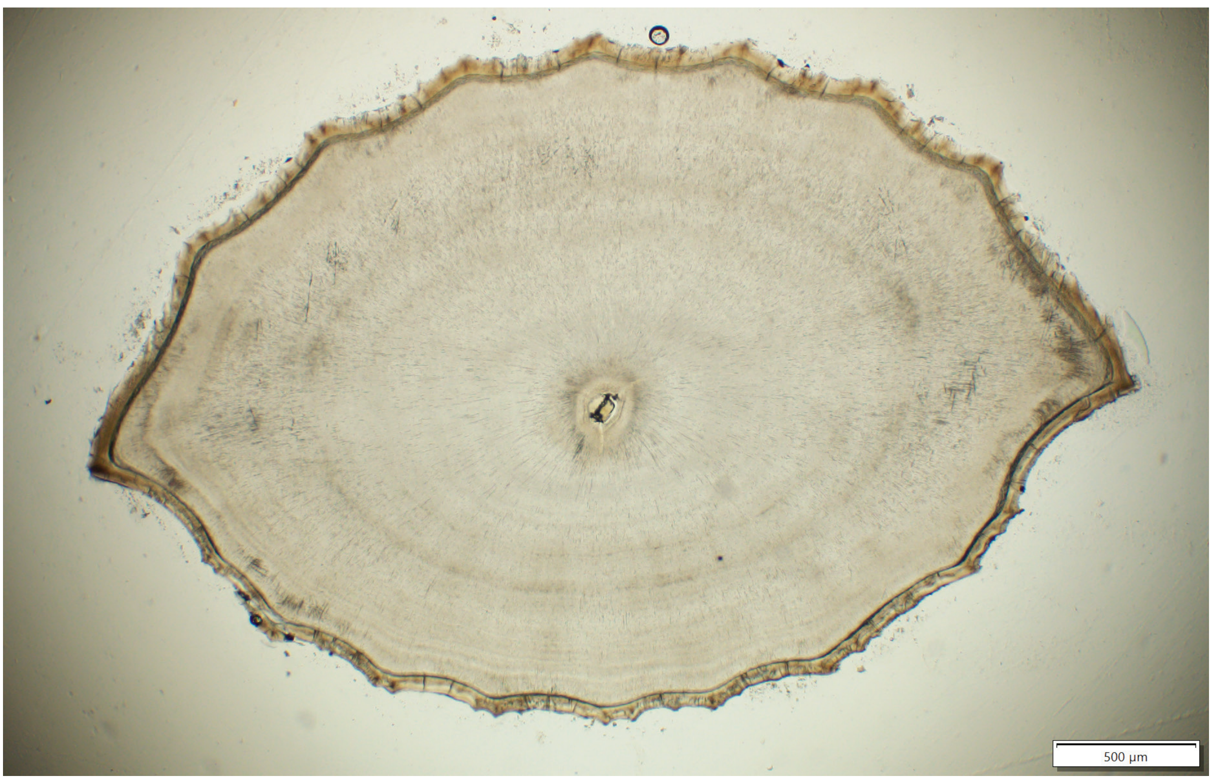
PROCEEDINGS OF THE ROYAL SOCIETY OF QUEENSLAND



2021 VOLUME 129

VOLUME 129

PROCEEDINGS OF THE ROYAL SOCIETY OF QUEENSLAND

Editor: Julien Louys

Special thanks are extended to the referees who reviewed papers submitted for publication in this volume of the *Proceedings*.

2021

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COVER ILLUSTRATION
Image of a histology cross-section through a tooth of a modern saltwater crocodile (*Crocodylus porosus*). The white band surrounding the exterior of the cross-section is enamel, whereas the internal area is mostly composed of dentine (Credit: B. Campbell and J. J. Miszkiewicz). On pages 37–46 Campbell et al. report on the first description of crocodile tooth histology from a 3.5-million-year-old deposit at Chinchilla, Queensland.

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The Royal Society of Queensland

The Royal Society of Queensland has an honourable history as the senior scientific institution in the state. It was established in 1884, with royal patronage continuing unbroken from 1885. Her Excellency the Honourable Dr Jeannette Young PSM, Governor of Queensland, is the present Patron.

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Proceedings of The Royal Society of Queensland

The *Proceedings* publishes original scholarship and investigation in natural history relevant to Queensland, including the biodiversity, conservation, use, management and economic significance of natural resources. All aspects of the natural sciences, including astronomy, geology, hydrology, botany and zoology, biomedicine, introduced species and dynamic land and water processes, are considered. The journal will also publish papers on general science, including science-related history, policy, education and philosophy. Papers written from within the social sciences, such as sociology, culture and heritage that deal with the use or management of a natural resource, are welcome.

Following initial appraisal by the Editor, all submitted papers are peer reviewed by a single-blind process. The following types of manuscript are considered:

> Scientific Papers, Short Communications, Historical Reviews, Opinion Pieces, Dissertation Abstracts, Book Reviews.

Authors are required to follow the instructions given in the *Guide to Authors* which is available on the Society website or from the Honorary Editor. The timeline to allow print publication by the end of each year requires authors to submit papers to the Editor by 30 June.

From Volume 124, papers are being placed online free of charge as they emerge from the editorial and typesetting procedures. Print publication will follow when the volume is completed.

A complete archive of the *Proceedings* with full search capability back to 1884, and the preceding three volumes of the *Transactions of the Queensland Philosophical Society*, are available online.

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Articles accepted for the annual *Proceedings of The Royal Society of Queensland* and Special Issues have been published online with free public access. The advent of digital scientific publishing means that it also becomes practicable to publish scholarly debate over published articles. The Society welcomes critical responses to articles that have been published, if addressing matters of scientific substance and expressed in a scholarly manner. Please refer to the *Guide to Authors* for guidance as to style and submit all such responses to the Honorary Editor. All critical responses will be subject to the review process undertaken for other submissions.

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EDITORIAL FOREWORD

It gives me great pleasure to introduce the 129th *Proceedings of The Royal Society of Queensland*, and my first as Honorary Editor. This year's *Proceedings* touches on many topics that help convey the width and depth of the science undertaken in Queensland and on topics that bear directly on Queensland and Queenslanders. The science reported in the following pages represents strong observational data, rigorous interpretations, and discourse that will resonate well beyond the state. Nevertheless, there is a wide-ranging perception, increasingly common across universities and funding bodies, that science should only be published in flashy, high-profile, or international publications. Unfortunately, excellent publications such as the *Proceedings* are not seen as desirable or even worthwhile venues to submit science. It has even reached the point where academics have been actively discouraged from publishing in more local or regional journals, being informed that such publications would detract from their professional records.

Needless to say, I vehemently disagree with this position, and one of my strong motivations for accepting the role of Honorary Editor was to support and ensure the longevity of local scientific publications like the *Proceedings*. Such journals provide one of the few remaining outlets for purely local or small-scale scientific observations. This scale may be small from a topical or geographical perspective but can be enormous from a scientific perspective. The grand narratives, the meta-analyses, and the increasingly popular 'big data' driven research agendas do not occur in isolation but critically rely on local observations and smaller-scale studies. In many of my own professional publications I have relied on studies published in low-profile, local, discipline-specific journals, and several of the analyses I have conducted would not have been possible without them.

In this year's volume, geology is particularly well represented, with three important contributions to palaeontology. Jell describes a new species of Cambrian trilobite from the Devoncourt Limestone, northwestern Queensland; Campbell et al. describe the histology of a 3.5-million-year-old crocodile tooth, likely from the genus *Paludirex*, from the Chinchilla Sand in southeast Queensland; and Jell et al. describe a rare fauna, including sponge spicules, brachiopods, trilobites, and assorted echinoderm plates, from the New England Orogen in central eastern Queensland. In more modern settings, Williams and Clouten provide an assessment of the Queensland survey guidelines for protected plants, focusing on *Ipomoea antonschmidii*. In two pieces exploring the history of scientific exploration in Queensland, Anderson and Orchiston describe the Sir Thomas Brisbane Planetarium and amateur astronomy in Queensland generally, while Stork examines the Daintree Canopy Crane. In addition to these papers, we publish two life membership citations, to Dilwyn J. Griffiths and Craig Walton, two thesis abstracts by Jones and Riedel, and an obituary for Raymond Louis Specht. Lastly, the Annual Report is provided, and the President's Address presents an important consideration on the nature of science, how this is judged, and its increasing politicisation.

Google Scholar has adopted "Stand on the shoulders of giants" as its motto. While the giants have their place in science, certainly, I see the development of science and the use of scientific literature in an analogy a little closer to home. The Great Barrier Reef, one of the natural wonders of the world and one of the few biological structures visible from space, is composed of thousands of individual reefs, each in turn composed of billions of coral polyps, each building on the structures left by previous polyps. In much the same way do scientific contributions build upon one another, dependent on the small, local and (according to some) seemingly insignificant outputs.

Julien Louys
Editor, PRSQ Volume 129, 2021

The Royal Society of Queensland acknowledges the Iningai Nation, their long custodianship and inherent connection to country, its springs and waterways, plants and animals. We pay respect to the knowledge and cultural values of First Peoples of Australia and acknowledge Elders past, present and future.

CONTENTS

Refereed Papers

Royal Society Reports

Citations, Abstracts and Obituary

Refereed Papers

A New Species of *Modocia* (Trilobita: Ptychoparioidea) in the Late Middle Cambrian (Guzhangian: Miaolingian) Devoncourt Limestone, Northwestern Queensland

Peter A. Jell[1]

Abstract

A new species of late middle Cambrian (Guzhangian: Miaolingian) ptychoparioid trilobite is described from the Devoncourt Limestone just west of the Burke River crossing on the Duchess to Cloncurry Road. This is an addition to the extensive study of the fossil fauna of that district in the Burke River Structural Belt and provides another link to the Georgina Basin fauna, albeit younger by one zone, about 200 km west on Mungerebar Station. Generic assignment of the new species is discussed in relation to a worldwide complex of similar solenopleurid genera with small eyes situated well forward on the cephalon. Some comments are made in relation to family placement of the species, but the question of family concepts relies heavily on revision of an extensive northern hemisphere literature on these standard trilobites; so, although placement in the Solenopleuridae is favoured, no formal family assignment is made until family groups in this large complex of genera are better defined.

Keywords: trilobite, Solenopleuridae, *Modocia*, Devoncourt Limestone, Burke River Structural Belt, *Lejopyge laevigata* Zone

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Introduction

The geology of northwestern Queensland has been studied extensively, primarily the Precambrian mineral field, but when regional studies of northern Australia began after the Second World War, the onlapping sedimentary successions also came in for close scrutiny. In the late 1940s the Commonwealth Bureau of Mineral Resources (BMR) began detailed mapping in the region, including the Duchess 1:250,000 map sheet that covers the headwaters of the Burke River. Armin Alexander Öpik, formerly Professor of Geology in the University of Tartu, Estonia, came to Australia as a displaced person at the end of World War II and upon appointment to the BMR began the study of the Cambrian biostratigraphy of northwestern Queensland in 1948. This would occupy the rest of his academic career.

Trilobite-dominated, Cambrian faunas from the northern part of the Burke River Structural Belt in northwestern Queensland were described by Öpik (1961), who also elucidated the geological succession of the area. Öpik's (1961) bulletin on Cambrian faunas from the headwaters of the Burke River was a classic for its time, and he remarked on the similarity of the trilobites to those found in Scandinavia. However, he did not describe a distinctive, small-eyed trilobite subsequently collected from the Devoncourt Limestone beside the Duchess to Malbon Road. In this paper I describe the new species, discuss its affinities with other similar trilobites described by Öpik (1967) from the Georgina Basin near the Queensland/Northern Territory border, and discuss possible relationships with other closely similar trilobites from elsewhere in the world. Comprehensive knowledge of the regional fossil fauna and biostratigraphy aids the search for minerals: The Burke River Structural Belt has proven phosphate reserves being mined at The Monument, south of Duchess, and is an exploration target for rare earth minerals.

Geological Setting and Age

All the figured material is from Queensland Museum Locality 1407 at 21°21′53″S, 139°59′ 20″E, beside the Duchess to Cloncurry Road in the last creek before crossing the Burke River, between Opik's (1961: fig. 2) localities D17A and D15 in the Devoncourt Limestone. Fossils are scarce in the flaggy limestones at this site, and about two hours' collecting produced only single specimens of the bradoriid *Aristaluta gutta* Öpik, 1961 (Figure 1A) and trilobite *Amphoton bensoni* Öpik, 1961 (Figure 1B). Both these species occur in the lower part of the Devoncourt Limestone (Öpik, 1961: fig. 15) allowing the collecting site to be placed in the early *Lejopyge laevigata* Zone, i.e. early Boomerangian Stage in the Australian scheme and internationally in the early Guzhangian (Peng et al., 2009; Geyer, 2019). This horizon may be correlated with Westergård's (1946, 1953) *Solenopleura brachymetopa* Zone in Sweden.

Systematics

The figured material is catalogued in the fossil collection of the Queensland Museum, Brisbane (QMF). Description of features in the sagittal [sag.] (or exsagittal) axis are described in terms of length, and features described in the transverse axis are described in terms of width.

Order PTYCHOPARIIDA Swinnerton, 1915
Suborder PTYCHOPARIINA Richter, 1933

Remarks. Fortey (1997) emphasised the identification problems of members of this suborder having such a generalised trilobite morphology – notably, where the absence of distinctive characters has led to stratigraphical and geographical criteria in the taxonomy. The result has been a proliferation of unresolved synonymous taxa. As with many other trilobite taxa, further problems also occur in defining a diagnosis for a species represented by variable morphologies of its holaspid growth stages (Fletcher, 2005).

Superfamily PTYCHOPARIOIDEA Matthew, 1888

Diagnosis. See "PTYCHOPARIACEA Matthew, 1888".

Family SOLENOPLEURIDAE Angelin, 1854

Diagnosis. Ptychoparioidea with a rather gibbous, tapering forward, rounded anterior glabella with relatively faint, short, lateral glabellar furrows; occipital ring with median node or spine; a convex preglabellar field, upstanding anterior border; anterior facial sutures inclined inward; small- to medium-size eyes [palpebral lobes] slightly forward of cephalic midpoint; eye ridges faint or absent.

Remarks. This family is based upon the type species of the nominal genus, *Solenopleura holometopa* (Angelin, 1851–1878) from the Swedish *S. brachymetopa* Zone; lectotype figured by Westergård 1953, pl. 4, figs 2a, 2b). In contrast, the Ptychopariidae is based upon the type species of its nominal genus, *Ptychoparia striata* (Emmrich, 1839) characterised by a less-swollen glabella tapering to a truncate anterior preglabellar furrow; "neotype" figured by Šnajdr 1958, p. 186, pl. 38, fig. 19.

Genus Modocia Walcott, 1924

Type species. *Arionellus (Crepicephalus) oweni* Meek & Hayden, 1861 from the upper Cambrian Deadwood Formation of South Dakota; by original designation.

Diagnosis. Updated from Walcott (1924, 1925), Lochman-Balk in Harrington et al. (1959) and Robison (1964). Cephalon semicircular, with evenly curved anterior margin, moderate to high convexity with steep downslope to anterior and straight posterior margin. Glabella with moderately converging lateral margins, anteriorly rounded, moderately to highly convex; glabellar furrows very shallow (commonly absent in internal mould). Anterior border and occipital ring upstanding, marked by well-impressed furrows. Occipital ring with or without node. Palpebral lobes short, at or just forward of cephalic mid-length; ocular ridges obsolete to distinct. Anterior branches of facial suture subparallel to convergent (up to 20° to sagittal line), posterior branches gently sigmoid, cutting posterior margin just inside the genal angles. Genal angles rounded or quite angulated, with or without genal spines, which usually are short and make an angle with cheek outline, but may be stout and continue the margin smoothly. Thorax of 12–14 segments, pleural furrow well impressed, pleural tips rounded or weakly spinose. Pygidium with axis of up to six rings plus terminus; pleurae with well-impressed pleural furrows; interpleural furrows distinct but weak; border poorly defined, if at all.

Remarks. Family assignment of *Modocia* Walcott, 1924 has been uneasy throughout its history. Even before this generic name was introduced, the species designated as type had had six different generic assignments (see synonymy list in Walcott, 1925, p. 106), though all those names implied that the type species was a solenopleurid (see Fletcher, 2017, p. 179). Walcott (1924, 1925) introduced the generic name but did not assign it at family level. Palmer (1954) dealt with *Modocia* in the section headed “FAMILY UNKNOWN”. Lochman & Duncan (1944) similarly treated *Modocia* under the heading “INCERTAE SEDIS”. Lochman-Balk (in Harrington et al., 1959) gathered a group of disparate genera, including *Modocia*, into the Marjumiidae, albeit in an exercise in which family arrangement was a high priority, though not mandatory. Rasetti (1963) and Robison (1964) were both highly critical of the family arrangement of ptychoparioid trilobites in the *Treatise on Invertebrate Paleontology* (Harrington et al., 1959), and whereas the former described the Quebec ptychopariods (including *Modocia*) without family assignment, the latter maintained *Modocia* in the Marjumiidae with a group of genera he considered could be shown to be related to *Marjumia*. Rasetti (1965) discussed *Modocia* under the heading “PTYCHOPARIIDA of uncertain affinities”, while Robison (1988), Sundberg (1996), Robison & Babcock (2011) and other recent authors have maintained *Modocia* in the Marjumiidae.

Öpik’s (1967) placement of *Modocia* in the Solenopleuridae appears to have gone unnoticed except for the mention by Cooper et al. (1990). No North American or European authors have mentioned Öpik’s suggestion, and moreover, very few comparisons of Laurentian vs Acado-Baltic genera or species of the Ptychopariida, particularly Solenopleuridae/Ptychopariidae, have entered the literature. Rushton (1978) describing *Modocia anglica* from the *Agnostus pisiformis* Zone in Shropshire, England, and Rushton & Berg-Madsen (2002) in discussing *Agaso* are exceptions. Most North American authors appear to confine comparisons to the one biogeographical, Laurentian Faunal Province when dealing with these very standard ptychoparioid genera. It must be emphasised that Öpik’s (1967) assignment of *immodulata* to *Modocia* was by way of direct comparison with the type species which has small eyes situated well forward and anterior facial sutures converging forward of the palpebral lobes – features not shared with numerous species that are at present placed in *Modocia* and have long eyes situated well posteriorly and facial sutures diverging forward.

In diagnosing the Marjumiidae, Robison (1964, 1988) properly emphasised axial structures and temporal and geographical factors such that members can be demonstrated to belong in an evolutionary lineage that includes the nominate genus. However, due to the very basic axial structure of *Marjumia* Walcott, 1916 as a standard trilobite, many solenopleurid/ptychoparioid genera from many parts of the world can be accommodated within Robison’s morphological diagnosis of the family, including for example not only *Solenopleura* Angelin, 1854, *Parasolenopleura* Westergård, 1953, *Brunswickia* Howell, 1937, *Braintreella* Wheeler, 1942 and *Jincella* Šnajdr, 1957 from the Acado-Baltic Province, but also genera from Siberia (Fletcher, 2007, fig. 7), China, and other parts of the world. It must be concluded that inclusion into the family relied heavily on temporal and geographical factors. While this approach is commendable and advocated by numerous authors, e.g. Rasetti, 1948, 1972, there are many examples of virtually worldwide distribution and extra-provincial occurrences of a wide variety of Cambrian trilobites. Indeed, *Modocia anglica* Rushton, 1978 and *Modocia immodulata* Öpik, 1967 are such pertinent examples, as noted by Fortey (1997, p. O296). Should they be excluded from *Modocia* because of their geographic (but not temporal) remoteness from the Laurentian province where most species of *Modocia* occur? Rushton (1978, p. 250) discussed his identification of three polymerid trilobites from England as exotic to the European fauna and noted the exotic occurrence of East Gondwanan *Drepanura* in Sweden. Surely these examples and numerous others in the literature provide strong evidence to negate geography as a stand-alone family discriminator and heighten the need for better morphological family definition or, if that is not possible, broader family boundaries that are recognisable.

Until that is achieved, I share the uncertainties of earlier authors who were not prepared to assign *Modocia* to any existing family but here follow Öpik and Kobayashi in recognising the presence of Australian solenopleurids. It may well be the basal member of the Marjumidae in North America as suggested by Sundberg (1996), but its relationships, particularly to contemporary solenopleurids to which its type species bears close resemblance, remain unexplored. Whether there are such relationships, what they may be and what implications they have for family boundaries are beyond the scope of this paper.

The new Australian species described below is tentatively assigned to *Modocia* Walcott, 1924 by comparison with the type species and a return to Walcott's (1924, 1925) original diagnosis and by recognising the validity of Öpik's (1967) comparison of his *M. immodulata* with *M. oweni*. While it is not the intention in this paper to review the Laurentian content of *Modocia*, it is important to note that the Australian species are both placed by comparison with the type species and not by comparison with those several other North American species assigned to *Modocia* that have long eyes set posteriorly and close to the axis. Walcott (1925, p. 105) erected *Modocia* for species distinguished by: "The cranidium, however, differs in the direction of the facial sutures through the frontal border and the very broad fixed cheeks." Both Australian species, *immodulata* and *priva,* have:

(1) the facial sutures running directly forward or gently converging from the anterior of the palpebral lobe to the border and then turning sharply across the border at a low angle to the margin; and

(2) fixigenae equal to half the glabellar width at midlength of eye, i.e. the same proportion as in *M. oweni*.

Glabellar shape, short inconspicuous palpebral lobes situated well forward, very weakly impressed glabellar furrows, convex preglabellar field with an anterior border of the same length and overall proportions of the cranidia match extremely closely. As mentioned above, the Australian species match the type much more closely than several North American "marjumiid-like" species assigned to the genus that have anteriorly diverging facial sutures, long posteriorly situated palpebral lobes defined by well-impressed palpebral furrows.

Discrimination of northern hemisphere middle–upper Cambrian solenopleurid/ptychopariid genera remains unresolved and subject to a variety of different approaches from different authors. Attaining agreed generic concepts in this complex is outside the scope of the current paper, so the new species is assigned to *Modocia* based on its close comparison, discussed below, with *M. immodulata* Öpik, 1967, the geographically and temporally closest solenopleurid species.

Modocia priva sp. nov. (Figures 1, 2)
https://zoobank.org/E26F04ED-499E-4808-9526-3B01D550FF31

Material. Holotype, QMF59832, a dorsal exoskeleton, except for the missing left librigena; paratypes QMF59831–59838, all from QML1407, detailed above.

Etymology. *privus,* Latin, meaning 'alone, each or single' and referring to the rarity of any accompanying fauna.

Diagnosis. Member of *Modocia* with moderately convex cephalon, sloping slightly more steeply forward than laterally. Glabella anteriorly rounded, moderately convex; glabellar furrows barely perceptible (Figure 1J). Occipital ring with small central node (Figure 1I). Palpebral lobes short, at or just forward of cephalic mid-length, narrow, gently upturned laterally; ocular ridges low, indistinct (Figure 1J). Anterior branches of facial suture convergent at about 15° to sagittal line. Genal angles with short, sharp genal spine continuing the margin smoothly. Thorax of 12 segments, pleural tips weakly spinose. Pygidium with axis of four rings plus small terminus finishing forward of posterior margin; pleurae with well-impressed pleural furrows; border not defined. Very fine tubercular ornament on exoskeleton, most prominent as pair of tubercles on each pygidial ring symmetrical about sagittal line.

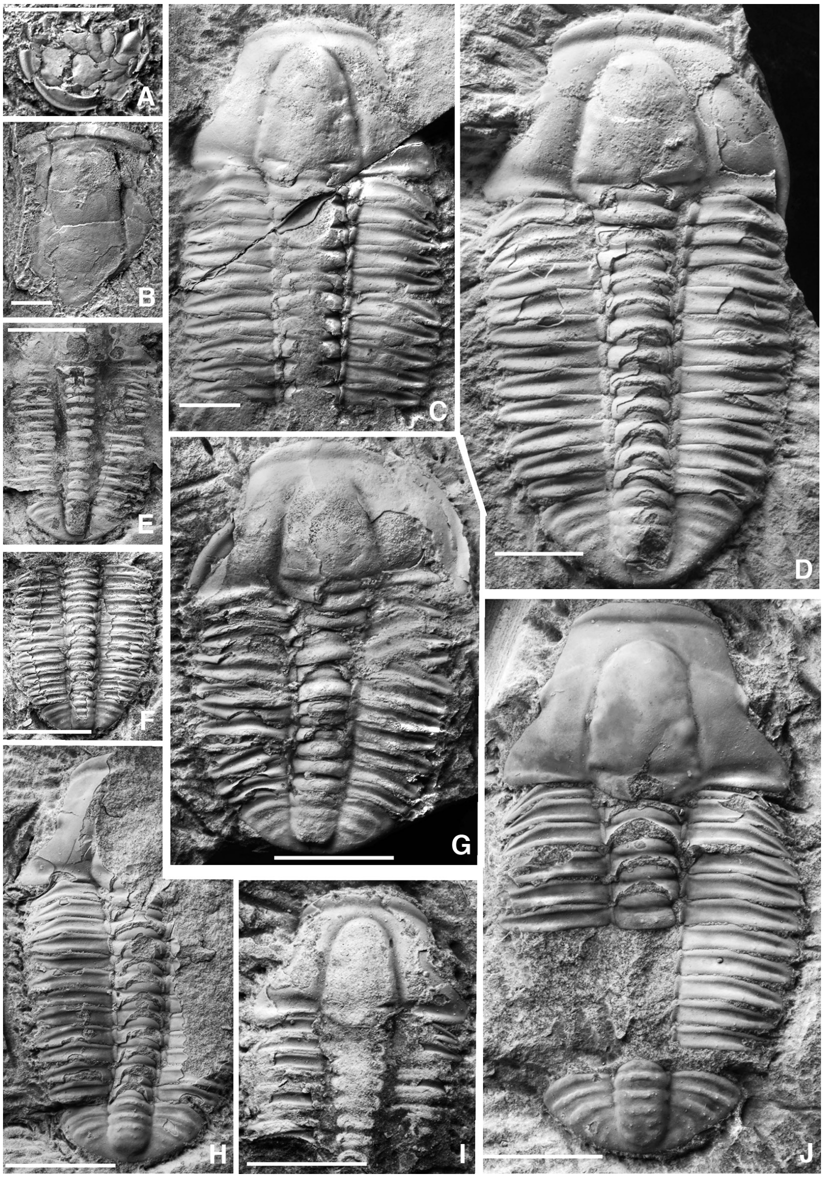

FIGURE 1. A, *Aristaluta gutta* Öpik, 1961, a bradoriid in lateral view, QMF59829. B, trilobite cranidium, *Amphoton bensoni* Öpik, 1961, QMF59830. C–J, *Modocia priva* sp. nov. C, QMF59831, large cranidium with incomplete thorax of 10 segments attached. D, QMF59832, holotype, exoskeleton missing left librigena. E, QMF59833, damaged exoskeleton showing thorax of 12 segments and transverse pygidium. F, QMF59834, thorax of 12 segments plus pygidium. G, QMF59835, exoskeleton with thorax partially dissociated and foreshortened. H, QMF59836, exoskeleton with damaged cranidium. I, QMF59837, poorly preserved cranidium with partial thorax attached. J, QMF59838, exoskeleton with damaged thorax. Scale bars in A, E, F, H, I = 5 mm; in B–D, G, J = 10 mm.

Description. Exoskeleton up to 35 mm long and 20 mm wide, moderately convex; cephalon about 30% overall length; pygidium less than 20% overall length; thorax of 12 segments. Exoskeletal surface smooth to very sparsely and finely tuberculate, more so on the pygidium.

Cranidium up to 13 mm long, 20 mm wide at rear and 13 mm across palpebral lobes. Anterior margin semicircular, evenly curved, with short genal spine continuing the curve; posterior margin straight. Glabella moderately convex, conical, with rounded anterior; axial furrows well impressed, straight and converging along sides of posterior half of glabella, then converging and curving forward into a rounded curve across the sagittal axis. Glabellar furrows in three pairs, very weakly impressed on external surface and absent on internal mould. Preglabellar furrow shallowing slightly across axis. Occipital ring mostly broken in available specimens; one (Figure 1I) shows a low medio-posterior tubercle and convex posterior margin. Occipital furrow transverse, shallowing across axis. Preglabellar field approximately equal in length to anterior border, gently downsloping to well-impressed border furrow. Anterior border on cranidium convex, of uniform length anterior to glabella but traversed by facial suture at low angle so that it tapers laterally to point where the facial suture turns sharply at posterior of the border. Ocular ridge weakly developed, very gently curved to anterior of palpebral lobe. Palpebral lobe short, narrow, situated forward of the glabellar mid-length, only very weakly upturned, poorly defined by shallow palpebral furrow. Anterior branch of facial suture slightly convergent to back of the anterior border, then strongly convergent across anterior border to reach margin where an anterior projection of the axial furrows would reach the margin (interpreted as indicating lateral extent of rostral plate). Posterior branch of facial suture sigmoidal, diverging weakly laterally; posterolateral limb long, narrow, downsloping lateral to fulcral point. Prominent fulcrum at posterior margin halfway between axial furrow and facial suture.

Librigena up to 5 mm wide, lateral margin curved and downward. Genal field gently convex. Border gently convex, of uniform width except anteriorly where the course of the facial suture across the anterior border produces a strong taper to a point in the librigenal border. Border furrow shallower than on cranidium.

Pygidium up to 8 mm long and 12 mm wide, subelliptical, moderately convex, with prominent anterior articulating half ring; anterior margin transverse from axial furrows to fulcral points, then curving weakly posteriorly lateral to the fulcral points; lateral and posterior margins in an even curve; border furrow and border not evident. Axis of four rings plus terminus no longer than each ring but reaching close to posterior margin, with pair of more prominent tubercles on each ring forming exsagittal column. Pleurae with three clear segments bearing distinct pleural furrows separated by interpleural indication, more by change of slope than by a furrow.

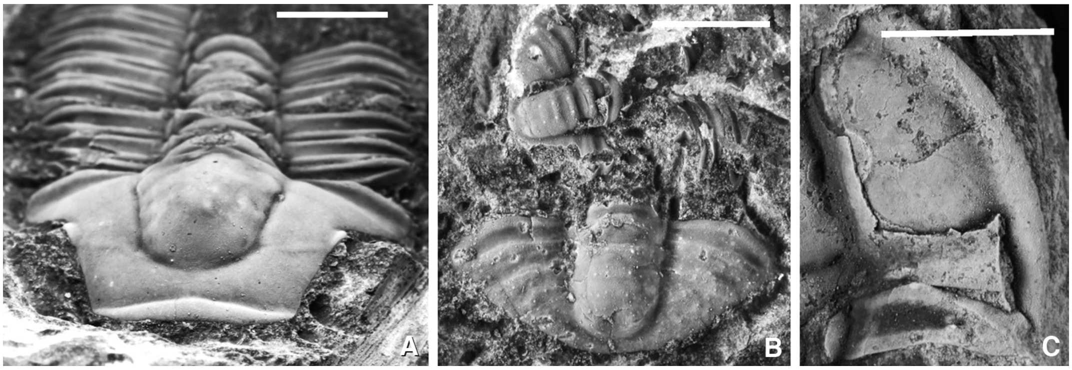

FIGURE 2. *Modocia priva* sp. nov. A, QMF59838, anterior view showing the moderate convexity of the cranidium. B, on back of QMF59838b, pygidia showing fine sparse tubercles. C, QMF59832, holotype, enlargement of right librigena showing continuous curve of margin onto the genal spine. Scale bars = 5 mm.

Comparison. *Modocia priva* sp. nov. is morphologically similar to several genera/species of the solenopleurid complex. One of the few demonstrably distinctive features of *M. priva* is its 12 thoracic segments. Species for which the full thorax is known are relatively few, and species with 12 segments could be considered rare; those I have been able to find are in three different genera, none of which is *Solenopleura*. They are *Cambroproteus lemdadensis* Geyer, 2015 from the *Ornamentaspis frequens* Zone (early middle Cambrian) of the Jbel Wawrmast Formation, in the western High Atlas Mountains, Morocco; *Nilegna sigmata* Öpik, 1967 from the *Glyptagnostus stolidotus* Zone, Georgina Limestone, western Queensland; *Modocia whiteleyi* Robison & Babcock, 2011 from the *Cedaria* Zone in the upper Weeks Formation, Utah; and *Modocia immodulata* Öpik, 1967 from middle–upper Cambrian passage Zone, Steamboat Sandstone, western Queensland. *Nilegna sigmata* has larger, more posteriorly placed palpebral lobes, closely spaced tubercular ornament, small, laterally deflected genal spines, wider interocular cheeks and short, falcate, pointed pleural tips in the thorax, all of which distinguish it from *M. priva*. The superficial similarity, in number of thoracic segments, very low convexity, glabellar shape and small palpebral lobes between the early middle Cambrian *C. lemdadensis* from Morocco and the early late Cambrian *M. immodulata* from Australia, exemplifies precisely the pitfall warned against by Rasetti (1972, p. 43). No relationship is inferred herein, except to note that they are among the rare species of Solenopleuridae with 12 thoracic segments. *Modocia whiteleyi* from Utah is temporally closer to *M. priva*, being from the *Cedaria* Zone younger in the Guzhangian, but it has much longer eyes set closer to the glabella and to the posterior, anterior limbs of the facial suture diverging forward, cephalic border furrow not impressed, quite different thoracic pleural furrows and broad re-entrant in the posterior pygidial margin. *Modocia priva* sp. nov. is similar to the only slightly younger (one zone) *M. immodulata* that occurs about 100 km to the south-west. However, Öpik (1967, p. 189) diagnosed his species as “a species without glabellar furrows, without ocular ridges, distinguished by its brim [preglabellar field] being longer than the rim [border], and by its subtriangular pygidium with weak pleural furrows”. *Modocia priva* has glabellar furrows, ocular ridges, its preglabellar field slightly shorter (sag.) than its border and transverse pygidium with well-impressed pleural furrows, so separating it at the species level. However, it would be difficult to justify separating them into different genera. Öpik (1967) only tentatively assigned *immodulata* to *Modocia*, and I here make assignment of *priva* similarly tentative. It is conceivable that if accurate generic discriminators are established, as so earnestly desired by most who have worked on solenopleurid and ptychopariid trilobites, these two Australian species may belong to an east Gondwanan genus, for which one discriminator may be possession of 12 thoracic segments.

Valid argument could be made for inclusion of the new species in a number of Acado-Baltic genera assigned to the Solenopleuridae based on comparison with particular species assigned across those several different genera. *Solenopleura*? *applanata* (Salter in Salter & Hicks, 1869) of Weidner & Nielsen (2015, fig. 50) from the *Ptychagnostus atavus* Zone on Bornholm, similarly dated *Jincella applanata* (Salter in Salter & Hicks, 1869) of Fletcher (2006, pl. 34. fig. 36), *Brunswickia* (*Jincella*) *applanata* of Fletcher (2007, fig. 7C–G) from the Manuels River Formation, Newfoundland in the “*Paradoxides hicksii*” Zone (=*Ptychagnostus atavus* Zone) and the two Siberian species of similar age, figured by Fletcher (2007, fig. 7I, J) are close in their short eyes, situated well forward, preglabellar field and anterior border of similar length, glabellar shape and pygidial features, but they have slightly wider fixigenae (cf. glabellar width) and curved facial sutures – but are these generic discriminators? Moreover, the significance of the temporal disparity is not yet understood; are these *atavus* Zone species long-ranging into the *Lejopyge laevigata* Zone or is it a case of convergent evolution well separated in time? *Parasolenopleura scanica* Westergård, 1953, pl. 6, figs 5, 6 from the *Ptychagnostus gibbus* Zone in Sweden is very close, differing, perhaps, only in the slightly longer preglabellar field (sag.) and smaller, more transverse pygidium. *Brunswickia robbii* (Hartt in Dawson, 1868) from the early middle Cambrian *Eccaparadoxides eteminicus* Zone in New Brunswick, Canada (Fletcher, 2005) is very similar in cranidial features despite the wide separation both temporally and geographically; only the length of the anterior border remaining uniform farther laterally, lack of glabellar furrows and more prominent eye ridges providing any morphological separation, and that could hardly be considered generically significant.

Other Australian Solenopleuridae

Despite the uncertainties of familial and generic placement of this new species, its overall morphology resembles most closely the Solenopleuridae. The new species is readily recognised as a standard ptychoparioid of the large complex of genera spread through the Solenopleuridae and Ptychopariidae and several families derived therefrom. Since no comparative marjumiids have been reported in Australia, a survey of Australian solenopleurids is provided here. Solenopleurid trilobites were first suggested as occurring in Australia by Kobayashi (1935, p. 265) who assigned early Cambrian *Conocephalites australis* Woodward, 1884 (Etheridge, 1898, 1919) and the synonymous *Ptychoparia howchini* Etheridge, 1898, to *Solenopleura*. Kobayashi (1942, p. 492) later recognised his error and designated *C. australis* as type species of a new genus, *Yorkella* (see Jell in Bengtson et al., 1990, p. 288).

Whitehouse (1939) erected *Asthenopsis* as a member of the Solenopleuridae; an action supported by Harrington et al. (1959, p. 275) and Öpik (1956, p. 19) who listed it as a subgenus of *Solenopleura*. Öpik (1967, p. 184) suggested that *Asthenopsis* could belong to either Solenopleuridae or Ptychopariidae, and Jell (1978) provided support for Ptychopariidae by introducing several species with glabellar anteriors more truncated than the conical shape in Solenopleuridae.

Solenopleura? *erista* Öpik, 1967 remains a questionable generic assignment, but nevertheless the only existing Australian taxon with this generic epithet. *Nilegna* Öpik 1967 (with type and only species *N. sigmata* Öpik, 1967) and *Modocia*? *immodulata* Öpik, 1967 were also described as western Queensland members of the Solenopleuridae.

In describing the solenopleurid *Changqingia chalcon* (Walcott, 1911) (as *Austrosinia chalcon*), Zhang & Jell (1987, pl. 40, figs 12–15) figured a cranidium and two pygidia of that species from a *Ptychagnostus punctuosus* Zone horizon in the Currant Bush Formation, 10 km west of Thorntonia station, northwestern Queensland. That pygidium is entirely different from that of the new species described above.

Solenopleuridae, gen. et sp. indet. of Jago (1980, pl. 1, figs 10–16) and *Menocephalites* (?) sp. of Jago & McNeill (1997, pl. 1, figs C, E, F) define the family's presence in Tasmania, but despite only dissociated exoskeletal elements being available, both taxa may be recognised as quite distinct from the species described above.

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Author Profile

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Addendum

Proceedings of The Royal Society of Queensland, *129*, 3–13. https://doi.org/10.53060/prsq.2021.1

A New Species of *Modocia* (Trilobita: Ptychoparioidea) in the Late Middle Cambrian (Guzhangian: Miaolingian) Devoncourt Limestone, Northwestern Queensland

Peter A. Jell[1]

Abstract

The Tasmanian species *Asthenopsis conandersoni* Bentley & Jago is recognised as closely related to *Modocia priva* Jell and transferred to *Modocia*, identifying a group of three Australian species (*immodulata* Öpik, *conandersoni*, *priva*) assignable to *Modocia*.

