also important to identify opportunities for society to benefit from and to benefit ecosystems. At this rather preliminary stage in our understanding of cling gobies and SSCS in the Australian Wet Tropics, a number of prospects for progress can be gleaned.

At the ecosystem level, it is encouraging that there are many small SSCS catchments in the Wet Tropics and that a number of these are currently within designated protected areas. These protected areas include National Parks and Indigenous Protected Areas, as well as the World Heritage area. Interestingly, these small catchments nested within protected areas present whole-of-catchment scale protection of reference catchments (Smith *et al.* 2003). In contrast, it is usually unacceptable to society to protect large catchments since the spatial and agricultural resources they contain are valuable, and inevitably within catchment scale management becomes the dominant paradigm in large floodplain river systems (Dale *et al.* 2014). Large floodplain river catchments comprise substantial expanses of flat and sometimes fertile land which are usually the first spaces to be colonised by humans or at least agricultural development.

Protection of reference catchments is essential both for preserving ecosystems and biodiversity and to act in informing management of human impacted catchments (Smith *et al.* 2003). In this regard there are real opportunities in the Australian Wet Tropics relative to the large river catchments, partly because there still remain many near pristine SSCS catchments and very few undeveloped large catchments. It is also likely to be logistically easier to protect and maintain essential habitat within small rather than large catchments and certainly the cost of restoration is scale dependent (Menz *et al.* 2013). A useful next step would be determining from a conservation planning perspective which SSCS would make useful reference catchments. At a minimum, we recommend that this is partly based on an appreciation of sicydiine population dynamics and assemblage structure. As a first step this would entail progressing from just recording the presence or absence of species from one off visits to sites to understanding their seasonal usage of SSCS habitat. Our observations since 2009, point toward a subset of streams hosting populations of adults of sicydiines, while other streams appear to be marginal sometimes containing low numbers of species and/or entirely comprising a single sex (usually males).

The potential tourism and ecotourism value of SSCS ecosystems represents an exciting opportunity for maintaining these catchments across a continuum from pristine to largely intact systems. It would be informative to develop a quantitative understanding of human impacts on SSCS catchments based on an adaptive management framework (e.g. Pahl-Wostl 2007), given the wide range of human activities and levels of occupation across these catchments (this study) regionally.

There are also potential benefits to controlling, managing and even eradicating pest species in small catchments, actions which are in contrast with what may be achievable in large river catchments. This is analogous to the situation of managing pests on small as opposed to large islands (Courchamp *et al.* 2003). In this regard, the current study highlights opportunities for pilot work on monitoring SSCS ecosystem recovery from cane toad and specifically cane toad tadpole control to determine if there is an impact of this amphibian on particular native taxa. Herbivorous cling gobies represent potential indicator taxa in this context, as does the tadpole phase of native frogs. Furthermore, cling gobies including high-flow-specialist and altitudinal specialists also have potential to make useful indicators of hydrological change and habitat quality (Ebner *et al.* 2011, Donaldson *et al.* 2013, Keith *et al.* 2015).

There is clear potential to market cling gobies as flagship species representing SSCS ecosystems. Freshwater fishes can serve as icons for conservation of aquatic ecosystems (Ebner *et al.*, in press) as well as indicators of system health. Cling gobies have featured on postal stamps in Pacific Island communities, and their bright colours render them attractive to aquarists (Ebner and Thuesen 2010) and snorkelers. Waterfalls are also a major tourism drawcard in the Australian Wet Tropics (e.g. Bermingham 2015). Their occupation of idyllic rainforest stream habitats, in conjunction with proximity to and climbing behaviour in association with waterfalls (Weaver 2002, King and Prideaux 2010, Schoenfuss *et al.* 2011, Newsome and Johnson 2013, Keith *et al.* 2015) provides further marketing opportunity for these fishes as regional conservation and ecotourism icons. Furthermore, there are a number of other colourful and interesting species occupying the lower and mid-course of SSCS that have potential as flagships species (e.g. Jungle perches, *Kuhlia* spp.; Freshwater moray, *Gymnothorax polyuranodon*). As with any ecosystem scale restoration and protection, engaging local people and establishing societal relevance will be essential to the long term protection of SSCS ecosystems in the Australian Wet Tropics (Menz *et al.* 2013).

