Feral pig exclusion fencing provides limited fish conservation value on tropical floodplains

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Running header: Fish occupying tropical wetlands affected by feral pigs

Abstract

Efforts to protect and restore tropical wetlands impacted by feral pigs (*Sus scrofa*) in northern Australia have more recently included exclusion fences, an abatement response proposing fences improve wetland condition by protecting habitat for fish production and water quality. Here we tested: 1) whether the fish assemblage are similar in wetlands with and without fences; and 2) whether specific environmental processes influence fish composition differently between fenced and unfenced wetlands. Twenty-one floodplain and riverine wetlands in the Archer River catchment (Queensland) were surveyed during post-wet (June-August) and late-dry season (November-December) in 2016, 2017 and 2018, using a fyke soaked overnight (~14-15hrs). A total of 6,353 fish representing twenty-six species from 15 families were captured. There were no multivariate differences in fish assemblages between seasons, years and for fenced and unfenced wetlands (PERMANOVA, Pseduo-F <0.58, *P*<0.68). Late-dry season fish were considerably smaller compared to post-wet season: a strategy presumably to maximise rapid disposal following rain. At each wetland a calibrated Hydrolab was deployed (between 2-4 days, with 20min logging) in the epilimnion (0.2m), and revealed distinct diel water quality cycling of temperature, dissolved oxygen and pH (conductivity represented freshwater wetlands) which was more obvious in the late-dry season survey, because of extreme summer conditions. Water quality varied among wetlands, in terms of the daily amplitude, and extent of daily photosynthesis recovery, which highlights the need to consider local site conditions rather than applying general assumptions around water quality conditions for these types of wetlands examined here. Though many fish access (fenced and unfenced) wetlands during wet season connection, the seasonal effect of reduced water level conditions seems to be more over-improvised compared to whether fences are installed or not, as all wetlands supported few, juvenile, or no fish species because they had dried completed regardless of whether fences were present or not.

Introduction

Wetlands (palustrine and lacustrine) that are located on floodplains away from riverine channels support rich aquatic plant and fauna communities [1-3]. However, some point after peak flood connection, aquatic organisms occupying these wetlands begin to face a moving land-water margin, until connection is broken, at which point the remaining wetland waterbodies typically support a non-random assortment of species, including fish [4, 5]. The duration, timing and frequency that off channel wetlands maintain lateral pulse connection to primary rivers is an important determining factor in broader contribution to coastal fisheries production [6-9]. In addition to connection, environmental conditions become important including water quality [10], access to shelter to escape predation and available food resources [11, 12]. Efforts by managers to restore wetland ecosystem values is increasing, nevertheless access to data establishing success of these programs are limited, which becomes important when attempting to establish biodiversity returns for the funding investment made by government or private investor organisations [13-15].

After floodplain wetlands begin receding and progressively disconnect from the main river channel, they become smaller and shallower [16] because of water loss via evaporation, groundwater recharge, or consumption by wildlife [17, 18]. In tropical north Australia, seasonal off channel wetlands are more pronounced owing to high evaporation rates, loss to groundwater [19], and in many situations waters quickly retract away from the banks and riparian shade [16]. At that point, it is thought that they become more prone to reduced water quality conditions - most notably reduced water depth [18], and high water temperatures [10, 20]. This increases aquatic fauna exposure risks to acute and chronic thresholds [21, 22]. In the late-dry season, fish confined to isolated wetlands on floodplains therefore have very limited avoidance options [10], unlike other fauna such as the freshwater crab also occupying seasonal tropical rivers in northern Australia, that will employ terrestrial re-location and access burrows when confronted with thermoregulation [23]. Fish must exploit available ephemeral aquatic habitats [24, 25], which can be specific to each wetland depending on orientation and location [26], depth and vegetation cover in the landscape [20], in order to survive until monsoonal rain reconnects overbank river networks again.

Across northern Australia, feral pigs (*Sus scrofa*) contribute wide scale negative impacts on wetland vegetation assemblages, water quality, biological communities and wider ecological processes [27, 28]. Feral pigs utilise an omnivorous diet supported by foraging or digging plant roots, bulbs and other below ground vegetation material over terrestrial or wetland areas [29]. This feeding strategy has a massive impact on wetland aquatic vegetation [30], which gives rise to soil erosion and benthic sediment re-suspension, reduced water clarity and eutrophication which becomes particularly critical late-dry season. The fact that limited data exits on the impact that feral pigs contribute to wetlands [31-34], places a strain on the ability for land managers to quantify the consequences of pig destruction [35]. Conversely, a lack of baseline data means quantifying success following expensive mitigation efforts is difficult.

Strategies focused on reducing or removing feral pigs from the landscape have been employed since their introduction to Australia [36], including poison baiting, aerial shooting, and trapping using specially constructed mesh cages [37]. Attempts to exclude feral pigs have also included installing exclusion fencing that border the wetland of interest. While advantages of installing fencing around wetlands has been examined only recently in Australia [32], those authors claim fencing might well be less effective particularly in situations where wetlands would normally dry during the dry season. Fencing is expensive to construct and maintain [37], but at the same time may prevent other non-target terrestrial fauna, such as kangaroos, from accessing wetlands which become particularly imperative late-dry season as regional water points [35]. Other terrestrial species including birds, snakes and lizards, for example, are generally able to access wetlands, though access for freshwater turtles might be hindered [38].

The aims were twofold: first to determine whether the model of non-randomness of fish stands here in wetlands, and secondly whether specific environmental conditions influence fish composition in wetlands with and without fences. These data are important and necessary given increasing government funding investment underway and planned in northern Australia for restoration of wetlands impacted by feral animals (including pigs) [10].

Materials and methods

Ethics Statement

This study was completed in accordance with the Queensland Animal Care and Protection Act 2001, and JCU animal ethics permit number A2178.