Keywords: trilobite, Solenopleuridae, *Modocia*, *Lejopyge laevigata* Zone

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Subsequent to the immediately preceding paper (Jell, 2021) being published online, I recognised a further Australian species of *Modocia*. Bentley & Jago (2014) erected *Asthenopsis conandersoni* Bentley & Jago, 2014 from the Christmas Hills of northwestern Tasmania as part of a moderately diverse fauna that includes the index species *Lejopyge laevigata* (Dalman, 1828), plus *Pianaspis sors* (Öpik, 1961) and *Centropleura phoenix* Öpik, 1961. These species occur with *Modocia priva* Jell, 2021 in the Guzhangian (*Lejopyge laevigata* Zone) Devoncourt Limestone, northwestern Queensland (Öpik, 1961). Bentley & Jago (2014) assigned exactly the same age to their Christmas Hills fauna with *Modocia conandersoni*.

Asthenopsis conandersoni Bentley & Jago, 2014 shares with *M. priva* a well-rounded glabella anterior (a solenopleurid rather than ptychopariid feature, though not definitive), small palpebral lobes situated anterior to the cranidial mid-length, 12 thoracic segments and a pygidium lacking a border furrow. In concert, these features place that species with *M. priva* in *Modocia* and not *Asthenopsis*. Bentley & Jago (2014) commented that their species differed from all other known species of *Asthenopsis* in possessing 12 thoracic segments rather than the 14 in *Asthenopsis*. Both Bentley & Jago (2014) and Jell (2021) regarded *Modocia*? *immodulata* Öpik, 1967 as a related species with 12 thoracic segments and with *Modocia priva* Jell, 2021 also possessing 12 thoracic segments, a group of three *Modocia* species (Figure 1) is identified occurring within two consecutive biozones in widely separated parts of Australia. *Modocia conandersoni* (Bentley & Jago, 2014) is distinct from *M. priva* in its longer (sag.) anterior border, more narrowly rounded glabella anterior, its thoracic fulcral line being closer to the axial furrow producing more extensive free thoracic pleurae and its lack of tuberculate ornament, particularly on the pygidial axis.

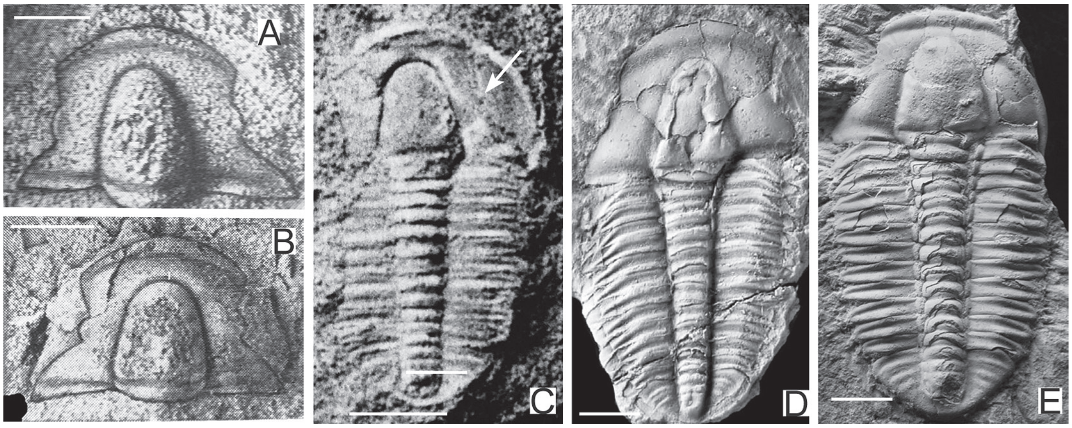

FIGURE 1. A, B, *Modocia oweni* (Meek & Hayden, 1861), exfoliated internal moulds of cranidia (B retains some exoskeleton), in dorsal view; from Walcott, 1924, pl. 16, figs 1 (USNM24581) and 3 (USNM1180), respectively; B is the holotype. C, *Modocia*? *immodulata* Öpik, 1967, CPC5388, incomplete exoskeleton in dorsal view, arrow indicates indistinctly preserved palpebral lobe, from Öpik, 1967, pl. 4, fig. 9 (© Commonwealth of Australia (Geoscience Australia) 2021, released under the Creative Commons Attribution 4.0 International Licence http://creativecommons.org/licenses/by/4.0/legalcode). D, *Modocia conandersoni* (Bentley & Jago, 2014), UTGD125577, incomplete exoskeleton in dorsal view (reproduced with permission from Bentley & Jago 2014, fig. 9G, AAP Memoir 45). E, *Modocia priva* Jell, 2021, QMF59832, incomplete exoskeleton in dorsal view, from Jell, 2021, fig. 1D. Scale bars = 10 mm.

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Ordovician Fauna in a Small Fault Block on the Yarrol Fault, South of Calliope, Central Queensland

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Abstract

Fossils, comprising sponge spicules, brachiopods, trilobites and assorted echinoderm plates, from a fault-bounded sliver along the Yarrol Fault 30 km south–south-east from the town of Calliope in central eastern Queensland, are described and illustrated for the first time. Due to their poor preservation, none of the fossils are identifiable to species level, but the trilobites, *Arthrorhachis* sp. and two pliomerid pygidia, belong to taxa not known outside the Ordovician, and *Illaenus* sp. compares closest with Middle Ordovician members of the genus. The brachiopods – including orthoids (?*Phaceloorthis* among others), plectambonitoids (*Sericoidea*), the protorthide *Skenidioides* and a siphonotretide – resemble forms previously described from the Late Ordovician (Katian) of central New South Wales and indicate an open marine deep-water habitat (120–200 m depth). This assemblage is significant in representing the first Ordovician fauna (and the oldest fossils) documented from the New England Orogen in Queensland. The tectonic implications of this confirmed Ordovician sedimentary succession within the New England Orogen in central Queensland are yet to be fully appreciated, but it does complement similarly aged successions occurring along the Peel Fault in the southern New England Orogen. Together these tiny fault blocks suggest that the island arc or arcs which developed during the early Palaeozoic were incorporated into the New England Orogen during the middle Palaeozoic, both in its northern part as well as in the south.

Keywords: Ordovician, shelly fossils, fault block, New England Orogen, Yarrol Fault

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Introduction

Eastern Australia has been thoroughly investigated by many geologists in the last 200 years and found to have had a structurally complex early Palaeozoic history (540–440 mya) made more difficult to interpret by later Palaeozoic (440–250 mya) orogenic events and the long period of weathering that has followed up to the present (Fergusson & Henderson, 2015; Glen, 2005). In Victoria, fossiliferous Cambrian rocks are sparsely represented, whereas Ordovician rocks, predominantly characterised by rich graptolite faunas, are widely distributed throughout the Lachlan Orogen, with rare occurrences of earliest and latest Ordovician shelly faunas at Waratah Bay and Deep Creek, respectively (Birch, 2003). Further north in eastern New South Wales, Cambrian fossils are only known from two isolated localities, one on the south coast and the other in the Tamworth–Nundle district in the New England Orogen (Packham, 1969; Percival et al., 2011). Ordovician faunas are widespread in the Lachlan Orogen in central and southern New South Wales where a complete spectrum of water depths from basinal cherts through open marine graptolitic shales to shallow water limestones with abundant shelly fossils fringing volcanic islands have been interpreted (Percival et al., 2011 and references therein). Ordovician fossiliferous rocks are also known from the Narooma Terrane on the south coast, and in parts of the southern New England Orogen adjacent to the Peel Fault near Tamworth and in the Port Macquarie area (Percival et al., 2011). However, in eastern Queensland, Cambrian fossils are yet to be discovered and fossiliferous Ordovician rocks are known only from the Broken River Province of the Mossman Orogen (Withnall & Lang, 1993; Dixon & Jell, 2012; Zhen et al., 2015), Charters Towers Province south-west of Townsville (Henderson, 1983) and the Fork Lagoons Subprovince of the Anakie Province (Fergusson & Withnall, 2012; Palmieri, 1978), both the latter in the Thomson Orogen. This paper identifies age constraints, based on palaeontological evidence, for the reported Ordovician age (Blake, 2013) of a small fault block on the Yarrol Fault about 30 km south–south-east of Calliope in central Queensland. Its significance is that, in contrast with the other Queensland Ordovician faunas just mentioned, it occurs within the New England Orogen (Murray et al., 2012).

Geological Setting

The New England Orogen is a major meridionally oriented tectonic feature in eastern Australia, exposed over 1500 km from the Hunter River Valley of New South Wales through central eastern Queensland as far north as Bowen (Glen, 2013; Donchak et al., 2013). Its depositional history is well represented by Silurian to Triassic age rocks. Rare outcrops of Cambrian and Ordovician strata are confined to fault blocks adjacent to major faults near Tamworth, northern New South Wales, and in central eastern Queensland near Calliope; the latter is the subject of this paper. Other Ordovician sedimentary rocks, as mentioned above, are known from scattered occurrences in the Thomson and Mossman orogens in central and north-eastern Queensland. Allochthonous Ordovician blocks and clasts are also present in younger (Silurian and Devonian) deposits, suggesting that Cambrian and Ordovician strata were widely distributed in the region prior to their erosion, redeposition and tectonic upheaval.

The relative rarity of lower Palaeozoic rocks, and fossil evidence of their ages, in the New England Orogen provides impetus for documentation of poorly known or new occurrences. In this contribution we describe trilobites and brachiopods from an infaulted block adjacent to the Yarrol Fault, on the ‘Santa Glen’ property 30 km south–south-east of the town of Calliope in the northern part of the exposed New England Orogen, central eastern Queensland. During regional field mapping of the New England Orogen in central Queensland by the Geological Survey of Queensland, Paul Blake discovered a fossiliferous horizon in a roadside channel on a station track at 24°14′17″S, 151°18′52″E, about one kilometre north-west of the Santa Glen homestead (Figure 1). He sent two samples to one of us (PAJ) for identification. One of these specimens had a cluster of large monaxon spicules, and the other was an articulated, badly damaged, pliomerid trilobite. On two subsequent occasions the senior author has spent hours collecting on the site, and the fauna described here is the result of that search. This locality was first mentioned in the literature (see Blake in Murray et al., 2012, p. 9; Blake, 2013, p. 311) as having Ordovician fossils of two different ages, but the fauna has not previously been illustrated or discussed in detail. The occurrence is of considerable significance in representing the sole known Ordovician fauna in the northern New England Orogen, and supports informed biostratigraphic correlation with the limited Ordovician sedimentary rocks previously recognised from the adjacent Thomson Orogen in central Queensland.

Blake (2013) also reported conodont-bearing limestones at two separate sites in the area. These conodonts have been briefly commented on and accorded Ordovician ages by Fordham (2012, table 1), but the identification and description of the conodonts from either site have not been published. One of the sites is interbedded in the same succession as the shelly fossils described herein, whereas the other, near the Santa Glen homestead, is a reworked boulder from a conglomerate that also contains Devonian clasts.

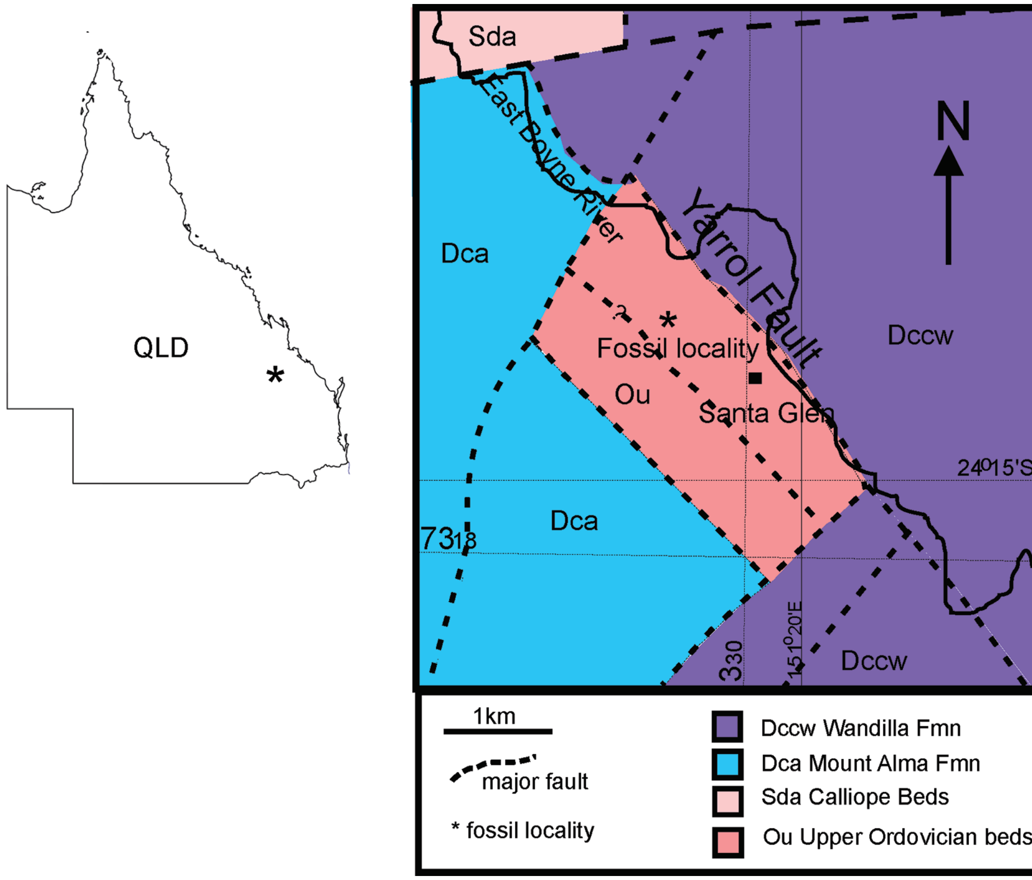

FIGURE 1. Locality map, showing the collection site relative to Santa Glen, the Yarrol Fault and surrounding geology. Redrawn from the 2001, 1st ed., Calliope 1:100,000 Geological Sheet (9149), Queensland Department of Natural Resources and Mines.

Although its boundaries are unclear due to poor outcrop, the succession containing the fossils described herein is interpreted as coming from a small fault-bounded sliver between other fault blocks of the Calliope beds (Murray et al., 2012) and bounded to the east by the regionally significant Yarrol Fault. The fault block is mapped on the Calliope 1:100,000 geological map published by the Queensland Department of Natural Resources and Mines in 2001. Within this fault block is a succession of well-sorted, fine- to medium-grained and thin-bedded volcaniclastic siltstone, sandstone and conglomerate sourced from basaltic to andesitic lavas and with minor interbedded conodont-bearing limestone. The volcaniclastic sedimentary rocks are well-sorted and the clasts are well-rounded. One of the fine-grained, siliceous siltstone units contains the sponges, brachiopods and trilobites, and a single limestone horizon yielded a meagre conodont fauna dated as Floian (late Early Ordovician) by Fordham (2012), though no identifications nor illustrations of the conodonts were given. Detailed description of the fault block is provided by Murray et al. (2012).

Limestone from a site near the Santa Glen homestead yielded an abundant and diverse Late Ordovician conodont fauna, not identified but reported to be comparable with eastern Australian faunas of that age (Fordham, 2012). This limestone block comes from a conglomerate that also contains Devonian limestone clasts and is interpreted as part of the Calliope beds and not part of the Ordovician fault block.

Geological Significance

The extensive compilation of the geological history of eastern Australia, termed the Tasmanides (Glen, 2005), though modified in some details in recent years, provides a background for the significance of the fauna described herein. In eastern Australia several major accretionary orogenic events have been interpreted along the eastern margin of Gondwana during the Palaeozoic (Glen, 2005; Fergusson & Henderson, 2015; Jessop et al., 2019). The older Delamerian, Lachlan and Thomson orogens to the west of the New England Orogen all have Cambrian and Ordovician histories. However, the younger, more easterly New England Orogen has very few clues to its Cambrian or Ordovician history in New South Wales (Glen, 2005, fig. 4b) and none at all in Queensland (Glen, 2005, fig. 4c). Discovery of this Ordovician fault block provides the first clues to the earlier geological history of the orogen in Queensland. Although unique, and much older than any other sedimentary units in the Queensland part of the New England Orogen, possible correlatives of these rocks may be found in Cambrian to Ordovician fault blocks along the Peel Fault near Tamworth in the southern New England Orogen (Packham, 1969; Cawood, 1976). The Peel Fault in New South Wales has been interpreted as an extension of the Yarrol Fault in Queensland, though interrupted by the Texas and Coffs Harbour oroclinal structures in the central New England Orogen (Donchak et al., 2013, figs 5.1, 5.2).

Numerous late Silurian to Middle Devonian fault blocks in the Yarrol Province of central eastern Queensland have igneous rocks that are chemically comparable to those of modern island arcs and are interpreted as being remnants of an island arc setting (Murray et al., 2012). The possibility of earlier, island arc development is now raised by the discovery of this very small fault block rich in volcanogenic sediments, and herein reliably dated as Ordovician.

Systematic Palaeontology

Phylum PORIFERA

Monaxon spicules indet. (Figure 2)

Material. QMF60314, QMF60315.

Description. The spicules are straight, circular in cross-section, and taper to a sharply pointed tip in all observed terminations. The largest spicule available is 15 mm long and 0.5 mm in diameter. Whether the twisted tuft of finer, apparently shorter elongate elements or spicules (Figure 2C) is part of a sponge body or a root mass is not certain.

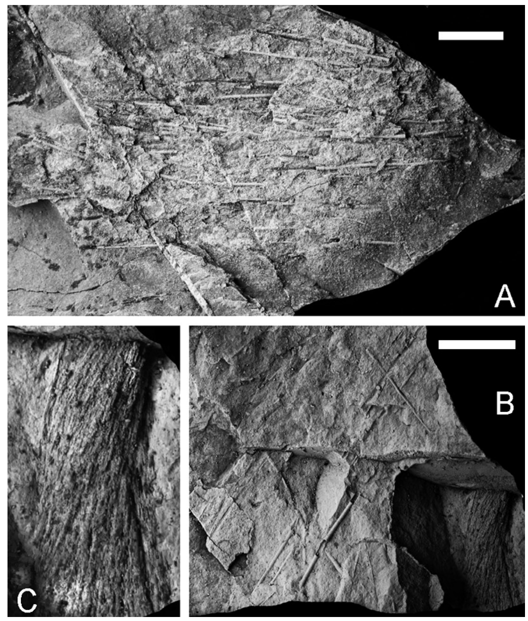

FIGURE 2. Monaxon sponge spicules indet.
A, QMF60314, mass of large long spicules aligned subparallel to each other and preserved as silica. B, QMF60315, few widely separated spicules with some at high angle. C, enlargement of tuft of much finer spicules in lower right in B. Scale bars = 5 mm.

Remarks. The paucity of available specimens and their less than ideal preservation allow two possible interpretations for these spicule assemblages.

An Ordovician (Darriwilian) sponge fauna from Wales (Botting, 2005) includes a species of *Pyritonema* McCoy, 1850 that bears resemblance to our Queensland material. Botting (2005) erected the Pyritonemidae as a monogeneric family for *Pyritonema*. Without entering into any issues of sponge classification, we note that his familial diagnosis would admit our Queensland material, his generic diagnosis less so. In our material large spicules generally isolated and probably dislodged from the skeleton (Figure 2A,B) are an order of magnitude larger than those in a twisted tuft (Figure 2C) that might easily be interpreted as a root tuft. However, the Welsh material shows a similar size range (Botting, 2005, fig. 14D,H) within the body of the sponge.

Alternatively, these spicules may be assigned to the Protomonaxonida Finks & Rigby, 2004, which is characterised as having "fibrous skeletons composed only of oxeas" (Finks & Rigby, 2004, p. 9) and to the Ascospongiae Botting, 2021, a new name for part of the polyphyletic Protomonaxonida. Most known members of the class occur in the Cambrian, but a post-Cambrian Australian representative is *Musaspongia amnicola* Jell & Cook, 2011, from the Lower Devonian of Victoria. Several authors have inferred close relationships between protomonaxonids and various sponge taxa throughout the geological column (Botting et al., 2013). The assemblage of spicules (Figure 2A) is very reminiscent of the illustration of *Halichondrites elissa* Walcott, 1920 (see Finks & Rigby, 2004, fig. 13) from the Middle Cambrian Burgess Shale, which genus was noted by Botting & Muir (2018, p. 12) as representing "… more derived parts of this lineage include *Halichondrites* …". Post-Cambrian relatives might, therefore, be expected.

Although it is tempting to assign our Queensland material to the Pyritonemidae, because its Welsh occurrence is in similar volcanogenic sediments and matches approximately the age we infer for our collecting site, we remain open-minded given the poor quality of our material and the difficulty of interpreting this type of specimen within current poriferan classification. These spicules offer little information on age but are recorded to illustrate the presence of sponges in the fauna.

Phylum BRACHIOPODA
Class LINGULATA Gorjansky & Popov, 1985
Order SIPHONOTRETIDA Kuhn, 1949
Family SIPHONOTRETIDAE Kutorga, 1848

Siphonotretid indet. (Figures 3A, 4E)

Material. QMF60316, external mould of a ?dorsal valve and QMF60349, fragment of an external mould (valve indeterminate).

Description. Ornamentation consists of radial ribs intersecting strong concentric lamellae that apparently bear small remnants of spine bases (particularly on the two most anterior lamellae of the specimen in Figure 3A).

Remarks. Although these external moulds are difficult to identify because internal features are not preserved and no ventral valve is definitely known, the ornamentation is distinctive and supports assignment to the Siphonotretidae. Comparable specimens dissolved from limestone of Katian age have been described from the Broken River Province, north Queensland. In such specimens, identified as *Nushbiella* Popov in Kolobova & Popov, 1986 (see Zhen et al., 2015, fig. 18d,e), the external surface is badly eroded and only tiny spine bases are preserved, similar in appearance to those figured here.

Class STROPHOMENATA Williams, Carlson, Brunton, Holmer & Popov, 1996
Order STROPHOMENIDA Öpik, 1934
Superfamily PLECTAMBONITOIDEA Jones, 1928
Family XENAMBONITIDAE Cooper, 1956
Subfamily AEGIROMENINAE Havlíček, 1961

Sericoidea Lindström, 1953

Type Species. *Leptaena sericea* J. de C. Sowerby var. *restricta* Hadding, 1913 from the Sularp Shale (Sandbian), Fågelsång, Sweden; by original designation.

Remarks. In an extensive review of all known species, Candela (2011) clearly distinguished *Sericoidea* from *Chonetoidea* Jones, 1928, with which the former had been synonymised by Cocks & Rong (2000). *Sericoidea* is restricted to rocks of Late Ordovician age, ranging from the lower Sandbian to middle Katian. It has a widespread distribution, having been described from Australia (New South Wales), USA (Virginia, Tennessee), Ireland, Scotland, Wales, Norway and Sweden. Two species are known from New South Wales, *S. sejuncta* Percival, 1979 and *S. minor* Percival, 1979, which are contemporaneous and confined to the middle Katian. They represent the youngest known species of *Sericoidea*.

Wherever it occurs, *Sericoidea* is restricted to deeper water clastic sediments as deep as Benthic Association (BA) 5. In his review of the genus, Candela (2011) analysed all known occurrences and determined a bathymetric window ranging from 120 m to over 200 m water depth. Thus, recognition of *Sericoidea* in the faunal assemblage from south of Calliope is very significant in not only constraining the age of the fauna but also assisting in interpretation of its likely depositional environment.

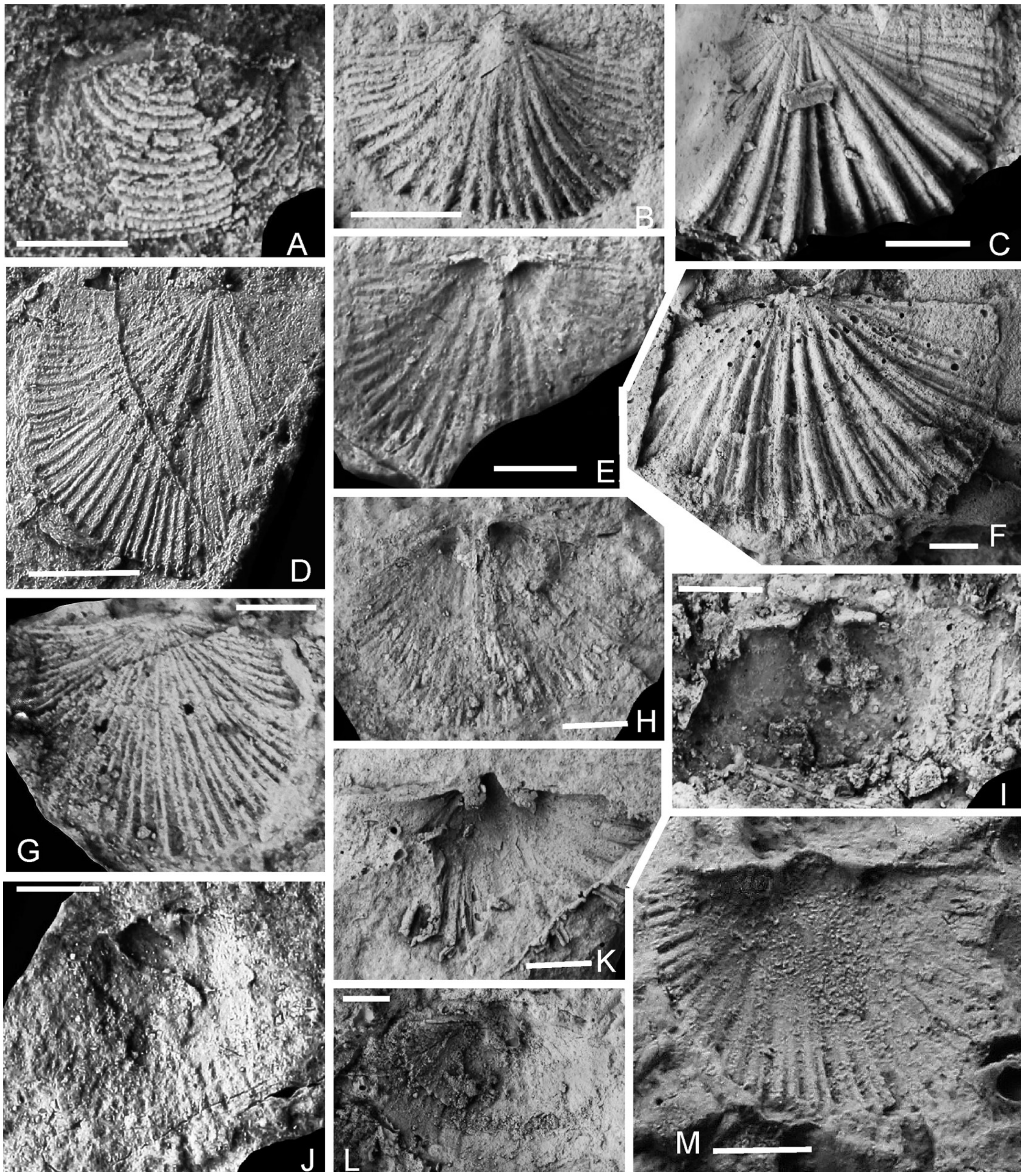

FIGURE 3. Brachiopods. A, QMF60316, Siphonotretidae indet., dorsal valve, internal mould. B, D, E, G, H, J, Orthide indet., QMF60317, latex cast from external mould of ventral valve: D, QMF60319, latex cast from external mould of dorsal valve; E, QMF60320, latex cast from internal mould of dorsal valve; G, QMF60322, latex cast from external mould of dorsal valve; H, QMF60323, latex cast from internal mould of dorsal valve; J, QMF60325, latex cast from internal mould of ventral valve. C, F, K, M, ?*Phaceloorthis* sp.: C, QMF60318, latex cast from external mould of dorsal valve; F, QMF60321, latex cast from external mould of ventral valve; K, QMF60326, latex cast from internal mould of ventral valve; M, QMF60328, latex cast from internal mould of ventral valve; I, L, Plectambonitid indet.; I, QMF60324, latex cast from internal mould of ventral valve; L, QMF60327, latex cast from internal mould of ventral valve. Scale bars = 1 mm.

Sericoidea sp. (Figure 4A–D)

Material. QMF60346–60348, three ventral valves.

Description. The three specimens are planar to very low convexity, thin shelled, diminutive, 2–3 mm long, 4–5 mm wide at hinge. Ornament sparsely finely costellate with additional costellae interpolated peripherally. Internal details poorly preserved on the sole available specimen (Figure 4C,D); muscle field bounded by a short divergent ridge extending from the hinge line; no myophragm apparent (although that may be due to inadequate preservation given the variability of the lithology).

Remarks. Lack of corresponding dorsal valves precludes meaningful comparison with other species of *Sericoidea*, particularly those known from the Macquarie Arc of central New South Wales.

Family LEPTELLINIDAE Ulrich & Cooper, 1936

?Leptellinid indet. (Figure 4F)

Material. QMF60350, internal mould of a ventral valve. Fortuitously preserved on the surface of this mould is a micromorphic (possibly juvenile) ventral valve.

Description. The larger ventral valve is strongly convex medially and flattened posterolaterally; transverse in outline, widest at the hinge line with width estimated at 10.2 mm, length 6 mm. Suggestion of a shallow anteromedian sulcus. Shell material presumably of moderate thickness as the external ornament is not reflected on the valve interior. Muscle field comparatively small and confined posteromedially. No obvious mantle canal impressions are preserved. Details of delthyrium obscured by matrix.

The micromorphic ventral valve (Figure 4F) may also represent a leptellinid. It is very slightly convex in profile, with a similar transverse outline to the valve in which it lies. Apart from a tiny, deeply incised muscle field confined to the delthryrial cavity, there are no obvious internal features of note.

Family PLECTAMBONITIDAE Jones, 1928

?Plectambonitid indet. (Figure 3I,L)

Material. QMF60324, 60327 both latex casts from internal moulds of ventral valves.

Description. One specimen (Figure 3L) shows a faint subperipheral rim and a short, low posteromedian platform supporting the muscle field. The other (Figure 3I) is more poorly preserved but also seems to display these features, together with an open delthyrium.

Remarks. The plectambonitoid *Taphrodonta* Cooper, 1956 is among several broadly related Ordovician genera that develop a subperipheral rim in the ventral valve and exhibit a rudimentary muscle field platform. In view of the lack of associated dorsal valves, further comparison is unwarranted and the Calliope material remains indeterminate.

Class RHYNCHONELLATA Williams, Carlson, Brunton, Holmer & Popov, 1996
Order PROTORTHIDA Williams & Harper, 2000
Family SKENIDIIDAE Kozlowski, 1929

Skenidioides Schuchert & Cooper, 1931

Type species. *Skenidioides billingsi* Schuchert & Cooper, 1931 from the Caradocian in Quebec; by original designation.

Remarks. *Skenidioides* is a long-ranging (Middle Ordovician–Early Devonian) genus with a cosmopolitan distribution. Most species are relatively small, widest at the hinge line and markedly transverse in outline with a planoconvex profile, often characterised by a median dorsal sulcus, and bear costellate ornamentation.

Skenidioides sp. indet. (Figure 4G–I)

Material. One dorsal valve internal mould (QMF60351) and two external moulds of a ventral valve (QMF60353) and dorsal valve (QMF60352).

Description. The internal mould, though not well-preserved, shows what appears to be a very small notothyrial platform restricted to the posterior extremity of the dorsal valve. Neither a cardinal process nor a narrow median septum is evident, though a broad median ridge is present. Externally, what is presumed to be a juvenile ventral valve bears an accentuated median rib. The external mould of the dorsal valve displays fine growth lamellae crossed by closely spaced fine costellae.

Remarks. Similar ornamentation characterises the only species of *Skenidioides*, *S. quondongensis* Percival, 1991, to be described from the Late Ordovician (Katian) limestones of the Macquarie Arc of central New South Wales. The type material of *S. quondongensis* is silicified and hence relatively well preserved, displaying features of the cardinalia and median septum that are not evident in the specimens from central Queensland.

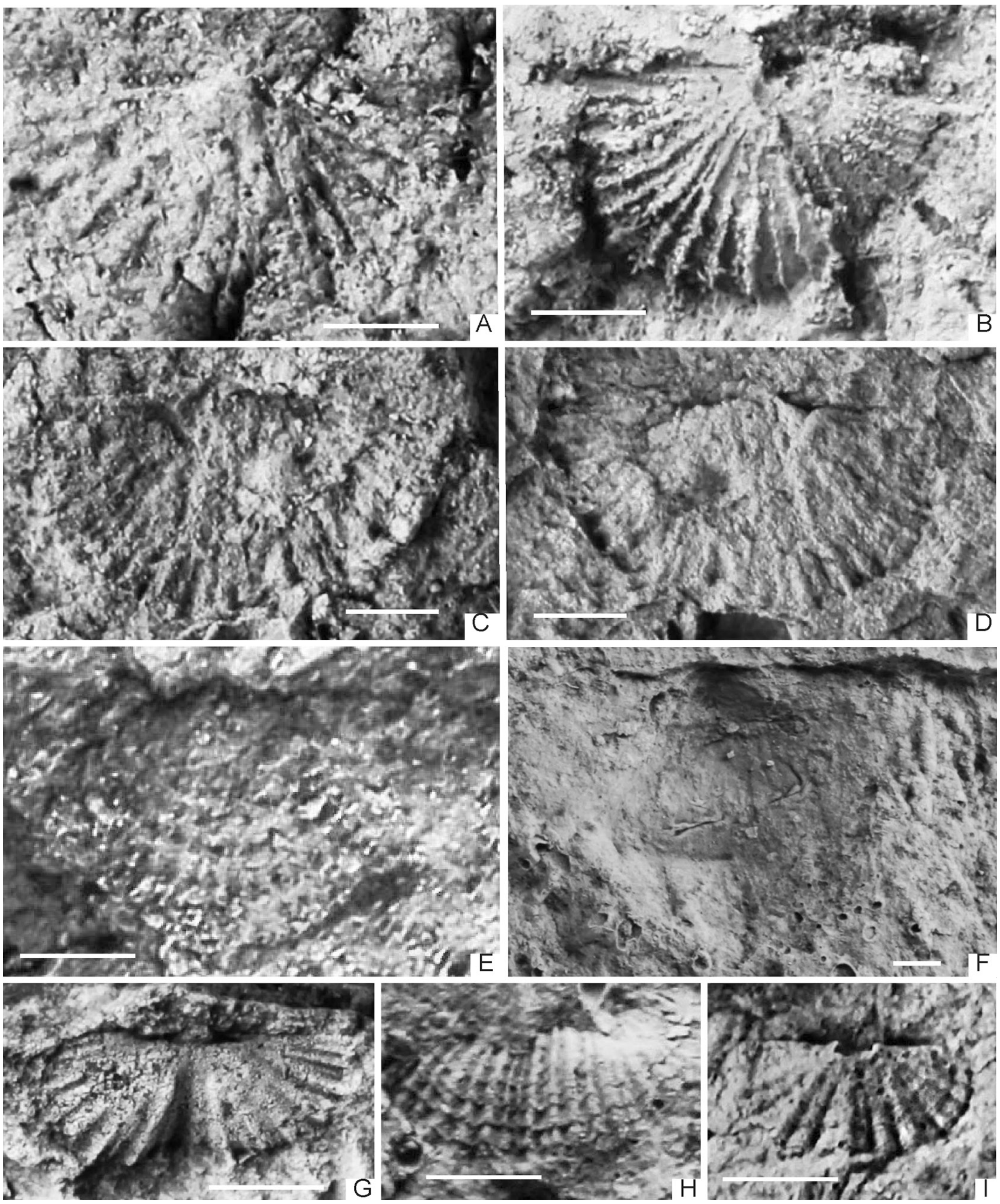

FIGURE 4. Brachiopods. A–D, *Sericoidea* sp.: A, QMF60346, latex replica from external mould of ventral valve, probably juvenile; B, QMF60347, latex replica from external mould of ventral valve; C, D, QMF60348, latex replica and internal mould of ventral valve; E, Siphonotretid indet. QMF60349, latex replica of external mould, valve indeterminate; F, ?Leptellinid indet. QMF60350, latex replica of internal mould of ventral valve. Note micromorphic ventral valve internal impressed on inner surface of valve. G–I, *Skenidioides* sp.: G, QMF60351, internal mould of dorsal valve; H, QMF60352, latex replica of external mould of dorsal valve; I, QMF60353, latex replica of external mould of ventral valve, probably a juvenile. Scale bars = 1 mm.

Order ORTHIDA Schuchert & Cooper, 1932
Superfamily PLECTORTHOIDEA Schuchert & LeVene, 1929
Family GIRALDIELLIDAE Williams & Harper, 2000

Phaceloorthis Percival, 1991

Type species. *Phaceloorthis decoris* Percival, 1991 from the Katian Quondong Limestone, in the Macquarie Arc, central New South Wales; by original designation.

Remarks. Originally assigned to the Plectorthidae by Percival (1991), *Phaceloorthis* was provisionally classified as belonging to the Giraldiellidae established by Williams & Harper (2000), with the qualification that it is more closely related to the stem group of both the Giraldiellidae and Plectorthidae. A fascicostellate (bundled) ornamentation is characteristic of several genera of the Giraldiellidae, but the robust shell that distinguishes *Phaceloorthis* from other members of that family is very distinct and is most similar to shell fragments preserved in the fault block on the Yarrol Fault.

?Phaceloorthis sp. (Figure 3C,F,?K,?M)

Material. QMF60318, 60321, both external moulds of fragmentary dorsal and ventral valves, respectively. Tentatively assigned: QMF60326 (Figure 3K) and QMF60328 (Figure 3M), both ventral valve internal moulds.

Description. Shell fragments of robust valves with coarse fascicostellate external ornament, including a dorsal valve of low convexity with a slight median sulcus (Figure 3C) and a specimen interpreted as a ventral valve because of its greater overall convexity (Figure 3F).

Remarks. Two internal moulds of ventral valves may possibly be related to the exteriors described above, based on the internal reflections of the coarse fascicostellate ornament that become more accentuated towards the periphery of these valves (Figure 3K,M). The shell material appears to be quite robust. The teeth in both specimens are stout (though not so well shown in Figure 3M due to the orientation of the hinge line) and supported on thin plates reaching the valve floor. These plates laterally delimit the muscle field which extends anteriorly for a short distance, estimated at no more than one-quarter of valve length. The only problem in attributing both these ventral valve interiors to ?*Phaceloorthis* is the delthyrium, which is open in Figure 3K (typical of *Phaceloorthis*) but apparently covered in part by a convex plate shown in Figure 3M. Closer examination of the latex mould at different orientations and lighting suggests in fact that this convex plate is likely an artefact of the process of replicating the specimen.

No corresponding valve interiors are currently known from this locality, and hence the genus identification, although likely, is tentative.

Orthide indet. (Figure 3B,D,E,G,H,J; Figure 5A–C)

Material. QMF60317, 60319, 60320, 60322, 60323, 60325, 60354–60356.

Description. Valves with flattened ventribiconvex profile, dorsal valve bearing shallow and narrow median sulcus confined posteromedially; outline equidimensional but modified by broadly arcuate anterior margin; maximum width up to 7–8 mm at about midlength, only slightly greater than hinge width; hinge line straight with beak of ventral valve only projecting posteriorly in smallest specimens; ornament finely costellate, with additional costellae intercalated in anterior and anterolateral part of larger specimens; costellae predominantly straight except where recurved posterolaterally to become parallel to hinge line.