Media and project communication

A number of public communications were made by the project team. This included informal discussions with people encountered during fieldwork at popular beaches and in National Parks, and in gaining access to private property. By way of media and formal public communication, we undertook local/regional, state and national communication, mostly simply to increase awareness of the existence of cling gobies in Australia. Newspaper, radio and the internet were used in this activity. Take home messages in these communications ranged from simply announcing that the project was underway, to describing our international research collaborations (e.g. collaborations in the Solomon Islands), whereas in other cases we elaborated on aspects of nominating, listing and gathering information regarding these newly found inhabitant of local streams. A list of formal communications is provided in Appendix 4.1.

Summary points

There is a diversity of stakeholders, potential stakeholders and relevant research and management agencies associated with SSCS and cling gobies in the Australian Wet Tropics. The lack of alluvium and flat landscapes associated with this ecosystem type translate to minimal if any agricultural interest. However, SSCS are exceptional areas for tourism and recreational interest and frequently coincide with indigenous community ownership and interest.

There are multiple potential and realised threats to SSCS and cling gobies in the Australian Wet Tropics. These threats include global scale factors such as climate change and highly localised issues such as direct harvest of fishes. We did not find evidence of alien fishes occupying SSCS, however, pigs, and toads and their tadpoles, represent an existing threat to SSCS and cling gobies. Water resource extraction also takes place in a subset of SSCS, with the potential to adversely affect cling gobies and SSCS function.

The current project and its associated report serves as a preliminary step toward understanding and communicating the plight of SSCS and cling gobies, regionally.

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CHAPTER 5 GENERAL DISCUSSION

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The current study has defined, described and mapped the distribution of short-steep-coastal-streams (SSCS) in the Australian Wet Tropics. A central characteristic of this ecosystem type is the absence of extensive lowland floodplain habitat and the immediate connection between riffle-run-pool sequences and tidal waters. These ecosystems are prolific on true oceanic islands (Smith *et al.* 2003) but less widespread on mainland Australia. It is perhaps not surprising then that SSCS catchments of the Australian Wet Tropics host a subset of the amphidromous fauna found on tropical Pacific Islands (Thuesen *et al.* 2011). The hydrology and ecohydrology of these ecosystems remains virtually unstudied in an Australian context, a situation that requires attention and investment, from a local sustainability perspective and in terms of contributing to understanding the biogeography, ecology and evolution of the Pacific islands.

The occurrence of a distinct fauna principally located within small coastal streams in the Australian Wet Tropics, creates a special issue for regional environmental managers. These small catchments are in some way analogous to desert spring complexes with substantial aquatic biodiversity value isolated in small wetted surface areas, rendering these systems vulnerable to relatively small levels of human disturbance, including pest species impacts and water extraction (Fensham *et al.* 2011). Obviously a major difference is the hydrology of these systems. Nevertheless, there are some opportunities for incorporating the sustainability of SSCS into the culture of stakeholders. These include maintaining the naturally beautiful locations comprising waterfalls, swimming holes, rainforests and beaches in recreational, ecotourism, and indigenous areas. Raising awareness of the life cycle and stunning beauty of the cling gobies that inhabit these systems also holds promise as flagship species (Chapter 4, Ebner *et al.*, In press). This will require ecologists communicating beyond the scientific domain, for instance through establishing signage in national parks, and may be best achieved by building on the local ecotourism experience and marketing campaigns that revolve around visiting the Great Barrier Reef, rainforests and waterfalls.