Description of Study System

The Archer River catchment is located on Cape York Peninsula, north Queensland (Fig 1). The head waters of the river rise in the McIlwraith range on the eastern side Cape York, where it flows and then enters Archer Bay on the western side of the Gulf of Carpentaria; along with the Watson and Ward Rivers. The catchment area is approximately 13,820 km^2, which includes approximately 4% (510 km^2) of wetland habitats (https://wetlandinfo.des.qld.gov.au/wetlands/facts-maps/basin-archer/), such as estuarine mangroves, salt flats and saltmarshes, wet heath swamps, floodplain grass sedge, herb and tree Melaleuca spp. swamps and riverine habitat. The lower region of the catchment includes part of the Directory of Internationally Important Wetland network (i.e. nationally recognised status for conservation and cultural value) that extends along much of the eastern Gulf of Carpentaria, including the Archer Bay Aggregation, Northeast Karumba Plain Aggregation and Northern Holroyd Plain Aggregation. Two national parks are located in the catchment (KULLA (McIlwraith Range) National Park, and Oyala Thumotang National Park). Land use in the catchment is predominately grazing, with some mining activities planned in the next few years on the northern bank of the river (not within the area of this study).

Rainfall is tropical monsoonal with a strongly seasonal pattern where between 60% and 90% of total annual rain occurs between November and February. Long-term rainfall records for the catchment revealed highest wet season rainfall occurred in 1989/1999 (2515 mm), while the lowest was 1960/1961 (563.5 mm) [39]. Total antecedent rainfall for the wet season prior (Nov 2014 to Feb 2015) to this survey was 1081 mm, which is below the 10th percentile for historical records. The wet seasons experienced through the years prior to this study (2010 to 2015) were among the wettest on record, within the 95th percentile of the long-term data records. The low rainfall experienced during this study may have contributed to a short flood duration, and connection between study wetlands and the main Archer River, when compared to average or above average rainfall years (Fig 2).

Twenty-one wetlands from the Archer River catchment were sampled for this project. These included both floodplain and riverine wetlands that were not on the main flow channels, but rather were on anabranches and flood channels that connect to the main channels only during high flow conditions. All wetlands have been historically damaged by pigs (and cattle to a lesser extent) for up to 160 years [40, 41], until recently, where a small number were fenced to abate feral pig and/or cattle from accessing wetlands, in accordance with the feral animal research and management agenda (to meet the objectives of traditional owners in the region) of both Kalan enterprises and Aak Puul Ngangtam, and their partner.

The characteristics of each wetland are summarised in Table S1. Here, sampling focused on two periods: 1) immediately following the wet season after disconnection between the river and wetlands (hereafter referred to as post wet season); and 2) late-dry season (hereafter late-dry) in 2016, 2017 and 2018. Each sampling campaign was completed over 14 days with six campaigns in total (post-wet and late-dry season in 2016, 2017 and 2018).

Field Methods

In each wetland, a calibrated high frequency Hydrolab multi-parameter logger (OTT Hydromet USA) was deployed (0.2m depth) for between 2 and 4 days to record epilimnion (0.2m) water temperature, dissolved oxygen (%), electrical conductivity and pH every 20mins; logging at this frequency provides explicit insight into diel changes in environmental water processes [20, 22]. Weather conditions were fine with wetlands surveyed on the falling limb of the hydrograph.

Fish were collected in wetlands using a fyke net (0.8m opening, double 4m wing panels, 1mm stretch mesh) that was soaked overnight (approximately 14:00 to 09:00). Wetlands substantially impacted by feral pigs; secchi disk depth < 0.1m, no submerged or floating aquatic plants exist, while the fenced wetlands were generally deeper (up to 1.5m), and had submerged aquatic vegetation (Fig. 1). Fish were placed in a tub (~150L) temporarily, identified, measured (standard length, mm) and returned to the wetland alive in accordance with Australian laws (except for a small number that were kept food web studies, not shown here, under Australian law).

Data Analysis

There are two main biases in the sampling method here: 1) that the sampling technique potentially capture large numbers of schooling fish along the wetland margins; and 2) the fact that predatory aquatic fauna including fish, snakes(macleays watersnakes (*Pseudoferania polylepis*), file snakes (*Acrochordus arafurae*)) and freshwater turtles (*Chelodina oblonga*, *Chelodina canni* and *Emydura s. worrelli*), were periodically trapped in the net for hours means that they could consume fish trapped in nets. To overcome these uncertainties, analyses were based on presence/absence of species. Presence/absence provide robust data when relative abundance are of doubtful validity because they treat species with a diversity of behaviours, trophic functions, and spatial distribute in a more equivalent way than fully quantitative techniques [42].

Multivariate differences were examined using PERMANOVA (Anderson, 2001), using the Bray-Curtis similarities measure [43] with significance determined from 10,000 permutations of presence/absence transformation. Multivariate dispersion were tested using PERMDISP, however, homogeneity of variance could not be stabilized with transformation, and therefore untransformed data were used. Three factors where included: years (fixed), season (fixed); and fenced/unfenced (random). These factors were determined *a-prior* during study design.

Spatial patterns in multivariate fish assemblage structure and the importance of explanatory data sets were analysed using a multivariate classification and regression tree (mCARTs) [44] package in R (version 3.4.4). Analysis was conducted using presence/absence transformed fish data for the 10 species that occurred in >20% of wetland sites (to remove rare species from this analysis). Selection of the final tree model was conducted using 10-fold cross validation, with a 1-SE tree; the smallest tree with cross validation error within 1 SE of the tree with the minimum cross validation error [45]. The relative importance of the explanatory variables were assessed to determine those with a high overall contribution to tree node split, with the best overall classifier being given a relative importance of 100%.

Kolmogorov-Smirnov (K-S) two-sample tests determined differences in the overall shape of fish body size distribution using a Bonferroni correction for multiple comparisons. K-S tests take into account differences between the location, skew, and kurtosis of frequency distributions; but do not identify which of these parameters are driving distributional differences. Therefore, we report the following characteristics of each body size distribution to further describe any differences found: mean, standard deviation (sd), minimum value (min), maximum value (max), the range of values, skewness, and kurtosis.

Results

Hydrology and Wetland Water Quality

Wet season rainfall totals in the Archer River catchment were low during the study period compared to the preceding years (Fig. 2), with rainfall within the 10th percentile for historical recordings held by the Australian Bureau of Meteorology. This means that some caution is necessary with interpretation of these data; namely that floodplain connectivity under higher rainfall years is likely to have a longer duration when compared to lower connection duration under the current rainfall conditions.