Ventral interior (Figures 3J, 5A): Muscle field extends to between one-quarter and one-fifth valve length, largely confined to shallow delthyrial cavity, bounded anteriorly by very low, curved ridge. No other details distinct.

Dorsal interior (Figure 3E,H): Cardinalia consist of a delicate ridgelike cardinal process flanked by and separate from small flared crural plates; cardinal process continuous with a very weak median septum extending to about mid-length. Adductor muscle scars apparently long, shallowly impressed adjacent to median septum. Mantle canal impressions not observed.

Remarks. This is the most common brachiopod in the faunal assemblage, and one of the largest. The shell is thin, with impressions of even the fine costellae visible on the internal surface of valves. No punctae are evident, although the preservation would not necessarily preserve such fine features if they were in fact present. There are no distinctive features that suggest a particular orthoid family, although the overall morphology (particularly the simple cardinal process) is consistent with that group.

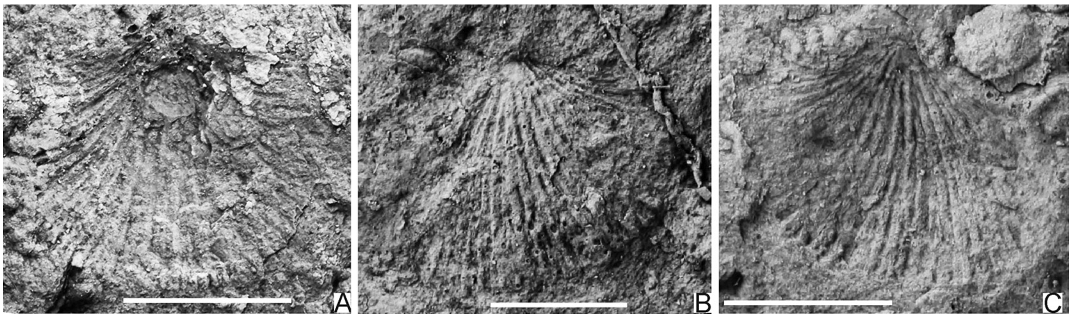

FIGURE 5. Brachiopods. A–C, Orthide indet.: A, QMF60354, internal mould of ventral valve; B, QMF60355, latex replica of ventral? valve external mould; C, QMF60356, latex replica of ventral valve external mould. Scale bars = 1 mm.

Phylum ARTHROPODA
Class TRILOBITA
Suborder AGNOSTINA Salter, 1864
Family METAGNOSTIDAE Jaekel, 1909

Arthrorhachis Hawle & Corda, 1847

Type Species. *Battus tardus* Barrande, 1846, by monotypy.

Remarks. Boundaries between Ordovician agnostid genera are difficult to define, and regular reshuffling of species by different authors is apparent (Nielsen, 1997). Generic discriminators often seem more reasonable as species discriminators, perhaps being attached to genera because the name is available and it is simpler to try to justify the name than to convince all readers of a synonymy. It is beyond the purpose of this paper to assess these generic taxa, so our assignment is made purely on the basis of comparison with previously named species and their current generic placement.

Arthrorhachis sp. (Figure 6A)

Material. QMF60335, an external mould of a cranidium.

Description. Cranidium 2 mm long by 1.5 mm wide. Border and border furrow approximately same length (sag.); border tapering in posterior half of cranidium. Glabella parallel-sided, with broadly rounded anterior, without transverse furrows, about 70 per cent cranidial length. Basal lobes present but indistinct.

Remarks. The single cranidium available is assigned to *Arthrorhachis* by comparison with Swedish specimens of the type species (Ahlberg, 1989, fig. 2). Note that our specimen figured here is a latex cast from an external mould so features of the inner surface of the exoskeleton, seen on internal moulds, are not available. Ahlberg's (1989, fig. 2E) illustrated specimen appears identical with our specimen, but because we have only one cranidium and no pygidia we leave the specimen in open nomenclature.

Suborder ILLAENINA Jaanusson in Harrington et al., 1959
Family ILLAENIDAE Hawle & Corda, 1847

Illaenus Dalman, 1827

Type Species. *Entomostracites crassicauda* Wahlenberg, 1818; by subsequent designation of Miller, 1889.

Remarks. Although effaced trilobites are notoriously hard to classify, and despite the poor state of preservation of the limited exoskeletal parts illustrated herein, we do make generic assignment based on close comparison with *Illaenus sinensis* Yabe in Yabe & Hayasaka, 1920 from the Middle Ordovician of China (see Lu, 1975, pl. 31, fig. 6; Zhou et al., 1998, pl. 6) and the co-occurring *I. cekovioides* Zhou, Z. Y., Yin & Zhou, Z. Q., 2014 (see Zhou et al. 2014, fig. 14). Zhou et al. (2014) assigned these species to Jaanusson's (1957) *Illaenus sarsi* Species Group based, principally, on the bicuspid anterior margin of the pygidial doublure. This part of the exoskeleton (i.e. the abmarginal edge of the pygidial doublure) is not evident on these Queensland specimens. The rounded genal angle, short, narrow pygidial axis, nature of the pygidial facet, along with overall shape and convexity, coincide closely with these Chinese species.

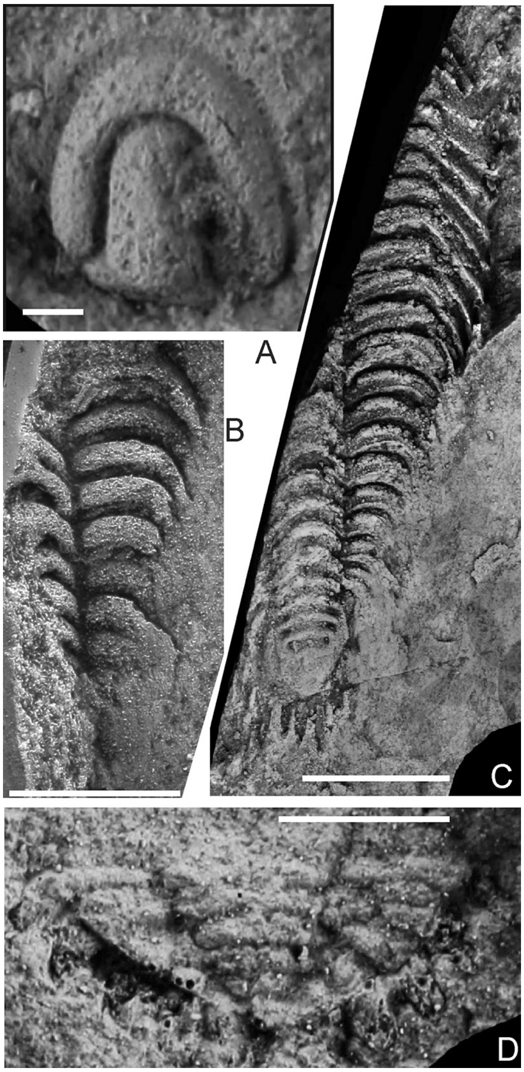

FIGURE 6. Trilobites. A, *Arthrorhachis* sp., QMF60335, latex cast of cranidium. Scale bar = 1 mm. B, C, Pliomerid indet. 1. QMF60336: B, latex cast from external mould from part of thorax in C; C, internal mould of incomplete thoracopygon showing pygidium plus partial thorax with more than 12 segments. D, Pliomerid indet. 2. QMF60337, pygidium, latex cast from external mould. Scale bars = 5 mm.

Illaenus sp. (Figure 7B–H)

Material. QMF60330–60334, one badly damaged librigena and five pygidia.

Description. Librigena with smooth lateral margin and rounded genal angle lacking any genal spine or sharp angle; eye relatively small, with steep eye socle.

Pygidium smooth, gently convex, subsemicircular, almost twice as wide as long. Axis short, narrow, subtriangular, 20–25% of pygidial length (though 38% in one specimen [Figure 7C]), elevated above the pleural areas anteriorly but descending to the rear. Axial furrows poorly impressed or simply a change of slope. Inter-ring furrows not evident. Pleural areas without any furrows, except for broad, shallow anterior pleural furrow, most obvious adjacent to fulcrum. Facet small, transversely oblique, subtriangular and steep. Doublure wide, extending to posterior tip of axis in one specimen (Figure 7C).

Remarks. With the relatively poor preservation and without a cranidium or clear ventral morphology we are forced to leave this material in open nomenclature. The geographically closest described species of the genus is *Eastonillaenus incertus* (Webby, 1973) from the Upper Ordovician Ballingoole Formation in central western New South Wales, but that species is not closely related, being distinguished by its longer pygidial axis that is wider at the pygidial anterior and narrower pygidial doublure. Webby (1973) did separate one pygidium because it had a narrower axis at the anterior margin and a broader doublure, so it could be considered more like the *Illaenus* sp. described herein.

It is not certain that all these pygidia represent a single species. The specimen in Figure 7C is more equidimensional than the other larger, more transverse pygidia, but this, in itself, is not sufficient to be sure of species differentiation.

Suborder CHEIRURINA Harrington & Leanza, 1957

Family PLIOMERIDAE Raymond, 1913

Pliomerid sp. 1 (Figure 6B,C)

Material. QMF60336, an incomplete thoracopygon.

Description. Thorax of at least 16 segments, tapering to posterior, with convex axis apparently of uniform width as pleural areas decrease in width posteriorly. Each segment with prominent, convex, pleural band and low, short (exsag.), articulating flanges along posterior margin. Pygidium (excluding marginal spines) subquadrate to subpentagonal with broadly rounded posterior; marginal spines in four pairs, posteriorly directed, with shortest pair the most posterior; axis of four rings plus a short, rounded terminus; rings relatively short in internal mould.

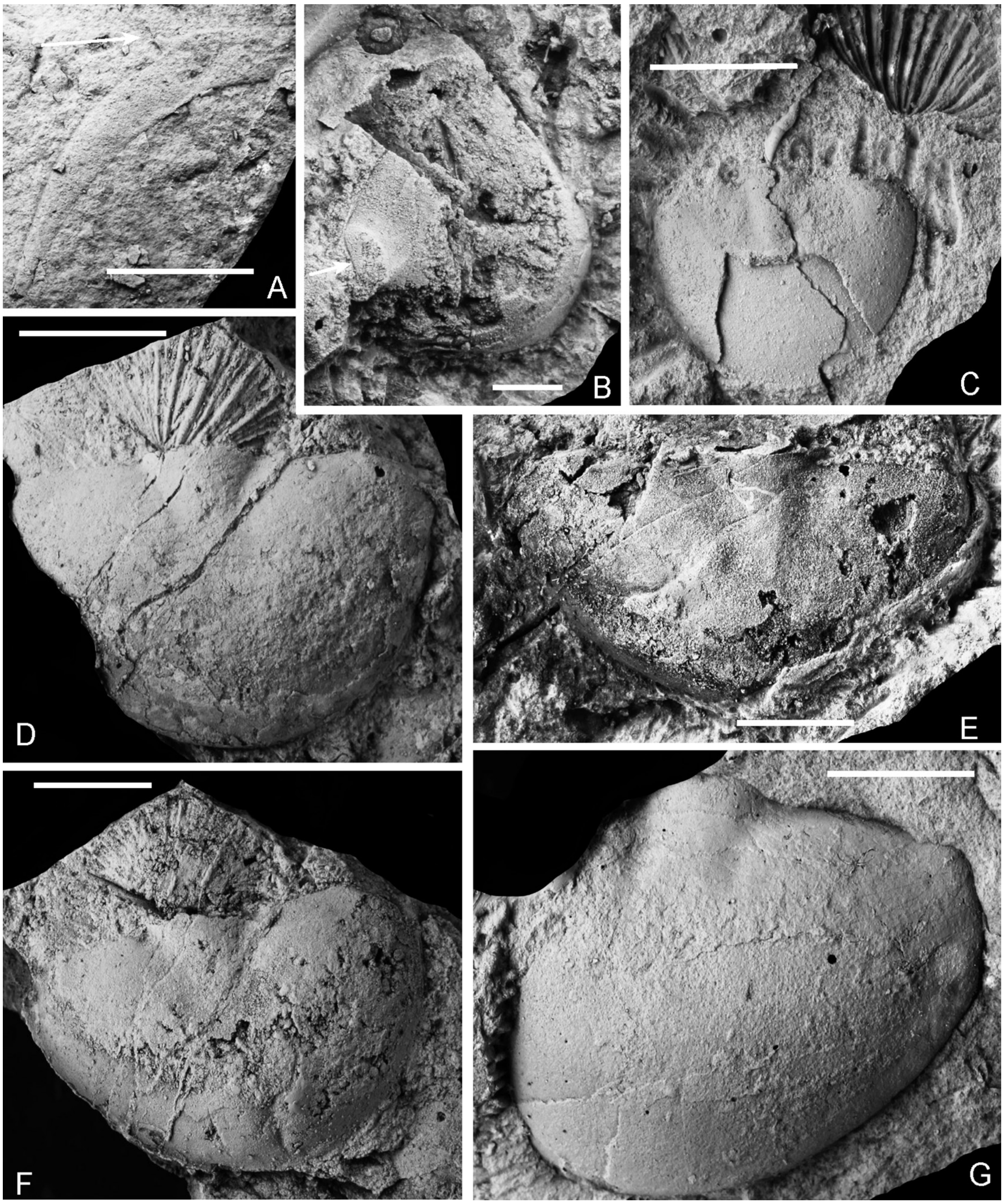

FIGURE 7. Trilobites. A, Cheirurid indet., QMF60329, latex cast of partial thoracic segment with prominent spine-like articulating process (arrowed). B–G, *Illaenus* sp.: B, QMF60330, badly damaged librigena showing position of the palpebral lobe (arrowed) and non-spinose, rounded, genal angle; C, QMF60331, internal mould of small pygidium with very wide doublure; brachiopod is ?*Phaceloorthis* sp.; D, F, QMF60332, latex cast from external mould and internal mould of partial pygidium showing short triangular axis and with brachiopod, *Sericoidea* sp., lying beneath articulating halfring; E, QMF60333, damaged internal mould of pygidium; G, QMF60334, latex cast of partial pygidium. Scale bars = 5 mm.

Remarks. The low ledge along the posterior margin of each thoracic segment is interpreted as an articulating flange by comparison with other pliomerids such as *Hintzeia* McAdams & Adrain, 2011a (see McAdams & Adrain, 2011a, pl. 8). It appears to extend beyond the fulcrum as it does in material figured by McAdams & Adrain (2011a). Slight forward rotation of the segments conceals the anterior margin of all segments where a similar articulating flange could be expected.

Taxonomic placement of this specimen is impossible, and none of the following comments are intended to imply relationship at generic level but merely to show some shared pliomerid family characters. Members of the Pliomeridae have up to 19 thoracic segments, and a specimen of *Hintzeia parafirmimarginis* McAdams & Adrain, 2011a (see McAdams & Adrain, 2011a, pl. 8) has 15 thoracic segments that compare closely with those in the specimen described here. However, the pygidium described here appears to be narrower and have four pairs of longer, more slender, marginal spines, features of *Panisaspis* McAdams & Adrain, 2011b evident, for example in *P. quattuor* (Hintze, 1953) (see McAdams & Adrain, 2011b, pls 27, 31, 32).

Externally the pygidial axial rings may be longer (sag.) than in the internal mould, a significant difference being inferred by comparison with *Protopliomerops lindneri* Jell, 1985. In that figure the difference between internal and external appearances of the axial rings is quite obvious and may be inferred to represent pliomerids in general, the family being known to have relatively thick carapaces.

Pliomerid sp. 2 (Figure 6D)

Material. QMF60337, an external pygidial mould.

Description. Pygidium subtriangular, 5 mm long and 9 mm wide, with five pairs of stout marginal spines directed posteriorly; axis triangular, tapering strongly to rear, almost half pygidial width anteriorly, of five rings plus tiny terminal axial piece; pleural areas crossed by five prominent pleural bands extending into the marginal spines and defined by deep pleural furrows.

Remarks. Among Australian pliomerids, *Hintzeia* sp. undet. (see Laurie & Shergold, 1996, pl. 6, figs 1–11) from the Bendigonian Emanuel Formation in the Canning Basin of Western Australia has pygidia that match fairly closely with this Queensland specimen, allowing for the extremely imperfect preservation of the latter, but beyond showing a pliomerid affinity this comparison is not meant to imply close relationship.

Order PHACOPIDA Salter, 1864
Suborder CHEIRURINA Salter, 1864

Thoracic segment fragment (Figure 7A)

Material. QMF60329, a small, left pleural fragment of thoracic segment.

Description. Inner (or articulated) pleural area with parallel anterior and posterior margins, without any furrows. Fulcral process prominent, tapering anterolaterally but with flattened extremity. Outer (or free) pleural area flat, curving and tapering posterolaterally to rounded tip (as preserved), without a pleural furrow.

Remarks. The distinctive feature of this specimen that allows placement in the Cheirurina is the very prominent, almost spine-like fulcral process and flattened, posteriorly sweeping free pleura. Comparison is drawn with *Nieszkowskia jakei* Edgecombe et al., 1999 (see Edgecombe et al., 1999, pl. 3, figs 7, 8) which has the spine-like fulcral processes of comparable proportion to that on the thoracic segment described here, and with *Holia secristi* Whittington & Evitt, 1953 (see Whittington & Evitt, 1953, pl. 31, figs 20, 21, 31, 34).

Phylum ECHINODERMATA
Class CRINOIDEA

Stem ossicles indet. (Figure 8A–E)

Material. QMF60338–60342, moulds of crinoid stem ossicles chosen as representing a much larger number in the collection from this site.

Description. Figure 8A shows the articular facet of a pentameric stem, about 1.5 mm in diameter, with a very large pentagonal lumen occupying more than half ossicle diameter.

Figure 8B is of a holomeric ossicle, also about 1.5 mm in diameter, with a large pentalobate lumen occupying just over half ossicle diameter.

Figure 8C is a more common form of articular surface having a relatively small circular lumen, narrow areola and wider peripheral crenularium.

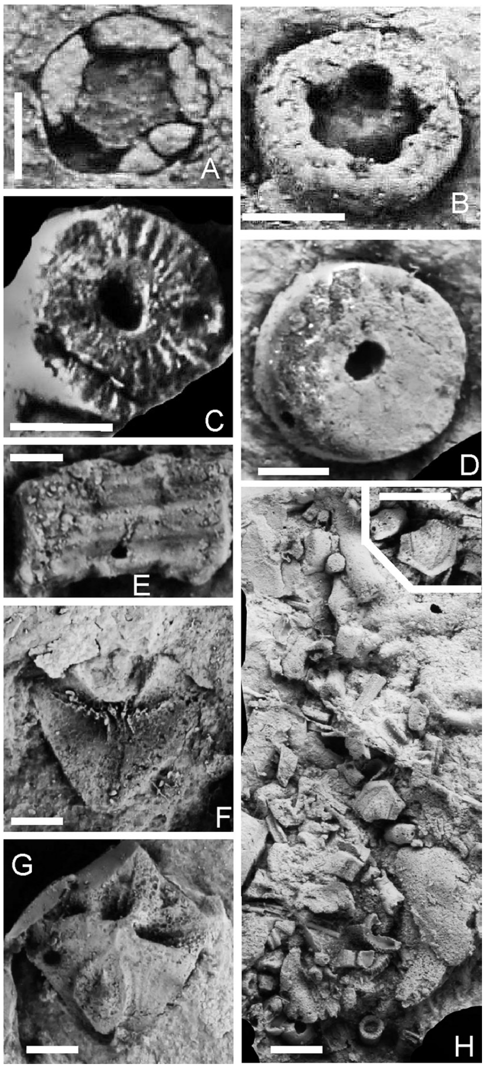

FIGURE 8. Crinoid stem ossicles and brachial plates. A, QMF60338, pentameric stem ossicle, end view. B, QMF60339, stem ossicle, viewing circular section and large pentalobate lumen. C, QMF60340, stem ossicle, end view with smooth circular face and small-diameter lumen. D, QMF60341, stem ossicle, end view showing prominent crenularium occupying entire radius except for the lumen. E, QMF60342, stem ossicle in lateral view, showing deep longitudinal grooves. F, QMF60343, articular face of brachial plate. G, QMF60344, articular face of brachial plate. H, QMF60345, accumulation of small, dissociated echinoderm plates (inset: an enlargement of single plate in centre of main image). Scale bars = 0.5 mm in A and B; = 1 mm in C–H and H inset.

In Figure 8D the articular facet is a plane surface with small lumen and no crenularium. This type of facet indicates synostosial articulation, possibly totally inflexible.

Figure 8E is a lateral view of a tiny, about 0.3 mm in diameter, elongate (about 3.5 mm long) stem ossicle with a tetragonal, almost cruciform cross-section.

Remarks. A variety of stem ossicles are preserved with this fauna, and although not definitive for age determination, they are, collectively, more in accord with an Ordovician age than any other age. The two ossicles in Figures 8A and 8B, each of very small diameter for crinoid stems and large lumens compared to stem diameter, have much more in common with Cambrian and Ordovician echinoderms than later forms. Pentameric stems, as in Figure 8A, occur in early crinoids (Guensburg et al., 2016). Ossicles with articular facets like that in Figure 8C are known through most of the Palaeozoic – Ordovician to Permian. They provide no assistance in dating the fauna. Donovan (1989) noted that synostosial articulating facets, as in Figure 8D, are rare, restricted to some early Ordovician forms and recent isocrinids, the latter having evolved this feature (more correctly called cryptosymplexy in that group) independently. We can find no ossicles comparable to the one in Figure 8E having been previously described in the literature.

This array of stem ossicle types is more suggestive of an Ordovician age than any other. Donovan (1989, p. 252) noted that "Crinoid columnal evolution in the Ordovician included the development of many novel morphologies, often utilising unusual symmetry elements. These represent 'experiments' in morphological variation which developed early in the history of the crinoids. Few of these unusual morphologies survived into the Silurian and after." Taking this observation into consideration, with the stem ossicle morphologies noted above they most probably represent an Ordovician fauna.

Brachial plates indet. (Figure 8F,G)

Material. QMF60343, 60344, external moulds of two dissociated plates.

Remarks. We interpret the exposed surface of these two plates as the articular surface of brachials dissociated from crinoid arms, by comparison with the cross-sections of Ordovician cyathocrinine and disparid arms illustrated by Guensburg et al. (2016, fig. 7B,C_2). The upper part of the cross-section is well illustrated by Guensburg et al. (2016), showing floor plates and cover plates, but in these Queensland specimens the upper plates have been dislodged and are damaged to a degree. However, in Figure 8F the floor of the ambulacral groove is well shown. In Figure 8G several pockets on the crest of the brachial are difficult to interpret but may be associated with podial pores, although they are larger and more prominent than those illustrated by Guensburg et al. (2016, fig. 7B). Their interpretation, and indeed the identity of this plate, are very tentative.

Thecal plate indet. (Figure 8H)

Material. QMF60345, external mould of an accumulation of tiny, mostly echinodermal plates.

Remarks. This tiny, damaged plate, less than 1 mm in largest dimension, was probably hexagonal and most likely a tegminal plate from a crinoid. It is not identifiable with any confidence but is the only discernible plate in an accumulation of very small, probably mostly echinodermal plates.

Age

The main aim of this paper is to confirm the previously reported Ordovician age of this fauna. The only indications of its age come from the trilobites and brachiopods. The sponge spicules and assorted echinoderm plates are not age diagnostic, though they are more consistent with an Ordovician age than any other. Among the trilobites, *Arthrorhachis* sp., the single agnostoid cranidium, is most instructive since that genus is restricted to the Ordovician (Shergold & Laurie, 1997). Its occurrence constrains the age of the fauna between the Tremadocian as the oldest and Hirnantian as the youngest possible ages. *Illaenus* is only known from the Ordovician, and species with which *Illaenus* sp. compares most closely (short, narrow, triangular pygidial axis) mostly derive from the Middle Ordovician. Pliomerid trilobites are not known outside the Ordovician. The Cheiruridae, of which only a partial thoracic segment is described, ranges through the Ordovician to Devonian. Thus, the trilobites clearly indicate an age within the Ordovician, most probably Middle or Late Ordovician.

The brachiopods are at best only able to be assigned at genus level, due to inadequate preservation and the scarcity of diagnostic valve interiors. Nevertheless, their age is undoubtedly Ordovician with a definite Katian (Late Ordovician) aspect. The dominant forms are orthides of the superfamily Plectorthoidea, of which two types are recognisable. Rare but distinctive because of their fascicostellate ornament are robust shells resembling *Phaceloorthis* (originally described from the Late Ordovician island arc limestones of central New South Wales). More commonly present is a medium-sized orthoid with a finely costellate ornament, the ventral valves of which have a profile of very low convexity. This genus is unable to be identified with any certainty. *Skenidioides*, a diminutive protorthide characterised by a strongly convex ventral valve and a dorsal valve with a pronounced median sulcus, is relatively long ranging, from Ordovician to Devonian. Two strophomenides are recognised; one internal mould of a strongly convex ventral valve with a small, deeply inset muscle field is probably a leptellinid plectambonitoid, but lacks a corresponding dorsal valve required to confirm the genus. More common (and most useful for the age determination) are valves of *Sericoidea*, a diminutive plectambonitoid known from the Macquarie Arc of central New South Wales in deeper-water clastic rocks of Katian age. The other brachiopod identified is a siphonotretide lingulate, which although not diagnostic of a precise age, is comparable to genera of this group described from the Upper Ordovician rocks from the Macquarie Arc in New South Wales and the Broken River Province, west of Townsville in central Queensland.

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Alex Cook is a Research Associate and former Curator of Invertebrate Palaeontology at the Queensland Museum. He has wide experience of Queensland geology, having published widely on many aspects; he was a major contributor to *Geology of Queensland*, and principal author of the Queensland Museum's *In Search of Ancient Queensland*.

Short Communication

Crocodile Tooth Histology from a Pliocene Deposit in Chinchilla, Queensland

Bryce Campbell[1], Gilbert J. Price[2], Julien Louys[3] and Justyna J. Miszkiewicz[1,4]

Abstract

Chinchilla in the Western Downs Region of Queensland is home to the Chinchilla Rifle Range, a palaeontological site that has produced a significant well-preserved Pliocene vertebrate assemblage. Here, we describe and discuss the histology of a crocodile tooth recovered from the ca 3.5-million-year-old Chinchilla Sand deposit in the Rifle Range. The tooth is from the posterior jaw and likely belongs to a species of *Paludirex*. We discuss the tooth micro-morphology in relation to what is known about tooth histology in extant and extinct crocodylians with brevirostine and platyrostral skull morphology. We hypothesised that there should be several similarities in the tooth micro-structures between related extinct and extant taxa. We found that the Chinchilla Sand fossil tooth is characterised by thin enamel that is likely prismless but shows incremental striations (also seen in dentine), similar to other crocodylians. This short study highlights the importance of microscopic techniques applied to fossil material. With further fossil evidence emerging from Chinchilla, and application of three-dimensional microscopy techniques to understand the nature of *Paludirex* enamel prisms, a better understanding of reptile palaeobiology can be developed for Queensland and Australia.

Keywords: dental microstructure, crocodile, enamel, *Paludirex*

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Introduction

Chinchilla Sand (previously 'Chinchilla Formation' Woods, 1956) is a collective of fluviatile deposits that extend for approximately 65 km between Nangram Lagoon and Warra, being predominately exposed along the Condamine River in Queensland (Price, 2012). Most, if not all known fossil deposits recovered from this region date to the Pliocene (Bartholomai & Woods, 1976; Wilkinson et al., 2021). Palaeontological surveys and collection from the Chinchilla Sand have recovered at least 63 taxa of fauna spanning fish, reptiles, birds and mammals (Louys & Price, 2015). The reptiles include at least one (Crocodylidae) or possibly two families (Gavialidae) of crocodylians represented by cranial and/or dental material (Ristevski et al., 2020, 2021). No microstructural analyses have yet been conducted on any crocodylian specimens recovered from the Chinchilla Sand. The aim of this study is to use histology to gain preliminary insights into the fundamental structure of tooth micro-morphology in a Pliocene crocodile at Chinchilla, and test whether it might have been similar to that reported for extant and extinct crocodile taxa that exhibit brevirostine and platyrostral (Griff & Kirshner, 2015) skull morphologies. With suitable microscopic preservation, similar analyses could serve as a possible methodological future avenue to shed light on ancient crocodile dietary and predatory behaviours.

Today, Australia is home to two extant crocodile species, *Crocodylus porosus* (the saltwater crocodile) and *C. johnstoni* (the freshwater crocodile) – both found along the north of the country stretching from Western Australia to Queensland (Johnson, 1973). Prior to the arrival of *Crocodylus* in the Pliocene (Molnar, 1977), crocodylians of Cenozoic Australia comprised species within the Mekosuchinae (Crocodylidae), and possibly the Tomistominae (a clade of uncertain familial representation but possibly part of the Gavialidae; Ristevski et al. 2020; 2021). Nuclear and mtDNA suggest emergence of *Crocodylus* in the Miocene of the Indo-Pacific, 9 to 16 million years ago, a point from which the genus spread globally throughout the world, with most extant species occurring within the tropics (Srikulnath et al., 2015). The geologically oldest mekosuchine is *Kambara* from the early Eocene (Willis et al., 1993).

Mekosuchines comprise several genera, with species of *Paludirex* being the largest in body mass and most widely distributed through the Plio-Pleistocene. Based on proportions of their massive, broad snout and dorsally positioned eyes, species of *Paludirex* likely had a lifestyle similar to the mugger crocodile, with a diverse diet of fish, birds and mammals. Two species of *Paludirex* are recognised: *P. vincenti* occurring during the Plio-Pleistocene (with Chinchilla yielding the type specimen of the genus); and *P. gracilis* known only from the Pleistocene (Ristevski et al., 2020). An isolated posterior button tooth of the lower jaw, likely belonging to *Paludirex vincenti* and recovered from the Chinchilla Sand at the Chinchilla Rifle Range, is the focus of our study.

Crocodylian dentition has been of key interest in the study of reptilian biology because crocodiles are equipped with a highly specialised continuous tooth replacement (Poole, 1961; Finger et al., 2019; Whitlock & Richman, 2013). This process has resulted in large, empty pulp chambers comprising most of the tooth's internal structure, with a cap of dentine filling most of the small crown, and a relatively thin layer of enamel coating the entire tooth, including the root. Mesenchymal stem cells in the dental laminae of the root grow a tooth bud adjacent to the functional tooth, growing through the root and into the pulp chamber (Wu et al., 2013). As the bud continues to mature, the crown of the functional tooth, which is defined from the root by a distinctive 'hip', is dislodged and replaced by the bud as it finally erupts, reabsorbing the previous crown's root (Figure 1; Fruchard, 2012). As a result, crocodiles are notable polyphodotonts able to replace their teeth up to 50 times in one lifetime (Poole, 1961). Understanding their tooth structure in the present and deep time is thus of great value to furthering knowledge of crocodile biology and tooth function.

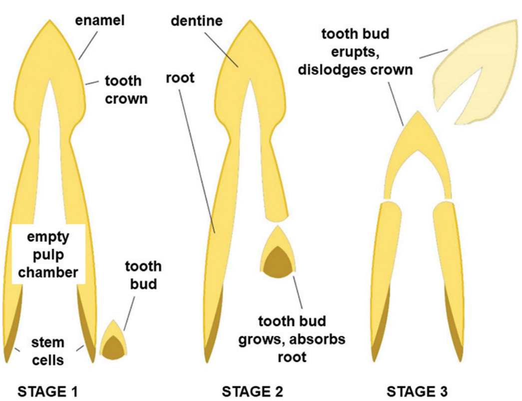

FIGURE 1. Schematic stages of crocodile tooth replacement. 'Functional' teeth are replaced by 'successor' teeth.

Generally, the morphology of teeth along the jaw of crocodylians does not vary as much as in mammals (Enax et al., 2013). Extant crocodylian teeth are thecodont, cone-shaped and unicuspid (Dauphin & Williams, 2008). They vary in shape and sharpness from the anterior to posterior in both the upper and lower jaws (Sellers et al., 2019). Tooth size and shape may also differ with sex and age. Mekosuchines have the fifth premaxillary tooth larger than first maxillary tooth, and a high degree of disparity in tooth size (although not expressed in species of *Quinkana*) (Willis, 1997). Species of *Paludirex* had mostly conical-shaped teeth, a feature seen in other brevirostrine members of the family (e.g. *Crocodylus*) and thought to be associated with a feeding behaviour related to the suppression of struggling prey (Stein et al., 2017).

Histology applied to palaeontological specimens reveals the microstructure of enamel and dentine, which can be used to understand tooth growth and formation in relation to jaw and dietary biomechanics, evolution, and environmental factors in deep time (e.g. Cabreira & Cisneros, 2009; Zanolli et al., 2016; Heckeberg & Rauhut, 2020; Whitlock & Richman, 2013). Both modern and fossil crocodylian tooth structure and function have been studied, including experimental biomechanics of biting force, tooth replacement questions, and dentine incremental lines in alligatorids (e.g. Enax et al., 2013; Poole, 1961; Finger et al., 2019; Dauphin & Williams, 2008; Kieser et al., 1993; Szewczyk & Stachewicz, 2020; Kundanati et al., 2019; Sato et al., 1990; Mishima et al., 2003), but limited dental histology data exist in other members of the order. Crocodile dental enamel is particularly thin (relative to dentine in other reptiles), reportedly in the order of 100–200 µm in *C. porosus* (Enax et al., 2013). Using synchrotron X-ray microtomography methods, Enax and colleagues (2013) also reported that enamel in *C. porosus* does not show defined prisms and enamel crystallites, and as such their enamel is often referred to as 'prismless' or 'aprismatic'. This is also one key feature that distinguishes reptile enamel from mammalian enamel (see Sander, 2000 for review in non-mammalian amniotes). The thin and aprismatic nature of crocodile tooth enamel may link to dental functionality in prey acquisition (Enax et al., 2013). Furthermore, the need for frequent tooth replacement could be justified by high frequencies of tooth damage resulting from grabbing prey (Enax et al., 2013). This study describes the histological features of enamel and dentine of the Chinchilla Sand tooth, and compares it to what is known for other crocodiles.

Materials and Methods

Chinchilla Sand, including its exposures in the Chinchilla Rifle Range, is located in the Western Downs Region of Queensland (Figure 2). The formation consists of fluviatile deposits up to 30 m thick and includes interbedded gravels, sand, silts and clay (Louys & Price, 2015). The exposures in the Chinchilla Rifle Range preserve multiple episodes of deposition and typical fluviatile structures such as cross-bedded sands. The Chinchilla Sand is thought to date to approximately 3.5 Ma based on biochronological correlation with other Pliocene vertebrate deposits in Australia (Bartholomai & Woods, 1976; Louys & Price, 2015).

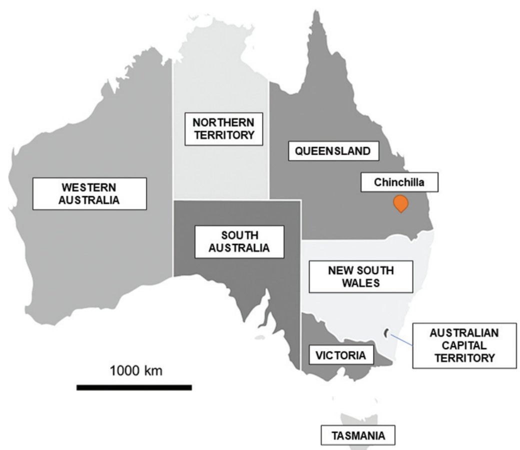

FIGURE 2. Schematic map of Australia showing (orange mark) Chinchilla in Queensland.

Several recent fieldtrips to the Rifle Range have yielded surface-collected fossils, including dental specimens, from which we selected a crocodile tooth for histology. The tooth likely belongs to *Paludirex vincenti*. Its gross morphology (Figure 3) closely resembles posterior or 'button-shaped' crocodile teeth (thecodont, cone-shaped, unicuspid, Dauphin & Williams, 2008; Sander, 1999). Further, species of *Paludirex* are similar in size to extant *C. porosus* and thus are relatively large-bodied crocodylids. On the basis of tooth morphology, we estimated the tooth to have come from the right side of the lower jaw. We acknowledge, however, that tooth shape may change throughout an individual crocodile's lifespan (Fruchard, 2012). The size also depends on age and sex, which are unknown in the case of our isolated specimen.

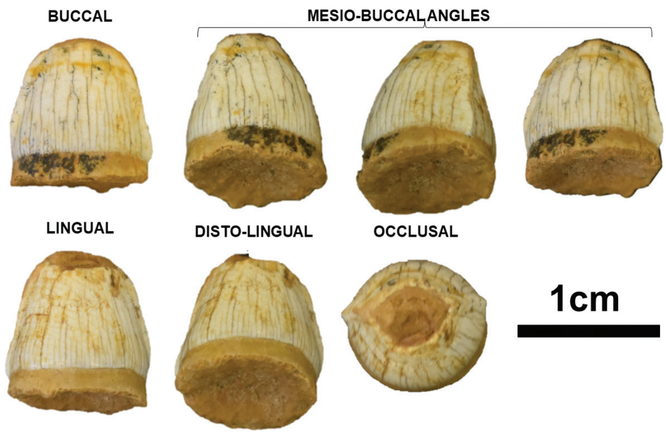

FIGURE 3. The crocodile tooth examined in the present study shown from different anatomical perspectives.

Poole (1961) termed crocodile teeth 'functional' and 'successor', with reference to their stage of formation and eruption. Based on Poole's (1961) classification, our specimen appears to be a complete crown with a root cervix of a successor tooth. A functional tooth would include a hollow root extending from the crown. We are unable to provide an ontogenetic age estimate for this individual, though the size of the crown (see measurements below) implies it was an adult (Sellers et al., 2019).

Photographs of the tooth were taken from multiple angles. Using standard digital calipers we also took three repeated measurements of the specimen: maximum length, crown height, mid-crown length, mid-crown width, crown base (bordering with cervix) length, and crown base (bordering with cervix) width. We then followed standard methods for the preparation of fossil material for histological thin sectioning (e.g. Mahoney et al., 2017; Miszkiewicz et al., 2019, 2020; Walker et al., 2020). The tooth was embedded in an epoxy resin solution and left to set overnight in 25 mm Buehler SamplKups® that had been coated with a release agent. This was followed by a section-cut made longitudinally (in a bucco-lingual plane) using a MICRACUT® 151 precision cutter equipped with a diamond cutting disc. The exposed surface was then smoothed with sandpaper, dried, coated with Araldite® glue, attached to glass microscope slides (46 × 27 mm) and left to dry. The glued sample was then trimmed on the Kemet MICRACUT® 151 precision cutter before being mechanically ground with a Buehler EcoMet 300® grinder-polisher until optical clarity and an approximate 100 µm thickness were achieved. The sample was cleaned in an ultrasonic bath and immersed in a series of ethanol baths to sequentially dehydrate the sample. This was followed by a coating of xylene to eliminate all remaining water. Finally, the sample was cover-slipped with DPX glue. The sample was imaged using an Olympus BX53 high-powered microscope equipped with a DP74 camera. Regions of interest were photographed at objective magnifications of 20×, 40×, 60× and 100× where applicable. The reported microscopic measurements (e.g. the width of enamel band, distance between enamel increments) were measured using the 'straight line' tool of the open access ImageJ® software. We also estimated average (AET) and relative enamel thickness (RET) from a two-dimensional (2D) image of the full crown following Conroy and colleagues (1995) where AET = *c* (area of enamel) / *e* (enamel–dentine junction, EDJ) and RET = $((c/e)/\sqrt{b}$ (dentine area) × 100) (Figure 4). We note the tip of the tooth crown is slightly worn, so RET and AET are not complete. We also acknowledge that defining prism morphology in reptilian enamel is best achieved using SEM methods (Sander, 1999) and, as such, ground histology has limited capabilities in clarifying whether enamel is aprismatic. Therefore, we provide only preliminary insights into enamel micro-morphology and focus more on a fundamental description of tooth micro-morphology, including enamel thickness, dentine–enamel proportions, and incremental nature of enamel and dentine (Kinaston et al., 2019).