Clearly, there is a need for monitoring of water extraction in SSCS if we are to manage these streams effectively. However, the cost of gauging station infrastructure is highly prohibitive in these small catchments. The current study has explored and developed some low cost solutions to this that warrant ongoing investment in the short to medium term. These costs should be factored into future approvals for water extraction in these systems. Arguably, this is most relevant to streams containing conservation listed species, in this case some of the cling gobies. It would also be useful to prioritise the installation of permanent gauging stations at a small number of key sites. These would likely inform conservation of high diversity catchments with substantial populations of cling gobies, and provide long-term data sets for assessing natural variability in population dynamics and aid in investigating long term climate change impacts. These water extraction issues including water resource and ecological monitoring should be factored into town planning including the approval process for resorts, caravan plans and tourism and recreational amenities at beaches.

Water extraction and infrastructure warrant further investigation in this ecosystem, and this should include adaptive management of water extraction and exploration of water resource management plans that explore ecologically sustainable solutions. March *et al.* (2003) discuss a number of solutions to these issues, including installing fish and crustacean ladders for passage. Arguably, the Australian Wet Tropics experiences a more prolonged dry season than many Pacific high island areas, so there is need to be cautious in assuming water supply is sufficient in the former. This is further complicated by combinations of stream size and subregional rainfall. Installing water supply from major river storages or off-channel storage of wet season discharge may ultimately overcome likely negative impacts of late dry season water extraction from SSCS. It may also be that water resource infrastructure provides some positive benefits to in-stream fauna. For instance, cling gobies were found immediately upstream of small dams in two near ephemeral streams at Ellis Beach in the current study. We recommend that aquatic ecologists and threatened species managers collaborate with water resource providers and management agencies as well as council planners to strategize for ecologically sustainable SSCS ecosystems in the Australian Wet Tropics.

The current study has provided the first detailed and systematic assessment of SSCS for cling gobies at the extent of the Wet Tropics. Specifically, it builds on a 6 year period of opportunistic surveys (Ebner and Thuesen 2010, Ebner *et al.* 2011, Thuesen *et al.* 2011, Donaldson *et al.* 2013) and has added surveys to the northern and southern extremities of SSCS in the region, and including the Mission Beach area. Generally, three functional groups of cling gobies, lowland specialists, upland specialists and altitudinal generalists are recognizable based on our findings (Fig. 3.7). Lowland specialists and the generalist, *Sicyopterus lagocephalus* were sometimes an order of magnitude or greater in abundance than upland specialists. The finding of an altitudinal cline in fish assemblage distribution is generally in agreement with pioneering research on cling gobies in Pacific Island streams and preliminary Australian surveys (Keith 2003, Ebner *et al.* 2011, Keith *et al.* 2015), although, the specialist upper course fauna (e.g. *Lentipes* and *Akihito* spp.) (Keith *et al.* 2015) found on certain Pacific Islands, has not been found in Australian systems to date. Additionally, species that specialize in occupying the lower course of streams in Australia are often found at substantially higher elevation in the Solomon Islands (Phillipe Keith, David Boseto, Robson Hevalao, Brendan Ebner, unpublished data; Paul Thuesen, pers. observ.). This may be a function of differences in climate and stream physical-chemical conditions, and possibly nutrient availability, however, this requires investigation.

The current study serves as a valuable resource for assessing the distribution and abundance of sicydiine gobies and what seems to be their primary habitat in Australia, in the form of SSCS. Notwithstanding this, systematic surveys of potentially suitable habitat in tributaries of large river catchments is a challenging next step, owing to the magnitude of the task. The rapid survey method refined here, provides one tool for the task, and the MaxEnt modeling provides a means for prioritizing site selection. In this regard, tributaries of the lower and mid-course of the Daintree River catchment are highlighted for exploratory surveys. The emerging methods of eDNA may also improve the efficiency of determining presence and absence of species from catchments and sub-catchments (e.g. Robson *et al.* 2016).