A full summary of water quality data are provided in Supplementary files (S1). In summary, water temperatures during the study period were generally about 26°C (Table 1). Minimum water temperature recordings as low as 18°C, while maximum temperatures occurred in November 2016 survey reached above 40°C for several hours of the day in some instances. The water column exhibited pronounced diel temperature periodicity; one or two hours after sunrise each day. Near-surface water temperatures began to rise at an almost linear rate for a period of 8.0 ± 0.5 hours, generally reaching daily maxima during the middle of the afternoon. The mean daily temperature amplitude was 6.2ºC (highest daily amplitude 9.6ºC, lowest

4.4°C). For the remaining 16 hours of each day, near-surface water temperatures gradually declined reaching minimum conditions shortly after sunset.

The electrical conductivity (EC) was very low (Table S1) during the post wet season surveys, while the late-dry season conductivity was generally higher in wetlands, a consequence of evapo-concentration. The lowest wetland in the catchment (AR08 located on the coastal floodplain) recorded the highest conductivity, suggesting connection with tidal water from the nearby estuary at some stage.

There was evidence of cyclical daily DO fluctuations supporting the contention that biological diel periodicity processes were probably not significantly inhibited in all wetlands (Fig. 3). Daily minimum DO concentrations were low enough to suggest there was enough respiratory oxygen consumption to measurably affect water quality, particularly so at the pig impacted wetlands, but also during the late-dry season survey in November 2016. Dissolved oxygen (DO) seemed to reach daily minima conditions, well below the asphyxiation thresholds of sensitive fish species, in the early morning hours during all surveys. In the examples shown, after the morning low DO, conditions generally recovered to approximately 50%, but reaching a high of 100-160% in the late afternoon (before sunset).

pH is also potentially subject to the same kinds of biogenic fluctuations as DO, due to consumption of carbon dioxide (i.e., carbonic acid) by aquatic plants and algae during the day (through photosynthesis), and net production of carbon dioxide at night. If respiratory oxygen consumption is predominant, DO concentrations are low and pH values are generally moderately acidic to neutral, which was the case for wetlands examined here. All photosynthetically active organisms utilise carbon dioxide as a preferred carbon source. Some species (including most green algae) are unable to photosynthesise if carbon dioxide is unavailable, but there are other species (including most cyanobacteria and submerged macrophytes) which can utilise bicarbonate as an alternative carbon source. Carbon dioxide consumption causes pH to rise to values in the order of 8.6 to 8.7 (but that was not the case here during this survey period).

Fish Community

A total of 6,353 fish were captured, representing twenty-six species from 15 families (Table 1). The most common species was the freshwater glassfish (*Ambassis sp.,* 51% total catch), delicate blue-eyes (*Pseudomugil tenellus*, 11%), and northern purple-spot gudgeon (*Morgunda morgunda*, 9%). A greater number of fish species were caught in the post wet season survey, with a lower number captured during the late-dry season, including the northern purple-spot gudgeon (*Morgunda mogunda*), chequered rainbow fish (*Melanotaenia s. inornata*), and the empire gudgeon (*Hypseloptris compressa*). In addition to fish, we captured a freshwater crayfish (*Cherax sp.*), macleays watersnakes (*Pseudoferania polylepis*) and freshwater turtles (*Chelodina oblonga* and *Emydura s. worrelli*) in most wetlands, notably during post wet season. Overall, there was no significant difference between seasons, fenced/unfenced wetlands and among years (PERMANOVA, Pseduo-F <0.58, *P*<0.68).

With a reduced list confined to dominant species, occurrence profiles for groups in the terminal branches of the mCART analysis (Fig. 5) show two initial wetland groups based on a split supported by region, with wetlands in the Coen (upper catchment) region separating from those wetlands in the coastal plains. Following the left branch there is inter-annual variation among wetlands, and a second terminal node based on whether wetlands were fenced in 2016, but not so in 2017 and 2018 data. Following the right branch (APN, coastal plains), the first node separates seasons, and following late-dry season wetlands further separate based on mean dissolved oxygen (~3.0%), and then mean temperature (~28.5^{o}C). The post-wet season branch appears to have more separation among data, with a separation based on mean water temperature (~26.5^{o}C), years, and then finally dissolved oxygen (~4%).

Mean fish body size distributions differed between the three sample years (with fish for each wetland and survey pooled) (KS, $P < 0.001$, Table S2 – S5), with larger fish measured in 2017 (50.5mm) compared to 2016 (38.7mm) and 2018 (31.6mm), despite the assemblages having similar size ranges. When comparing the overall fish size distribution by pooling years, post wet season fish were larger (44.9mm) when compared to fish in the late-dry season (39.7mm) (KS, $P < 0.01$). For some fish species such as the chequered rainbow fish (*Melanotaenia s. inornata*), the post wet season (32.5mm) was similar when compared to late-dry season (38.4mm) (KS, $P = 0.06$, S3). In contrast, the northern purple-spot gudgeon (*Mogurnda mogurnda*) was larger post-wet season (52.8mm) compared to late-dry season (37.1mm) (KS, $P < 0.01$, Figure 5, S4).

Discussion

While installation of fences can protect terrestrial ecosystem services from feral impacts [46], however, in the case here abatement fences appear to offer little over-improvised fish additional value compared to those that are not fenced. Many fish indeed access both fenced and unfenced wetlands during wet season connection, however, the seasonal effects of reduced water level conditions and the loss of fish assemblage as the dry season progresses is a pattern that remained regardless of fencing. To this end, installation of expensive exclusion fences might not offer additional protection to fish species occupying these tropical floodplain wetlands. The same conclusion was reported by [32] where those authors surveyed strongly seasonal wetlands (similar to the wetlands here) elsewhere in northern Australia, and concluded that the seasonal dry down of wetlands ultimately prohibits the wetland contribution to future year successful fish recruitment.