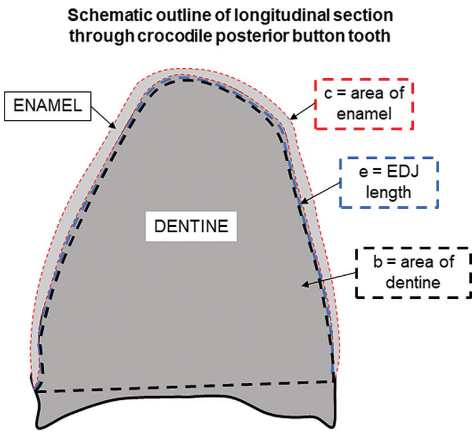

FIGURE 4. Schematic illustration of how tooth longitudinal section measurements used to calculate average enamel thickness = *c* (area of enamel) / *e* (enamel–dentine junction, EDJ), and relative enamel thickness = $((c/e)/\sqrt{b}$ (dentine area) $\times$ 100), are derived. The measurements follow methods by Conroy et al. (1995).

Results

The gross anatomical dimensions of the tooth were: maximum length = 11.01 mm, mid-crown length = 9.60 mm, mid-crown with = 9.33 mm, crown base length = 9.81 mm, and crown base width = 8.76 mm. The preservation of histology was suitable for outlining its basic descriptions. The dentine proportion of the tooth was ~99.87%, showing the enamel to be relatively thin (~0.13%, area of cap = 6.91 mm^2, mid-crown average width taken from 15 measurements = 202.29 µm, min = 167.77 µm, max = 247.69 µm). The estimated AET was 0.35 mm, whereas RET was 4.77 (unitless). Histologically, dentine showed increments (von Ebner's lines) and typical tubule structures that measure an average of 1.06 µm peripherally (close to EDJ) (Figure 5). Enamel appeared possibly prismless, as is typical of reptiles, with no clear cross-striations detected in the 2D section and using light microscopy. Upon higher magnification examination and multiple re-focus attempts, small regions of cross-striation-like enamel were possibly seen (Figure 6), but it is inappropriate to evaluate this sufficiently using ground histology methods alone. Sander (1999) notes that prior ground histology attempts have found it difficult to examine enamel prisms in reptilian teeth. However, longer incremental striations running parallel to the EDJ were observed, although they were irregular in appearance, showing frequent curving (Figure 6). It was not possible to count the exact number of these striations per the entirety of the enamel thickness, but they appeared to occur every 3.4 µm (Figure 6).

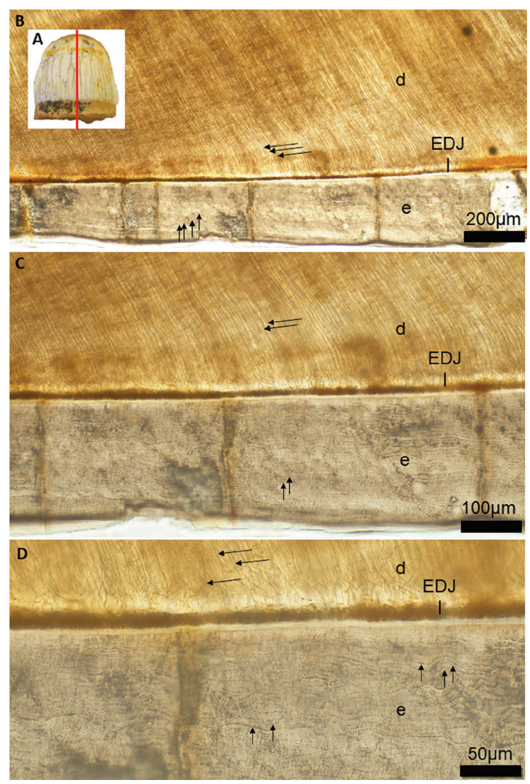

FIGURE 5. A series of histology images captured at the mid-crown of the crocodile tooth sample at an increasing magnification from B to D. The images are from an axial (longitudinal, A) cut of the tooth made into a thin section and viewed through light microscopy. d: dentine, e: enamel, EDJ: enamel–dentine junction. Vertical arrows point to incremental striations in the enamel, whereas the horizontal diagonal arrows point to dentine tubules.

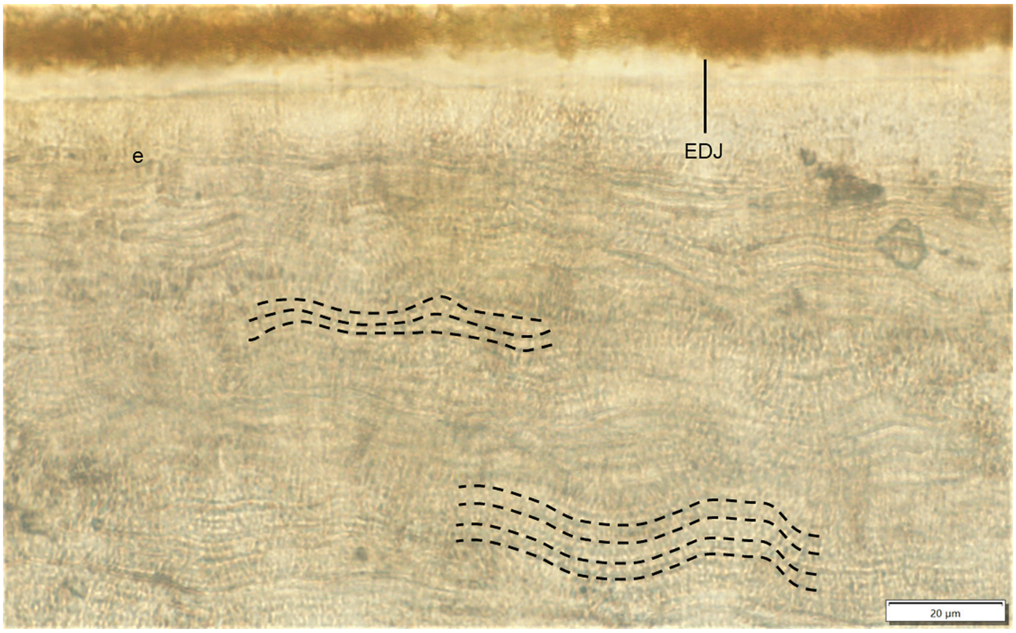

FIGURE 6. A close-up on a selected region of interest in regional enamel (e) from the mid-crown of the tooth. Enamel displays an irregular orientation of long incremental lines that run parallel to the enamel–dentine junction (EDJ). A series of localised successive lines can be identified – see dashed lines.

Discussion

The crocodile tooth from the Pliocene Chinchilla Sand shows microstructures that resemble features reported for other extant and extinct crocodylians – enamel is relatively thin, incremental and likely aprismatic, with incremental dentine consisting of numerous tubules (Enax et al., 2013; Sander, 2000; Sellers et al., 2019). The average width of enamel band in our specimen is in the range of measurements (100–200 µm) reported for *C. porosus* (Enax et al., 2013) and *Alligator mississippiensis* (Sato et al., 1990). Isolated posterior tooth specimens from fossil *Iharkutosuchus* and *Allognathosuchus* show AET (0.21 mm in *Allognathosuchus*) and RET (4.07 in *Iharkutosuchus*) measurements similar to that of our specimen (Sellers et al., 2019: 175). However, the Chinchilla Sand *Paludirex vincenti* RET value appears more similar to *Iharkutosuchus*. Sellers and colleagues (2019) reported AET and RET for a range of ontogenetic series of *A. mississippiensis* showing that enamel thickness increased with skull and body size. The AET and RET data for our specimen mirror closely those of the adult *A. mississippiensis*. We note that Sellers and colleagues (2019) used micro-computed tomography (micro-CT) measurements rather than 2D histology methods. However, Olejniczak and colleagues (2008) had previously concluded that three-dimensional (3D)- and 2D-based measurements for AET/RET calculations remain highly agreeable. Because crocodylians possess the strongest bite-force of any extant animals (up to 16,414 N in *C. porosus*, Erickson et al., 2012), yet develop thin enamel, the extreme mechanical stresses which crocodylians place upon their teeth must be accommodated through their dental morphology. As such, root-dentine is far softer than crown dentine, resulting in a greater capacity for withstanding high impacts without deformation (Enax et al., 2013). The large roots maximise the amount of surface area in contact with the jawbone, dissipating the high energy loads from the individual's powerful bite (Enax et al., 2013). The use of crocodile teeth in grappling prey does also mean more frequent damage to a tooth that is coated with thin enamel, which can lead to higher rates of replacement. Indeed, it has been proposed that the specialised dental stem cell niche in crocodiles allows them to generate new teeth rapidly and when necessary (Wu et al., 2013). We speculate that the Chinchilla crocodile would have exhibited similar prey-grappling behaviours to those known for modern crocodiles.

The lack of well-defined enamel rods found in the Chinchilla specimen agrees with the aprismatic nature of enamel reported for fossil and extant crocodiles, as well as other reptiles (e.g. *A. mississippiensis*, Sato et al., 1990). As prior studies using synchrotron X-ray microtomography or SEM have shown, the crystallites in crocodylian enamel are packed very tightly (Enax et al., 2013), oriented perpendicular to the surface of the tooth, forming a configuration known as parallel crystallite enamel (Sander, 2000). Enax and colleagues (2013) and Sato and colleagues (1990) reported findings very similar to ours, where longitudinal striations running parallel to the EDJ were seen with no shorter-period cross-striating incremental lines in *C. porosus* and *A. mississippiensis*, with Sato and colleagues (1990) naming those "lamella-like" (p. 167). Dentine tubule diameter in our specimen is also in the same range (1–2 µm) as a Thai *C. porosus* reported by Dauphin and Williams (2008). The existence of dentine incremental lines in our specimen, likely von Ebner lines, is also corroborated with those reported for *A. mississippiensis* and *Caiman crocodilus* (Erickson, 1996). These comparisons imply that the Chinchilla crocodile showed tooth characteristics similar to those of extant crocodylians. However, we emphasise that these prior studies have used SEM, micro-CT and Synchrotron X-ray microtomography methods to examine enamel crystallites at 3D resolution and orientation. As our study is limited to histology, future analyses using complementary microscopy techniques will provide more insights into the comparison between samples from extinct and extant specimens, and will allow for a better integration of new with published data (Sander, 1999). This may be particularly useful for noting evolutionary differences in hydroxyapatite crystallite micro-morphology and texture. For example, a recent study by Vallcorba and colleagues (2021) noted postdepositional enamel differences between an Upper Cretaceous fossil crocodylomorph from Spain and *C. niloticus*, having applied Synchrotron X-ray microdiffraction techniques.

We acknowledge that the small sample size in our short study makes it difficult to make any more concrete conclusions for reptile palaeobiology in Queensland. Follow-up studies with larger sets of teeth and utilising multiple microscopy techniques will help build a more in-depth picture of Australian crocodylian dental structure and function.

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An Appraisal of the Queensland Flora Survey Guidelines for Protected Plants, Through a Survey of *Ipomoea antonschmidii*, a Near Threatened Plant of the Northwest Highlands Bioregion

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Abstract

The Flora Survey Guidelines for Protected Plants are the basis for pre-clearing assessments of Threatened or Near Threatened flora listed under the Queensland *Nature Conservation Act 1992*. They require targeted searches for listed plants in designated 'high risk areas'. High risk areas are based on a 2 km radius of a herbarium specimen collection site or a vetted sighting record, with extensions to the 2 km radius using habitat modelling for some species. High risk areas only cover approximately 2.1% of Queensland, encompassing a higher proportion of South East Queensland and the Wet Tropics compared with other bioregions. This paper describes a survey method interpreting the Queensland Flora Survey Guidelines, which was used to evaluate *Ipomoea antonschmidii*, a Near Threatened plant of the Northwest Highlands. We found the timed meander survey method described in the Guidelines provided a useful approach for detecting *I. antonschmidii*. However, high risk areas do not adequately cover *I. antonschmidii*, as 84% of the locations where it was detected in 2011, prior to the amended legislation, are currently outside any high risk area. It is important for botanists and ecologists to be aware of the need for replicating specimen and sightings data over the scale of only a kilometre to improve high risk area maps across the state. Further assessment is required to test and refine modelled habitats of rare flora that contribute to high risk areas. Suggestions of interpretation and refinements of the Guidelines are provided, including the reinstatement of suitable non remnant areas into high risk areas, and a pathway for emerging plant ecologists to become suitably qualified to lead protected plant surveys.

Keywords: threatened flora, protected plants, *Ipomoea antonschmidii*, flora survey guidelines, Queensland Nature Conservation Act

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Introduction

Flora Survey Guidelines for Protected Plants

Of Queensland's 8636 native vascular plant species, 942 (10.9%) have an Extinct in the Wild, Threatened (Critically Endangered, Endangered or Vulnerable) or Near Threatened status under the Queensland *Nature Conservation Act 1992* (NCA; Brown & Bostock, 2020). A further 20 species, such as *Eucalyptus raveretiana*, have a common NCA status and are not covered by the Flora Survey Guidelines discussed in this paper, but are listed as either Endangered or Vulnerable under the Federal *Environmental Protection and Biodiversity Conservation Act 1999* (EPBCA).

Determining the locations of Threatened or Near Threatened flora is a fundamental aspect for species conservation, and designing an effective method of survey requires consideration of complex factors (Keith, 2000). The NCA provides legal protection to listed fauna and flora across the state. Amendments to the NCA in 2014 introduced guidelines on how and where to survey for the presence of rare flora, which have been updated as *Nature Conservation (Plants) Regulation 2020 Protected Plants Assessment Guidelines* (Queensland Government, 2020a).

The Flora Survey Guidelines for Protected Plants (Queensland Government, 2020b – here after referred to as the "Guidelines") require targeted surveys for Threatened or Near Threatened plants, where proposed disturbances fall within a "high risk area". A high risk area is defined under Section 132 of the *Nature Conservation (Plants) Regulation 2020* (Queensland Government, 2020a):

A high risk area is an area –

(a) in which threatened plants or near threatened plants are present or are likely to be present; and

(b) shown as a high risk area on the flora survey trigger map.

In 2014, these high risk areas simply covered a 2 km radius of the collection location of a herbarium-stored specimen, or a vetted sighting record on the *WildNet* database, of a Threatened or Near Threatened plant. *WildNet* is the Queensland government's database of species records, including herbarium samples and sightings. In 2019, changes to the delineation of high risk areas were made in Version 7.1 of the Guidelines. These changes removed high risk areas from within protected areas (e.g. national parks) and most non-remnant vegetation, excluding category A areas and category C (high value regrowth) areas, as defined in the Queensland *Vegetation Management Act 1999*. In some instances, the high risk areas were expanded beyond a 2 km radius of a record, based on modelled potential habitat of a Threatened or Near Threatened plant. Combined, these revisions caused an overall decrease in the high risk area across the state from 56,156 km^2 in Version 6, to 36,952 km^2 in Version 7.1 – a one-third reduction.

Under the NCA, a survey for Threatened or Near Threatened plants in advance of a disturbance (e.g. land clearing) is only required within high risk areas. If a proposed activity is outside a high risk area, there is no need for a survey, and a permit or exemption under the NCA is only required if the proponent is already aware of, or becomes aware of, a Threatened or Near Threatened plant growing within 100 m of a planned disturbance (Queensland Government, 2020b: Section 47C).

This means surveys of Threatened or Near Threatened plants in advance of impacts are confined to high risk areas that are largely based on a 2 km radius of an existing herbarium collection or high-quality sighting record. This raises the question of what proportion of Threatened or Near Threatened plant populations grow outside currently mapped high risk areas. That is, do we currently know enough about rare flora distributions in Queensland to focus pre-disturbance surveys on a 2 km radius of an existing herbarium sample or sighting record?

Ipomoea antonschmidii

Ipomoea antonschmidii R.W. Johnson (Convolvulaceae) is a trailing vine with large, alternate, hairy leaves (Johnson, 1986). It has large pink- to mauve-coloured flowers (Figure 1) that are open during the day, closing in the afternoon. The seeds are found inside dry capsules (Figure 2).

Australasian Virtual Herbarium data indicate *I. antonschmidii* has been collected in 20 locations from north of Mt Isa in North West Queensland to the Northern Territory – Western Australian border (AVH 2021). Seventeen of the 20 collections are from the Northwest Highlands bioregion of Queensland (duplicates of some individual collections are held in multiple herbaria). Plants have been recorded flowering between January and June. *Ipomoea antonschmidii* has a Near Threatened status under the NCA but is not listed federally under the EPBCA.

There has yet to be a published methodology interpreting the Guidelines, or an assessment of their effectiveness in finding Threatened or Near Threatened flora. Ecological information on *I. antonschmidii* is also limited. This paper uses data collected on *I. antonschmidii* before and after the establishment of the Guidelines, to evaluate aspects of its survey requirements and to document ecological aspects of this rare vine. It describes a survey method based on an interpretation of the Guidelines.

FIGURE 1. *Ipomoea antonschmidii* in flower, April 2011.

FIGURE 2. *Ipomoea antonschmidii* capsules, April 2011.

Methods

The extent of high risk areas was calculated for each of the 13 Queensland bioregions defined in Neldner et al. (2019) to assess the distribution of high risk areas across the state, using the ArcMap® Version 9.3 geographical mapping program (ESRI, 2009).

In April 2011, prior to the development of high risk areas and the Guidelines, *I. antonschmidii* plants were observed at 37 locations spanning approximately 100 km^2 at a location >100 km north of Mt Isa, in the Northwest Highlands bioregion (the exact location has been withheld out of respect for the privacy of the property owner). These 37 separate locations were recorded during an environmental assessment while walking across the landscape to document regional ecosystems and species composition. The *I. antonschmidii* plants seen in 2011 are represented in the Queensland Herbarium by a single voucher specimen (collection P. R. Williams 1905 + J. Stibbard, Queensland Herbarium reference BRI AQ0834094). At the time, a single voucher combined with additional geographical data for all sighting locations, submitted as part of an environmental impact assessment, was deemed sufficient documentation of the species extent across the area.

In mid-October 2017, subsequent to the development of the Guidelines, work was proposed within a 2 km radius of the voucher specimen collection site. Following the 2014 protected plant legislation, this had become a high risk area and a protected plant survey was undertaken following the Guidelines (Queensland Government, 2020b). The Guidelines require a survey of the disturbance footprint, plus a 100 m buffer surrounding the proposed disturbance, where it falls within a high risk area. This is called the clearing impact area.

Under the Guidelines, the flora survey must follow either a timed meander method, where the clearing impact area is divided into habitats with 30-minute surveys undertaken in each habitat; or a systematic transect search where large areas are divided into 10 ha blocks and each block is surveyed as an individual unit; or an alternate method that has prior approval from the chief executive.

The timed meander is the most commonly used flora survey method and was used in this study. The Guidelines require at least one 30-minute meander in each habitat of <2 ha that falls within a high risk area, two meanders in each habitat of 2 to 10 ha, four meanders for 10 to 100 ha, and six meanders for >100 ha (Queensland Government, 2020b).

The initial step of the survey was a ground-truthed assessment of the distribution of habitats across the survey area. We determined the extent of each individual regional ecosystem, which we used to define separate habitats, although the Guidelines allow a broader view of a habitat, which can combine similar regional ecosystems. The area covered by each habitat was calculated to determine the required number and location of meanders. A survey for Threatened or Near Threatened plants was undertaken using seventeen 30-minute meanders, across seven regional ecosystems spanning 62 ha. A search for protected plants was also undertaken in a small, highly modified non-remnant cleared area (although not using the timed meander survey method).

The timed meander survey method followed the Guidelines (Queensland Government, 2020b). At the start of each meander, a brief general vegetation description was recorded, including the dominant species. A full plant species list was not recorded for each meander. The search for plants was made while walking slowly, in a meandering pattern to cover a broad area. Approximately every 5 minutes, a geographic coordinate was recorded (i.e. a GPS waypoint) which, combined with the meander track log, documented the pattern and location of the meander.

The meander was complete when no Threatened or Near Threatened plant species were seen within a 30-minute period. If a Threatened or Near Threatened plant was observed (in this case *I. antonschmidii*), the timer was paused to document details about the plants, including abundance. Plant locations were recorded with a GPS coordinate. All individual *I. antonschmidii* plants in each location were counted, as numbers were sufficiently low and individual plants were easily distinguished. If the plants were too numerous to count, or differentiating individuals was difficult, such as for a grass, an estimate of their abundance would have been made by surveying a CORVEG-style transect, described by Neldner et al. (2019). Where the landowner provides consent, a plant sample should be collected and submitted to the Queensland Herbarium for confirmation of identification and as a voucher.

Once intercepted individuals of *I. antonschmidii* were documented, the meander was continued from the outer boundary of the observed *I. antonschmidii* plants. The timer was continued from the point at which it had been paused until 30 minutes had elapsed from the start of the timed meander, without further observations of *I. antonschmidii* or any other Threatened or Near Threatened plant.

Seven of the 37 *I. antonschmidii* separate locations observed in 2011 were re-surveyed to assess the persistence of the plants. These seven locations were chosen because they were close to the protected plant survey area and were easily accessed.

Results

Overall, 2.1% of Queensland is regulated under the NCA through high risk area mapping (Table 1; Figure 3). This does not represent buffers around all NCA listed Threatened or Near Threatened plant collections because those within the protected area estate or areas mapped as category X (representing non-remnant regional ecosystems or areas that have been 'locked in' as category X areas, through a Property Map of Assessable Vegetation) on the Queensland Government regulated vegetation management map, are no longer within the scope of the high risk area mapping.

The number of Threatened and Near Threatened plants and the coverage of high risk areas vary considerably amongst Queensland's 13 bioregions

(Table 1). The Brigalow Belt, South East Queensland and the Wet Tropics have the highest numbers of Threatened and Near Threatened plants, which account for around 4–5% of their total flora. In contrast, the Channel Country, Desert Uplands and Northwest Highlands bioregions have few Threatened and Near Threatened plants, representing ≤1% of their flora.

Although the Brigalow Belt has the largest expanse of high risk areas, they cover only 3.6% of this large bioregion. In contrast, South East Queensland, New England Tableland and the Wet Tropics have a larger percentage identified as high risk areas. The Channel Country, Gulf Plains, Mitchell Grass Downs, Mulga Lands and Northwest Highlands each have <1% of their bioregion classified as a high risk area containing, or potentially containing, protected plants.

Ipomoea antonschmidii plants were found to be perennials that die back to thick tubers in the late dry season (Figure 4). The tubers of some other *Ipomoea* species, such as *I. polpha*, are important food for Aboriginal people (Crase et al., 2010), and this may also be the case of *I. antonschmidii*, given its large tap roots. During the October 2017 protected plant survey, *I. antonschmidii* plants had dried leaves and large dry capsules, which is not the best season for a survey, but plants remained observable.

Ipomoea antonschmidii was the only Threatened or Near Threatened species seen during the survey, and it was found in eight of the 17 meanders. A total of 39 *I. antonschmidii* plants were seen within three regional ecosystems during the protected plant survey (Table 2). None of these plants had been found when doing the broader landscape assessment in 2011, indicating the value of fine-scale surveys using the Guidelines. No *I. antonschmidii* plants were found in the highly modified non-remnant environment, which mainly consisted of grasses and herbs growing on hard gravel, disturbed soil and tracks.

Table 1. Protected plant high risk areas in each of Queensland's bioregions*

Bioregion	Number of threatened or NT species listed under NCA†	Percentage threatened or NT species of total species in bioregion	Combined high risk areas (km^2)	High risk areas as percentage of bioregion area
Brigalow Belt	258	3.7	13,136	3.6
Cape York Peninsula	180	4.0	5,130	2.2
Central Queensland Coast	54	1.4	526	3.5
Channel Country	14	1.0	528	0.4
Desert Uplands	8	0.4	2,744	4.0
Einasleigh Uplands	166	3.3	3,742	3.2
Gulf Plains	24	1.0	506	0.2
Mitchell Grass Downs	38	1.9	1,554	0.6
Mulga Lands	29	1.6	599	0.3
New England Tableland	53	2.7	661	8.5
Northwest Highlands	6	0.4	290	0.4
South East Queensland	278	4.1	6,037	9.6
Wet Tropics	284	5.1	1,501	7.5
Total	**942‡**	**10.9%**	**36,952 km^2**	**2.1%**

* Bioregions defined by Neldner et al. (2019).
† NT refers to Near Threatened species; data are from *WetlandInfo* (Department of Environment and Science, Queensland, 2017).
‡ Several Threatened and Near Threatened species occur in multiple bioregions so that the total of 942 NCA listed Threatened or Near Threatened species differs from the sum of species per bioregion.

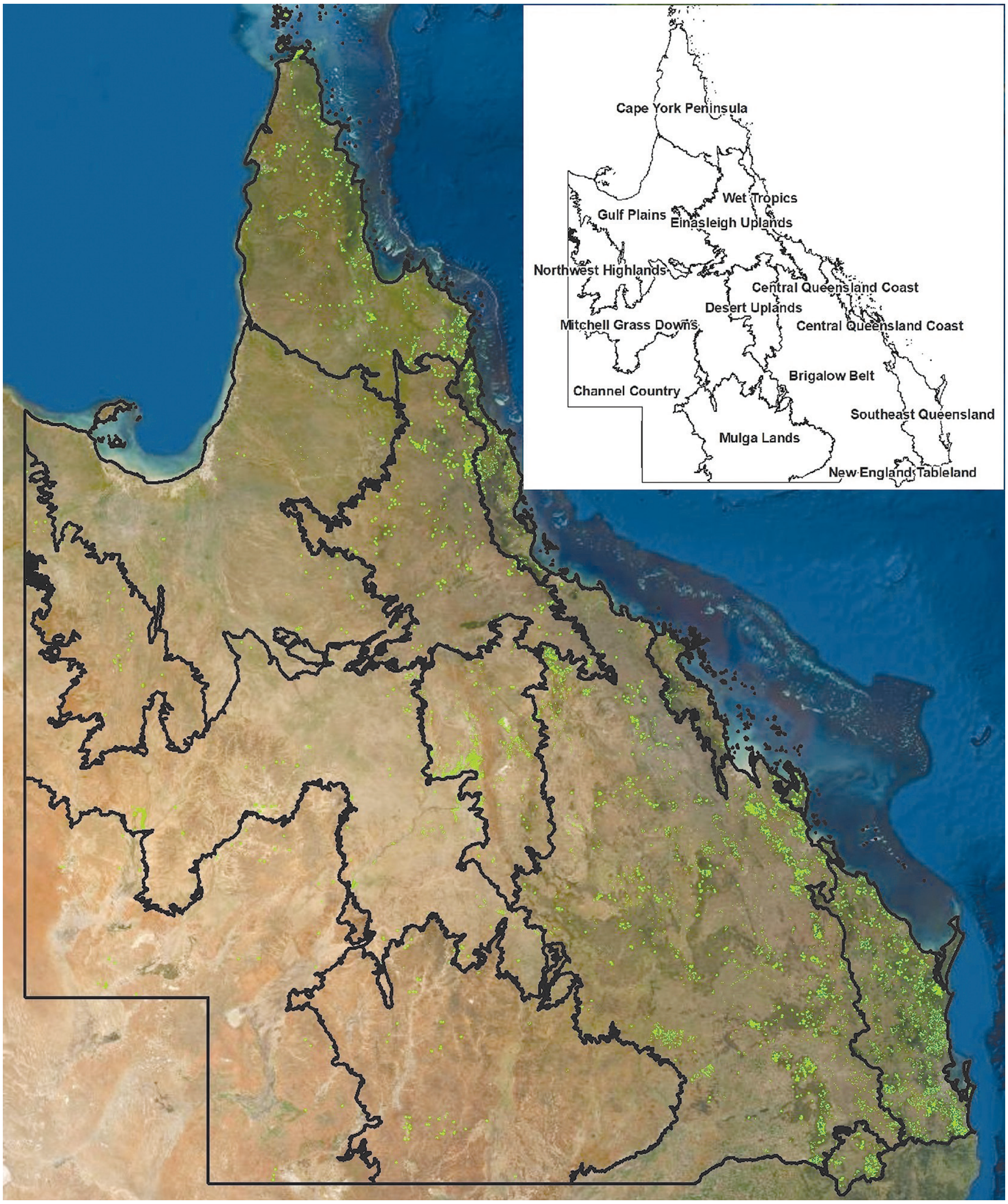

FIGURE 3. High risk areas (light green) within the 13 Bioregions of Queensland (black outline).

Combined, the protected plant survey and the re-survey of seven 2011 *I. antonschmidii* locations in October 2017 detected a total of 151 *I. antonschmidii* plants over approximately 10 km^2. In locations where *I. antonschmidii* grows, they averaged one plant per 2.1 m^2. Of the total 37 separate locations of *I. antonschmidii* seen in the 2011 survey, only six fall within a high risk area. The furthest known *I. antonschmidii* location is 7 km from a high risk area.

FIGURE 4. *Ipomoea antonschmidii* thickened stem base, October 2017.

Table 2. The area of each regional ecosystem present within the protected plant survey area, the number of meanders undertaken and numbers of *I. antonschmidii* plants recorded.

Regional ecosystem	Vegetation	Area covered (ha)	Number of meanders	Number of *I. antonschmidii* plants surveyed
1.3.6a	Box and ghost gum flats (*Eucalyptus leucophylla; Corymbia aparrerinja*)	3.5	2	25
1.3.7b	River red gum (*E. camaldulensis*)	5.7	4	1
1.7.1	Rough-leaved ghost gum (*C. aspera*) laterite hillside	1.6	1	0
1.7.5	Lancewood (*Acacia shirleyi*)	3.9	2	0
1.7.7	Small-fruited bloodwood (*C. capricornia*) on silcrete hill	0.4	1	0
1.11.2	Snappy gum (*E. leucophloia*)	5.0	2	0
1.11.8	Arid peach and bloodwood (*Terminalia aridicola, C. terminalis*) metamorphic rocky hillsides	34.7	5	13
Non-remnant	Cleared, bare ground and plastic covering	7.0	0 – visual inspections only	0

Ipomoea antonschmidii plants were found growing in all but one of the seven separate locations originally observed in April 2011 and re-surveyed in October 2017. The site in which *I. antonschmidii* plants were not seen in 2017 is an alluvial flat with heavy cattle grazing pressure. Grazing may have removed the above-ground parts, with the plants potentially remaining as dormant tubers.

Although density data was unfortunately not collected in 2011, a total of 112 plants were observed in the seven re-surveyed sites in October 2017 (Table 3). Three of the seven locations where *I. antonschmidii* were seen in 2011 occur within the high risk area that is a 2 km radius of the herbarium sample collection site. Three sites are outside the high risk area, and one straddles the margin. A total of 63 *I. antonschmidii* plants were observed outside the high risk area.

Table 3. The number of *I. antonschmidii* plants observed in the seven 2011 locations re-surveyed in 2017, and the regional ecosystem.

2011 survey location number	Regional ecosystem	Vegetation	Number of *I. antonschmidii* plants surveyed in 2017
1	1.3.6a	Box and ghost gum flats (*Eucalyptus leucophylla*; *Corymbia aparrerinja*)	0
2	1.11.8	Arid peach and bloodwood (*Terminalia aridicola, C. terminalis*) metamorphic rocky hillsides	37
3	1.11.2	Snappy gum (*E. leucophloia*) hills	1
4	1.11.2	Snappy gum (*E. leucophloia*) hills	6
5	1.3.5	Large-leaved cabbage gum (*C. grandifolia*) alluvial flats	26
6	1.3.5	Large-leaved cabbage gum (*C. grandifolia*) alluvial flats	37
7	1.3.6	Ghost gum and blood wood (*C. aparrerinja*; *C. terminalis*) alluvial flats	5

Discussion

Protected plant surveys are required under the NCA for proposed disturbances in mapped high risk areas, which currently only cover approximately 2.1% of Queensland. The one-third reduction in high risk areas in the most recent version of the Guidelines, due to the removal of all protected areas and category X areas, requires further consideration. It may be worth reinstating protected plant searches in advance of infrastructure clearing in national parks. Some category X areas contain potential habitat for Threatened or Near Threatened plants, and their complete removal from high risk areas should be reconsidered.

The higher proportion of South East Queensland and Wet Tropics bioregions covered by high risk areas reflects the greater number of rare flora, linked to the broad variety of habitats. It would also be influenced by the high density of botanical surveys and plant samples in the herbarium from those bioregions. Of concern is the low percentage of high risk areas in central and western bioregions, including those with the greatest mining exploration, such as the Brigalow Belt and Northwest Highlands. While this may be a true indication of fewer rare flora, it would also be influenced by lower numbers of botanical surveys and collections. Threatened or Near Threatened plants may be widely scattered in the highly fragmented Brigalow Belt, making them more difficult to detect, so that the high risk areas may underestimate their distribution. The very low number of Threatened or Near Threatened plants in the Channel Country, Desert Uplands and Northwest Highlands suggests less is known about the flora of those bioregions, so that current high risk area maps may not be sufficient to ensure regulation of their rare plants.

In a field-based review of rare flora in the poorly collected Channel Country, Mitchell Grass Downs and Mulga Lands bioregions, Silcock et al. (2014) reported several of their important plant finds were outside targeted survey areas that had been determined on the basis of herbarium specimen and habitat preference knowledge. This highlights the benefit of observations beyond predictable locations. For the extensively cleared Brigalow Belt bioregion, Fensham et al. (2018) considered herbarium specimen records and the extent of clearing for each regional ecosystem, as an approach to identifying Threatened or Near Threatened flora.

The timed meander survey method, preferred by the Guidelines for small- to moderate-sized clearing impact areas (Queensland Government, 2020b), was successful in finding new locations of *I. antonschmidii* in the Northwest Highlands, which had not been observed in an earlier, broader survey. The Guidelines requirement of searching all habitats was valuable in finding *I. antonschmidii*, most of which were found in different regional ecosystems from that of the original 2011 herbarium sample. Each separate location of *I. antonschmidii* had sufficiently few plants to be directly counted, rather than sampled using quadrats within transects, both of which are useful options available under the Guidelines.

If the survey was designed using the New South Wales guide for surveying Threatened plants (NSW Department of Planning, Industry and Environment, 2020), 10 m spaced traverses would have been used to search for this herb. These are estimated by NSW Department of Planning, Industry and Environment (2020) to require 12.5 hours' survey time to cover around 50 ha. This is in comparison to 8.5 hours' active searching in seventeen 30-minute meanders across 62 ha. These two methods are broadly similar and likely to result in similar detection rates.

Ipomoea antonschmidii plants showed persistence over six years in six out of seven locations, probably as a result of their large tap roots and stem base. The inability to observe plants in one of the 2011 locations may have been due to the high grazing pressure along that alluvial woodland, removing the above-ground biomass of the plants. The plants may have died, or their tubers could remain alive, with the plants more obvious in the wet season.

Based on the IUCN criteria (IUCN, 2019), the current status of Near Threatened is supported for *I. antonschmidii*. The species has an extent of occurrence of between 20,000 to 40,000 km^2, an assumption of <20,000 individual plants in total, and may have suffered a potential decline of >10%, based on the inability to find plants in one of the seven separate locations originally observed in 2011 (i.e. potentially a 14% decline within 10 years).

The 2017 protected plant survey considered each regional ecosystem as a unique habitat. Under the Guidelines, similar regional ecosystems can be considered the same habitat. If the seven regional ecosystems in this survey were merged into three habitats (i.e. riparian, woodlands on hills, and lancewood), eight rather than 17 meanders could legitimately have been surveyed. It is probable that *I. antonschmidii* would still have been detected using half the meanders, but plants in some locations may have been missed.

No *I. antonschmidii* plants were seen growing in the highly modified environment, which was mainly cleared bare earth with scattered grasses and herbs. The Guidelines state highly modified environments, defined as mown, slashed and ploughed areas, impervious surfaces and gravel roads, can be excluded from the required survey area in the 100 m buffer surrounding proposed disturbance areas. Whether they can be excluded from the survey in the proposed disturbance area is not mentioned in the Guidelines. The first author has found many instances of highly modified environments within high risk areas, such as mown and impervious areas, during over a dozen protected plant surveys using the Guidelines in recent years. We assume all highly modified environments were intended to be removed from high risk areas along with all category X areas (containing non-remnant regional ecosystems), and the persistence of some is simply due to inaccuracies of mapping at a fine scale. On this basis, it is recommended that highly modified environments encountered during a protected plant survey are excluded from the required survey area. This should apply to the proposed disturbance impact areas, as well as buffers, because they are considerably altered habitats, not simply disturbed regrowth, and divert survey effort from suitable habitats.

In contrast with highly modified environments, surveys within regrowth areas are important for ensuring a thorough assessment because many Threatened or Near Threatened plants regenerate after disturbance. For example, many species of *Acacia* germinate after fire and mechanical topsoil disturbance, such as the Vulnerable *Acacia purpureopetala* (PW pers. obs., 2020). Other plants regenerate vegetatively via root suckering, such as the Critically Endangered *Zieria gymnocarpa* (Williams & Collins, 2020). Excluding non-remnant areas containing regrowth from surveys creates a risk that protected plants may be missed in advance of proposed disturbances. Version 7.1 of the Guidelines removed all category X areas, which are particularly extensive in South East Queensland, from the high risk areas across the state. Given the potential habitat for Threatened or Near Threatened plants in some of these category X areas, it is recommended that a review be undertaken to ensure likely Threatened or Near Threatened plant habitats in non-remnant vegetation are restored to high risk areas.

In some circumstances, such as clearing for a 10 m wide, several kilometre long track, the required 100 m buffer surrounding the impact area is significantly larger than the disturbance footprint. In this example, the required survey area width would be 210 m for a 10 m wide disturbance over many kilometres. This potentially distracts the ecologist from focusing on the proposed disturbance and leading to most of the survey in the buffer. It is recommended that the focus of every protected plant survey be concentrated in the planned disturbance impact area, with much less time spent in the buffer area, even where the latter is larger.

The high risk area (i.e. a 2 km radius from the 2011 herbarium sample collection point) was a useful focal area for searching for the Near Threatened *I. antonschmidii*. However, of the 151 plants counted in 2017 during both the protected plant survey and the re-survey of seven nearby 2011 survey locations, 63 *I. antonschmidii* plants were recorded outside the high risk area. That is, 42% of *I. antonschmidii* plants would not have been detected using the Guidelines.