Long-term persistence of cling goby populations in the Australian Wet Tropics is unknown. Only relative species counts have been obtained in the current study and these should be interpreted with caution. As discussed previously, the counts of *S. lagocephalus* (and other rarer *Sicyopterus*) are almost certainly underestimates of true abundance given the cryptic and elusive behaviour of this species in the presence of snorkelers, and we suspect underestimation is most pronounced in large streams with complex riffle-run habitat and countless interstitial spaces. Whereas, counts for most of the other species may approximate true abundance. Caughley and Gunn (1996) caution against such assumptions, and therefore we recommend that calibrations of single pass snorkel surveys for sicydiine gobies be conducted. Currently, there is only a single published account in the form of multiple-passes by snorkelers counting *S. pelewensis* in a single pool that is any way relevant (Ebner and Thuesen 2010). This is major knowledge gap that could be overcome with systematic surveys of multiple habitats in SSCS based on removal experiments possibly combined with tagging of subsamples of populations (cf. Pusey, *et al.* 1998, Bird *et al.* 2014). Nevertheless, the single pass counts of nine cling goby species represent a useful baseline for future surveys in the Wet Tropics, and the project design provides a template for auditing this ecosystem within Australia outside of the Wet Tropics (e.g. Whitsundays, Eastern Cape York) and in the Pacific High Islands.

Our hypotheses were that SSCS in high rainfall areas would contain greater diversity of cling gobies than drier SSCS and that large SSCS would contain greater diversity than smaller SSCS. The first of these hypotheses was largely upheld. One of the dry sub-regions (Hinchinbrook Island) produced no cling gobies and the other (Ellis Beach) contained low abundance of all cling gobies except the generalist *S. lagocephalus* which was moderately abundant in two streams at Ellis Beach. Notably there were reasonably high levels of species richness in two of the four creeks surveyed there, specifically in Turtle Creek and Cascade Creek.

On first inspection (Fig. 3.6), large SSCS do not necessarily contain greater cling goby diversity than smaller SSCS in the Australian Wet Tropics. For instance, Hartleys Creek, the second largest catchment surveyed, contained two cling goby species in low abundance, and Russell Heads Creek, a small catchment contained six species with a few of these species in moderately high abundance. We propose that Hartleys Creek is unfavourable for cling gobies, at least late in the dry season, due to the open canopy and absence of rainforest. A similar explanation may apply to the absence of cling gobies from Bessie Creek, at least in the lowlands. However, large catchments in wet sub-regions tended to hold high species richness and high abundance of cling gobies. Pauls Pocket Creek, Noah Creek and Myall Creek supported the highest cling goby diversity recorded in the study. All of these systems experience almost year round flow in wet sub-regions, are rainforest dominated and are sourced from peaks in excess of 750 m ASL. It appears that the streams that contain high species richness of cling gobies and high counts of each species, are generally the medium to large size streams in high rainfall, rainforest dominated catchments.

There are practical implications from the outcomes of testing these hypotheses. First, some creeks appear to be hotspots for cling goby diversity, and probably warrant special protection. Among these are, Noah, Myall and Pauls Pocket creeks, but also some of the smaller systems including Ashwell and Russell Heads creeks. Notably human water extraction is occurring from two of these systems, and certainly warrants scrutiny at Russell Heads owing to the size of the stream. These priority creeks are candidate systems for longer term monitoring of interannual variability in juvenile recruitment and adult population abundance. Furthermore, we recommend further rapid surveys concentrating on exploring large SSCS, particularly in the upper reaches. To this end, further work developing aquatic ecological capacity and ecotourism ventures within the Eastern Kuku Yalanji and Djunbunji Ranger groups holds promise, as does the potential to initiate scientific collaborations with emerging ranger groups at Yarrabah and Cedar Bay.

The high species richness encountered in the relatively small SSCS from the Ellis Beach to Turtle Creek sub-region warrants further investigation. Human water extraction is occurring from all four of the streams surveyed, and cane toad tadpoles were recorded from each of these locations. Given the small scale of this particular set of streams, a mixture of government and landholder resourced water and pest management may yield for some tangible, affordable and community oriented adaptive management exercises, which could potentially be facilitated by Terrain Natural Resource Management, Incorporated. Given the proximity of the James Cook University, Cairns Campus, this is an ideal opportunity for involving postgraduate students in community based science elements of the ecology and social science required to support such an initiative.