The low species richness in wetlands relative to the main Archer River channel might be a consequence of the frequency and duration of connection between wetlands and the main Archer river channel. The wet season rainfall immediately prior, and during this survey, was within the 10th percentile for historical records. In research elsewhere, a longer connection duration was shown to result in more fish present post wet season, and conceivably more species present late-dry season [6, 47]. Examples exist where longer connection between main river channels and wetlands contributes positively to fish growth rates and higher abundance and diversity of fish [24, 26, 48]. It is also possible that the field methods used here confound our ability to determine the full species composition in wetlands – this could be overcome by using additional survey techniques, including multi-panel gill nets, traps or electrofishing (though we attempted to electrofish these wetlands however, conductivity was too low to effectively use that method).

An obvious characteristic of the fish data were larger, presumably adult, individuals following the disconnection of wetlands after the wet season compared to small individuals present in the late-dry season. On this basis, it is possible that the wetlands serve as important refugia for successful recruitment of freshwater fish, that adult fish remaining in the wetlands after disconnection are able to complete important life cycle stages. The fact that we did not catch large fish in the late-dry season suggests that adult fish might be lost as the dry season progress, consumed either by larger predators such as estuarine crocodiles (*Crocodylus porosus*), or birds feeding in the shallow waters. Wetlands are also popular feeding and roosting locations for birds [2, 49]; we observed a large number of birds at most wetlands in the late-dry season. The value of wetlands to wader birds is limited by the condition of wetlands [50, 51], but wetlands provide an important nutrient subsidy more broadly on seasonal floodplains [52, 53]. Hurd et al. (2017) postulates that differences in fish communities among off channel waters could be more influenced by the presence of piscivorous predators which reduce or eliminate prey species, or even via a function of competitive exclusion may occur within fish guilds as resources diminish in the late-dry season. Examining this point could be achieved by investigating the species niche width [54, 55] in drying waters by constructing food webs in individual waters to determine species ranges and changes with fencing treatment and comparing post wet season and late-dry season conditions.

In the late-dry season for the few fish species present, juveniles dominated the catch regardless whether wetlands were fenced. Having small recruits in the late dry period might be an important strategy in maximising, quick, dispersal after connectivity with the onset of the wet season [56]. Moreover, late season conditions with no flow and warm conditions might favour larval development [57, 58]. *Melanotaeniid* rainbowfish, for example, have a flexible reproductive behaviour that is well adapt to deal with the vagaries of temporal variation in habitat conditions [59]. The same is true for both *Eleotrid gudgeon* species found here, with smaller recruits presumably ready for wide-scape distribution with the onset of seasonal flow. Pusey et al. (2018) provides a case that the reproduction success of freshwater fish in northern Australia could in fact hinge on antecedent flow patterns across the landscape, and that this flexibility ensures population level success [60]. This production strategy might be particularly pertinent given the below average summer rainfall totals witnessed during this survey, particularly when compared to previous years.

As the dry season takes hold, water quality conditions progressively deteriorate owing mostly to increasing impact from rooting pigs accessing wetland vegetation. Generally, fenced wetlands change little in terms of water conditions (Figure 6). However, it is the late-dry season when water conditions are poorest and therefore most critical to fish. Unfenced wetlands tended to be shallower, highly turbid, and most notably experience water temperatures that exceed acute thermal thresholds for fish [31]. The solubility of dissolved oxygen in water is strongly affected by temperature (i.e. high temperature reduces dissolved oxygen solubility [61]. Data on hypoxia tolerances of local freshwater fish species in northern Queensland is available [62], and while tolerances vary between species and life stages, there were obvious periods in wetlands when these threshold limits are exceeded. During the critical periods, fish must regulate breathing either via increasing ventilation rates [63], or by rising to the surface to utilise aquatic surface respiration and/or air gulping (e.g. tarpon, *Megalops cyprinoides*). In any case, the capacity for fish to do that safely depends on the timing of the oxygen sag and antecedent conditions, though notably it appears that most of the hypoxia-induced fish kills is actually due to exposure (e.g., thermal stress and sunburn) resulting from the animals' need to remain at the surface during the heat of the day in order to access available oxygen for respiration. Increasing these risks to fish can have important chronic effects including reducing physical fitness of fish to successfully contribute to future populations [64, 65].

[illegible] -A. M. G.

The cultural and ecological value of coastal wetlands means that management intervention is increasingly necessary to ensure they remain productive and viable habitat (Creighton *et al.*, 2015). These data support a model that damage to wetlands from pig activities not only contributes to reduced aquatic habitat, through loss of aquatic vegetation communities, but also probably has secondary impacts including water temperature and asphyxiation risks for many hours each day, that are higher than when compared to fenced wetlands (Figure 6). However, fish occupying fenced and unfenced wetlands here were similar, particularly in the late-dry season where those remaining few species were juveniles ready for wet season re-distribution. On this basis, installing fences to both floodplain and riverine wetlands that were not on the main flow channels, but rather were on anabranches and flood channels that connect to the main channels only during high flow conditions, seems to offer little additional habitat value for fish. Where wetlands are largely ephemeral and will dry anyway, or where wetlands remain until the next seasons rain connection; species abundance and/or diversity is not improved by restricting feral pig access. Further research is necessary to examine climate change resilience on permanent wetlands (and managed wetlands) particularly whether they provide a similar level of refugia [66].

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Author Contributions

NW conceived and designed the study, NW performed the data analysis. NW and JS completed fieldwork and prepared the manuscript.

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List of Figures

Fig 1. Location of wetlands in this study: a) location of the Archer River catchment in northern Queensland, Australia and b) wetland sites on the coastal floodplain and mid catchment where feral pig fencing has been completed around wetlands preventing access (yellow circles). The three wetland typologies (C – pig impacted wetlands that are shallow (typically <0.5m deep), without submerged aquatic vegetation, turbid and eutrophic; D – fenced wetland preventing pig access that are deeper (typically <2m deep), clear with submerged aquatic vegetation present) exist across the catchment, and E – permanent wetlands that are deeper (typically <2m deep), steep sides limiting pig access, clear with submerged aquatic vegetation present. Archer River gauge station (red circle).