Further to this, high risk areas do not cover 84% of the *I. antonschmidii* locations seen in 2011. Clearly, the first author of this article should have collected additional specimens of *I. antonschmidii* during the 2011 survey, or at least submitted sighting records to *WildNet*, rather than assuming data from the 2011 environmental impact report would be automatically incorporated into *WildNet* and flora trigger maps. With the current focus of protected plant surveys on buffers around specimens and sighting records, it is important for botanists and ecologists to be aware of the need for replicating herbarium collections and/or sightings data over the scale of only a kilometre to improve high risk area maps.

Searches for Threatened or Near Threatened flora are also undertaken across the state as part of environmental impact assessments for large developments. These assessments can be quite broad in scope and do not necessarily use the Guidelines to meet NCA requirements, because clearing activities may be many years away. The protected plant survey reports have a two-year expiry date. Therefore, to some extent, protected plant surveys are considered thorough pre-clearing surveys, undertaken not long before clearing is proposed.

The protected plant legislation has inadvertently limited plant collection opportunities. This is because of the requirement for landowner approval for collecting plant samples and the view of many that having a high risk area on their property could impact their management options. A recent court case is a documented example of this concern (Land Court of Queensland, 2020). While herbarium-based specimens provide the highest quality data, vetted sighting records on *WildNet* could greatly improve our knowledge of Threatened or Near Threatened plant distributions. For example, the state-based *NSW BioNet* records are used in New South Wales to determine rare flora survey requirements (NSW Department of Planning, Industry and Environment, 2020; J. Hunter pers. comm., 7 July 2021). However, it remains critical that only high-quality records are used to retain confidence in the high risk mapping. Currently, not all rare plant sightings on *WildNet* are used in determining high risk areas. For example, a few *WildNet* records of the Near Threatened *Cerbera dumicola* in the Brigalow Belt are not represented in high risk areas. These are recorded in non-remnant areas immediately adjacent to remnant woodlands, and it is possible the species grows in the remnant vegetation, therefore warranting a high risk area.

The purpose of mapped high risk areas is to indicate there is an elevated danger of damaging a protected plant during a proposed clearing, because a particular species is known to occur, or likely to occur in close proximity. The effectiveness of protected plant surveys would therefore be improved if the names of listed Threatened or Near Threatened species responsible for a high risk area (i.e. the species at high risk of being disturbed) are supplied with the trigger map to approved suitably qualified persons. While it is essential that all potential Threatened or Near Threatened flora in a district are considered during surveys, given our imperfect knowledge of plant distributions, suitably qualified persons undertaking pre-clearing surveys should be made aware of the species at greatest risk. Knowing which species triggered the high risk area will help ensure appropriate survey timing and the search image for the appropriate plant(s). For example, it would be valuable for the plant surveyor to know whether the high risk area has been triggered by an epiphytic orchid, a forb or a tree. Currently, the ecologist must make an educated guess, with records of some plant groups (e.g. orchids and cycads) generalised to 0.1° (i.e. 11 km) of their collection location, yet orchids make up 11% of Queensland's Threatened or Near Threatened flora. Knowing which Threatened or Near Threatened plant to target is even more difficult where the high risk area has been expanded beyond a 2 km radius of a sighting record on the basis of modelled potential habitat. Indeed, the habitat modelling of Threatened or Near Threatened flora distributions used in determining high risk areas requires testing and potential refinement.

A clear pathway is needed for emerging plant ecologists to become a "suitably qualified person" to lead a protected plant survey under the Guidelines. Currently, the criteria for a suitably qualified person are heavily weighted towards academia (i.e. "a relevant qualification from a recognised institution" and/or published papers), and the field experience component only allocates points for people who already have experience at leading multiple rare flora surveys within the last 2 years and/or have collected plant samples that are incorporated into the herbarium. It is recommended an additional criterion be added that credits experience assisting in protected plant surveys. For example, "the person has assisted a suitably qualified person in protected plant surveys annually for at least three years, with 5 points allocated per survey, to a maximum of 60 points".

In conclusion, we found the Guidelines provide a useful approach for surveying Threatened or Near Threatened plants. Some refinements are suggested which could improve their effectiveness as a search method. Currently, the high risk areas underestimate the extent of Threatened or Near Threatened flora. This will improve with ongoing collections and sighting records, which should be undertaken at the scale of only a kilometre between observations.

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The Sir Thomas Brisbane Planetarium and Amateur Astronomy in Queensland

Peter E. Anderson[1] and Wayne Orchiston[2,3]

Abstract

Planetariums are a worldwide public educational, teaching and research phenomenon. In this paper, we very briefly examine their history in Australia, before focusing on the twentieth-century development of amateur astronomy in Brisbane, the founding of the Sir Thomas Brisbane Planetarium in 1978, and the involvement of the South East Queensland astronomical community in this event. We also review the backgrounds and interests of the Planetarium's first two Curators, Jeff Ryder (1977–2002) and Mark Rigby (2002–2021), rank them as amateur astronomers when they joined the Planetarium, and present them as atypical examples of the amateur-turned-professional (ATP) syndrome in Australian astronomy.

Keywords: planetariums, Sir Thomas Brisbane Planetarium, amateur astronomy, Mark Rigby, Jeff Ryder, ATP syndrome

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Introduction

A planetarium is a facility that contains a domed ceiling onto which a night sky can be projected for an audience below with either an opto-mechanical star projector and ancillary projectors; or with digital/video projector systems that enable full-dome video projections for recreating the night sky or, indeed, 'flying' through the Universe and using various data sets. Either system may be adjusted for viewing the sky at any time of night, from any part of the world, and can be set to show the night sky on a particular date (including in historical times). It also displays the position and movement of the Moon, planets, etc. Planetariums are excellent educational and teaching aids (Yu et al., 2017; Plummer & Small, 2018; Creighton & DeVasto, 2019; Daut, 2020), and they occasionally are used also for archaeoastronomical, ethnoastronomical or historical research (Vahia & Halkare, 2013).

In August 1923, the first planetarium projector was set up in a dome on top of the Zeiss factory in Jena, Germany, for the world's first unofficial presentations. It was installed for its first official demonstration at a congress in Munich's Deutsches Museum on 23 October 1923. It was returned to Zeiss for finishing touches before being permanently installed back in Munich during May 1925 (see King & Millburn, 1978). The Adler Planetarium opened in Chicago, USA, in 1930, and increasing numbers of planetariums appeared throughout the nation over the next 40 years (Marché, 2005). Planetariums are now a worldwide phenomenon (see the International Planetarium Society: https://www.ips-planetarium.org).

Australia gained its first planetarium in 1950 (Jacob, 2010; Anon., 1950), when a Spitz projector was installed under a small (14 ft diameter) dome at the Museum of Applied Arts and Sciences in Sydney (Figure 1). After a hiatus of 15 years, planetariums emerged in rapid succession in Australia, first at the Science Museum of Victoria in Melbourne in 1965 (Cavill, 1968; Hirst, 2002) and then at the Queen Victoria Museum and Art Gallery in Launceston, Tasmania, in January 1968 (George, 2021). It was followed in 1972 by one that was used as a teaching aid, mainly for surveying students, at what was then the Levels Campus of the South Australian Institute of Technology in Adelaide. Queensland's first planetarium, the Sir Thomas Brisbane Planetarium, opened in the Brisbane Botanic Gardens, Mt Coot-tha, in 1978.

FIGURE 1. The small planetarium established in 1950 at Sydney's Museum of Applied Arts and Sciences in Harris Street, Ultimo (Photo: Peter Anderson, 25 September 1963).

In 2021 there are six long-established Australian planetariums with fixed, solid domes with diameters of 8 metres or more that are institutional members of the Australasian Planetarium Society. There are others either planned or soon to open, as well as numerous portable/inflatable planetarium domes that are either located permanently at a facility or transported to and set up at locations such as schools (Martin George, pers. comm., June 2021). We are reminded by Wollongong planetarium guru, Glen Moore (2020, p. 13), that a notable feature of the Brisbane Planetarium is its stand-alone status: "Coupling a planetarium with a science centre can be a winning strategy. Every major planetarium in Australia apart from the Sir Thomas Brisbane Planetarium, is associated with a science centre." In this paper we explore events leading up to the founding of the Sir Thomas Brisbane Planetarium, and the role that Brisbane amateur astronomers played in this process and in the subsequent history of the Planetarium.

The Development of Astronomy in Queensland

Although Indigenous astronomy has a history extending back tens of thousands of years in what is now the state of Queensland (Fuller et al., 2014a, 2014b, 2014c; Norris, 2016), Western astronomy only arrived with the first explorers, surveyors and settlers, beginning with the charting of the coastline in 1770 by James Cook (1728–1779) and Charles Green (1734–1771), the astronomers on the barque *Endeavour* (Beaglehole, 1963, 1968). Lieutenant Cook also commanded the vessel and led the expedition (Beaglehole, 1974), and by the time he was slain in Hawaii on 14 February 1779, at only 50 years of age, he had become "… a colossus of British discovery, exploration, hydrographic surveying and nautical astronomy" (Orchiston, 2016, p. 191).

As in other colonies, active astronomers were rare in Queensland during the first half of the nineteenth century. In 1859, Queensland separated from New South Wales and became a stand-alone colony, but unlike the other Australian colonies, the government in Brisbane never saw fit to establish a professional observatory (Haynes et al., 1996). What they did commit to, however, was the provision of a local time service, and commencing on

14 October 1861 a 'time ball' was dropped daily at 1.00 pm from a mast on the top of the old windmill building on Wickham Terrace (Anderson, 2019). On 18 June 1866, this was replaced by a 1.00 pm time gun fired from the same site. The sound of the firing gun could be heard far beyond the visual confines of the old windmill.

Prominent amateur astronomer[a] Captain Henry O'Reilly (1824–1877) (Anderson, 2020) had developed a considerable reputation for keeping his own accurate time and regulating marine chronometers, although there is no indication that he participated in the official time service.

After O'Reilly's death in 1877, the government purchased his observatory and associated instrumentation and set up the Brisbane Observatory on Wickham Terrace in 1881, where an 'Astronomical Observer' employed by the Survey Department made regular observations with the transit telescope and provided a local time service (Haynes et al., 1993). But the Brisbane Observatory was a modest wooden building, and it quickly became dilapidated and had to be closed in 1919. An impressive-looking new Queensland Observatory was planned and foundations were even laid, but the project was abandoned due to costs. Subsequently, timekeeping was conducted from a hut with a transit telescope erected atop a city building – the cost of this arrangement was one-tenth of the cost of the new dedicated observatory.

In Queensland towns outside Brisbane, timekeeping and/or meteorology occasionally were the domain of amateur astronomers, such as Townsville's Charles Sydney Norris (1859–1935) (Orchiston & Darlington, 2017). Some of these amateur astronomers also attempted to contribute to non-meridian observational astronomy. For example, J. Ewen Davidson (1841–1924) (Orchiston & Darlington, 2017), a 'sugar baron' from Branscombe, near Mackay, discovered new comets and made observations of known ones. In the process he was able to acquire international visibility, no mean feat for an amateur scientist from the Antipodes. Other Queensland amateur astronomers living in the countryside, such as Irvinebank's Dr William McFarlane (1866–1919) (Orchiston, 1985), saw their brief as providing astronomical education and outreach for local residents, and especially schoolchildren. At a national level, amateurs collectively made a major contribution to the astronomical education of the Australian public (Orchiston, 1998), and their work should be viewed as complementary to that of the professional astronomers in the colonial and state observatories (Orchiston, 1991).

Orchiston (1998, 2017) has documented how, following earlier abortive attempts in the 1870s and 1880s, the time was ripe by the 1890s for the establishment within Australia of astronomical societies, and these were formed in Adelaide in 1892, Sydney in 1895, Brisbane in 1896 and Melbourne in 1897. But whereas those in the southern colonies could boast close amateur–professional relations and amateur astronomers with international reputations who could serve as ideal role models, in Brisbane there was neither. Moreover, the Brisbane Astronomical Society (BAS) was formed primarily to prevent a 6-inch refracting telescope that was put up for sale from transferring interstate, rather than to encourage and foster amateur astronomy and promote serious observing projects. Elsewhere (Anderson & Orchiston, 2020), we have traced the history and inevitable demise of the BAS in 1917, which also was marked by conflict and competition between two leading Brisbane astronomers, Dudley Eglinton (1850–1937) and James Park Thomson (1854–1941). Thus, personalities and politics helped stifle Brisbane's first attempt to formalise amateur astronomy in the state's capital city.

After the demise of the BAS, Eglinton formed the Queensland Popular Science and Art Society in 1919, which had a wider remit than the BAS in that its portfolio was not restricted to astronomy. Nonetheless, the Society acquired a fine 12-inch reflecting telescope from a Sydney amateur astronomer in order to promote observational astronomy among members with such interests. Sadly, Eglinton became blind soon after the telescope was operational, and without his leadership the Society quickly became defunct (Anderson & Orchiston, 2020).

Not long after, the body that was soon to be titled 'The Astronomical Society of Queensland' (ASQ) held its inaugural meeting on 3 October

[a] For the purposes of this paper, an 'amateur astronomer' is defined as someone involved in astronomy for the love of it, and who normally does not derive a primary income from astronomy (Orchiston, 2015).

1927, with Dudley Eglinton becoming one of the Vice-Presidents. Thomson is not recorded in any prominent role. Although blind and in his 70s, Eglinton continued to write papers that his wife delivered on his behalf. He also managed to transfer the funds of the old Brisbane Astronomical Society to the new Society. In 1935, Eglinton was made an honorary life member of the Society. He died two years later in 1937.

Later, from 1942, the driving forces in this long-running Society were William (Bill) Newell (1912–1971) and his wife 'Molly'. Bill Newell was the Queensland Government's 'Astronomical Observer' and was responsible for maintaining Brisbane's time service between 1947 and 1957. As Secretary from 1942 until his death in 1971, Bill Newell oversaw the affairs of the Society, and his policy of encouraging armchair[b] amateur astronomy rather than just observational astronomy increasingly irritated some of the more active members:

> It is the duty of the Society … to suit the general interest of members, an interest though serious and studious still being primarily of a recreational nature … The aspects of astronomical interest are most varied and observing is only one phase of astronomical interest (Newell, 1969, p. 57).

As detailed later, they eventually broke away and formed the Astronomers' Association, Queensland (AAQ) in 1969. Both organisations catered for Brisbane's growing amateur astronomy fraternity until 1978 when they amalgamated. By this time, the vigour had gone from the earlier arguments, and the chief protagonists had mellowed or passed on. Consequently, the amalgamation vote was unanimous, and the new combined organisation was called the Astronomical Association of Queensland. Thus, the acronym AAQ continued in use, but readers should be aware that post-March 1978 this describes the newly merged organisation.

The merger occurred about the same time that the Sir Thomas Brisbane Planetarium opened, and the respective involvement of the two earlier societies in events leading up to the founding of the planetarium is outlined below.

Events Leading Up to the Construction of the Sir Thomas Brisbane Planetarium

The retiring Curator of the Sir Thomas Brisbane Planetarium, Mark Rigby, advises (pers. comm., March 2021) that to his knowledge the first documented attempt to establish a planetarium in Brisbane was in 1954 when a group of Brisbane businessmen estimated the cost of the facility to be £100,000. They had been in contact with the agency of the Zeiss Optical company in Australia. It was also suggested that it might be named after Inigo Owen Jones (1872–1954), the long-range weather forecaster who had just died (Anon., 1954). Three possible sites were suggested: the Botanic Gardens in Brisbane city, Mt Coot-tha, or the grounds of Queensland University (St Lucia, Brisbane). This concept, comparable in scale to the later Sir Thomas Brisbane Planetarium, was floated without detailed designs or costing in an attempt to attract official support through the cooperation of either the State or the Federal Government. This was not forthcoming, and little more was heard of the idea.

The next occasion for consideration of a planetarium and supporting infrastructure came to the fore as the result of a visit by West German Zeiss representatives in 1966. The initial approach had been through the Museum Society. However, given the nature of the proposal, the Astronomical Society of Queensland (ASQ) soon became involved. The proposal, subsequently championed by the ASQ, was for:

(1) an observatory to house the venerable 12-inch reflector previously mentioned that had come into the Society's possession and was then on temporary loan;
(2) a building to hold meetings/lectures, etc.; and
(3) if feasible, a planetarium provided that appropriate support was forthcoming. This was a real possibility given the interest of the Brisbane City Council following the Zeiss visit.

The Brisbane City Council offered two potential sites that a group of ASQ members inspected in August 1966. These were atop adjacent knolls at Mt Coot-tha on a spur approached by a short gravel road, now called the Honeyeater Track, some 400 m further on from the Lookout. The image

[b] 'Armchair' is used here as a purely descriptive term and does not imply any derogatory connotations.

of the inspection party taken at the time is telling (Figure 2). The architect Fred Lafferty, who had recently joined the Society, his son Lee, and Arthur Page are in discussion with Bill Newell at the left of the image. As the lead author of this paper observed from first-hand experience, tensions had already been building and the go-slow attitude of the Newells was frustrating many.

The situation was complex but finally came to a tipping point over the refusal to establish a finance committee for the project and start serious fund-raising. In fact, only a few hundred dollars were ever subscribed, and the 25 × 75 ft (7.6 × 22.9 m) meeting building alone was estimated to cost around $10,000. Dissatisfaction festered, and the dissatisfied members slowly withdrew from participation in the affairs of the ASQ.

Quite possibly using the constitution of the recently established professional body, the Astronomical Society of Australia (Lomb, 2015) as a model, a new body known as the Astronomers' Association, Queensland (AAQ) was formed on 8 February 1969. Any further serious interest in the project within the ASQ soon fizzled out. Later, after the Planetarium had been established for some years, key optical parts from the historic 12-inch reflector that were in storage were donated, and occasionally these are on display at the Planetarium.

With more than 60 years' experience in local astronomical societies, the first author of this paper can understand the Newells' reluctance to get involved in a major project such as the construction and maintenance of the meeting building, observatory, and possible planetarium. It may well have been a hard-headed realisation and realistic assessment and knowledge of the demographics and capabilities of the general membership (Newell, 1966). After its formation in 1969, the AAQ focused on observational matters and did not become involved in any further such projects. However, this same story was to be repeated a number of times – for example, there was another such detailed proposal in 1983 for a Mt Coot-tha observatory and meeting site, and the later leasing of the Morningside clubhouse (1996–2001). A project, large or small, was enthusiastically supported and approved by AAQ members, but the actual work was left to a few volunteers, so projects either foundered or produced very meagre results.

In any event, after the late 1960s, John O'Hagan of the Museum Society continued to promote the planetarium concept with some support from the ASQ and AAQ. He even proposed the name. However, the eventual detailed planning and construction were entirely Brisbane City Council initiatives and succeeded brilliantly, with contracts being issued for the detailed design in early 1976, construction taking place from early 1977 and completion in 1978.

FIGURE 2. Members of the Astronomical Society of Queensland inspect a proposed observatory/meeting rooms/planetarium site at Mt Coot-tha on 27 August 1966 (Photo: Peter Anderson).

The Sir Thomas Brisbane Planetarium

The Sir Thomas Brisbane Planetarium is built at the base of Mt Coot-tha, Brisbane, on its eastern, city side. The Mt Coot-tha botanical gardens largely surround it to the south. It was named after the Scot Sir Thomas Brisbane (1773–1860) (Figure 3), who was the Governor of the New South Wales colony between 1821 and 1825 and who also gave his name to the settlement of Brisbane, which was founded in 1824. Sir Thomas was a keen astronomer, and at his own expense he erected and equipped a private observatory close to his residence, Government House, in Parramatta (about 21 km west of Sydney Cove), where he employed a trained astronomer, Charles Rümker (1788–1862) from Germany, and a Scottish technical assistant named James Dunlop (1793–1848) (Lomb, 2004). The staff at Parramatta Observatory (along with Sir Thomas Brisbane) were very actively involved in observational astronomy (Saunders, 2004; Letchford et al., 2017), and apart from the discovery of comets, the Observatory is best known for its catalogue of southern stars (Richardson, 1835). Given the astronomical focus of Brisbane's new planetarium, it is particularly appropriate that it was named after Sir Thomas Brisbane.

The Sir Thomas Brisbane Planetarium was built and is operated by the Brisbane City Council. The instigator of the project within Brisbane City Council was the long-term (1961–1975) and highly respected Lord Mayor, Clem Jones (1918–2007). On 28 December 1973 he unveiled a plaque atop Mt Coot-tha (Figure 4), but upon the decision to co-locate with the Brisbane Botanic Gardens on Mt Coot-tha (opened in 1970), the Planetarium was instead constructed adjacent to the Gardens' entrance.

The Planetarium, with its original East German Zeiss projector, was officially opened by Lord Mayor Frank Sleeman (1915–2000) on 24 May 1978 (Ryder, 1979), as shown in Figure 5. It is a substantial building (Figure 6) that includes a domed observatory, a small lecture theatre, a foyer, and an exhibition area with a circular display gallery around the 130-seat main theatre (originally there were 144 seats). This theatre is topped by the 12.5-metre projection dome (an improved one was installed in 2013).

The original projector continued in use until 2010 and was later installed for display in the foyer (Figure 7). Its use overlapped with a digital system with eight CRT projectors installed in 2004. While sacrificing some projected star image quality, this upgrade provided freedom for computerised simulations. Further major upgrades were made, the latest completed in May 2019 with a new digital system installed and with a resolution of nearly 7K (7,000 pixels) across the dome. Regular upgrades and maintenance occur as appropriate.

Although over the years the Sir Thomas Brisbane Planetarium has made a major contribution to the astronomical education and entertainment of Queenslanders and visitors to Brisbane (Axam et al., 2006; Ryder, 1984), its survival was not always guaranteed. In 2001, after a period of operational and financial tightening, the Soorley administration of the Brisbane City Council considered the possible closure of the Planetarium.

FIGURE 3: *General Sir Thomas Makdougall Brisbane*, 1894 by Jessie Drummond after John Watson-Gordon (1788–1864), oil on canvas – gift of the Town Council of Largs, Scotland, 1954, City of Brisbane Collection, Museum of Brisbane.

FIGURE 4. Brisbane Mayor Clem Jones unveiling the plaque at the site of the proposed planetarium atop Mt Coot-tha on 28 December 1973 (© Brisbane Images, courtesy of Brisbane City Council).

However, a case was made that planetariums should be compared with museums, libraries, and even parks. The Sir Thomas Brisbane Planetarium provided a scientific and educational service to the community, and although funded by a council or government, it could not be expected to provide a surplus. At best, ticket sales might cover day-to-day expenses and wages. Therefore, the Planetarium should be treated as a cultural asset, not as an unsuccessful commercial venture that should be discarded.

There was considerable public objection to the possibility of closure, including a public protest outside the Planetarium in May 2001 that drew extensive media attention. Former Lord Mayor Clem Jones expressed his concern, and famous British astronomer Sir Patrick Moore (1923–2012) also came out in support of Brisbane's planetarium (Mobberley, 2015). This was at a time when Jeff Ryder was heading into planned retirement. Uncertainly surrounded the future of the Planetarium for two years before the Brisbane City Council, under the administration of Lord Mayor Tim Quinn, made the commitment in September 2003 to upgrade the facility. Since then, the Planetarium has remained open, and apart from short closures for maintenance and upgrades, and the recent COVID-19 lockdown, it has operated continuously as a unique Brisbane educational attraction since 1978.

FIGURE 5. The opening of the Sir Thomas Brisbane Planetarium on 24 May 1978 (© Brisbane Images, courtesy of Brisbane City Council).

FIGURE 6. The Sir Thomas Brisbane Planetarium in June 1978 (Photo: Peter Anderson).

FIGURE 7. Mark Rigby and Jeff Ryder with the retired Zeiss projector on display in the foyer in 2012 (Photo courtesy of Mark Rigby).

Amateur Astronomy and the First Two Curators

The founding Curator of the Sir Thomas Brisbane Planetarium in 1978 was Jeff Ryder, who retired in 2002. He was succeeded by Mark Rigby, who continued until the end of February 2021, when he went on long service leave pending his retirement in August 2021 at age 67. Mark had joined Jeff Ryder as Assistant Curator in 1985, and his 36 years of service make him the longest-serving staff member of the Planetarium. The position of 'Curator' has now been discontinued, replaced by the position of 'Planetarium Venue Manager' that was advertised in February 2021.

The Inaugural Curator, Jeff Ryder

Jeff Ryder (b. 1947) had first joined the Astronomical Society of Queensland (ASQ) as a teenager in 1961. On 9 March 1962, the 14-year-old gave a presentation at a General Meeting of the Society, detailing his lunar observations and the history of lunar observation. Later that year, he arranged a Society observing night held on 6 October 1962 at Brisbane Boys' College in Toowong. He contributed to the Society's journal – for example, with an article on lunar observations in the December 1967/January 1968 edition. With two other speakers, he gave the address at the April 1969 meeting of the Society. In July 1969, he succeeded the first author of this paper as the Society's Observing Officer. Between late 1969 and mid-1971, he occupied the positions of Observing Officer and Assistant Secretary.

The Astronomers' Association, Queensland (AAQ) had been formed on 8 February 1969, and until 1978 both organisations ran in parallel, sharing a number of members. The AAQ was a very active and observationally oriented body, whereas the ASQ concentrated more on members with an 'armchair' interest in astronomy. After joining the AAQ in 1971, Jeff Ryder was elected to full membership in 1972 and became very active in AAQ affairs. In 1972–1973 and 1973–1974 he was General Secretary of the AAQ, and a Councillor in 1974–1975 and 1976–1977. In 1977–1978 he was Vice President and continued in this position until shortly after the amalgamation. In addition, between 1975 and 1978 he was Director of the observing section devoted to lunar observations, including lunar transient phenomena, employing coloured filters to detect possible anomalous transient glows.

Over the years, Jeff Ryder became an experienced astronomical observer, but as with many young amateurs at this time who had a deep commitment to observational astronomy but shallow pockets, he started with a modest 50 mm refractor. As means allowed, he progressed to a 152 mm reflector, and by the mid-1970s had a 254 mm reflector, plus a 102 mm refractor as a portable instrument (Figure 8).

FIGURE 8. Jeff Ryder with his 4-inch refractor at Murray Bridge State School in 1976 (Photo: Peter Anderson).

Prior to his appointment on 4 July 1977 as the founding Curator of the new Sir Thomas Brisbane Planetarium (then under construction), Jeff Ryder worked for the City Insurance Company. After moving to the Planetarium, he considered it appropriate to place himself at arms' length from direct astronomical society participation, although he was a member of the amalgamated society in 1978 when the AAQ and the ASQ merged, and remained so until 1993. Through his position at the Planetarium, Jeff was able to travel widely, and he endeavoured to keep up to date with various aspects of astronomical research.

The Second Curator, Mark Rigby

Mark Rigby (b. 1954) first attended ASQ meetings in early 1967 and joined the Society in 1968. He was the ASQ Planetary Section Director from July 1973, a title later changed to the Lunar and Planetary Section. For his observations, he made use of a 152 mm reflecting telescope that he had built. In 1978 he became a member of the newly merged organisation (the AAQ) as a full member and Councillor. By the end of December 1979, he was Technical Secretary and Editor, and retained these positions in 1980 and 1981. In 1982 he continued as Editor, and in 1983 and 1984 he was President. He remained a member until 1988. His close contact with the AAQ came to an end when he became Assistant Curator at the Planetarium in 1985.

By the time he joined the Planetarium staff, Mark Rigby was an experienced science writer and astronomy educator. From the 1970s he wrote on space activities for the Brisbane *Courier-Mail*, prepared other publications, and produced 'teacher kits' and student material on subjects ranging from space exploration to ancient civilisations. He also had a deep knowledge of space exploration missions and travelled widely to pursue this interest. Thus, over the decades he visited many US and Russian space facilities and was at the Baikonur Cosmodrome in Kazakhstan for the launch of a Soyuz crew to the International Space Station. In 1975 he met Wernher von Braun, the famous German rocket scientist (Figure 9), and years later stumbled through the ruins of the V-2 rocket development and production sites in Germany. In more recent years, his extensive travel included observing total solar eclipses in various parts of the world. Since going on leave pending retirement in August 2021, Mark has served as an astronomy commentator on two chartered Qantas Dreamliner flights south of Australia to observe auroras. All these interests and activities were certainly relevant to his employment at the Planetarium.

FIGURE 9. Wernher von Braun and Mark Rigby in July 1975 (Photo courtesy of Mark Rigby).

Obviously, his position as Curator at the Planetarium also entailed travel to attend conferences (usually self-funded). He was a long-term Treasurer of the Australasian Planetarium Society from 2003 to 2019, except while serving as its President from 2008 to 2012, and he has represented the region at meetings of the International Planetarium Society.

Finally, Mark also has a particular interest in Sir Thomas Brisbane, who was known also for establishing Parramatta Observatory near Sydney. During his lifetime, Sir Thomas also established observatories on his estates in his native Scotland (e.g. see Morrison-Low, 2004). In 2018, Mark accepted the position of Honorary Vice President of the Brisbane Observatory Trust in Scotland.

Classifying and Ranking Amateur Astronomers

How should we classify and rank Jeff Ryder and Mark Rigby as amateur astronomers when they joined the staff of the Sir Thomas Brisbane Planetarium in 1977 and 1985, respectively?

The US astronomer Dr Tom Williams (2000) has analysed American amateur astronomers, and he distinguishes between those who actively contributed to science and those who engaged in astronomy for recreational purposes only. When they joined the staff of the Sir Thomas Brisbane Planetarium, both Ryder and Rigby were 'active' rather than 'armchair' amateur astronomers.

Since the late 1970s, the Canadian Professor of Sociology and amateur astronomer Robert A. Stebbins has pioneered a whole new field of research, the sociology of 'amateurs' (e.g. Stebbins 1977, 1978, 1979, 1980a, 1992). In the context of this paper, amateurs straddle the nebulous boundary between work and leisure and are 'amators', a melding of the words 'amour' and 'amateur', in the strict sense in that they love their hobby and are happy to invest time, money and effort in it for the sake of the expected 'rewards' (Williams, 2000). Five of Stebbins's later papers (1980b, 1981, 1982a, 1982b, 1987) deal specifically with avocational astronomy, and these form an important contribution to our discipline.

Using 'dedication' as a criterion, Stebbins distinguishes 'devotees' from 'dabblers', and before they came to the Planetarium, both Rigby and Ryder were clearly 'devotees' – individuals who were happy to make a substantial commitment to the science in terms of both time and money. Using another dimension, 'knowledge and involvement', Stebbins differentiates between 'active' and 'armchair' astronomers, just as Williams (2000) does. However, Stebbins also seeks to categorise individual active astronomers within an apprentice–journeyman–master continuum. Apprentices were beginning their astronomical 'careers', while masters were the acknowledged experts who were making a meaningful contribution to science whatever their area(s) of astronomical involvement. Jeff Ryder and Mark Rigby were both active amateur astronomers who in an Australian context sat at the 'master' end of the continuum. Therefore, at a local level they were accomplished, highly regarded amateur astronomers, even if they lacked formal academic qualifications in astronomy, or even undergraduate degrees, that usually were demanded of candidates seeking professional positions in astronomy.

Jeff Ryder, Mark Rigby, and the Amateur-Turned-Professional Syndrome in Australian Astronomy

During the nineteenth century, before the advent of 'giant' telescopes and the emergence of astrophysics, most observational astronomers were committed to positional astronomy, which focused on the positions of stars, planets, comets and other objects, and on the appearance, particularly the changing appearance, of the Sun, comets and particular planets. There was also strong interest in discovering and measuring double stars, and discovering and measuring the changing magnitudes of variable stars. In this environment, there was little difference between the intellectual prowess and astronomical achievements of professional astronomers and the world's leading amateurs: they conducted the same types of research using similar telescopes, belonged to (and in some cases led) the same astronomical societies, received the same medals and awards, and published in the same journals. In this environment, amateur astronomers were able to make important contributions to astronomical science (e.g. Dunlop & Gerbaldi, 1988), and it was possible for leading amateur astronomers to make the transition to professional ranks. This is termed the amateur-turned-professional (ATP) syndrome.

This idyllic situation changed rapidly in the late nineteenth century when amateur and professional astronomers realised that they could apply photography, spectroscopy and photometry to astronomy, and study the composition, dynamics and evolution of the Sun, stars, gaseous nebulae and what later became known as galaxies (Clerke, 1903; Langley, 1884). As a result, "… astronomy underwent an observational, experimental and theoretical revolution as the long-entrenched classical (positional) astronomy was replaced by the 'new astronomy' known as astrophysics … [which] focussed on patterns, processes and mechanisms; with changes through time; and with interrelations. It was largely non-descriptive, and emphasized the dynamic rather than the static" (Nakamura & Orchiston, 2017, pp. 1–2). As professional astronomers underwent formal academic training in astronomy and gained access to ever-larger refracting and reflecting telescopes, amateur–professional relations began to sour (see Hetherington, 1976; Lankford, 1981a,b, 1979; Orchiston, 1999), and by the mid-twentieth century it was rare for amateur astronomers to conduct cutting-edge research and publish their results in professional astronomical journals. It also was challenging for all but the most accomplished amateurs to make the transition to professional ranks.

To some extent Australia mimicked international trends, but only after World War II with the development of galactic and extra-galactic astronomy at Mt Stromlo Observatory, and the phenomenal growth of radio astronomy where Australia quickly became a world leader (Orchiston & Slee, 2017; Sullivan, 2017). Before the founding of the Commonwealth Solar Observatory in 1924 (Bhathal et al., 2013), Australian professional astronomy was steeped in positional astronomy, thanks largely to the over-ambitious Astrographic Catalogue and Carte du Ciel project (Débarbat et al., 1988; Turner, 1912). Although Robert Ellery (1827–1908) (Gascoigne, 1992) and Pietro Baracchi (1851–1926) (Orchiston, 2017) at Melbourne Observatory and Henry Russell (1836–1907) (Bhathal, 1991; Orchiston, 2017) at Sydney Observatory did dabble in astrophysics during the 1880s (for details, see Orchiston et al., 2017), most observational astronomy at the colonial and, from 1900, the state observatories was positional (Haynes et al., 1996). This made it relatively easy for the ATP syndrome to operate: Ellery and Edward John White (1831–1913) (Orchiston, 2017) in Melbourne; Robert Innes (1861–1933) (Orchiston, 2001, 2003), C. J. Merfield (1866–1931) (Orchiston, 2015) and James Nangle (1868–1941) (Orchiston, 2017) in Sydney; while in 1862, Windsor's John Tebbutt (1834–1916) (Orchiston, 2017) was offered but declined the prestigious Directorship of Sydney Observatory.

Overseas studies of the ATP syndrome in the nineteenth century identify research programs, publications and societal involvement as key characteristics of most of those amateurs who made the transition (Chapman, 1998; Williams, 1988; Ashbrook, 1984; Clerke, 1893); and in cities devoid of professional astronomers, before they became professionals these ATPs often ran their private observatories as de facto city observatories, offering the full range of services and facilities normally available from government- or university-funded public observatories: public viewing nights; astronomical and meteorological information (particularly through the local media); a local time service; and public lectures, or even courses, on astronomy (Orchiston, 2015).

Moreover, before they became ATPs, in most respects these leading amateur astronomers were behaving as though they were already professional astronomers, even though they were not yet employed as such, and they were viewed by many of their colleagues and interested members of the public as de facto professional astronomers. To all intents and purposes, they were professional astronomers in all but name only! (Orchiston, 2015).

In Australia the story was more complicated, where some of the above factors were irrelevant. Rather, "… timing, the available competition for newly-created positions and an element of good luck, rather than a distinguished international record in astronomy, were sometimes enough to allow one to move along the ATP continuum" (Orchiston, 2015, p. 334). In the case of Robert Ellery, for example, opportunism and political expediency came to the fore: he was the right man in the right place at the right time. Thus, he scored the founding Directorship of Williamstown Observatory in 1853 without having an international record as an amateur astronomer (Orchiston, 2015).

In the case of the Sir Thomas Brisbane Planetarium, it appears that there also was an element of luck and timing involved in the appointment of both Jeff Ryder and Mark Rigby. They too were the right people, in the right place at the right time, yet although each had built a local reputation in amateur astronomy, neither had a major international profile. Nor did they have university training in astronomy, even though this was available at the time in Brisbane. As Haynes et al. (1996) have documented, it was only in the 1960s that Australian universities began to offer undergraduate and postgraduate programs in astronomy. Queensland joined this movement very early when the theoretician Donald Mugglestone transferred to the Department of Physics at The University of Queensland in 1958, and Keith Jones joined the Department in 1963.

By the time Ryder and Rigby went to work at the Sir Thomas Brisbane Planetarium, there were already undergraduate courses in astronomy on offer at The University of Queensland, not to mention graduate research programs on edge-on and active spiral galaxies and the variability of active stars (Haynes et al., 1996). It is telling that neither Ryder nor Rigby saw fit to bolster their amateur astronomy backgrounds with degrees in astronomy, although Rigby had started a BSc degree but changed to a BA that included journalism because of his developing passion for communication that started as early as primary school. Their employer, the Brisbane City Council, did not require formal astronomical qualifications, which could have been obtained through part-time studies, for promotions or to successfully negotiate salary bars. As such, Jeff Ryder and Mark Rigby remain interesting examples of amateur astronomers who were able to make the transition to professional ranks in the second half of the twentieth century.

Thus, the ATP syndrome was still alive and well in Australia at this time, but the fact that it related in these two instances to appointments at a planetarium, rather than a professional observatory or a university astronomy (or physics) department, should not be overlooked. Planetariums were rare in Australia prior to the 1980s, and those employed at this time in Sydney, Melbourne and Brisbane lacked formal training in astronomy, although Dr Con Tenukest, an astronomer at what would later become the University of New South Wales, was actively involved in preparing programs for the planetarium in Sydney during the 1950s and

1960s (see Orchiston, 1990). It was only later, with the appointment of Glen Moore in Wollongong, Robin Hirst in Melbourne and Martin George in Launceston, that people with formal training in astronomy were appointed to head these planetariums.

Conclusion

In the absence of a strong tradition in professional astronomy, Brisbane developed a vibrant amateur astronomical community, dating from the 1890s. However, as so often happens in amateur societies, personalities, politics and deaths intervened. These resulted in the demise of the moribund original society (1917), followed by the formation of a short-lived society (from 1919). Then in 1927 a new astronomical society was formed that lasted over 50 years. As outlined, events in 1966 caused internal dissatisfaction, and in 1969 a separate observational and research-oriented society was formed attracting many active members. In 1978, after only nine years, these two bodies amalgamated to form the present Astronomical Association of Queensland.

It was against this backdrop of amateur astronomical activity that initiatives began in 1954 to establish a local planetarium, which culminated in 1978 with the opening of the Sir Thomas Brisbane Planetarium. Initially, the astronomical societies were involved in these plans, specifically in 1966, but their focus was more towards a society observatory and meeting rooms, with a planetarium only a consideration if funds were available. However, it was a daunting task given the makeup and demographics of the membership and was never seriously attempted. In the end, it was the Museum Society and specifically the Brisbane City Council, not the amateur astronomical community, that were responsible for bringing Brisbane its first planetarium.