Major recommendations

a) SSCS should be integrated into the existing Queensland Wetland mapping and conceptualization.
b) The conservation status of all nine recognized Australian cling goby species should be reassessed based on this newly acquired dataset which is far less spatially biased than was the previous knowledge base.
c) Investment in the ecology of sicydiine goby ecology including monitoring of threatened species abundance, growth, reproduction at key sites within an inter-annual schedule, is required to aid the conservation of this fauna. Management of water availability and temperature as well as alien species interactions should be a feature of this work. In this regard, consolidation and further development of collaborations between traditional owner groups and university researchers may provide the long-term platform for progress.
d) The degree of (genetic) connectivity between Australian and overseas adult populations of cling gobies remains an urgent scientific priority to inform management of these relatively rare species in an Australian context (Ebner *et al.* 2011).
e) That cling gobies be integrated into existing promotional and educational initiatives relating to the biodiversity value of the Australian Wet Tropics. The elevational zonation of individual species as shown in Figure 3.7 may provide a starting point for advertising the existence of these fishes in the region.

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APPENDICES

Appendix 3.1 Current conservation status and distribution of sicydiine gobies in Australia. Information based on listings under the Nature Conservation Act 1992 (Qld) and the national Environment Protection and Biodiversity Conservation Act 1999 (EPBC). Sub-regions of the Short-steep-coastal-streams in the Australian Wet Tropics are depicted in Figure 3.2. Note that all sicydiine gobies are no take species under the Queensland Fisheries Act.

Species	Common name	Legislative status	Wet Tropics subregional distribution
Sicyopterus cynocephalus	Cleft-lipped goby	Not listed	Malbon-Thompson (Russell Heads only)
Sicyopterus lagocephalus	Rabbit-headed goby	Not listed	All subregions except Hinchinbrook; also in Barron, Bloomfield, Liverpool and Russell-Mulgrave catchments
Sicyopus discordipinnis	Red-bum goby	Not listed	Cedar Bay, Cape Tribulation, Malbon Thompson
Smilosicyopus fehlmanni	Calligraphy goby	Not listed	Cedar Bay, Cape Tribulation, Malbon Thompson, Port-Douglas/Cairns
Smilosicyopus leprurus	Moustache goby	Not listed	Cedar Bay, Cape Tribulation, Port Douglas/Cairns
Stiphodon pelewensis (formerly *S. atratus*)	Emerald cling goby	Vulnerable (Qld)	All subregions except Hinchinbrook; also in Liverpool and Russell-Mulgrave catchments; (additionally, record from Cape York)
Stiphodon rutilaureus	Orange cling goby	Vulnerable (Qld)	All subregions except Port-Douglas/Cairns and Hinchinbrook
Stiphodon semoni	Opal cling goby	Critically Endangered (EPBC)	All subregions except Hinchinbrook; also in Liverpool and Russell-Mulgrave catchments
Stiphodon surrufus (formerly *S. birdsong*)	Birdsongs goby	Vulnerable (Qld)	All subregions except Port-Douglas/Cairns and Hinchinbrook

Appendix 3.2 Biophysical attributes of streams surveyed rapidly in their entirety (listed north to south) in the Australian Wet Tropics.

Sub-region	Stream	Stream network length (km)	Catchment area (km^2)	Alluvium (%)	Average slope (%)	Rainforest (%)	Max. elevation of stream (m)	Max. elevation of catchment (m)
Cedar Bay	Ashwell	26.5	9.3	24	14	99	543	780
Cape Tribulation	Mason	20.5	3.2	14	13	87	608	1121
Cape Tribulation	Myall	52.7	12.4	11	14	96	938	1049
Cape Tribulation	Noah	150.9	32.41	5	17	94	1110	1320
Port Douglas/Cairns	Turtle	8.7	2.1	0	11	88	217	527
Port Douglas/Cairns	Hartleys	110.6	29.05	8	9	67	574	1011
Port Douglas/Cairns	Spring	2.4	0.48	5	22	22	455	580
Port Douglas/Cairns	Cascade	5.5	1.73	2	28	82	528	601
Malbon-Thompson	Bessie	55.4	9.96	6	16	22	605	761
Malbon-Thompson	Pauls Pocket	15.2	6.62	0	12	65	446	780
Malbon-Thompson	Russell Heads	4.2	1.67	0	17	100	420	600
Mission Beach	Unnamed	2.8	0.47	6	18	96	233	360
Mission Beach	Kingys	4.1	0.72	0	8	88	163	350
Mission Beach	Wylie	5.5	1.15	17	7	92	125	358
Hinchinbrook	Goold Island	4.0	1.77	0	11	12	167	402
Hinchinbrook	Warrawilla	17.7	4.22	0	19	11	760	870
Hinchinbrook	Banksia	5.0	1.25	0	11	0	224	300
Hinchinbrook	Zoe	8.5	5.78	0	6	6	543	756