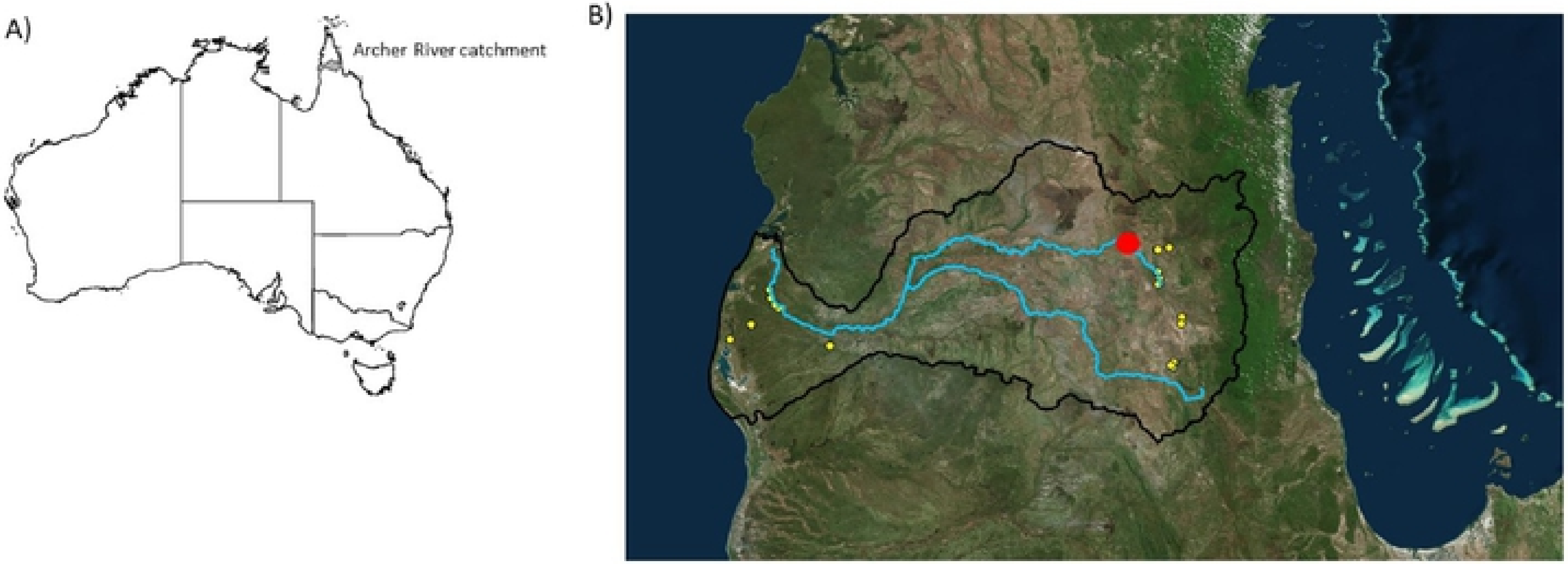
Fig 2. Daily discharge at the Archer River roadhouse gauge (Figure 1) before and during (dashed insert box) this study. Sampling occasions (arrows) are indicated. Data provided by the Queensland Government.

Fig 3. Examples of the diel dissolved oxygen, pH, water temperature and conductivity cycling in Archer River wetlands. These examples are from KA06 during post-wet season (a), and late-dry season (b) in 2016, and AR01 during post wet season (c) and late-dry season (d) in 2016.

Fig 4. Multivariate regression tree showing the major divisions in the database on assemblage composition. Each of the splits are labelled with the contributing variable, and the division threshold (in the case of electronic conductivity; EC, and dissolved oxygen; DO). The length of the descending branches is proportional to the divergence between groups. Bar plots represent the fish assemblage composition at the corresponding colour code node sharing the same attributes. Values in the bar plots represent the relative frequencies of occurrence of each taxon within a same node.

Fig 5. Pooled fish length (standard length, mm) frequency comparison of (a) 2016, (b) 2017 and (c) 2018. Comparison for *Mogurnda mogurnda* (d) post wet season; and (e) late-dry season (years combined).

Fig 6. Conceptual diagram of wetland ecosystem conditions during (a) wet season, and (b) late-dry season. During the wet season, the lateral connection between the Archer River channel and wetlands occurs, during which fish can access wetlands and water quality is generally best because feral pig impact is minimal regardless of fencing. The dry season results in water retracting from the land margins, allowing pigs to access unfenced wetlands. At this stage, water quality conditions are poor in unfenced wetlands with high turbidity/nutrients and temperature, and dissolved oxygen is generally critical for fish. Fenced wetlands become shallower too, through temperature and dissolved oxygen cycling reduced, turbidity is low, while nutrients can be also high. Regardless of fencing, fish community reduced to a few resilient species dominated by juveniles ready for rapid dispersal when wet seasons commences again.



D) unfenced wetland

E) fenced wetland

F) persistent wetland

Fig 1.