However, the ASQ and AAQ did contribute in a unique way to the success of the new planetarium by providing the first two Curators, Jeff Ryder and Mark Rigby. Both were accomplished observers and had played leading roles in Brisbane amateur astronomy, and they rank highly within the framework for analysing individual amateur astronomers. Ryder and Rigby also are recent Australian examples of amateur astronomers who turned professional (the ATP syndrome), but we regard them as atypical, given their lack of international visibility when they joined the staff of the Planetarium and the fact that they lacked formal academic training in astronomy. Yet we see this as a feature of the early appointments made to planetariums in Australia.

The cases of Ryder and Rigby illustrate the need to revise the ATP concept as it applies to twentieth-century amateur astronomers and planetarium appointments. In the nineteenth and early twentieth centuries, most ATPs were involved in astronomical research as amateurs, and continued these commitments when they joined the ranks of professional astronomers. However, the nature of professional astronomy has changed dramatically since the founding of the International Astronomical Union (IAU) in 1919 (Andersen et al., 2019; Sterken et al., 2019), and in addition to astrophysicists also accommodates those involved in designing, developing and building astronomical instrumentation; in researching the history of astronomy, archaeoastronomy and ethnoastronomy (collectively referred to as 'cultural astronomy'); and in conducting education and outreach activities. Thanks largely to the IAU, all of these are now regarded as legitimate areas of professional astronomy.

Planetariums are primarily involved in education and outreach, but not all planetarium professionals – and especially ATPs – conduct research into the effectiveness of different teaching methods, or the range of programs that they offer. Indeed, some planetarians do not even bother to document changes that take place in their planetariums: new instrumentation, new shows, new displays, and new planetarium-related school programs geared to designated curriculum needs, etc. We need to recognise that unlike those ATPs who make the transition to astrophysics, many of those amateur astronomers who come to professional astronomy education positions often will not engage in any form of astronomical research. This is unlike ATPs involved in instrumentation development or cultural astronomy who typically remain research active.

Following their Planetarium appointments, both Ryder and Rigby felt it politic to distance themselves personally from the Brisbane amateur astronomical fraternity, while at the same time offering special services to the AAQ. Thus, from time to time they arranged presentations for Society members, and from 2001 to 2009 the monthly meetings were held in the Planetarium's small lecture theatre. But with Mark Rigby taking leave from 1 March 2021 pending retirement (Figure 10), has the 43-year link (1978–2021) between the Sir Thomas Brisbane Planetarium, the AAQ and the amateur astronomers of Brisbane finally come to an end? Only time will tell.

FIGURE 10. Mark Rigby during his retirement interview on 3 March 2021 (Photo courtesy of ABC Online News).

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Author Profiles

Peter Anderson has been President of the Astronomical Association of Queensland and its predecessors on five occasions since 1966. In addition to active participation in astronomical tourism, especially to observe total solar eclipses, Peter has been a guest lecturer on cruise ships for nine years presenting astronomical topics. He has also written many articles and is an active contributor in the field. For the last 40 years he has conducted astronomical research from his observatory at The Gap, Brisbane, specialising in the field of lunar and asteroidal occultation of stars. Peter also maintains a strong interest in the history of Queensland astronomy.

Professor Wayne Orchiston is affiliated with the Centre for Astrophysics at the University of Southern Queensland. A former amateur astronomer and President of the BAA (NSW Branch) and the Astronomical Society of Victoria, he has published extensively on Australian astronomy, including a book about John Tebbutt. He has also published on aspects of Chinese, English, French, German, Indian, Indonesian, Japanese, New Zealand, Philippines, South Korean, Thai and US astronomical history. Currently he is Immediate Past President of IAU Commission C3 (History of Astronomy), and Minor Planet '48471 Orchiston' has been named after him.

The Daintree Canopy Crane: Conception, Installation and Operation

Nigel E. Stork[1]

Abstract

The forest canopy is where the biosphere meets the atmosphere, and yet it has been poorly understood due to its inaccessibility. In the early 1990s, interest in the canopy of forests was increasing and researchers sought to attain greater access through the use of industrial cranes. In 1998 a crane was lowered, section by section, by helicopter and constructed in an area of lowland rainforest in the Daintree area of North Queensland. The constructed crane is 47 m high with a 55 m length jib providing access to the canopy of forest covering almost a hectare and including roughly 680 tree stems >10 cm DBH of 82 species. Since its installation, the crane has been used to provide novel insights into a range of fields including plant ecology and physiology, forest microclimate, and faunal and floral diversity. There has been a strong focus on insects including pollination and ant ecology, vertical distribution of insects from the ground to upper canopy, and the hidden diversity of insects and flowers. Current research using the crane is largely focused on the impacts of experimentally induced drought on trees and saplings and the consequences for insects. This paper describes the installation of the crane and initial management and functioning of the research facility. It provides insights on how best to install a canopy crane and maximise its use, as well as the pitfalls to avoid. Also addressed are the potential experimental problems posed by having a single site facility.

Keywords: last biotic frontier, forest canopy, tropical rainforest, canopy access, forest drought experiment

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Introduction

The first so-called 'canopy crane' was inspired by Smithsonian Tropical Research Institute (STRI) scientist Alan Smith who, when passing through Miami Airport to Panama from the USA, saw all the construction cranes and realised that these might be a novel way of accessing the tops of trees for researchers. With funding from UNEP, this led to the first canopy crane being installed in the Parque Natural Metropolitano on the outskirts of Panama City in 1990 (Parker et al., 1992).

Forests house a large proportion of Earth's terrestrial biomass, and the forest canopy is the functional interface with the atmosphere (Ozanne et al., 2003). I was interested in the question of how many species of insects there were in the world and what proportion were only found in the rainforest canopy (Erwin, 1982; Stork, 2018; Stork & Grimbacher, 2006) but had previously collected samples of insects from the tops of trees using knockdown insecticides released from a fogging machine hauled up into the canopy (Stork, 1991). Other canopy scientists had been using single rope techniques to haul themselves into the tops of trees, but safe access to the outer canopy had been difficult or impossible. The beauty of the canopy crane is that the researcher(s) could be lifted into the canopy in a traditional 'dog-box', now called a gondola by canopy scientists, and could take up equipment and sample directly from leaves and branches with ease. Over a 10-year period from the establishment of the first STRI crane, more than 10 other canopy cranes were established for different research purposes in forests around the world (Basset et al., 2003; Stork et al., 1997). Currently, there are six canopy cranes in China alone (Nakamura et al., 2017).

I visited STRI shortly after their crane had been installed and saw the immense possibilities for different kinds of research that the crane provided. In October 1995, I moved to Australia from the Natural History Museum in London to take up the position as CEO of the Cooperative Research Centre for Tropical Rainforest Ecology and Management (Rainforest CRC) and Professor at the new Cairns James Cook University campus. In the first few months, I explored the possibility of seeking Australian Research Council funding to fund the purchase and installation of a canopy crane. The idea was enthusiastically supported by JCU's Professor Peter Arlett (Deputy Vice Chancellor Research) and Professor Rhondda Jones (Head of Department of Zoology) and by their equivalents at The University of Queensland (UQ) and Griffith University (GU). Most importantly, it was supported by former Chief Scientist, Professor Ralph Slatyer, who was Chair of the Rainforest CRC, as well as other Board Directors of the CRC.

In April 1996, JCU submitted the proposal I'd written to the ARC Large Infrastructure grant scheme. As is usual in such large research infrastructure, the ARC likes to see that it is shared and used by other universities, and UQ and GU partnered JCU for this submission. The proposal outlined why a canopy crane was a much-needed device to support terrestrial research and argued that just as marine scientists used deep-sea submersibles to access the deep waters of oceans, canopy scientists needed cranes to provide safe and repeatable access to the tops of trees. In the proposal, several researchers, including myself, Professor Craig Moritz (UQ) and Professor Roger Kitching (GU), outlined how, if it were funded, we would use the crane for a range of studies, including plant biology, genetics, ecology and entomology.

In November 1996, the ARC announced that it had awarded $800,000 to the consortium for the canopy crane – the largest large infrastructure grant awarded that year. In addition, JCU, UQ and GU had put up $200,000, $100,000 and $80,000 matching funds, respectively, giving a total of $1,180,000.

Crane Site Assessment, Building Approvals, and Installation

There were four main hurdles to overcome: first, to select a site to locate the crane; second, to decide what crane to buy; third, to get the necessary planning permits to erect it; and fourth, to erect the crane in the forest with minimal impact on the surrounding forest. In early 1997, Fiona Barron was appointed as the project officer to manage the crane project. Fiona had recently completed an Honours degree working in the Daintree, was familiar with the local people and local issues, and was well equipped to do most of the planning work and discussions with contractors.

By the time the grant was awarded, there were several canopy cranes in action, including one in Washington State in the USA and one in Venezuela which was funded through the Austrian Academy of Science. These, in addition to the original Panama crane, were all tower cranes. This type of crane has advantages over other types, as the arm of the crane stands above the forest and provides access to a large area underneath the arc of the arm. Other cranes would still need to be fixed to a tower above the forest but would not be so easy to use for accessing the forest. At that time there were only a couple of tower cranes operating in Australia, and we approached Morrow, a company specialising in crane hire, purchase and maintenance based in Sydney. The Daintree location meant that the crane would need to withstand high humidity, potentially some salt erosion as it would be located not far from the coast, and most important of all, the ability to withstand cyclonic weather. At that time there were a lot of second-hand cranes in Asia and we could have purchased one of these and saved a lot of money, but we planned for the crane to be standing for many years in harsh conditions and did not take up this option. Morrow's agent, Bill Jones, recommended that we buy a Liebherr Tower crane, noting that in the previous year one such crane had withstood a cyclone in Guam. We were also aware that the Venezuelan crane was a Liebherr crane, and through discussions with Professor Wilfried Morawetz, who was the leader of the Austrian-funded project, we were familiar with its construction and installation. Through Morrow we purchased a Liebherr 70 EC Tower crane built in Germany. The crane comprises some 40 parts, and all the metal standing components were treated to ensure longevity before being shipped to Australia.

Where to site the crane was a critical issue. One possibility was in the forest directly behind the new JCU Cairns campus in Smithfield, but this forest had been logged more than once, as had so much of the lowland forest in Far North Queensland. We were seeking an area that had been lightly impacted and preferably not logged. To explore the best option, we sought the advice of Peter Hitchcock, then CEO of the Wet Tropics Management Authority and responsible to Federal and State governments for the safe management of the World Heritage area. Another site considered was in the rainforest at Davies Creek in the Atherton Tablelands where University of California, Santa Barbara, researcher, Professor Joe Connell, had worked for many decades; access to the site was the problem here, especially for the trucks bringing in the crane parts. Peter Hitchcock and I considered that a location in the Daintree would be the best option, as modelling by Professor Henry Nix (ANU) indicated that during recent ice ages, rainforests of the Wet Tropics had contracted down to just a few areas, with the small coastal area north of the Daintree River being one of the main refuges (Nix, 1991). We visited the Daintree. Peter knew the area exceptionally well because of the buy-back program where privately owned areas of exceptional world heritage value were being purchased and incorporated into the World Heritage area. We looked at a number of sites, and one that stood out as relatively pristine was in the forest behind Coconut Beach Resort near Cape Tribulation. This was our favoured choice.

In mid-November 1996, we were informed that our grant application had been successful. In our press release, which was covered nationally, we included a short video clip with an animation of what the crane would look like in action. As a result of this coverage, I was approached by Darryl Bresnahan, a Cairns businessman and owner of Coconut Beach Resort, who had seen the news. We then commenced negotiations to locate the crane in forest on land behind the resort. These negotiations were delayed for more than six months, as a consortium had an option to purchase the resort and associated land. Once that option expired, Darryl agreed to lease an area of forest and land in front of the forest for a peppercorn rent. The agreement also allowed us access to the site using an unused track which led to Cape Tribulation Road.

Planning permission from Douglas Shire Council was required to install the crane, and we hired the services of a local planner to prepare a proposal. One of the criteria we needed to satisfy council was that the crane would not be obvious from the road and from out at sea. To do this a large, coloured balloon was tethered 50 m from the ground where the crane was to be located, and we then had photographs taken to show that it was not visible from either the road to Cape Tribulation or from the sea. Further, we had the crane painted matt black as this would mean that it would be less visible against the forest backdrop. Plans were submitted, and Douglas Shire Council approved planning permission in 1997. The area for the crane did not fall in nor have a boundary with the Daintree National Park, part of the Wet Tropics World Heritage Area, and hence we did not have to meet any particular requirements. Nonetheless, we briefed both WTMA and Queensland Parks and Wildlife Service of our plans and kept them informed.

Identifying the precise site for the crane to be located and the new track to it from the edge of the forest took some careful thought. We needed to be careful to make sure that the crane tower was tall enough to allow the arm and suspended gondola free movement above the canopy, but not too tall since moving the gondola from one place to another required raising it close to the jib, moving the jib round and then lowering into the canopy – failure to do this would result in the gondola swinging around. We used a clinometer to calculate the height of the tallest trees. Standing 15–20 m from the base of a tree, the clinometer measures the angle needed to sight the top of the tree. In essence, the estimated height of the tree is based on that angle and the distance from the base of the tree where you are standing. We chose a reasonably level area and avoided the east of the site where the ground rose sharply. The base of the crane required a clear area roughly 7 m × 7 m, and no large trees were removed (Figure 1a). The proposed 2 m wide track was flagged on the ground, and the highly experienced local field botanist, Andrew Small, was employed to check that no endangered species of plants were inside the crane base area or the proposed track. Although no heavy machinery was to be used in the forest, the track was covered with a fabric that spread the load and then covered with gravel as proposed by Guy Chester of GHD. A culvert was created to allow a very large matchbox vine to continue to pass under the track. In the clearing for the crane tower, four concrete pads were made – one for each corner of the base of the tower – and each had large bolts protruding (see https://nqheritage.jcu.edu.au/849/ for additional photographs of the installation of the crane).

One of the Directors of the Rainforest CRC, Dr Ken Chapman, Managing Director of Skyrail, shared his considerable experience of how to install large infrastructures in rainforest with minimal damage to the environment. He had the towers for Skyrail installed by lowering them into place using powerful helicopters. He advised that there were only a few helicopter pilots in the world who had the skill to carry out these kinds of operations. His words of advice resonated when I saw footage of the Austrian team trying to lower crane sections into place at the Venezuelan site using the Venezuelan air force helicopter pilots. The crane sections were swinging around wildly, and they had to abandon their attempt and wait six months until they could get a team of industrial pilots to perform the operation safely.

Consequently, we employed the services of Hevilift, who had lowered Skyrail's towers into place. For this kind of operation Hevilift uses a Kamov Russian-made helicopter which has two counter-rotating blades and can lift 5 tonnes in a single lift. The helicopter has two pilots and several other crew to manage the lifting. Inside the helicopter the instructions are in Russian, so at least one of the team needed to be able to read Russian. Finding the right time in late 1998 to carry out the installation was difficult as the helicopter was in heavy demand assisting mining operations in PNG, as well as helping with water bombing in south-east Australia during fire season. We were particularly concerned that the crane be installed before the onset of the wet season, and Hevilift agreed to a date of 18 November. To do this we had to pay for the costs of the helicopter flying up from Sydney and for three days' use. This amounted to a quarter of our budget.

The crane parts were loaded on a convoy of transporters and brought up from Sydney. To get to the site they had to negotiate their way through the very windy Cape Tribulation Road, many parts of which were still unsealed, and cross the renowned Noah Creek wooden bridge. They were then unloaded and laid out on an open area of land near the staff quarters of Coconut Beach Resort (Figure 1b). We were praying for good weather and no wind, as any delays in the construction would add to our costs for helicopter time. Bill Morrow had some months earlier suggested that the large concrete blocks that fit into a frame at the stabilising end of the jib needed to be very exact in their measurements. If one or more didn't fit in the cradle, this would result in immense delays and additional costs. We had intended the blocks to be made locally but agreed that they should be made in Sydney and shipped up with the other equipment (Figure 1d).

On the morning of 16 November, the scene was set for an extraordinary construction feat. The Kamov helicopter and crew were ready on the grass launching pad at Coconut Beach resort, as was a second smaller helicopter Hevilift had brought in to film the whole operation. Laid out in front of the Kamov were all the crane parts. Next to the Kamov were some 30 drums of aviation fuel which the helicopter would go through over the next few days. As the Kamov rose up it lowered a 100 m cable, and the first piece, the base of the tower, was attached and lifted into the air (Figure 1c) (see https://nqheritage.jcu.edu.au/850/ for video of the helicopter installing the canopy crane). The longer the cable the more difficult it is to control the swing of the object being carried, but a shorter cable would result in considerable damage to the forest because of the immense downdraft from the rotating blades; hence the 100 m cable length. At the crane site a team of experienced riggers, led by Craig Jones, Bill's son, and colleagues were attaching the crane pieces as they were lowered. Once the tower base was lowered and bolted in place, the next pieces to be individually lifted and placed were the 16 concrete ballast slabs on the four sides of the tower base. Gradually, the crane tower was built up and bolted in place (Figure 1e). Much of the construction was captured on film by the small helicopter, including some exciting footage of the platform and jib sections being lowered gently down and bolted into place. There was some strong wind damage to the forest on one side of the crane site where the Kamov had repeatedly made its approach; however, much of this damage looked like leaf fall, and we considered that this would recover in a matter of months. The constructed crane is 47 m in height with a jib length of 55 m, and hence the arc of the crane covers an area of 0.95 hectares.

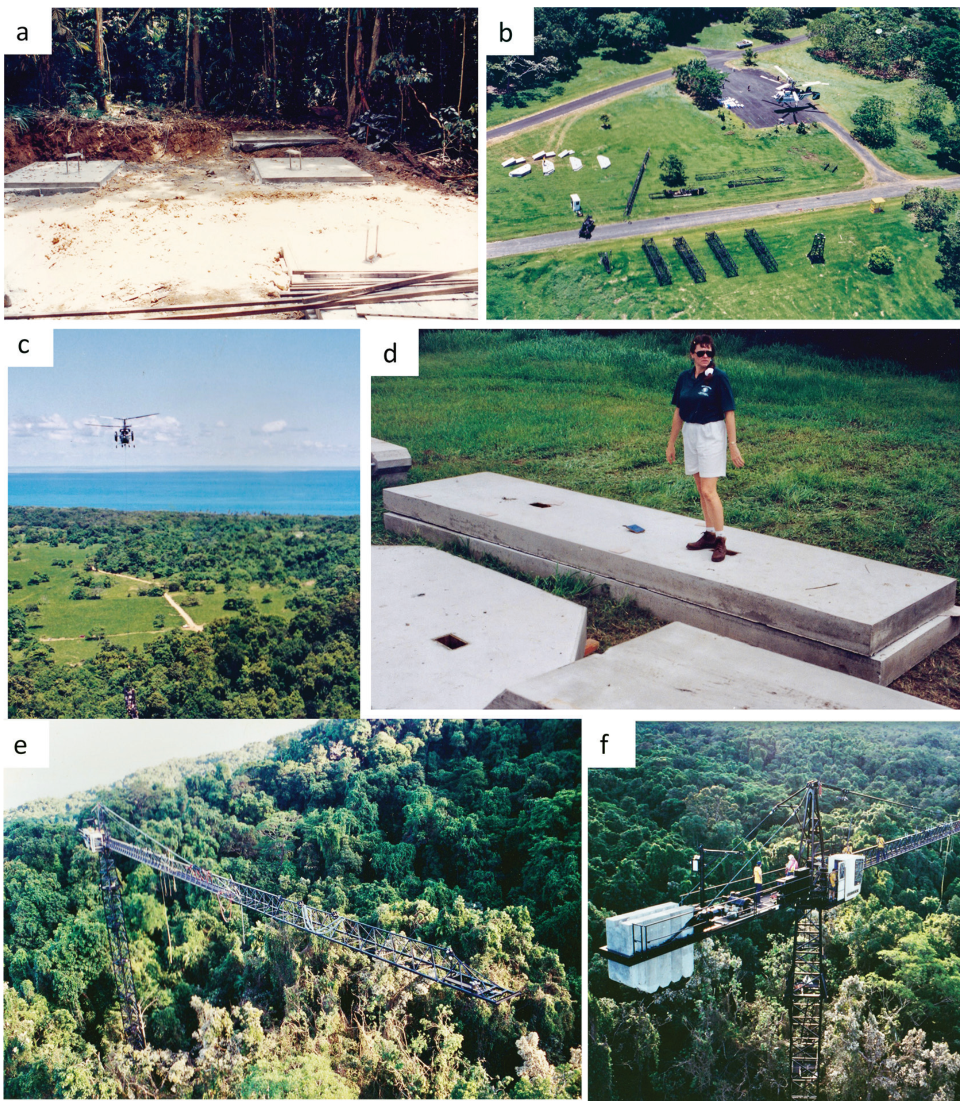

FIGURE 1. (a) Initial concrete slabs set in the ground as the base for the crane; (b) all of the crane parts laid on the ground with the helicopter located close by to make the lifts; (c) the helicopter carefully lowering a section of the jib; (d) Fiona Barron inspecting the concrete ballast and base section weights; (e–f) all sections of the crane attached by the rigging team, including ballast weights.

With the crane erected, the next job was to fence the area around its base and to install power to it. Power was provided by a large diesel-fuelled generator which was located in a purpose-built shed set outside the forest, along with a fuel tank. A power cable sheathed in a metal pipe was passed through the forest to a control panel with safety switches in a small shed in the fenced area. A gondola had been constructed according to the design suggested by Morrow, but it was found to be too heavy and could not be taken out to the end of the jib without setting off an alarm. A new, lighter gondola was constructed which would accommodate three people. The driver could control the crane from the gondola using a control system attached to his waist (Figure 2b).

Developing a Research Program

Establishment of a research program at the crane took several years and was impacted by delays caused by damage to the site and facilities by Cyclone Rona, a category 3 cyclone that hit the site on 11 February 1999 – the eye of the storm passing over Port Douglas some 50 km south. The canopy crane came through unscathed, but the forest was heavily impacted. A couple of medium-sized trees fell across the base of the crane, demolishing the shed and flattening some of the fencing (Figure 2c). The five-minute walk to the crane from the edge of the forest now was a 30- to 40-minute walk as the winds had brought many large trees to the ground. In addition, many of the vines, including all the lawyer cane vines, were brought down, making it hazardous to get through. Most of the trees survived on the site, but a lot had the top branches snapped off and very few leaves were left intact.

The area under the arc of the crane was surveyed, and the positions of all the trees of >10 cm diameter at breast height (DBH) were tagged, plotted and identified in 2000 and subsequently again in 2005 (Laidlaw et al., 2007). The 2005 survey found there were 680 stems of >10 cm DBH and 82 tree species. At first, it was difficult to identify individual trees when up in the canopy without lowering the gondola to the ground and looking at the tags on the trees. To overcome this problem a map was created showing the positions of the trees, their DBH and their maximum height in the canopy (Figure 2e). A copy of the map was attached to the ceiling of the gondola, and it was easy then to refer to the tree list to find particular trees of interest. In addition, a steel ring was added to the tower below the jib showing points of the compass. Increasing 10 m distances from the tower were marked on the jib, and this made it easier to determine where you were on the plot (Figure 2f). In practice, the canopy crane drivers became very familiar with many of the individual trees that were commonly used for research and could navigate to these quickly.

Prior to installation of the crane, Fiona, accompanied by Professor Roger Kitching, visited the Wind River crane in Washington State. This was managed by the University of Washington, and they had developed a safety manual and safety procedures. Fiona brought this back and we adapted it for the Daintree crane, adhering to the Queensland Workplace Health and Safety guidelines for tower cranes. Harnesses were worn in the gondola as well as safety hats, although the need for a safety hat was removed later since the gondola had a hard roof. Safety hats were to be worn under the arc of the crane at ground level if the crane was in operation. All newcomers to the site were given a safety briefing, signed to say they understood the regulations, and checked in and out when they entered and left the site. Only a certified crane driver could operate the crane.

For the first two years of operation, accommodation for the crane driver and researchers was rented from the staff area of Coconut Beach resort. This was not sustainable and also meant the crane site was not always secure. A field station for 8–19 people was constructed using four portable cabins at a cost of around $220,000 (Figure 3b). One was a two-bedroom unit that was established for the crane driver. The other three were placed together under a curved roof and had a wooden connecting deck (Figure 3d). One of the units was in two parts: the kitchen and a laboratory (Figure 3c). One of the other units comprised an office and two bedrooms which shared a bathroom. The third unit was four bedrooms, again with paired bedrooms sharing bathrooms. A large battery bank was placed in the generator shed and was charged either by the main generator when the crane was idling or from an additional smaller generator. This provided sufficient power to run lighting, washing machine, and air conditioning units for the office, laboratory and bedrooms. Large water tanks collected and stored water from the roof of the buildings. Waste went to an underground septic tank. In 2014 the research station was redeveloped and expanded as the Daintree Rainforest Observatory through a Commonwealth grant.

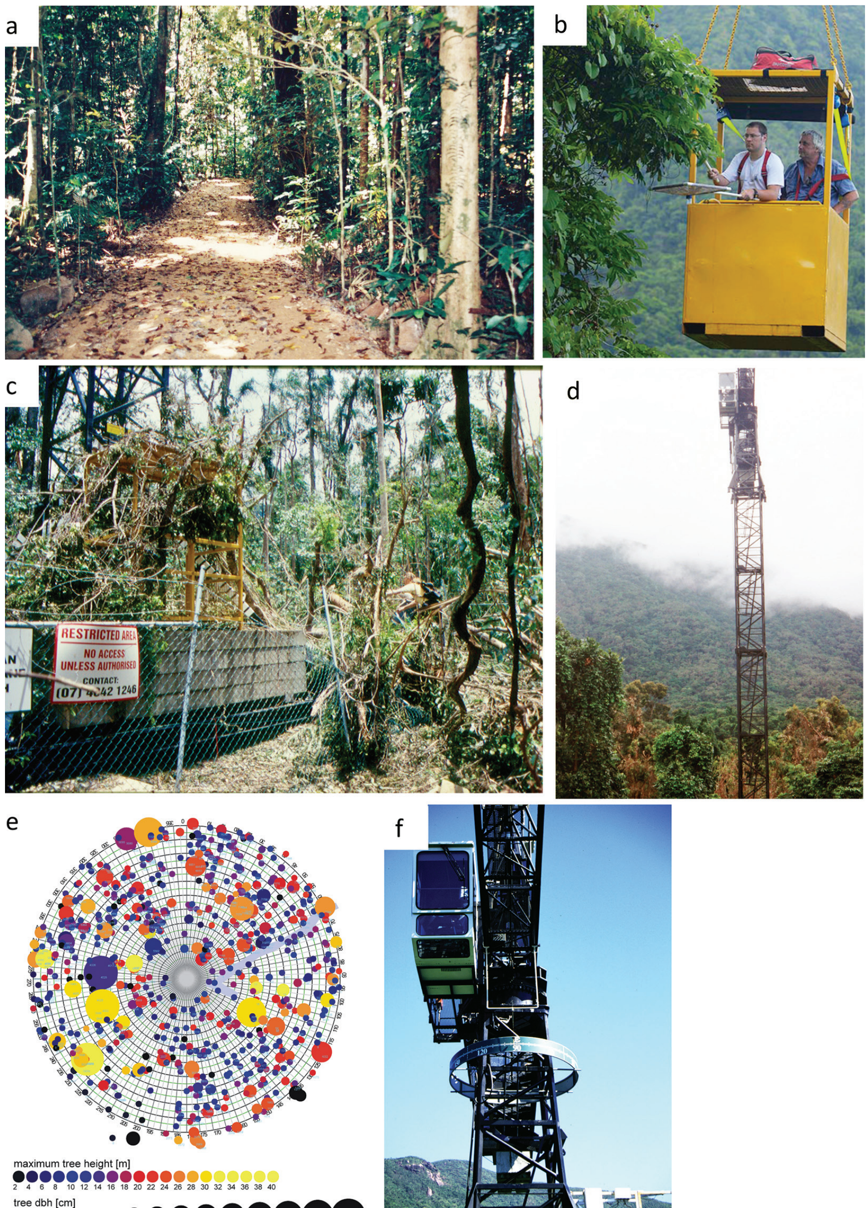

FIGURE 2. (a) Track to the base of the canopy crane; (b) modified gondola showing Dr Carl Wardhaugh collecting insects using a beating tray, with the crane driver using the remote-control unit to operate the crane; (c) the damage caused by Cyclone Rona at the base of the crane; (d) the crane tower; (e) map of the crane site showing the numbered trees, their DBH and height; (f) the metal compass band on the crane tower.

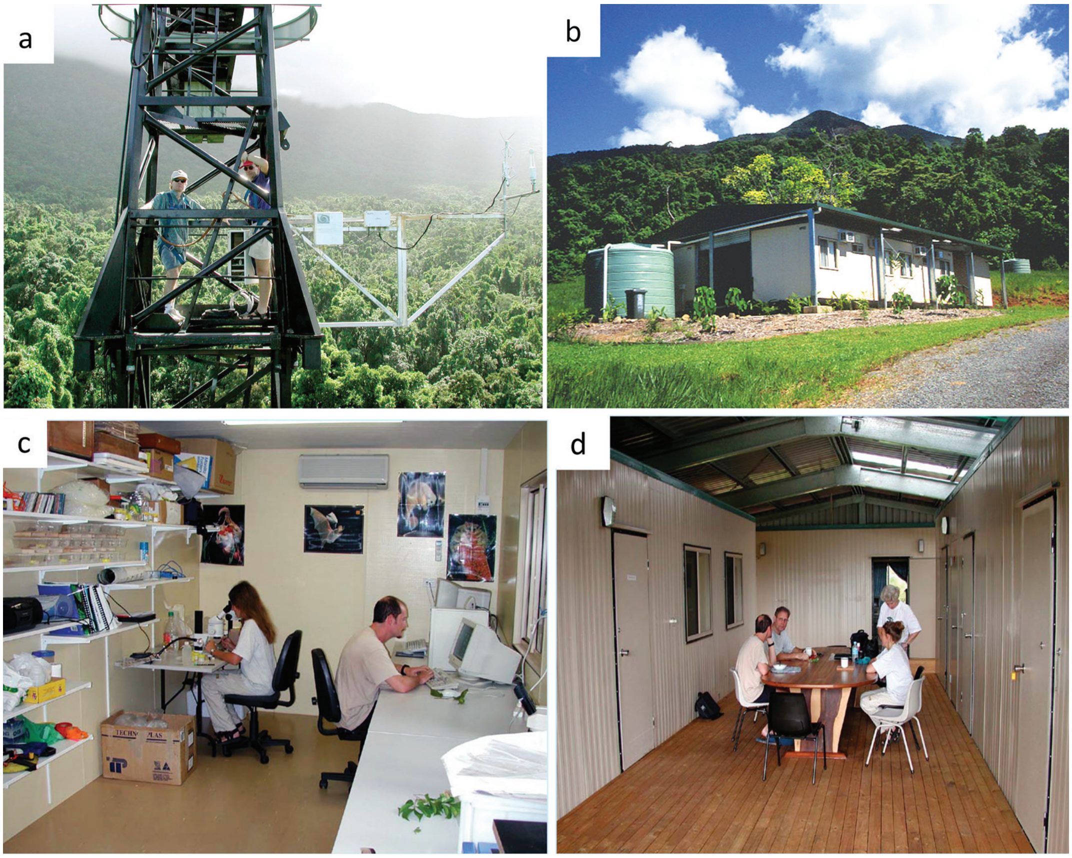

FIGURE 3. (a) Professors Steve Turton and Michael Liddell and the carbon flux apparatus; (b) canopy crane field station; (c) laboratory; (d) community area.

An incorporated company, the Australian Canopy Crane Company, was established to manage the canopy crane. The three universities each had a Director, with the JCU Director, by that time Professor Norman Palmer, also the Chair. NES was the CEO and Ms Carole Peacock, the CRC Business Manager, was the Secretary. Over the next 10 years both UQ and GU resigned their positions on the company, and the facility became wholly owned by JCU. Driving the crane continued to be only by certified tower crane operators, and while several research staff were trained and became certified, there has always been a non-research crane operator on staff to operate the crane.

The Daintree Rainforest Observatory is a Terrestrial Ecosystem Network (TERN) Supersite, and its utility for research has been enhanced by the addition of key infrastructure. This includes weather stations both on the crane tower and outside the forest, a carbon dioxide and water flux station (OzFlux eddy flux covariance) (Figure 3a), sensors measuring soil water content, soil water potential and soil temperature, dendrometer bands on tree trunks, and sap flow sensors.

Research at the Canopy Crane

In recent years there has been increasing call for whole-ecosystem landscape approaches to experimental manipulations including those targeting weather and climate, nutrients, biotic interactions, human impacts and habitat restoration (Fayle et al., 2015). For tropical forests it could be argued that canopy cranes are an essential tool to study whole-ecosystems, for without access to the canopy how can one understand the ecosystem? A number of canopy cranes have been used for single experiments, such as those examining forest level responses to increases in CO_2 or O_3 (Basset et al., 2003), while others have been used for a more diverse range of projects. The Australian crane has been used for a very wide range of studies across many fields of research. Early research focused on forest and epiphyte microclimate (Freiberg & Turton, 2007; Turton & Siegenthaler, 2004), ground truthing remote sensing data (Lucas et al., 2004), height strategies of dicot trees (Falster & Westoby, 2005) and leaf level plant physiology (Franks & Brodribb, 2005; Franks, 2004). More recent studies have included many aspects of plant ecology such as liana ecology (Buckton et al., 2019; Cox et al., 2019). There has been a strong and continuous effort on insect ecology. Blüthgen and colleagues used stable isotope analysis to look at the feeding ecology of ants in the canopy, showing the importance of sap from Hemiptera and extra-floral nectaries for some largely herbivorous ant species (Blüthgen & Fiedler, 2002; Blüthgen & Fiedler, 2004; Blüthgen et al., 2004). There have been surprisingly few detailed long-term studies analysing patterns of diversity in the canopy around the world, but the Australian crane has been used for several. Wardhaugh, as part of his PhD, looked at how insects in the canopy were distributed with respect to different food resources and showed that flowers supported invertebrate densities that are up to ten thousand times greater than on nearby foliage when expressed on a per-unit resource biomass basis (Wardhaugh, Edwards et al., 2013; Wardhaugh et al., 2015; Wardhaugh, Stork, & Edwards, 2012; Wardhaugh, Stork et al., 2013; Wardhaugh, Stork, Edwards et al., 2012). After sampling 1473 beetle species from canopy and ground traps over four years, a key question for global species estimates was resolved, with similar proportions of species being indicators of ground or canopy and with undescribed species being equally likely to be found in either stratum (Stork & Grimbacher, 2006; Stork et al., 2008). Other important insect papers have included those on pollination (Boulter et al., 2006; Boulter et al., 2005), host specificity of fruit-eating beetles (Grimbacher et al., 2014), and vertical stratification of insects in the canopy (McCaig et al., 2020; Stork et al., 2016).

With climate change now being acknowledged as one of the greatest threats to biodiversity and humanity, it is not surprising that in recent years the canopy crane is now being used for a drought experiment where through-fall rain is intercepted with plastic sheeting, hence reducing the amount of rain reaching the ground. This study, led by Professor Susan Laurance, is looking at tree and sapling responses to drought (Tng et al., 2018) and what may kill droughted trees. A new model examining how different guilds of insects respond to drought (Gely et al., 2019) is now being tested, with first results indicating that there are significantly more trees with wood borer damage in the droughted area compared to the control (Gely et al., 2021).

At the time of writing this manuscript the canopy crane is 22 years old, and while normally industrial cranes are installed and dismantled over short periods of time, this is a very long time for a crane to be standing in the tropics and experiencing sometimes more than 6000 millimetres of rain a year. So far it has withstood the elements extremely well and could well continue *in situ* for another 10 years. This description of the research that has been carried out using the crane mentions only a few of the more than 100 publications. Many aspects remain to be investigated, and the long-term data on the site flora and insects and the biophysical data will ensure that it is a critical site for a new range of studies in the future.

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Author Profile

Nigel Stork is an Emeritus Professor at Griffith University. He previously worked for James Cook University, the University of Melbourne and Manchester University. While working at the Natural History Museum in London from 1980 to 1995, he developed a keen interest in the diversity of insects with field work in tropical forests of South America, Africa and South-East Asia. He became the CEO of the Rainforest Cooperative Research Centre in 1995, based in Cairns, where he managed a broad portfolio of industry-led research on all aspects of the Wet Tropics rainforest and its people. He is best known for his research on tropical forest canopies and answering the question of how many species of insects there are on Earth.

Royal Society Reports

Presidential Address 2021

Edges of Science and Challenges of Communication: Confusion in the Community and Finding a Way Forward

Ross A. Hynes

Introduction

We live in a period some researchers are calling an Anthropause, a time of crisis, when humanity can and must rethink and change the way it lives on this planet. However, presently in this period of pandemic, climate change and biosphere degradation, many fields of science are both under attack and employed selectively by different actors. There are many reasons. This address briefly overviews the evolving nature of modern science and explores the misuse and negligent use of science and the demanding strategies we may be forced to follow if we are to urgently and intelligently clarify and implement effective change towards an ethical and sustainable future for humankind and our biosphere.

A Basic Definition of Scientific Method

For science to work, it needs to be carried out using rigorous, consistent and ethical methods. Traditionally in the basic process, an hypothesis (an explanation) is proposed, predictions that best fit that hypothesis are developed, and these are tested to see whether they can be proven false. Is this enough in 2021? Science has evolved rapidly over the last century or so across a wide spectrum of scales along a number of pathways. Here I present a rapid summary of these as I understand them, acknowledging at the outset that this can only briefly flag the scope and depth of the expanding knowledge involved.

Pathways of Modern Science (with some defining characteristics)

The scope of science has changed substantially, particularly since the 1950s. Further, our concepts of scientific certainty and uncertainty have changed dramatically at both the nano and super-macro ends of the scientific scale, examples being the ongoing refinement in our understanding and interpretation of quantum physics and our ever-expanding discoveries and insights in the field of cosmology. Let us briefly explore some features that characterise the main approaches.

Traditional (Predictive – following hypothesis testing)

The traditional method of scientific investigation in the West is widely regarded as stemming from Aristotle (384–322 BC) (Southwell, 2013), through to Newtonian physics (Newton, 1726)[1], and many other scientists and scientific philosophers to Karl Popper (Popper, 1965, 1972) and then to the present. This pathway has defined the traditional disciplines and operates at defined scales, seeking observational understanding, but since the Enlightenment (~mid-1600s) dualistic, 'yes/no' answers. The method is binary, and if the initial hypothesis is falsified, the problem can be redefined in a second hypothesis and the investigation, if justified, starts again. (Nevertheless, most investigations tend to present their findings in terms of orders of confidence using traditional statistics. Statistics, however, can usually

[1] Perhaps the most accessible English translation is: Newton, I. (1999). *The Principia: Mathematical Principles of Natural Philosophy*. Translated by I. Bernard Cohen, Anne Whitman with Julia Budenz. University of California Press.

describe only the variation within the set of data generated by the study. It cannot predict beyond this domain.)