Appendix 4.1 Project communication during the project

Date	Title	Publisher	Type of media	Audience	Link
15/03/2015	Pretty fish gets bright future	Tully Times	Newspaper	Local	
19/03/2015	Rare fish gets helping hand	Port Douglas Gazette	Newspaper	Local	
23/06/2015	Pretty fish gets bright future	TropWATER	Website	Regional	
18/08/2015	Opal cling goby	Terrain Natural Resource Management	Website	Regional	http://tinyurl.com/pwkd8hz
27/08/2015	Another discovery in the Wet Tropics	Wet Tropics World Heritage Area	Website (Facebook)	Regional	
28/08/2015	Wet Tropics - home to Australia's only known species of freshwater moray	Wet Tropics World Heritage Area	Website (Facebook)	Regional	
28/08/2015	Finding goby	Living Knowledge Place	Website	Regional	https://vimeo.com/114521165
28/08/2015	Cling goby article	Djunbunji Land & Sea Program	Website (Facebook)	Regional	
4/09/2015	Three sub-species of goby fish now listed as vulnerable, Queensland scientist says	ABC news	Website	National	
7/09/2015	Cling goby interview	612 ABC Brisbane	Radio	State	
7/09/2015	Cling goby interview	ABC Far North	Radio	Regional	
8/09/2015	Scientists work to save fish species	Tablelander	Newspaper	Local	
26/09/2015	World Cassowary Day		Direct community engagement	Regional	
17/11/2015	Surveying rare fishes in rivers	River Ecology and Research	Website	National - limited	http://tinyurl.com/h5fg9zl

Appendix 5.0 Glossary of technical terms

Amphidromy is a term used to describe species that live the majority of their life in freshwater where they grow and breed, but where their larvae travel to sea for a period of time to develop and disperse.

Elevational zonation – is the climatic, ecological and biogeographic layering of ecosystems that occurs as a function of varying environmental conditions. For instance, the availability of light, temperature, moisture and pressure effect the living conditions for plants and animals.

Goby – fishes typically with paired pelvic fins fused into a single cup underneath the body. Any fish of the family Gobiidae.

High Islands – A geological term used to distinguish an island of volcanic origin rather than sedimentation or coral reef growth.

Macrophyte – An aquatic plant.

Massenerhebung Effect – Variation in the tree-line based on mountain size and location. Relates to thermal and evapotranspiration rates and how nearby topography effect local climate.

Recruitment – The number of young fish surviving through to adulthood or at least to an advanced development phase (e.g. post-larvae). An indication of production from previous breeding events which is historically used to predict the future abundance of a fishery stock.

Rithron – The section of a river or stream with typically fast flowing, cold and well oxygenated water and favouring particular organisms with a high demand for dissolved oxygen and sometimes with adaptations for living in flowing waters.

Sicydiinae – A mostly tropical subfamily of fishes in the family Gobiidae, predominantly with marine larvae and a freshwater adult phase.

Short-steep-coastal-stream – A freshwater ecosystem type that is common on many high islands throughout the Pacific, typically occurring in steep, high rainfall areas close to the coast. Seldom do these streams have an estuary and if so it is rudimentary.

Species distribution models (SDMs) **–** Use of mathematical relationships to combine species occurrence records with spatial layers of ecologically-relevant environmental data and predict suitable habitat. Typically applied across large areas/landscapes.