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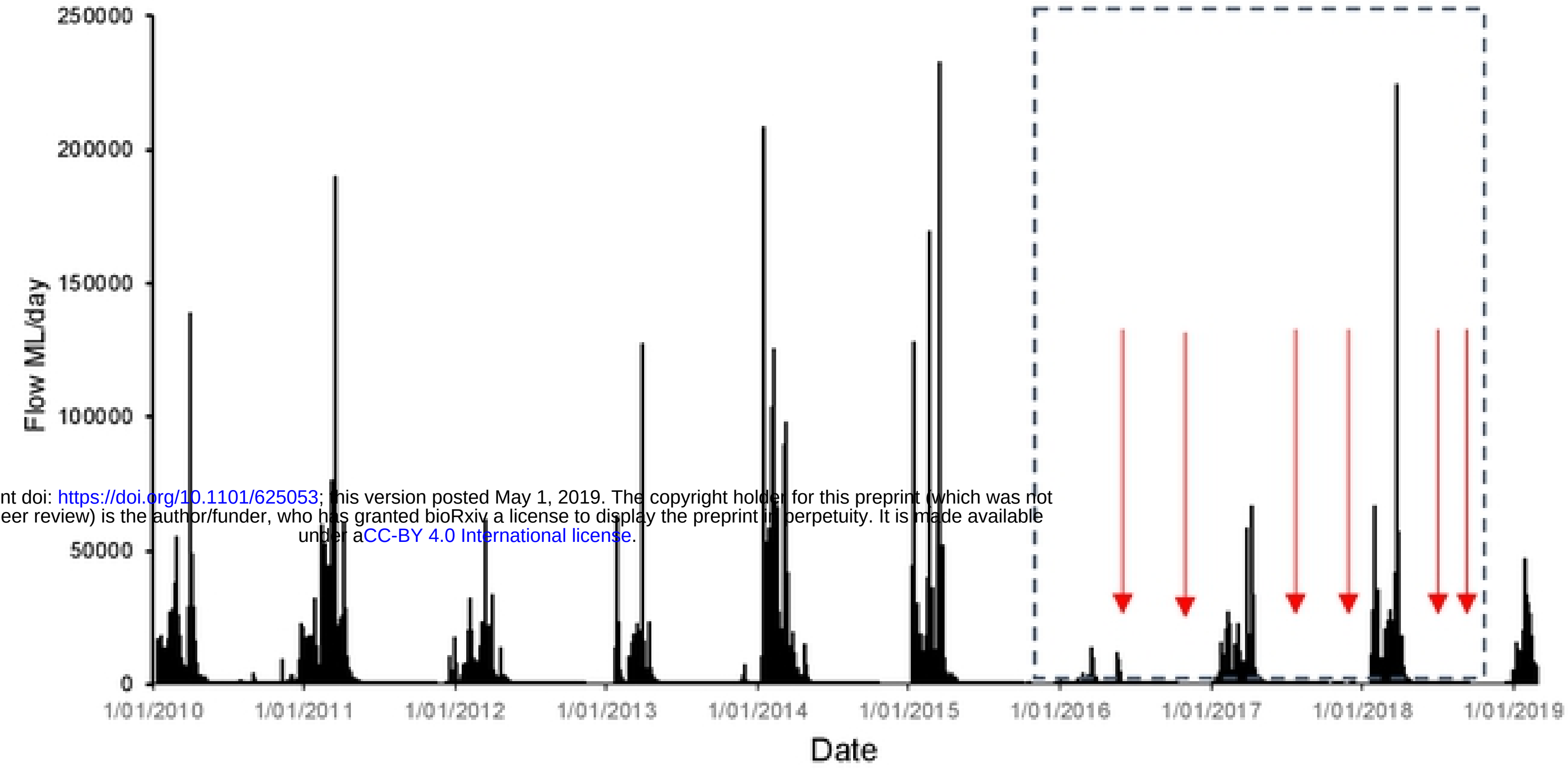

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50 Fig 2

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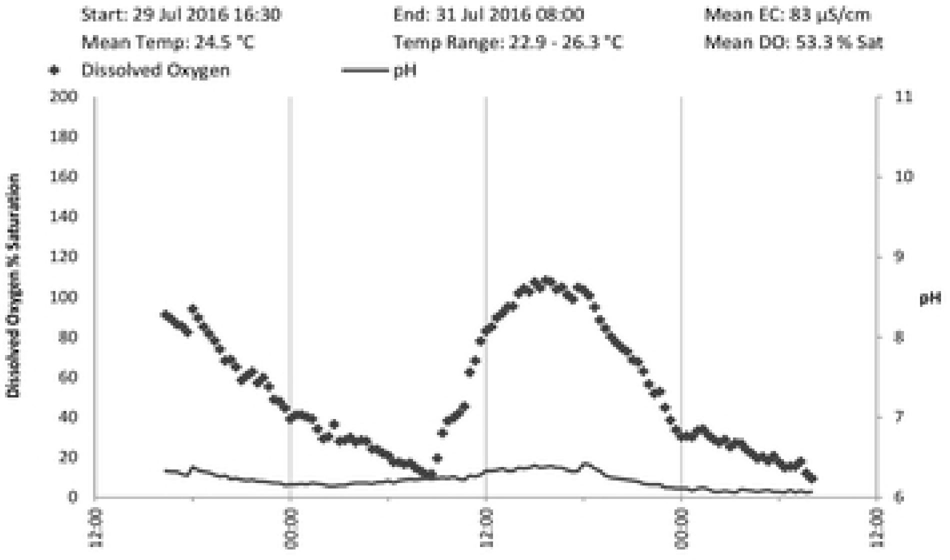
A)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End: 31 Jul 2016 08:00
Mean EC: 83 µS/cm
Mean Temp: 24.5 °C
Temp Range: 22.9 - 26.3 °C
Mean DO: 53.3 % Sat
Dissolved Oxygen
pH
Dissolved Oxygen % Saturation
200
180
160
140
120
100
80
60
40
20
0
11
10
9
8
7
6
pH
12:00
00:00
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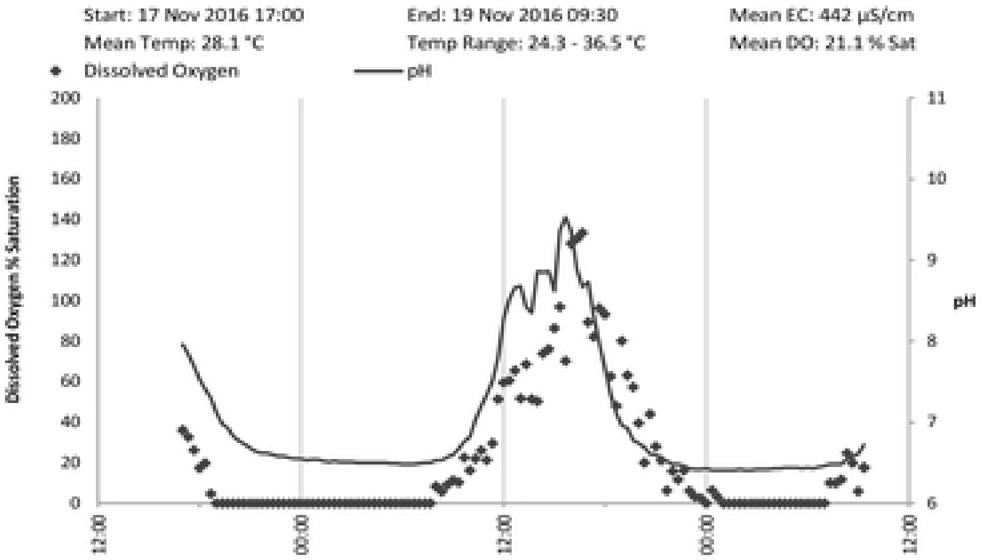
12:00