This methodological category covers most of basic science such as interpretations and applications of the classical laws of physics, explanations of how elements combine to form compounds, classical experimental design and investigation in physics, chemistry and biology, and the application of most methods of contemporary statistics. This is the basis for the logical positivism that has dominated much of the science of the twentieth century; i.e., only statements of science and maths are meaningful. Some say it has gone too far in this mode.

This method was questioned in part by Thomas Kuhn. He advanced a view of science as proceeding not by careful hypothesis and testing, but by the formation of paradigms (a term introduced by Aristotle) established when by a consensus of key scientific leaders, the concepts on which they form their assumptions and understandings from associated discoveries allow the development of a framework[2] to progress scientific investigation (Kuhn, 1962). Science, he suggests, advances via radical and abrupt paradigm shifts when the internal contradictions of the prevailing paradigm are unable to explain crucial advances in knowledge. This initiates a scientific revolution and a new paradigm emerges.

Both approaches contribute to the framework within which contemporary science operates and in which relevant theory can place the results of traditional science in context with the traditional peer-review process.

Quantum (Predictive – but with uncertainty)

This field of enquiry examines the strange and wonderful world of sub-atomic particle physics in seeking an understanding of how entities behave at a nano scale and has been the subject of scientific investigation for more than 120 years. Various descriptors have been used: 'weird', 'fuzzy' and 'baffling'. (A nanometre is 10^{-9} metres, i.e. one billionth of a metre.)

In 1900 Max Planck assumed that radiation emitted from a perfectly absorbing 'black body' comes in the form of discrete packages of energy or quanta. Albert Einstein, following this in 1905, assumed that quanta were real and act like discrete, particle-like entities called photons (Brooks, 2021). Heisenberg's uncertainty principle (Heisenberg, 1930) suggests that we can never be exactly sure of both the position and the velocity of a particle; the more accurately we know the one, the less accurately we can know the other (Hawking, 1988). Richard Feynman calls this the "wave-particle duality", the "only mystery" of quantum physics (Brooks, 2021). Investigations at nano levels of scale presently employ big instrumentation, e.g. CERN, and have led to the discovery of the Higgs boson – the first and only elementary scalar particle yet observed. Fuzzy logic science (Kosko, 1994; Brooks, 2021) simultaneously recognises that in the two states, super-positioning cannot usually be verified.

The status quo has five theoretical models (Brooks, 2021), viz.:

1. Copenhagen interpretation (quantum theory is merely a tool for making predictions – keep calculating).
2. Many worlds interpretation (the wave function is real and does not collapse – it splits into many copies of itself, across many worlds).
3. Quantum Bayesianism (provides a way to represent our subjective knowledge, with collapse being a process of updating each observation, and the fuzziness being in our minds).
4. Objective collapse theory (objectively real, quantum reality is independent of the observer, with collapse happening spontaneously with no observers necessary).
5. Pilot wave theory (objectively real and deterministic, with pilot waves guiding the evolution of quantum states into unseen layers of reality – everything is interconnected irrespective of scale).

[2] A scientific paradigm contains all the accepted views, conventions about research direction and how it should be conducted in a nominated field; it involves a discrete system of concepts and thought patterns.

There are pros and cons regarding each theory. It is an emerging and somewhat bewildering field not understood by many scientists and not generally understood by the community. Presently, an important intersection is where nano science and quantum physics overlap. If quantum coherent functionality is achieved, then nano-scale applications can be employed with everyday materials, electronics, medical and health applications, energy applications, environmental remediation and numerous resulting products, e.g. water- and stain-resistant clothing and upholstery, sunscreens (titanium oxide), car paints, nano-glues, solar panels, computers (www.nano.gov; www.understandingnano.com; www.en.wikipedia.org/wiki/industrial_applications_of_nanotechnology).

Big Data–Whole System (Predictive – using big data trend analyses and iterative simulation processes)

Multivariable, cross-scale, non-linear, whole-systems science (Hynes, 2020) identifies major trends, optimises the application of big data and has integrating power, through simulation models based on defined assumptions that are run, often repeatedly, with increasingly tightened assumptions to seek refined outcomes that better reflect reality. The Intergovernmental Panel on Climate Change's (IPCC) Volume 6 (2021) was prepared by 234 authors who emphasise that their conclusions are based on "multiple lines of evidence". The findings of this big data–whole system approach have been presented with progressively greater confidence since IPCC 1 in 1990 (see Figure 1 for representation of temperature change ranges from Reports 4, 5 and 6, which incrementally predict, at higher levels of confidence, the likelihood of our dire situation). This approach has built upon models that have themselves been tightened progressively since intensive attention became more focused on climate science in the 1980s. Supporting these processes at the analytical and interpretative stages are advanced statistical methods, ever-increasing database stores and more rigorous data quality control. The outputs expressed in terms of probabilities can be frustrating for non-expert stakeholders who seek binary explanations.

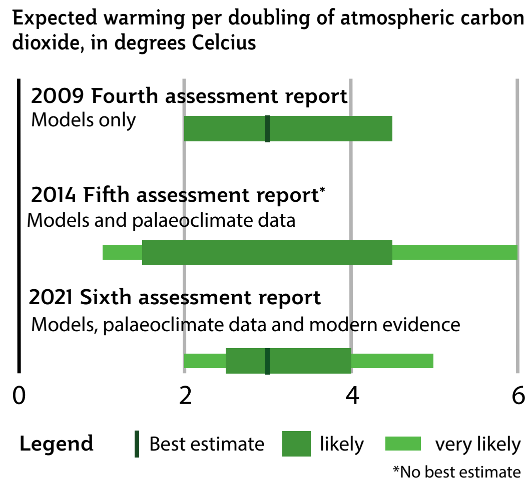

FIGURE 1. A graphic representation of the increasing confidence levels of the likely temperature range predictions as the data employed has been enriched and incorporated in the modelling and analysis process. This is particularly clear between Reports 4 and 6, irrespective of the outcome that indicates the best estimated mean temperature rise is almost identical. (This information has been derived from IPCC Report 6 (2021) and adapted from Anon. (2021, p. 62).)

Most of the current threats to global life-support systems such as global warming, critical loss of biodiversity, pollution and global zoonoses cannot be readily solved using reproducible science methods alone. Why? Because these are whole systems-level problems with solutions needing both the essential findings of reproducible science and the integrating and modelling power of systems science, while being mired in the wider unpredictability of messy human behaviour. A limitation here is that systems science is an immature and simultaneously rapidly developing field.

The effective management and application of big data is integral to success in this pathway. The essential skills needed include: best practices for developing and sharing data, code, software, and entire scientific flows; comprehensive analyses of vast quantities of data on distributed cyberinfrastructure; and collaborative skills in an open science framework that facilitate large-team science (Balch et al., 2020). Parallel to this is an urgent need to develop a strong underlying theoretical base for this level of scientific work. We have not achieved this to date.

As I mentioned in my 2020 presidential address on this theme (Hynes, 2020, p. 176):

> Ecology has recently seen rapid growth, driven mainly by advances in technology, greater access to 'big data' and a growing awareness of the interconnections between humans and natural systems. As a discipline it has expanded beyond traditional themes and reductionist investigations to cover anthropogenic and contemporary data-rich, micro- and macro-scale themes. Increased availability of complex data, coupled with advances in technology and analytical capacities (e.g. the relevant use of super computers) have enabled this expansion from a classical theoretical discipline to a data-driven, multidisciplinary science that can apply knowledge to whole systems and their problems.

Clearly, ecological research themes have shifted significantly over the past four decades (McCallan et al., 2019).

Notwithstanding this, without a strong underlying theoretical base, I re-emphasise here: "… denialists presently have relatively easy targets because the current methodologies do not have theoretical and practical coherence, rational tests of connectedness and verifiable understanding of information-flow between levels of scale in space and time" (Hynes, 2020, p. 182). Nevertheless, we do have a kitbag of increasingly powerful digitally based tools and associated instrumentation that needs to be optimised in this context.

To get astronauts to the Moon and back demanded both traditional predictive (reproducible) science results and integrated suites of logically developed systems, which in this instance meant science-based engineering. We urgently need a similar but more evolved approach to enable us to proactively address the present global challenges. And we need to look beyond just the bio-geo-physical sciences into the power dynamics operating in public arenas that may distort evidence-based policy analysis.

Reconstructive (Retro-predictive)

This path seeks to explain the past as a way of better understanding the present. It covers a wide range of big-picture fields: cosmology and relativity (Einstein, 1905, 1915[3]; Hawking, 1988); tectonic processes, plate tectonics and geomorphology starting with Wegener (1929); archaeology and the evolution of *Homo sapiens* and culture, biological evolution with genetics and DNA (Darwin, 1859; Mendel, 1866; Watson & Crick, 1953), and beyond.

There are epistemological challenges that relate to the fields of palaeontology, cosmology, evolutionary biology, geomorphology, plate tectonics, and archaeology to name a few. However, these are not new: the underlying concepts have been actively addressed in a number of these fields for more than 150 years. This is clearly an authentic pathway to engage in scientific investigation.

Also, the methods and tools available for 'reconstructive science' are becoming more powerful. Examples include DNA analysis in evolutionary biology of *Homo sapiens* and other genetic studies of many other species; and the increasing development of science-based technologies related to cosmology such as higher-powered space-based telescopes, Solar System probes and remote on-surface, technically versatile 'explorers', to list just a few. And these, when linked to the exponentially increasing power of relevant expanding digital databases, make the future of 'reconstructive science' exciting and worthwhile.

Contemporary 'reconstructive "origins" science' uses intensive, prolonged and creative scientific method in conjunction with relevant modelling and statistical methods (e.g. in certain cases, Bayesian statistics) to retro-predict how geological formations, biological evolution, archaeological human cultural evolution, the Solar System, past climates (using for example the planned one-million-year-old ice core by the Australian Antarctic Division), etc., respectively evolved or originated. Notably, the scientists involved and the scientific methods and knowledge bases being developed and implemented are quickly achieving greater rigour over time.

Both 'whole-system' and 'reconstructive' sciences need to critically address issues of time, space and scale. In this setting, twenty-first century challenges can be confusing to our wider society as research

[3] Perhaps the most accessible reference is: Einstein, A. (1952). *The Principle of Relativity: A Collection of Original papers on the Special and General Theory of Relativity*. Dover.

groups can selectively employ methods across pathways to strengthen the overall research strategy when investigating these complex problems, particularly in the applied sciences such as medicine, agriculture, and biodiversity conservation.

The science of the big problems, such as climate change, biosphere degradation and pandemics, encompasses all pathways but with varying degrees of application and certainty. The average person usually prefers clear, simple answers, which are presently literally impossible to provide. As explained, a further difficulty is that the status of underlying theory is uneven across the pathways.

Additionally, a sobering current factor in gaining acceptance of scientific knowledge relates to the dynamics of some of those with wealth and power, where facts and the sciences often have little to do with their success in getting their agenda implemented.

This overview is clearly non-exhaustive. In this address I have not included many areas of scientific activity that are worthy of further consideration, e.g. the science underlying AI and the longer-term potential impacts on human society; nor have I commented on chaos theory, catastrophe theory, Occam's razor or even offered a more penetrating discussion on the epistemology of science. Further, I have not here addressed the acknowledgement and incorporation of First Nations people, their knowledge and epistemology into contemporary science.

However, it is possible to identify some substantive trends and to summarise some in tabular form. The scope of scientific research is obviously changing and continues to change (Table 1). The comparisons presented acknowledge the continuity of traditional science methods, but also show that there is an ongoing exploration, evolution and consolidation of novel and future approaches of scientific research, their outcomes and potential user-relevant deliverables.

Table 1. Changes in the approaches to science and knowledge in the 1990s and beyond (adapted from Gibbon et al., 1994: in Hynes, 1998, 2015).

Ongoing traditional approach	Strengthening of new and future approaches
• Traditional disciplinary and cognitive science	• Multidisciplinary and participatory within a social, economic and application context
• Homogeneity of focus	• Heterogeneity of focus
• Hierarchical	• Heterarchical and transient structures
• Quality control by peers	• Quality control through social, economic and political accountability, reflexive and multi-dimensional collaboration: – supply and demand of knowledge variable – production of knowledge rather than science
• Economy of scale of operations within disciplines	• Economy of scope across disciplines: – solutions beyond any single discipline
• Communication through institutional channels: – technology transfer	• Communication through involvement of others: – technology interchange and linkages of skills and instructional sites together
• Research staff on permanent employment	• Research staff transient, regrouping for particular issues
• Management by control	• Management by facilitation
• Individual agencies have defined roles and objectives	• Agencies have fuzzy boundaries and move into and out of alliances
• State-wide and centralised decision making	• Regional and catchment-based decision making

The Weakening of Bridging Communication Methodologies

The rundown of agricultural extension and nature conservation interpretive services has severely affected our capacity to translate science into practice, particularly in regional and rural areas. Importantly, both agricultural extension officers and conservation interpretive officers were the eyes and ears of government and were able to feed information from rural communities into government agencies and vice versa:

> Extension, technology transfer influencing farming practice, is now very much in the hands of consultants who focus on individual farm businesses. Government-based extension services were also focused on education. I suspect that this is now very much lost (David Lloyd, former principal pasture scientist DPI, pers. comm., 2021).

That said, the complexity of the information environment in 2021 enables an immediate capacity to unthinkingly react to sound scientific information with fake news, cancel culture messaging and conspiracy theories, and exposes the limitations of earlier communication strategies.

The recognition that information does not clearly satisfy the principles of conservation and cyclical flow (Hynes, 1979) is seldom acknowledged, and this has never been more obvious than in the present.

Further, filters (sender, receiver and combination) that degrade the quality and effectiveness of communications (Hynes, 1979) seriously reduce the efficacy of science understanding and uptake. Filters in our current context are significantly more complex, and accurate, fair and trustworthy communication is substantially more difficult to attain.

In an earlier era, attitudinal and behavioural change was usually perceived as moving through four stages (Hynes, 1981). In very simple terms, typical attitudinal and behavioural changes usually advanced often slowly, but sometimes quickly:

- No talk → No do; Talk → No do; Talk → Do; No talk → Do;
- 1. No communication → No attitudinal or behavioural change.
  2. Communication → No change.
  3. Communication → Change.
  4. No communication → Attitudinal and behavioural change adopted (Hynes, 1981).

Understanding how attitudes and behaviour may change and participatory involvement of stakeholders in identifying relevant, practical solutions to enterprise-related problems can be crucial in linking the people on the ground with scientific research and its application.

However, in the digital age where the tendency for any scientific explanation that is contrary to a particular group's worldview rapidly incurs unjustified outrage, the above model no longer provides an adequate basis for understanding. We need to develop relevant communication techniques and strategies for our time and its technological context. The ongoing enrichment of translational methods in science is supported by an increasing body of published knowledge. The information presented on the following topics is limited to personal experience. I consider the two methods examined below, viz. Action Research and Translational Science, worthy of deeper inquiry as relevant contemporary bridging approaches.

Action Research

Critical elements at the centre of participatory action research (PAR) usually involve three actions, i.e. 'plan … act … reflect'. However, these actions have been applied in different sequences and can express different researchers' experience. These include: the continuing 'plan-act-observe-reflect' cycle; the 'observe-reflect-create-apply' model and the experimental learning mode 'plan-action1-reflect-generalise – re-plan-action2-reflect-generalise' sequences (Hynes, 1999a). Ian Plowman (pers. comm., 2000) considers it is more realistic to think of the process as a continuing spiral rather than a series of cycles. The key to PAR is reflection on current practice (McTaggart, 1991, 1998). I have respectively used the 'plan-act-reflect' approach in a two-cycle strategy with the Desert Uplands Build-Up and Development Committee in two case studies (Hynes, 1999a), and the 'observe-reflect-create-apply' approach with the Savannah Guides (Hynes, 1999b).

Regarding the ongoing perceived disconnect between scientists and farmers, I quote Dr Jim Davie, former research manager and senior researcher QNPWS:

> In my view the basis for farmers' complaints with scientists is that scientists tend to research the same questions generated by their own disciplinary and theoretical foundation. Through the Land Care movement of the 80's farmers gained a stronger voice at the land management decision-making table and were able to influence the way federal money flowed. For a while they were successful in taking control – much to the frustration of the old school of DPI scientific business. Then scientists wrested it back and the farmers fell out of the loop again.
>
> I think by acknowledging the value of a model where scientists work with farmers to identify the scientific questions that farmers grapple with but cannot enunciate in terms that science can address, would be very productive. This is the model central to the approach of the MS Swaminathan Research Foundation in Chennai, India. Perhaps that [approach] would take the debate somewhere positive. Action Research and Translational Science! (J. Davie, pers. comm., 2021).

Translational Science

This is the nexus where knowledge meets action. It is situated at the intersection of a broad spectrum of institutions and information pathways where scientists, practitioners and stakeholders work together to build trust and develop ideas, products and outcomes that are accessible and actionable. Translational ecology, for instance, must comprise more than clear speech, lexical equivalence and good intentions. To be effective it requires understanding of the languages, cultures and currencies of policy, management and the societies in which relevant decisions are made. Here, real-world contexts need to be understood to enhance the likelihood of acceptance and then good application (Enquist et al., 2017; Hynes, 2020). Parallel integrating and communication strategies are needed for all streams of scientific enterprise if workable, community-owned applications are to succeed. Clearly, approaches such as those overviewed are needed across the full spectrum of scientific endeavour if we are to ethically strengthen the quality of science communication to the wider community.

Peer Review as a Foundation of Public Trust in Science

It was in 1665 that the Royal Society, based initially in Oxford University and then in London, published what was arguably the first scholarly journal dedicated to science: *Philosophical Transactions, Giving some Account of the present Undertakings, Studies, and Labours of the Ingenious in many considerable parts of the World*. The first editor wrote that "We must be very careful as well of regist'ring the person and time of any new matter, as the matter itselfe, whereby the honor of the invention will be reliably preserved to all posterity" (Oldenburg, 1664). This crystallised the primary distinctive features of a scholarly journal: registration (date stamping and provenance), certification (peer review), dissemination and archiving. It is on this foundation that the body of scientific knowledge has expanded, article by painstaking article, to the present day.

In other words, scientific knowledge is recorded, validated by knowledgeable experts and built into the foundations of future knowledge. Peer review is not a guarantee against fraud or error, for weak research may be exposed only after experiments are repeated by others, and sometimes this may take years or decades. But peer review is a first line of defence, a filter that sieves out most weak research and improves even good research. Understandably, it is of ongoing concern to the science community that the cases of substandard research that come to public attention only give weight to those who find scientific advices inconvenient.

Most people do not have a strong or rigorous understanding of the scientific process and its ongoing evolution. Scientific research, whatever the path, is a dynamic process seeking to find a closer, more accurate understanding of reality. So, scientists learn to live with a degree of ambiguity regarding their work and its interpretation. Each new finding usually takes human knowledge one step closer to a more complete understanding. Sometimes the scientific process leads up blind alleys and mistakes occur. Science learns from such mistakes. However, the wider public generally prefer definitive, black-and-white answers. A subset of society is threatened and frustrated by uncertainty and by whatever inconvenient interim truths may be revealed by scientists, even though such findings are steps on the way to a deeper understanding of the subjects or problems under investigation.

An opinion piece by the Chief Executive Officer of AgForce, Queensland's peak body for broadacre agriculture, in *Queensland Country Life* on 1 July 2021, (Guerin, 2021a, p. 18), displays this propensity to cast doubt on inconvenient scientific information. The article commences unremarkably enough:

> We live in a confusing time – where opinion-dominated social media and sophisticated marketing tactics overshadow seemingly outdated virtues like reason and fact.

The article then proceeds to rail against the Reef Scientific Consensus Statement (Anon., 2020; https://www.reefplan.qld.gov.au/science-and-research/the-scientific-consensus-statement), used by the Queensland Government as justification for a raft of regulations designed to protect the Great Barrier Reef. The government's website explains that the Consensus Statement "draws on independent, peer reviewed research from more than 1600 reports. A panel of 48 experts from a range of disciplines (for example biology, ecology, economics and social science) compiled the document".

The conclusions of the Consensus Statement have been unpalatable to AgForce, which disparaged it as peer-reviewed not by independent scientists but by "friends and colleagues close to them … to support the views of the gang of 48 – most of whom were dependent on reef funding for their jobs" (Guerin, 2021a, p. 18).

AgForce is correct to observe that government reports, even when written by credentialled scientists, are not necessarily peer-reviewed by anonymous, disinterested referees, as is the norm for scientific journals, but to dismiss the Consensus Statement in such ad hominem terms displays a worrying lack of trust in the honesty of people and public institutions established to translate science into policy. This column could be dismissed as a piece of political theatre, except for the announcement that:

> This is why AgForce is so hellbent on getting an Office of Science Quality Assurance up and running – to validate the authenticity of ALL science, not only that related to the reef (Guerin, 2021a, p. 18).

My response was published in *Queensland Country Life* on 22 July. I argued that:

> Our era is saturated with 'spin'. It is commonplace that politicians, commentators and lobbyists offer distorted or partial facts as the 'real truth'. If rural communities are to resolve the complex challenges cascading upon them, they must have access to trustworthy knowledge, the best antidote to spin.
>
> In arguing for an Office of Science Quality Assurance to "validate the authenticity of ALL science" relevant to Queensland, the CEO of AgForce may be desiring to improve the reliability of scientific knowledge, but such an office is likely to have the diametrically opposite effect.
>
> The publication of the first scientific journal, in 1665, by the Royal Society of London, ushered in an era of rapid expansion of scientific knowledge that continues.
>
> The core tool in this expansion of knowledge has been the peer-reviewed journal. The entire body of scientific knowledge rests on a commitment to peer-review, reproducibility and caution in drawing conclusions. The Royal Society of Queensland stands in this proud tradition and has recently published the 128th edition of its peer-reviewed *Proceedings*.
>
> AgForce, a partner since May 2018 with the Society in the Rangelands Policy Dialogue, seems to be proposing that only scientific knowledge approved by the government should find its way into policy. Every significant scientific finding would become fodder for partisan argument. Independent investigation would be suffocated as only state-endorsed research programs would be deemed worth pursuing.
>
> It would not be possible to constitute an Office of Science Quality Assurance without political complexion. The office would be vulnerable to stacking with political appointees, meaning that the direction of scientific research would seesaw from one administration to another as

> partisan enthusiasts grabbed the privilege of appointment.
>
> A new office would also undermine the traditional capacity of the public service to provide trustworthy advice. Any disparity between advice from these two sources would be elevated to ministers to resolve, further politicising what ought to be objective scientific findings …
>
> Through peer-reviewed publication, the entire international science community strives to avoid distortions and to bring its expertise to bear on the challenges facing humanity from the pressures being placed on the earth's resources. Yes, like all human endeavours, the process has shortcomings and lapses, but the remedies lie more in reforming the procedures by which research is funded than in adding another state-sanctioned layer of procedures on top (Hynes, 2021a, p. 21).

The CEO of AgForce responded in a column published on 3 August:

> But from where AgForce, other industry groups, and rural communities and producers stand, science has been in bed with political parties of all colours and stripes for decades …
>
> Science has, in fact, with each passing decade and astonishing advancement, become less trustworthy because of the very 'spin' Dr Hynes would like politicians, commentators, and lobbyists to avoid …
>
> In calling for a national Office of Science Quality Assurance, AgForce and industry groups are pursuing a reform into 'trustworthy knowledge', untarnished by politics, activists, or funding-dependent scientists.
>
> Why any scientist worth his salt would question that level of independent oversight and rigour should perhaps be the subject of its own independent analysis (Guerin, 2021b; https://www.queenslandcountrylife.com.au/story/7367482/science-and-politics-already-joined-at-the-hip/).

Interpreting this as a direct challenge on the independence of the Society, I responded on behalf of its members and the Queensland scientific community with a column published on 10 August. In it I claimed that:

> AgForce has misunderstood the real gap in the suite of bodies working at the interface between science and farming. Science arrives in piecemeal findings, presented via articles in disparate journals and via official reports from various jurisdictions. It arrives at different scales, different levels of complexity and with widely varying implications for practical action … A multilateral statutory authority established to produce comprehensive assessments of resource condition and trend, then to advise governments independently on opportunities and limitations for future land use, using a "whole systems" perspective, is likely to enjoy enthusiastic support from the scientific community (Hynes, 2021b, p. 19).

The need for a new trustworthy agency that would translate science as distinct from validating science, a traditional role of the peer-reviewed journals, was raised during the Rangelands Policy Dialogue co-organised by the Society in 2019 and 2020. This proposition, however, has gained little public traction and does not seem to be on the agenda of bodies representing farmers, who would have much to gain from a more orderly, transparent and trustworthy process of land-use decision making. By contrast, momentum seems to be building for a new office to cast judgement on scientific advice sourced from research. At the July 2019 Convention of the Liberal National Party in Brisbane, a motion was passed calling on an incoming LNP government to establish an Office of Science Quality Assurance (Birmingham, 2019). Reportedly, the National Party's Federal Council shortly afterwards in 2019 endorsed a motion to establish a national scientific quality assurance agency (Johnson & Walker, 2019). On 14 October 2021, the Institute of Public Affairs launched an appeal for funds for a "Project for Real Science" (https://ipa.org.au/).

So, far from building public institutions that will use peer-reviewed scientific knowledge as a basis for public policy making and decision making, we now see a campaign to undermine confidence in peer-reviewed science and/or in the credibility of scientists employed in public agencies whose role involves interpreting peer-reviewed science.

The published advocacy by AgForce, associated conservative parliamentarians and the Institute of Public Affairs expresses little concern about the parsimonious funding for scientific research, casualisation of the scientific workforce, the corporatisation of universities or the underfunding of public interest scientific bodies that can explain a great deal of such weaknesses that may exist in the conduct of scientific research in this country.

As my predecessor Dr Geoff Edwards has observed (Edwards, 2018, pp. 73–74):

> Science, like any other human endeavour, is an imperfect process. What makes science robust, however, is its relentlessly self-critical approach. Like opposing barristers, scientists continually challenge each other, but with consensus gradually building over time as the position best supported by evidence prevails.
>
> Science replaces private prejudices with publicly verifiable evidence. Admittedly, some journals, notably those termed 'vanity journals', are known to take shortcuts with editorial review. It is also true that in some disciplines, false leads can be pursued for years before being invalidated. But none of these imperfections should be used to undermine public and political trust in the essential veracity of scientific research.
>
> No-one close to the editorial process for a journal run by a not-for-profit society like our own, conducted by unpaid volunteers, evaluating articles by authors not paid for their submission and printed at the expense of members, could doubt that the entire process is driven by a desire to expand knowledge in the public interest. Nor could they doubt the earnestness with which those responsible seek to uncover and eliminate mistakes.

David Lloyd, an author in our *Proceedings* Volume 127, has expressed this astutely:

> I do agree that an office of 'scientific oversight', as apparently suggested by Agforce, would be completely regressive. The broad, world-wide, peer review process for scientific publication is time-honoured, underpinning the landmark research done across the decades in Australia and other countries, right up to the present … (David Lloyd, pers. comm., 2021).

Concluding Remarks

There are many techniques that conduce towards reliability of scientific knowledge, as well as dispatching research reports to externally independent referees. Internal institutional reviews, commitment to ethical codes of practice, embedded research ethics, coalitions of qualified, critical, analytical and sceptical reviewers, disciplinary and cross-disciplinary conferences and seminars, parallel development of methods and theory have traditionally shaped the preparation of research reports for publication and will continue to do so.

However, the communication of scientific findings to wider society, relevant stakeholders and key decision makers largely lies outside these procedures. This is an ongoing, seemingly formidable challenge. Clearly, there is a pressing imperative to improve the transfer of scientific knowledge and enable end-users to action useful findings for the betterment of all society.

A rigorous, evolving framework for fact-checking science communication for wider audiences is under development, viz. the European Union-initiated ENJOI[4] project, which has grown out of the need to counter the misinformation, i.e. the "Infodemic" (Alam & Chu, 2020), which has caused great confusion and often tragic consequences during the COVID-19 pandemic.

Standards, principles and indicators for effective science communication to the community are being rapidly assessed, developed and strengthened. These include criteria and performance indictors:

- Ethical rules: Avoid being an advocate; be fair to differing viewpoints.
- Rigour: Use reliable, rigorous and relevant sources; fact-check uncertain text.
- Sources: Persistently use reliable, rigorous and verifiable sources.
- Networking: Establish good networking with all key actors.
- Target audience: Approach the communication as a service to the public.
- Engagement: Ensure effective, ethical bi-directional communication.
- Newsworthiness: Present new, impact-rich knowledge.

[4] Engagement and Journalism Innovation for Outstanding Open Scientific Communication (EU).

- Perspective: Set the topic in a temporal, scientific and social context.
- Message and language: Use clear, correct, comprehensible language.
- Story telling: Tell a story whose subject represents the scientific data to be conveyed.
- Media format: Use innovative, creative formats to engage the widest audience.
- Video and audio: Plan content and practice before producing.
- Scientific posters: The title is the main conclusion; use a flow chart format.
- Social media: The pace and dynamics of conversations differ across platforms; it is essential to adapt strategies to the public's habits and use in this complex digital environment.
- Infographics: Include at least one main theme, e.g. causal properties, causal processes, a key scenario, statistical analyses, measures of physical magnitude.
- Structure: Clear and ordered, with a focus on a central idea or a few key points.
- Impact: Pay attention to life-related issues and what can be done to solve problems.

This process and the resulting strategy and communication framework can assist in reaching the necessary standards to counterbalance fake memes and misinformation that so easily spread in our time. We need to use it or a similar effective approach when communicating Queensland- and Australia-wide science.

Society-wide, persistent, clear and accurate communication and public education are essential in developing and maintaining the public's trust in science. There is required a dedicated approach to encouraging and educating politicians and bureaucrats on the essential need to consistently incorporate rational scientific information into their policies and decisions. This is a very difficult process in a world where people are exposed to short or obtuse media or internet grabs. Nevertheless, we need to urgently develop and apply the best strategies we can identify. This is a demanding task, especially for civil society bodies lacking the resources of government and business.

The framework presented above suggests a path that could substantially increase the effectiveness of science communication to the wider community. And therein lies another lesson that we can draw from the foregoing narrative: the lack of resources for those involved in and defending public-good science lies at the heart of many of the ills that are perceived, both by scientists and their critics. Lack of resources is a policy setting that is open to policy remedies.

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[5] In 1905 Einstein published five papers; in the first he proposed that light is not a continuous wave, but consists of localised particles.

[6] Einstein presented his Theory of General Relativity on how gravity affects the fabric of space and time; this expanded his Theory of Special Relativity published 10 years earlier.

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[7] Four full translations in English of the 'Principia' have appeared, all mainly based on Newton's third edition in English of 1726. These comprise the 1st by Andrew Motte (1729); 2nd by I. Bernard Cohen, Anne Whitman with Julia Budenz (1999), University of California Press; 3rd by Ian Bruce, published with other Enlightenment mathematicians (last updated 2021); and the 4th by Charles Leedham-Green (2021). Motte's version was timely as Newton died in 1727.

The Royal Society of Queensland Annual Report 2020–2021

Overview

This report covers the period from 16 November 2020 to 30 October 2021. The Society's work program has been less intensive than in the previous year. Uncertain, variable restrictions on movements of personnel on account of COVID-19 have discouraged the Society from attempting to convene face-to-face meetings.

Just as Council reported last year, the Society remains in excellent intellectual health but precarious financial health.

Corporate Affairs

During the year the continued engagement of Mrs Pam Lauder as part-time (2–3 hours per week) Administration Coordinator and John Tennock on a retainer as Webmaster for both the Society's website and the Queensland Science Network (QSN) website have enhanced the Society's administrative capacity. John Brisbin continued as Webmaster of the Rangelands Queensland website. Tony Van Der Ark has continued as Membership Coordinator. Dr Anne-Marie Smit resigned as Royal Society Newsletter Coordinator on account of a career transfer to New South Wales. Col Lynam continued as Editor of the Queensland Science Network Newsletter and took up the role of Coordinator of the Research Fund. Ms Shannon Robinson, Queensland Museum's Librarian, continued in her role as Society's Honorary Librarian.

Associate Professor Julien Louys of Griffith University offered to fulfil the position of Honorary Editor, responsible for the annual issue, volume 129, of the *Proceedings*. This does not include editing the long papers produced under the Rangelands initiative (q.v.).

The Royal Society of Queensland Council

The Council elected at the Annual General Meeting on 10 December 2020 comprised Angela Arthington, Heather Douglas, Geoff Edwards as Vice-President, Communications and Policy, Andy Grodecki, James Hansen as Secretary, Ross Hynes as President, Trevor Love, Col Lynam as QSN Newsletter Editor and Joseph McDowall as Treasurer.

No face-to-face meetings of Council were held this year. Three meetings were held by Zoom – on 4 March, 12 August and 23 September 2021. Most issues are debated via email traffic, telephone and Zoom.

Finances

The Society exhausted its accumulated reserves during the reporting year, primarily to fund the publication of its *Proceedings*. The officers have been unsuccessful in securing significant general-purpose sponsorship.

The Society's banking accounts are in the process of being consolidated and transferred from the Commonwealth Bank to Bank Australia. The requirement for two signatories for cheques remains. Internet transfers can now be set up remotely by two authorised Councillors (whereas the Commonwealth Bank insisted on two signatories being in a branch at the same time). This has streamlined and expedited payments as well as access to banking records. Membership fees were reviewed and a new structure established, as well as provision for Supporter categories. The practice of supplying free copies of the *Proceedings* has been reviewed. Members can access this information electronically cost-free, but members desiring print copies are now charged for them. Adherence to the style guide for the *Proceedings* is now to be more strictly enforced. Authors whose papers require exceptional additional editorial work and complex typesetting now are expected to pay the additional costs involved in preparing for publication.

Membership Roll

At 30 October 2021, the Society has 133 paid-up and honorary members, one more than as reported last year. There are seven Honorary Life Members: Dr A. Bailey, Dr J. S. Jell, Dr J. O'Hagan, Ms C. Melzer, Prof. C. Rose, Mr Craig Walton and Prof. Dilwyn Griffiths. Science lost Prof. R Specht, Honorary Life Member, during the year.

Council resolved to introduce a new form of voluntary financial support in Platinum, Gold, Silver and Bronze Supporterships, costing $1,000, $500, $250 and $100, respectively. Several current and new members have taken out Supporterships and this has made a highly substantial difference to the Society's finances.

Annual General Meeting

For the first time the Annual General Meeting was held online, on Thursday 10 December 2020. Six members attended in addition to Council members.

Awards

Dr Russell Reichelt AO was honoured in the Australia Day Awards 2021.

Members' Interests Page

A list of members with their fields of particular interest is available on the "Members' Page" of our website. The purpose of this new facility is to allow members to identify other members with scholarly or curiosity-led interests matching their own. This page is accessible only by financial members of the Society via a password-protected login. The table is populated on an opt-in basis. By the end of the reporting year, only 19 members had availed themselves of this facility for networking. Responsibility for broad Society networking remains that of the office-bearers.

Information Management

An offer by Councillor Col Lynam to prepare a knowledge management strategy, covering in particular the RSQ library, the archive of *Proceedings*, social media and the enduring items assembled for the Newsletters, was accepted.

Publications

Proceedings of The Royal Society of Queensland

The annual issue of the *Proceedings of The Royal Society of Queensland*, volume 128 containing 11 refereed papers, was completed on time and printed in January 2021. Given that all articles are now available free of charge online, a reduction in the cost of printing copies for His Excellency our Patron's library, statutory deposits, Queensland Museum and other presentation purposes was expected. However, a decision to give free copies to all authors or lead authors reduced the savings.

There will be savings in future on the cost of posting complimentary copies to most of the subscribing overseas libraries, who were advised during the year that all articles are now available online. International free exchanges have been scaled back, with only four International Free Exchanges and six Australian Free Exchanges receiving printed copies.

The *Proceedings* are uploaded to six different sites including Informit; BHL Biodiversity Heritage Library; Scopus (BD Elsevier); State Library of Queensland; the National Library; and CrossRef.

Life Members are sent free copies of the annual *Proceedings*, as are Council Members. With the introduction of Membership Supporters, those who pay Platinum receive a free copy for three years; Gold, for two years; and Silver, for one year. There are eight Standing Orders including three internationals. There is a Master List of recipients now available for the distribution of the *Proceedings*.

A Special Issue on *Preventative Health* has been foreshadowed but will be delayed. Volume 129, the 2021 annual issue, is on track to be completed and printed by the end of the year.

On the advice of its Honorary Editor, during the year the Society registered as a member of CrossRef, the international NGO that assigns DOI numbers (document object identifiers). All articles published in future *Proceedings* will be accompanied by a DOI. The Society was gratified to receive advice from the National Museum, Victoria, which is managing a project on behalf of the Biodiversity Heritage Library, USA to apply DOI numbers, that it would work through our archive of *Proceedings* back to its origin to assign DOI numbers at no charge to the Society.

Newsletters

Fourteen Members' Newsletters were produced during the reporting period, against a target of monthly communications. These Society Newsletters are privileged to members. All Newsletters are available on a members-only section of the website.

The mailout software reports that only about half of the members open their Newsletter email and fewer click on the link that downloads the PDF.

With issue No. 7 of the Newsletter for the Queensland Science Network, completed in August 2021, this Newsletter reached its anniversary. It continues to receive warm praise. The QSN Newsletter is distributed to leaders of the member groups with an invitation to pass it on to their mailing lists. It is also published on the QSN website https://scienceqld.org/category/member-groups/. About 27 members of the general public have subscribed. Given that this is a newsletter of general science with now an established track record (issue No. 8 was distributed during October 2021), it is considered appropriate to embark on wider advertising to broaden the distribution and improve knowledge of the activities of the 26 member groups. A descriptive announcement was sent to the Department of Education with a request to distribute to teachers in the public and private school networks. A regular feature now of the Newsletter is a listing of other newsletters, which by itself is a valuable scientific resource.

Occasional Papers

Council resolved to open a line of peer-reviewed "Occasional Papers" for scholarly-type articles that did not fit the format that made them eligible for the annual *Proceedings*, or were outside its scope. Council had in mind, in particular, the half-dozen long papers written for the Rangelands initiative in October 2020.

Education Project

No progress was made during the year on development of new materials for the senior Queensland science curriculum as no funding was secured.

Events and Activities

On 15 June 2021, a reception was hosted at Government House by our Patron, His Excellency the Governor of Queensland, the Honourable Paul de Jersey AC CVO, to officially launch the five volumes of *Proceedings* published in 2020, and to invest Prof. Dilwyn Griffiths and Past President Mr Craig Walton as Honorary Life Members.

FIGURE 1. Two annual volumes and three Special Issues on display in the reception room at Government House, 15 June 2021 (Photo: Office of the Governor).

An online themed members' discussion on origins science scheduled for 27 July was postponed to allow further refinement of the discussion paper that is to serve as the basis for the debate. The second in what Council hopes to be a series of themed discussions was held on 21 October on the proposal for an Office of Science Quality Assurance (see Commentary below). A third on carbon trading and the Land Restoration Fund was scheduled for November.

Dr Geoff Edwards and Dr Peter Dart made presentations on 3 September at a Griffith University online and virtual workshop *Repairing the Environmental Deficit in the Land Management Sector* organised by members Dr Philippa England and Dr Nelson Quinn.

Rangelands Policy Dialogue

The Rangelands Policy Dialogue launched in July 2019 was paused at the end of December 2020, following a workshop on 21 December attended by some 20 invited guests. The workshop was held at Griffith University, Southbank, per kind favour of Dr Philippa England and colleague Ms Melanie Davies. This workshop was recorded and summarised by Dr Peter Dart.

The online discussion group remains open. However, participants were advised that the discussion was being placed on hold to allow the Society to assemble sufficient funds to engage a remunerated executive officer, as the initiative warranted full-time executive support and because the capacities of the office-bearers of the Society were required for other initiatives.

At the end of the reporting year no funds had been sourced for this purpose, and the Dialogue remains in limbo.

Stewardship of Country

The Society participated actively in the organising of a series of webinars in February–March 2021 by the Royal Societies of Australia, with three members (John Brisbin, Dr Geoff Edwards, Dr Nelson Quinn) serving as members of the steering committee and John Brisbin acting as master of ceremonies. Some of the presentations were subsequently edited and published by the Royal Society of Victoria.

Commentary

On 1 July 2021, *Queensland Country Life* featured a provocative opinion piece "Fear, not facts, now shapes views of most" by the CEO of AgForce, arguing in favour of a new Office of Science Quality Assurance to validate all scientific input to public policy-making. The President responded with a rebuttal published as a Letter to the Editor on 22 July, leading to another column by the CEO on 3 August and another Letter to the Editor by the President on 10 August. The theme of an Office of Science Quality Assurance was the subject of the online meeting of members on 21 October.

RSQ and QSN Websites

During the year the *pro bono* developer of the Society's website advised that they wished to surrender the site and transfer the code to our own host server, HostPapa.com. This was done successfully with no disruption to the online presence.

The site is written in WordPress and the version used had not been updated since establishment. Following enquiries, the Society engaged Johanna Follett of Net Duet to update the version, a process that required an experienced WordPress developer as it ran the risk of breaking our membership roll, payments gateway, *Proceedings* archive and search engine. Ms Follett has offered to complete the task *pro bono*.

Webmaster John Tennock has advised that it is time to review the structure of the site as it has some awkward features including unnecessary duplication. An invitation to members (via the Newsletter) to contribute suggestions towards a revamping of the site did not attract any feedback.

Research Fund

Consistent with the commitment in 2018 to fund grants in three successive years, a fourth round of grants to a value of $5,000 was announced, closing on 30 October. A charitable bequest from the estate of the late Professor Trevor Clifford for another $5,000 was received. Council resolved to expend this amount rather than add it to the reserve. It is uncertain whether this will be via a special Round 5 or via award to a second winner from Round 4. The capital reserve of $40,000 remains intact. Council records its thanks to the

Coordinator and to two members who offered to serve as technical assessors.

There has been a requirement, under the *Public Ancillary Fund Guidelines 2011* promulgated under the *Taxation Administration Act 1953*, for the Society to expend at least $8,800 per annum from its Research Fund every year from 2021–2022. The statute also requires a minimum of 4% of total Research Funds to be expended each year if 4% exceeds $8,800.

Final Words

Despite the best efforts of the dedicated members of Council and other office-bearers and the membership at large, the year has seen several significant disappointments. Regulated restrictions on movements have discouraged the Society from holding face-to-face meetings. Our inability to secure funding to continue the Rangelands Policy Dialogue in a vigorous manner has discouraged us from continuing to drive the Dialogue through relying on volunteer effort. Our inability to secure general-purpose funding support has discouraged us from taking on new initiatives with uncertain financial cost.

The Society's situation is of course not unique. The year has seen significant financial deterioration in the budgets of Australian universities, and this has flowed through to reduced budgets for curiosity-led scientific research. With unprecedented transformations occurring in the biophysical world, the need for enhanced research capacity in the natural and social sciences is more urgent than ever.

On a broader scale, the continuing arrival of new evidence of accelerating climate change and the dire effects it is having on natural ecosystems highlights the gap between the Society's earnest capacity to disseminate scientific information and the capacity of policy-makers to heed scientific advice. Despite the increased urgency of a focused policy response, the year has not seen the emergence of any entity in Queensland willing to perform the role of scientific and policy coordination that, for example, the Society pursued in 2019 and 2020 through the Rangelands Policy Dialogue. Policy responses to the major challenges of our times remain inadequate, and the potential role that the Society can serve on behalf of Queensland science remains unfulfilled.

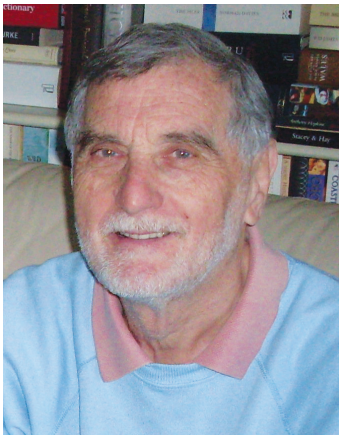
On behalf of all RSQ members, I extend our thanks to all who have been involved in the Society's activities in the past year. I end the year in hope that the need for effective generation and transmission of scientific knowledge will impress itself on those with capacity to fund these essential activities during the year ahead.

Ross Hynes
President
Date: 31 October 2021

Hynes, R. A. (2021). Royal Society of Queensland Annual Report 2020–2021. *Proceedings of The Royal Society of Queensland*, 129, 107–111. https://doi.org/10.53060/prsq.2021.annrep

Citations, Abstracts and Obituary

The Royal Society of Queensland
Award of Life Membership to Dilwyn J. Griffiths, 15 June 2021



Born in 1932 and brought up in a rural farming community in West Wales, UK, Dilwyn Griffiths received his early education at Brynconin Primary School and later at the nearby County Secondary School in Narberth, Pembrokeshire. His ambition was to train as a schoolteacher, and in his later school years (the two-year sixth form of the Welsh Joint Education System), he developed an interest in science. Candidates for the Higher School Certificate were required, in those days, to submit for examination a piece of practical independent work of their own choosing and design. He decided to carry out and report on some simple experiments to measure the growth of selected plants under different conditions – his first attempt at trying to obtain reportable quantitative data to describe basic physiological processes.

Later, at University College Swansea in the University of Wales, he was taught by Professor Florence Mockeridge (Head of the Department of Botany). After graduating with an Honours I in botany, with zoology and pure mathematics as subsidiary subjects, Dilwyn sought to combine his interest in plant growth studies with his aptitude for quantitative data by experimenting with pure cultures of unicellular microalgae, where growth rates could be more precisely evaluated and expressed than was practicable for higher organisms. In pursuing these studies, he noted that different microalgal species used different nutritional processes to fuel their growth requirements, ranging from obligate autotrophy (i.e. photosynthesis), facultative heterotrophy (i.e. photosynthesis supplemented by alternative methods of acquiring carbon and energy) to obligate heterotrophy (entirely dependent upon non-photosynthetic processes).

There was growing worldwide interest at the time in using microalgal cultures for biomass production and in the design of culturing systems to maximise production. This focused attention on the facultative heterotrophs, which can maintain high growth rates even under conditions of limited photosynthetic production. This became the subject of Dilwyn's doctorate, supervised by Professor H. E. Street, a leading specialist in plant tissue-culture and organ-culture techniques.

Dilwyn's subsequent research career developed along two major pathways. The first continued a more academic investigation of aspects of microalgal growth and metabolism; the other, a more applied approach, largely dating from his relocation to Australia in 1967, investigated microalgal ecosystems and associated environmental effects, much of the work in the form of client-funded contract research projects.

Microalgal Cell Growth, Cell Division and Chloroplast Development Studies

These studies commenced with a review of the process of oxidative assimilation of organic substrates by microalgae. Then followed a series of papers describing the metabolism of these organic substrates by different microalgal species and the factors influencing cell growth and cell division, including the application of ultrastructural studies at the sub-cellular level. These studies led to the identification of a strain of *Chlorella* having a special light requirement for cell division without which the cells, under heterotrophic conditions, grew to 'giant' dimensions. Application of techniques of cell synchrony identified the cell division requirement as being linked with photosynthetic chloroplast-centred events. Studies of the recovery of cell division in 'giant' cells confirmed an apparent link between cell division and protein-related events located in the chloroplast. The observed special role, in this strain, for L-arginine was interpreted as being consistent with evidence from other experimental systems (other microalgae, plant and animal cells and yeast) of the involvement in the cell-cycle of certain regulatory proteins (cyclin-dependent kinases – CDKs).

Marine and Freshwater Microalgal Ecosystems

Studies of marine microalgal ecosystems used isolated and cultured phytoplankton species to provide estimations of their contribution to the productivity of marine waters, and of their susceptibility or tolerance to copper, commonly used as an algicide in 'nuisance' microalgal ecosystems. *In situ* incubations in coral reef waters pointed to a relatively low contribution from the phytoplankton to the productivity of coral reef waters. Observations that the microalgae of tropical marine waters frequently occurred in symbiotic association with a range of invertebrate hosts prompted further investigation of these particular microalgal ecosystems. These studies then focused on symbiotic associations between a range of invertebrate hosts and a unique 'microalga' *Prochloron* having ultrastructural affinities with prokaryotes (i.e. bacteria-like organisms) and pigment characteristics resembling those of green microalgae and higher plant chloroplasts – both features of particular relevance to considerations of the evolution of chloroplasts, as summarised in a later review of the *Prochloron* group of organisms (the Prochlorophytes).

Much of northern Australia, especially away from the coastal fringe, is arid with high rates of evaporation and large seasonal and annual variabilities of rainfall and runoff. There are very few natural lakes, and more recent settlement of the region has been supported by the construction of water storages to provide year-round supplies of water for domestic, agricultural and industrial use. Such developments inevitably create novel aquatic ecosystems, with microalgae as an important, but not always a dominant component, requiring careful management based upon extensive scientific monitoring and study. Studies commissioned by Mount Isa Mines, for example, over the years yielded a comprehensive body of information describing the hydrobiology of a number of the artificial lakes of the region and contributing substantially to improving the efficiency (and reducing the cost) of a range of water-treatment processes.

Similar studies were carried out at Lake Dalrymple in the Burdekin Irrigation Area and at Solomon Dam on Palm Island off the east coast of Queensland; the latter in response to what was to go on to receive worldwide attention as one of the more serious cases ever recorded of human poisoning by cyanobacterial (blue-green microalgal) toxins. The study recommended various remedial water treatment processes and tested the effectiveness of various water-column management procedures. More extensive investigations of the toxic causal agent (the cyanobacterium *Cylindrospermopsis raciborski*) followed. Dilwyn's most recent publications have taken the form of more general reviews of specific subjects reflecting his continuing interest in the biological sciences, but with particular emphasis on topics relevant to northern Australia.

Career Summary

Dilwyn's contribution to teaching and research in the biological sciences has come from his career-long work as an academic – as assistant lecturer, later lecturer, in the University of Wales, Bangor, 1958–1967; as Senior Lecturer at La Trobe University, Melbourne, 1967–1974; and as Professor and Head of the Department of Botany within the School of Biological Sciences, James Cook University, Townsville. He considers himself to have been fortunate to have started his academic career at a time when the subject was in transition from what had previously been largely descriptive to one that gradually became more experimental, with increasing application of available technological advances and improved instrumentation. His work as a teacher (and his understanding of the subject) has benefited from his allied research interests, while his involvement in both pure and applied research projects has provided opportunities for training young researchers in the wider environmental aspects of the subject. The latter have been able to acquire skills in a range of monitoring techniques, data processing and interpretation, reporting and interacting with professional officers in the water industry. Many of these scholars have gone on to successful careers in industry and other professional areas.

Dilwyn Griffiths has had a long commitment to The Royal Society of Queensland as a member and, with his wife Mrs Elen Griffiths, as a dedicated attender of Society meetings. He is recognised for his major contribution to biological sciences in Queensland's tropical ecosystems over many decades. After an extensive and distinguished career, he has been Emeritus Professor for the past twenty-four years and during that period has published four significant works: *Microalgal Cell Cycles* (2010), *Microalgae and Man* (2013), *Freshwater Resources of the Tropical North of Australia: A Hydrobiological Perspective* (2016) and *Tropical Ecosystems in Australia: Responses to a Changing World* (2020). He has been an inspirational academic leader, researcher and teacher at James Cook University, where his dry, whimsical wit was greatly appreciated. He is recognised for both his scholarship and his contribution to The Royal Society of Queensland.

The President and Council of The Royal Society of Queensland congratulate Professor Griffiths on his outstanding career and honour him with its highest award of Life Membership.

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The Royal Society of Queensland
Award of Life Membership to Craig Walton, 15 June 2021

Craig grew up on a small farm at Toodyay in country Western Australia and was immersed in the natural world from an early age. His growing interest in the history of science led to an undergraduate Bachelor of Science degree from the University of Western Australia, majoring in botany and zoology, with honours in botany completed in 1987. This was followed by a Master of Science (Plant Physiology) from the University of Guelph in Canada in 1993.

In his early botanical research Craig focused on pulse crops and salt tolerance of wheat in Western Australia and soybean physiology in Canada, followed by quarantine issues involved in the risk assessment of new plant species in Canberra. In 1999 he moved to Queensland and began a long involvement with the Department of Natural Resources – in its various forms – where he has worked ever since. For six years he was an invasive species ecologist, from which experience he wrote three book chapters (Walton, 1999; Walton, 2001; Walton, 2009). In addition, he has published seven refereed papers and 25 reports and strategies, including nine strategies for Weeds of National Significance and the first Pest Animals Strategy for Australia. He has been a regular speaker at domestic conferences, also travelling to New Zealand, Brazil, South Africa and the United States to present on these topics. His invasive species policy work culminated in the publication of a book on the history of the science of weed biological control in Queensland (Walton, 2005); soon after it was published, the key research station profiled in the book was sold for its real-estate value and much of the history was institutionalised. This research was the topic of his first presentation to The Royal Society of Queensland in 2005.

Craig's interests in the intersection of history and science found a welcome home in his enduring relationship with The Royal Society of Queensland. He was elected Secretary in 1999 and held the role for three years. In addition, as part of this role he was a member of the RSQ Review Panel in 2002.

He cemented his commitment in 2003 when elected President – enjoying a 10-year term that made him the Society's longest-serving President – overseeing a decade of significant change in both national and state leaderships. He conscientiously and effectively served in this position; then from June 2013 he remained on Council as an active Immediate Past President and mentor to the incoming President Geoff Edwards until November 2019 when he retired.

This is a remarkable 20 years of service in an office-bearing position. The Society owes an immense debt of gratitude to Craig for his leadership and contributions.

National cooperation between state societies in the early 2000s saw the Society co-fund a three-year Eureka Prize and other national initiatives under the national banner, although the Society declined membership of the Royal Societies of Australia in 2008 due to concerns over its constitution and management. National activity waned with the election of the Newman government in 2012, which saw the commencement of cuts to financial incentives to the sciences, as well as cuts to libraries and research bodies involved in science. Craig worked to counteract these changes by promoting cooperation between more than 20 not-for-profit scientific groups in Queensland, including citizen science groups, culminating in the creation of the Queensland Science Network in October 2016.

His belief that anyone could, and should, be involved in science was best demonstrated by his work with Dr Alistair Melzer, the Central Queensland Koala Volunteers and Royal Society members to create a research fund to support projects which escape the attention of the mainstream grant programs. The fund sought to encourage applications for small-scale projects such as those by NGO groups or early-career researchers. After several years of planning and evolution of the funding arrangements, this culminated in the establishment of the RSQ Research Fund, which was launched by the Society's Patron the Governor in June 2014.

Craig has always seen the *Proceedings* as an enduring legacy of the Society, and his small committee always kept its publication to the fore of Council activities. During his presidency he oversaw the production of two special editions of the *Proceedings*: Volume 115: *Life in a Fire-Prone Environment: Translating Science into Practice* (2006) and Volume 117: *A Place of Sandhills: Ecology, Hydrogeomorphology and Management of Queensland's Dune Islands* (2011).

However, he is most proud of the Queensland Gambling Fund grant in 2013 that underwrote the digitisation of all the Society's *Proceedings* back to 1884, as well as early minute books and other important documents and letters, and the creation of the contemporary RSQ website. By archiving historical records and proceedings in electronic form and then deposition in the State Library and on the web, the early history of the Society lives on and can be accessed.

Craig continues to work in science. During his presidency he moved professional space into strategic water policy, including Queensland statewide responses to both the Millennium Drought – including policy for both the recycled water and demand management programs – and supported responses to the catastrophic weather events of 2011, managing global interest in understanding Queensland's response and a range of international scientific visits. This experience was his foundation for coordinating the Queensland Government's involvement in the International Water Association's World Water Congress – held in Brisbane in 2016 – with over 2000 Congress registrations and participants from 108 countries. More recently, his professional interests have centred on water management in the Great Artesian Basin, assisting communities to make the Basin watertight through funding programs, education and research. He is currently policy advisor to both the state Ministerial Advisory Council and the equivalent national body. In 2020 he served on the editorial panel of the Society's *Proceedings* Vol. 126 (Springs of the Great Artesian Basin).

As a Principal Policy Officer, among other roles in the Queensland Department of Natural Resources and Mines, he has made a significant professional contribution to natural resource policy, planning and management, initially in terrestrial ecosystems and more recently in water resources. These contributions would by themselves warrant an award for high achievement in science. However, it is for his immensely valuable service to the Society over more than 20 years that Council without hesitation resolved to offer him its highest award. The President and Council of The Royal Society of Queensland congratulate Mr Craig Walton on his outstanding career and honour him with its highest award, that of Life Membership.

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Pathological and Clinicopathological Features of Canine and Feline Bladder Disease

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Thesis submitted for the degree of Doctor of Philosophy, The University of Queensland

Abstract

Dogs and cats commonly present to veterinary hospitals with urinary bladder disease, but despite their clinical importance and comparative potential to human diseases, bladder diseases in Australian dogs and cats are under-investigated. In veterinary pathology, diagnostic agreement is influenced by the pathologist's own experience, training, and cognitive biases. Logistic regression is a statistical technique which has the potential to improve veterinary pathologist agreement. The main thesis goals were to investigate the pathology and comparative potential of canine and feline urinary bladder disease in Australia, and to explore the utility of logistic regression modelling in improving inter-pathologist agreement.

This project evaluated pathology cases of canine and feline bladder tissue from the veterinary pathology archives of The University of Queensland and Murdoch University, with prospective sampling from veterinary clinics and a veterinary pathology laboratory in South East Queensland. The dataset demographics and a comprehensive analysis of histological features were examined using logistic regression to identify associations between the diagnosis and animal factors and histological features, respectively. Next, a subset of canine and feline bladder tissues was tested for biomarker expression using immunohistochemistry and polymerase chain reaction. To further investigate the comparative potential of feline idiopathic cystitis (FIC), a systematic review was conducted on biomarkers in bladder pain syndrome (BPS) compared to FIC. Finally, the modelling of histological variables was used to formulate a predictive probability tool which was tested on four veterinary pathologists.

The demographic analysis showed a higher risk of bladder neoplasia in dogs compared to cats and increasing risk for bladder neoplasia with age. Next, logistic regression modelling on the histology features identified six significant variables that were associated with the diagnosis – urothelial ulceration, urothelial inflammation, neutrophilic submucosal inflammation, submucosal lymphoid aggregates, amount of submucosal haemorrhage, and species. The pathologist agreement study revealed a good level of agreement between the four pathologists when diagnosing neoplastic lesions, but poor to fair agreement for cystitis, urolithiasis and normal bladder tissue. Agreement between pathologists was variable when the predictive probability tool was used; however, using the predictive tool increased the agreement between the study pathologists' diagnosis and the reference diagnosis. A systematic review on biomarkers in bladder pain syndrome revealed that nerve growth factor is the most likely urine biomarker to be useful in the diagnosis of human BPS. Finally, investigation of biomarkers of canine and feline bladder diseases showed that tight junction protein-1 may be a promising tissue biomarker for differentiating between some urinary bladder diseases in these species.

This thesis has undertaken a comprehensive analysis of the pathogenesis and comparative potential of canine and feline bladder diseases and is the first to apply logistic regression modelling to veterinary

histopathology diagnosis and to improving inter-pathologist agreement. Dogs and cats are potentially good comparative models for human bladder diseases; however, inconsistent case definitions in human research complicate veterinary and medical field alignment. Finally, a collaborative multicentre approach would be invaluable to collect high quality prospective samples of feline idiopathic cystitis cases to allow further investigation into this disease.

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Evolution and Ecological Adaptations of Microornamentation in Australian Geckos (Gekkota, Squamata)

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Abstract

Morphological adaptation to different ecological demands is a driver of diversity. Squamate reptiles, including the diverse Australian gecko fauna, have evolved microstructures on their outermost skin surface. Geckos' toepads feature adhesive hair-like setae, while the remaining skin surface features hydrophobic, self-cleaning spinules and small sense organs called cutaneous sensilla. I studied the evolution and ecological adaptation of these microstructures, applying scanning electron microscopy and comparative phylogenetic methods.

I described the diversity of dorsal microstructures of 27 gecko species. Quantifying scale size, spinule length and density, among others, I correlated these traits with habitat use (arboreal, saxicoline or terrestrial) and relative habitat humidity (desert, woodland or rainforest). Terrestrial species had long spinules and more complex sensilla, saxicoline species had larger diameter sensilla, and arboreal species had large granule and small intergranule scales. Desert and woodland species overlapped highly morphologically, differing through smaller-diameter sensilla from rainforest species. These associations suggest that epidermal microstructures evolved in response to environmental variables.

Hydrophobicity is common in nature, but its evolutionary drivers are unclear. I predicted that high hydrophobicity should coevolve with terrestrial microhabitat use, due to higher prevalence of dirt and debris. I reconstructed the evolution of hydrophobicity in 24 gecko species in relation to habitat use, and determined the morphological traits associated with hydrophobicity. Terrestrial species were, indeed, more hydrophobic than arboreal ones. Longer spinules and smaller scales were correlated with high hydrophobicity. Thus, hydrophobicity has co-evolved with terrestrial microhabitat use via selection for long spinules and small scales, likely to keep the skin clean and prevent fouling.

Gecko toepad diversity can be categorised into terminal versus basal toepads. The evolution of toepads is poorly understood because intermediate morphological configurations between pad-less and pad-bearing forms are rare, particularly for terminal toepads. I assessed the subdigital scale morphology of phylogenetically distinct lineages of the mostly terrestrial Bynoe's gecko species complex (*Heteronotia binoei*): it is described as pad-less, but two distantly related saxicoline lineages have enlarged terminal scales. I reconstructed the ancestral scale size of nine lineages and compared the subdigital microstructures of the saxicoline lineages to their respective sister lineages. The saxicoline lineages independently evolved enlarged terminal scales, and their setae were longer, and branched more often. Thus, the saxicoline lineages evolved more complex adhesive structures in parallel, and their morphology represents a candidate for an intermediate state in terminal toepad evolution.

Broad-scale evolutionary questions require a thorough ecological knowledge of the species analysed, but quantitative ecological data are often scarce, particularly for Australian geckos. Surveying gecko communities from 10 sites, spanning deserts, woodlands and rainforests across Queensland, Australia, I quantified ecological niche and habitat use of 34 species, 9 arboreal, 4 saxicoline, 13 terrestrial and 8 generalist. I quantified perch height and diameter for climbing species and compared them to *Anolis* 'ecomorph' categories. Species richness was lowest in rainforests and highest in woodlands. Most species used a perch space comparable to the 'trunk-ground' ecomorph, but the genus *Strophurus* preferred shrubs or twigs of small trees, thus occupying the perch space similar to 'grass-bush' anoles.

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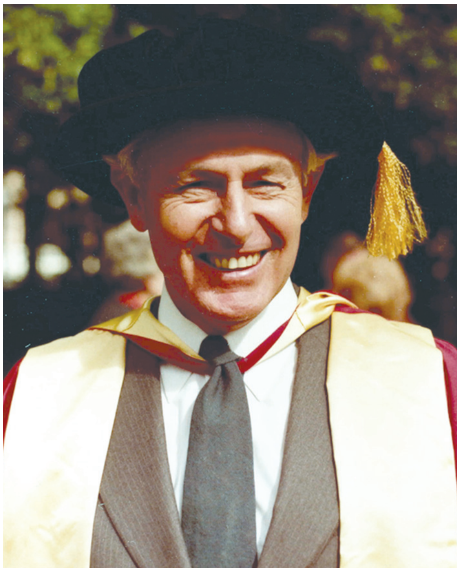
Obituary
Raymond Louis Specht, 1924–2021



Raymond Louis Specht, PhD (Adel), DSc (Adel), AO, Professor Emeritus at The University of Queensland, died on 13 February 2021, after a long life of 96½ years. He had a very rich life of enormous productivity in his chosen fields (Australian flora, the study of ecosystem processes, and the conservation of Australia's biota) and was a tireless promoter of the better education of young Australians in the sciences.

General Introduction

Ray was born into a close-knit family in Adelaide and quickly showed his scholastic aptitude and curiosity to learn. He was dux of his primary school in Richmond and was part of a band of bright young men at Adelaide Boys High, including Glenorchy McBride (who became Professor of Psychology at The University of Queensland). These boys kept in contact for the rest of their lives. The Second World War was in full flight when he graduated from high school and, teachers being in short supply and family funds limited, he attended Adelaide Teachers College and very soon after was sent to a small school at Riverton to teach students not much younger than himself. Luckily, he had the slightly longer experience of another Adelaide High School graduate, John Womersley, to draw upon, and the mentoring eye of their extraordinary teacher, Stan Edmonds, later of the University of Adelaide and the South Australian Museum. Ray transitioned to university (the two institutions were quite intertwined), studying biology and ecology, despite having previously excelled at the hard sciences. He was inspired by the teaching of J. G. Wood, writing as an honours student in 1946: "… ecology is really a pure science aiming at the study of communities for the sake of knowledge. Who knows what may evolve from it? Did Thomson, Rutherford, Bohr, or any other early atomic physicist realize whither they were going when they delved into the secrets of the atom?" (Specht, 1946).

Profs J. G. Wood, C. T. Madigan and Sir Douglas Mawson, world-renowned authorities in their fields, were teaching at the University of Adelaide at this time, and they impressed the young Ray. In addition, he was exposed as a student to the Koonamore Vegetation Reserve, which was established in 1925 by J. B. Cleland and T. G. B. Osborne. This reserve (later known as the T.G.B. Osborne Vegetation Reserve) was globally unique at the time and impressed on Ray the value of long-term observations (Hall et al., 1964) and integrating teaching with field work. Shortly after gaining his honours degree, for an ecological survey of the Adelaide Hills (Specht, 1951), he had the first of his formative scientific experiences, as a grassland ecologist on a survey of the south-east of South Australia. Bob Crocker, a soil scientist, also had a great influence on the development of Ray's understanding of the whole-of-ecosystem approach which came to the fore in his selection of his doctoral sites some years later.

Ray's second formative experience was as the botanist on the National Geographic, Smithsonian Institution and Australian Department of the Interior (via the enthusiastic support of Arthur Calwell) Expedition to Arnhem Land in 1948 led by C. P. Mountford. It was a position to which Prof. Wood 'co-opted' him, as Ray liked to say. It was a mammoth task as the youngest member of the team, but he acquitted himself with great credit, collecting 13,500 specimens in total, replicated to send to ten herbaria including Kew, the Smithsonian, and the Rijksmuseum in the Netherlands. Ray's participation was clearly a seminal part of his career. Apart from an immense practical learning experience, he was instrumental in ensuring that the work of the Expedition was published (see Specht, 1958a–e, 1964; Specht & Bateman, 1958; Specht & Mountford, 1958). Through this expedition he made lifelong friendships with fellow expeditioners and associates in the USA and Australia. Both before and after the Expedition, he visited the Herbarium in Brisbane to consult with the crucially important reference collections of tropical species and avail himself of the expertise of staff of the calibre of C. T. White, Stan (S. T.) Blake and Selwyn Everist, among others. It was in Brisbane that he met his future wife, Marion Gillies, a zoology student at The University of Queensland.

His connection with Arnhem Land was revitalised some years into his retirement. In 1998, he (with the author's help) ran a reunion of the Arnhem Land expeditioners in Sydney, which proved to be the last time they all got together (except for one member who had died much earlier) (Specht & Specht, 1998). When 'outsiders' started to realise the unique nature of the Expedition, and people started studying it, Ray took this very seriously and organised and donated documents and artifacts, submitted willingly to interviews, and generally took on the role of spokesperson for the expeditioners. In 2009 the National Museum ran a Symposium 'Barks, Birds and Billabongs', by which time Ray was one of only two expeditioners left alive, shortly after to be the only one. His memories were captured in two chapters of the publication resulting from the Symposium (Thomas & Neale, 2011).

After the Arnhem Land adventure he returned to Adelaide University, completing his PhD in 1953 under the supervision of J. G. Wood, with a comprehensive study of the heath of the Ninety Mile Desert (a system of ancient sand dunes, described by Crocker) in eastern South Australia. It was this study and the several publications that emerged that launched the next phase of his career, the nutritional aspects of heathland vegetation. He obtained Fulbright, Smith-Mundt and Carnegie Fellowships to study in the USA and France in 1956. His scientific standing and international connections were further expanded. In 1961, he was awarded the Verco Medal of the Royal Society of South Australia for distinguished scientific work, the highest honour that the Society can bestow.

After Joe Wood's untimely death in 1959, Ray took up a position at the University of Melbourne as Senior Lecturer and then Reader (the equivalent of Associate Professor) in Botany. It was arguably the happiest phase of his career, with few administrative responsibilities, a great team of fellow staff and students, and under the inspired leadership of John Stewart Turner (FAAS) with whom Ray formed a great friendship as well as intellectual companionship. This time took him to Oxford University on a Royal Society–Nuffield Foundation Commonwealth Bursary to work at the Department of Agriculture under the sponsorship of Prof. Geoffrey Blackman. Through this, and the mentorship of Prof. Turner, he was given responsibility for three programs in Australia (and one internationally) in the newly established International Biological Program (IBP) which is further described later.

In 1966, Ray moved to The University of Queensland as Professor and Head of Department, after the retirement of Prof. Herbert, the noted biogeographer whom he had met and greatly respected. Ray often enjoyed telling the story that when he arrived, the head of the technical staff of the Botany Department, Albert Steginga, informed him that as a baby he had been "dandled on the knee" of Ray's great-grandfather. That was Wilhelm, the first of the Spechts to settle in Australia, who had moved from Adelaide to Rockhampton where for a time he was employed at the railway workshops. Ray liked to think that a piece of rolling stock had his name stamped into it.

Ray brought the IBP with him to Queensland. This was a key motivator for his engagement with the Queensland scientific and practitioner community. This community included the strong research and modelling teams of the Queensland Department of Primary Industries, which were greatly influenced by the innovative management style of the research directors and the intellectual leadership of Dr Joe Ebersohn. It was an exciting time to be in Queensland. He took pleasure in integrating the research of the botany staff with the teaching program, with a notable focus on North Stradbroke Island, a place which complemented his PhD work on the dynamics of the vegetation on the ancient dunes in South Australia.

Throughout his life, Ray maintained active collaborations with scientists around the world. When he retired in 1989, he was appointed Professor Emeritus of The University of Queensland. He was thrilled to receive life membership of The Royal Society of Queensland in 2015, and an AO in 2020. He greatly enjoyed being a member of the advisory committee for Queensland's Statewide Landcover and Trees Study (SLATS) long into his retirement, and continued publishing many articles and books, only slowing down with the ill-health of his wife and later of himself.

The following sections cover some of his contributions in more detail.

Contribution to Education

Ray applied his expertise as a trained high school teacher in several ways, in particular through his use of field work in his undergraduate classes. He was an early promotor of self-reflection on teaching methods long before this became routine in Australian universities. He advocated North Stradbroke Island as a great opportunity for field studies to enhance learning outcomes (e.g. Specht, 1975), and he and his good friend Professor Emeritus H. T. Clifford, AM, wrote *The Vegetation of North Stradbroke Island, Queensland*, which was used by generations of students and visitors to the island (Clifford & Specht, 1979).

Particularly notable was his promotion of new advances in high school teaching being made in the United States of America in the 1960s and '70s. He was a contributor to and champion of the 'Web of Life' program for Australian high schools, which was developed under the auspices of the Australian Academy of Science in the late 1960s. This was inspired by the innovative Biological Sciences Curriculum Studies program in the United States of America, and Ray visited their headquarters in Boulder, Colorado in 1970. It emphasised the 'inquiry method'[a] of teaching and was demonstrably better for student understanding and retention, but often a challenge for educators! Together with his wife, he steered the adoption of the method in Queensland (Specht & Specht, 1995).

In his university teaching he established a new third- and fourth-year subject, 'Community Physiology', in which his students used a computer model created by him (initially in Fortran) to predict the effects of different environmental scenarios

[a] Scientific inquiry involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in the light of experimental evidence; using tools to gather, analyse and interpret data; proposing answers, explanations and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (National Research Council, 1996, p. 23).

on Australian ecosystems. This model, COMSIM, used the index-based approach published in his article in *Oecologia* (Specht, 1981a) and his book chapter in the *Ecological Biogeography of Australia* (Specht, 1981b). This semester-long exercise provided great learning opportunities as well as amusement, as students assessed different scenarios, such as the creation of a rainforest in Canberra or central Australia, and predicted how much irrigation and protection from evaporative loss would be required to do so.

Ray did not have a vast number of doctoral students and postdoctoral researchers, but those he did have were greatly treasured and made significant contributions in their turn, for example Richard Groves, Richard Jones, David Jeffrey, Bob Parsons, Matt Bolton, Jim Davie, Elwyn Hegarty and Rhonda Melzer. He was noted for his constructive feedback at every seminar and contributed actively to all the postgraduates who came into his orbit.

After his retirement at the age of 65, he embarked on the production of a major textbook entitled *Australian Plant Communities: Dynamics of Structure, Growth and Biodiversity*. This was published by Oxford University Press and sold so well as to merit a second edition and a subsequent reprint (Specht & Specht, 1999, 2002). This text, shortlisted as *The Australian* newspaper's Tertiary Scholarly Reference of the Year in 2000, encapsulated the extensive scientific experience accumulated through his long career, making it a seminal text for Australian university courses in ecology, eco-physiology and geography, among others, as well as a great boon for environmental practitioners.

Research Leadership and Contribution to Conservation

Ray attained global pre-eminence due to his knowledge of the nature and dynamics of sclerophyll vegetation, established through his PhD work on Dark Island Heath, South Australia. This was evidenced by his editorship of the 'Heathlands and Related Shrublands' volumes in the *Ecosystems of the World* series (Specht, 1979, 1981c) published by Elsevier (series edited by David Goodall AO), and other books by international publishers (e.g. de Castri et al., 1981; Keast & Specht, 1981).

The International Biological Program (IBP) (Specht & Specht, 2020) was an innovative global initiative to examine the biological basis of productivity and human welfare, recognising that traditional methods of biological research were insufficient to tackle complex environmental problems. Ray was assigned an amalgamated suite of responsibilities: productivity, production processes, and the conservation of terrestrial communities (Section PCT). He was convinced of the potential of the integrated nature of the work proposed, both in the range of ecosystem components being simultaneously studied and the interdisciplinary nature of the teams required to do the work. He gathered a diverse team of experts at The University of Queensland to establish an integrated laboratory and field installation (in Brisbane at the Archerfield Aerodrome), the envy of most facilities in Australia at the time. For the conservation stream, with a team of collaborators at The University of Queensland and across the nation, he conducted an Australia-wide assessment of the conservation status of Australian plant communities, which became known as the 'Specht Report' (Specht et al., 1974). At the regional scale he applied a methodology established through the IBP for the determination of conservation areas (Bolton & Specht, 1983), later adapted by Purdie (1990) for the systematic selection of conservation reserves. Ray's last publication was a reflection on the IBP and its place in Australian engagement internationally (Specht & Specht, 2020).

One of his most influential contributions set the standard for the description of the structure of vegetation, until then a very contentious matter. Ray proposed a simple vertical and horizontal classification of vegetation by which plant communities could be categorised structurally (Specht, 1970; Specht, 1981d; Specht & Morgan, 1981). Without such consensus, conservation efforts fell to nought as ecosystems could not be consistently described and their descriptions shared adequately to establish their conservation status. This was further refined in Specht & Specht (1999, 2002). The 'Specht structural classification' is the foundation of the measurement protocols established by many organisations. Foliage Projective Cover (FPC), the horizontal component of this classification, is reliably determined remotely allowing vegetation cover and cover type to be monitored

(Armston, 2009; Johansen et al., 2015; Fisher et al., 2018). FPC continues to be used effectively in assessments of biomass, Net Primary Production (NPP), nutrient dynamics, and carbon sequestration at various scales through input to models like Aussie GRASS (Carter et al., 2000) and Century (Parton, 1996).

Ray was committed to optimal conservation of biodiversity and ecosystems, especially Australian ecosystems. He was President of the Victorian National Parks Association in the 1960s, on the founding committee of the Australian Conservation Foundation, and a founding member of the Ecological Society of Australia. He was not an activist, but worked to provide the basis for sound assessments, relying on the data and work he produced to speak for him. He supported the publication of Australian-focused scientific journals, only newly emerging in the 1950s and 1960s, especially through his many publications in the *Australian Journal of Botany*.

Ray was a pioneer in the application of digital technologies in science, particularly in the determination and assessment of our native biota. He was ahead of his time as a 'Big Data' innovator, inspired by his experiences with the IBP, various scientific committees and projects. Recognising the limitations of expert opinion in determination of the occurrence of plant communities used for the Specht Report, and inspired by the new computing capacity and work using non-parametric analyses to define 'clusters' in otherwise impenetrable datasets (e.g. the techniques developed by Bill (W. T.) Williams, FAAS), Ray embarked on a project to find and digitise all the vegetation surveys published in Australia, with a vision of objectively defining them. In this he was amply assisted by the data science team at CSIRO in Brisbane, which included Bill, but also the talented Mike Dale. This project was larger than initially anticipated and took him well past retirement age. Finally, with the help of co-authors and despite opposition from various quarters, in 1995 the *Conservation Atlas of Australian Plant Communities* (Specht et al., 1995) was published, and launched by the head of the Australian Conservation Foundation.

Much of the raw data assembled and collected for the definition of Australian Plant Communities has recently been recovered (Specht et al., 2018a) and deposited in open-access repositories, including the *Atlas of Living Australia* (https://collections.ala.org.au/public/show/dr8212) and the USA-based Knowledge Network for Biocomplexity (Specht et al., 2018b). This is a testament to the enormous amount of work accomplished by Ray and collaborators.

Closing Remarks

Over the course of his life Ray published 106 scientific articles (48 as sole author), 77 book chapters (15 as sole author), was the author or editor of 16 books (4 as sole author), and spoke at countless conferences and symposia. It should be remembered that:

(a) until the 21st century, publications were all in print, and correspondence was by post;
(b) books with voluminous appendices were the norm (there were no online data repositories); and
(c) publications in ecology normally were (and still are) fewer in number than those in the laboratory or molecular sciences.

Given these limitations, he may be seen to have been very productive. He fervently hoped that his work enhanced understanding of our biota, influenced the way it is managed, informed the way we educate the next generations, and encouraged original, critical thinking.

Ray's work was his life, and his students and colleagues became friends for life. He had a passion for acquiring and sharing knowledge. His networks were wide but also deep, and in many cases extended across generations.

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