B)


Start: 17 Nov 2016 17:00
End: 19 Nov 2016 09:30
Mean EC: 442 µS/cm
Mean Temp: 28.1 °C
Temp Range: 24.3 - 36.5 °C
Mean DO: 21.1 % Sat
Dissolved Oxygen
pH
Dissolved Oxygen % Saturation
200
180
160
140
120
100
80
60
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pH
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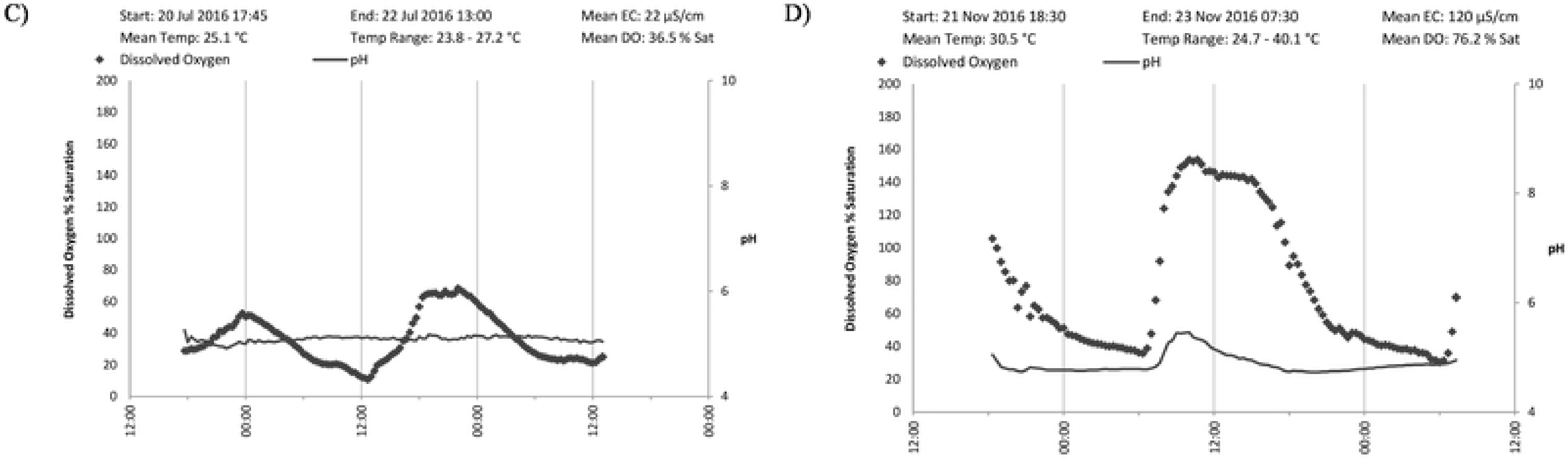
12:00


C)
Start: 20 Jul 2016 17:45
End: 22 Jul 2016 13:00
Mean EC: 22 µS/cm
Mean Temp: 25.1 °C
Temp Range: 23.8 - 27.2 °C
Mean DO: 36.5 % Sat
Dissolved Oxygen
pH
Dissolved Oxygen % Saturation
pH
200
180
160
140
120
100
80
60
40
20
0
10
8
6
4
12:00
00:00
12:00
00:00
12:00
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D)
Start: 21 Nov 2016 18:30
End: 23 Nov 2016 07:30
Mean EC: 120 µS/cm
Mean Temp: 30.5 °C
Temp Range: 24.7 - 40.1 °C
Mean DO: 76.2 % Sat
Dissolved Oxygen
pH
Dissolved Oxygen % Saturation
pH
200
180
160
140
120
100
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Fig 3.

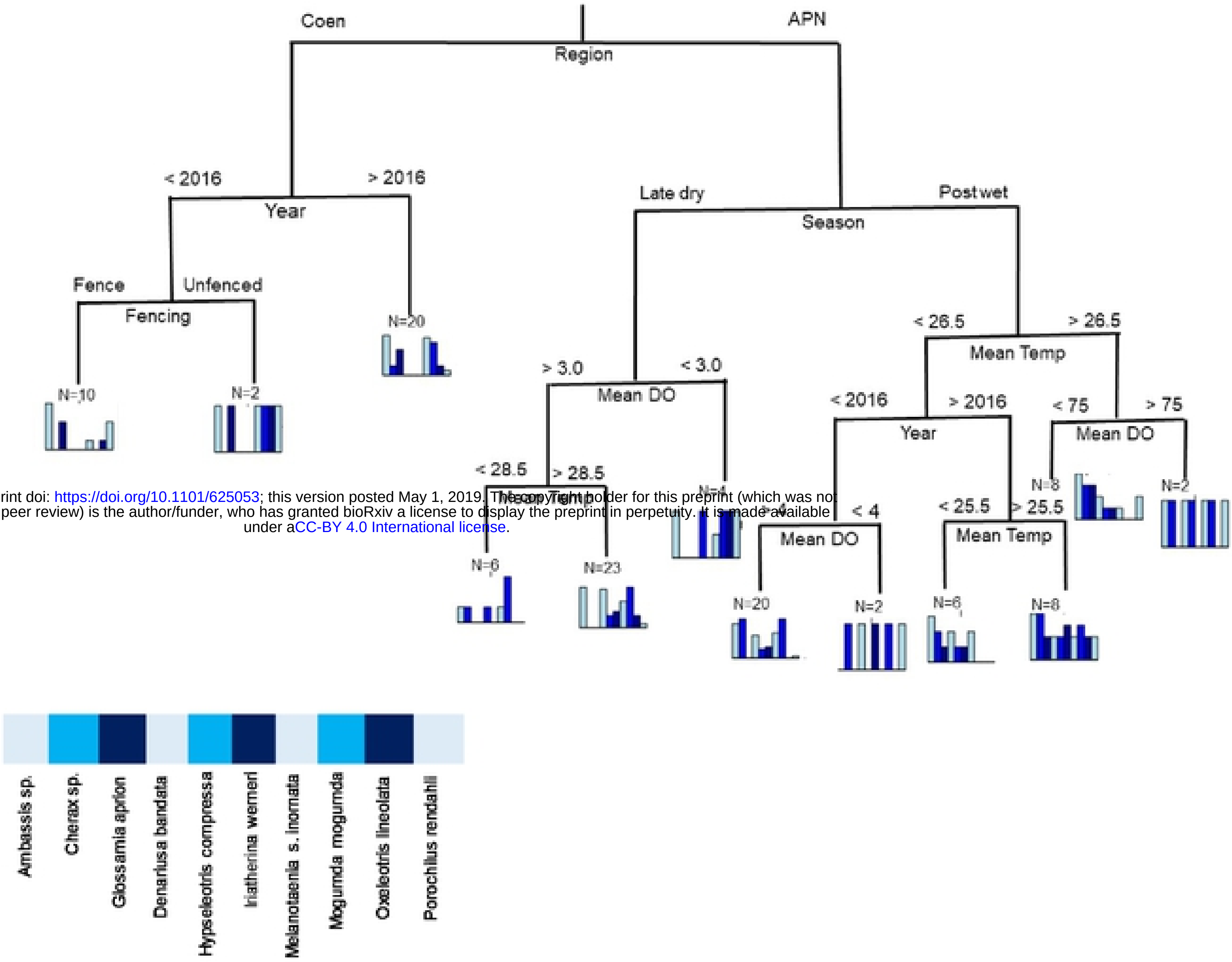

Coen
APN
Region
< 2016
> 2016
Year
Late dry
Post wet
Season
Fence
Unfenced
Fencing
N=20
< 26.5
> 26.5
Mean Temp
> 3.0
< 3.0
Mean DO
N=10
N=2
< 2016
> 2016
Year
< 75
> 75
Mean DO
< 28.5
> 28.5
Mean Temp
N=4
N=8
N=2
> 4
< 4
Mean DO
< 25.5
> 25.5
Mean Temp
N=6
N=23
N=20
N=2
N=6
N=8
Ambassis sp.
Cherax sp.
Glossamia aprion
Denariusa bandata
Hypseleotris compressa
Iriatherina werneri
Melanotaenia s. inornata
Mogurnda mogurnda
Oxeleotris lineolata
Porochilus rendahli

Fig 4.

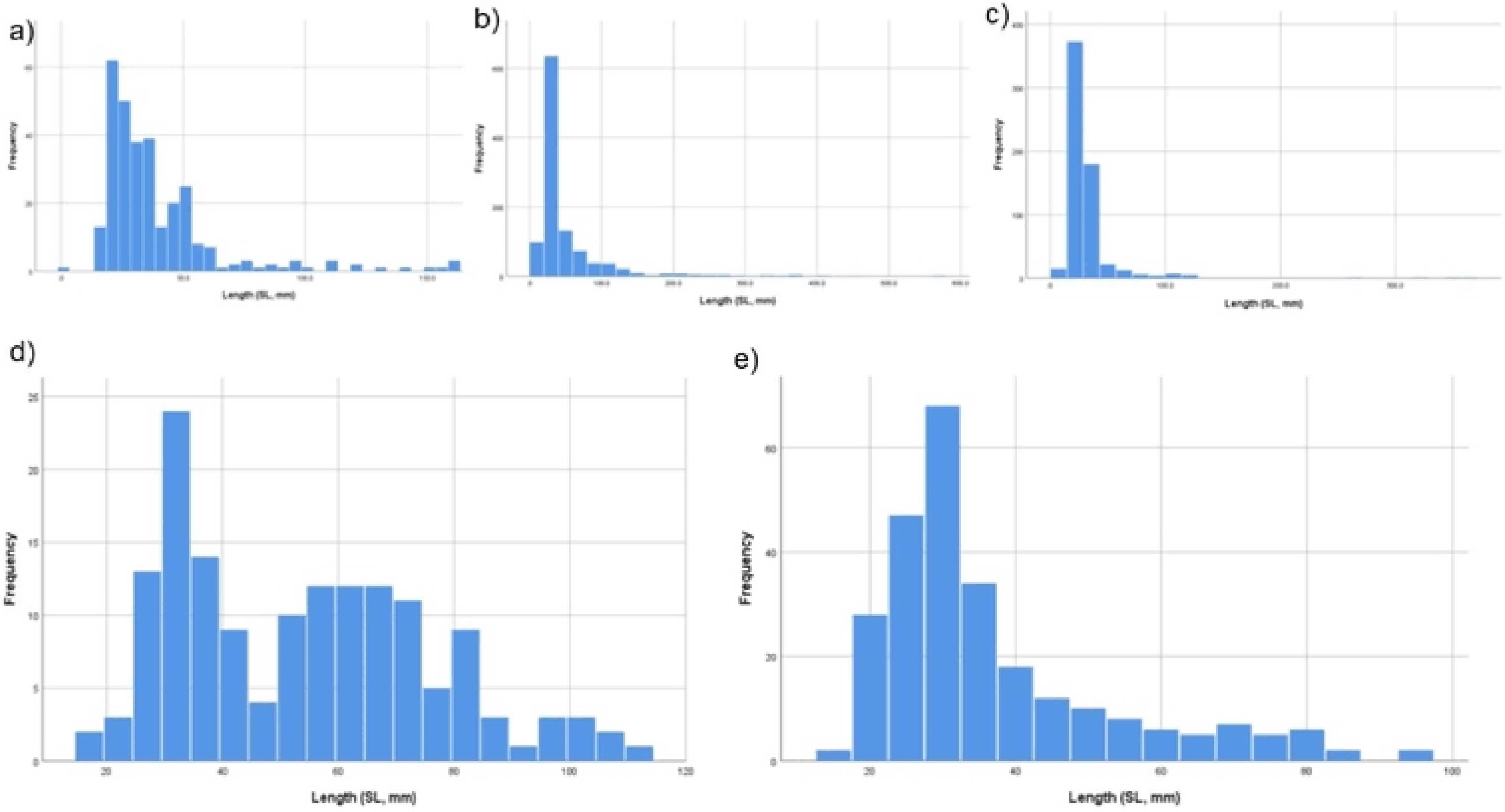
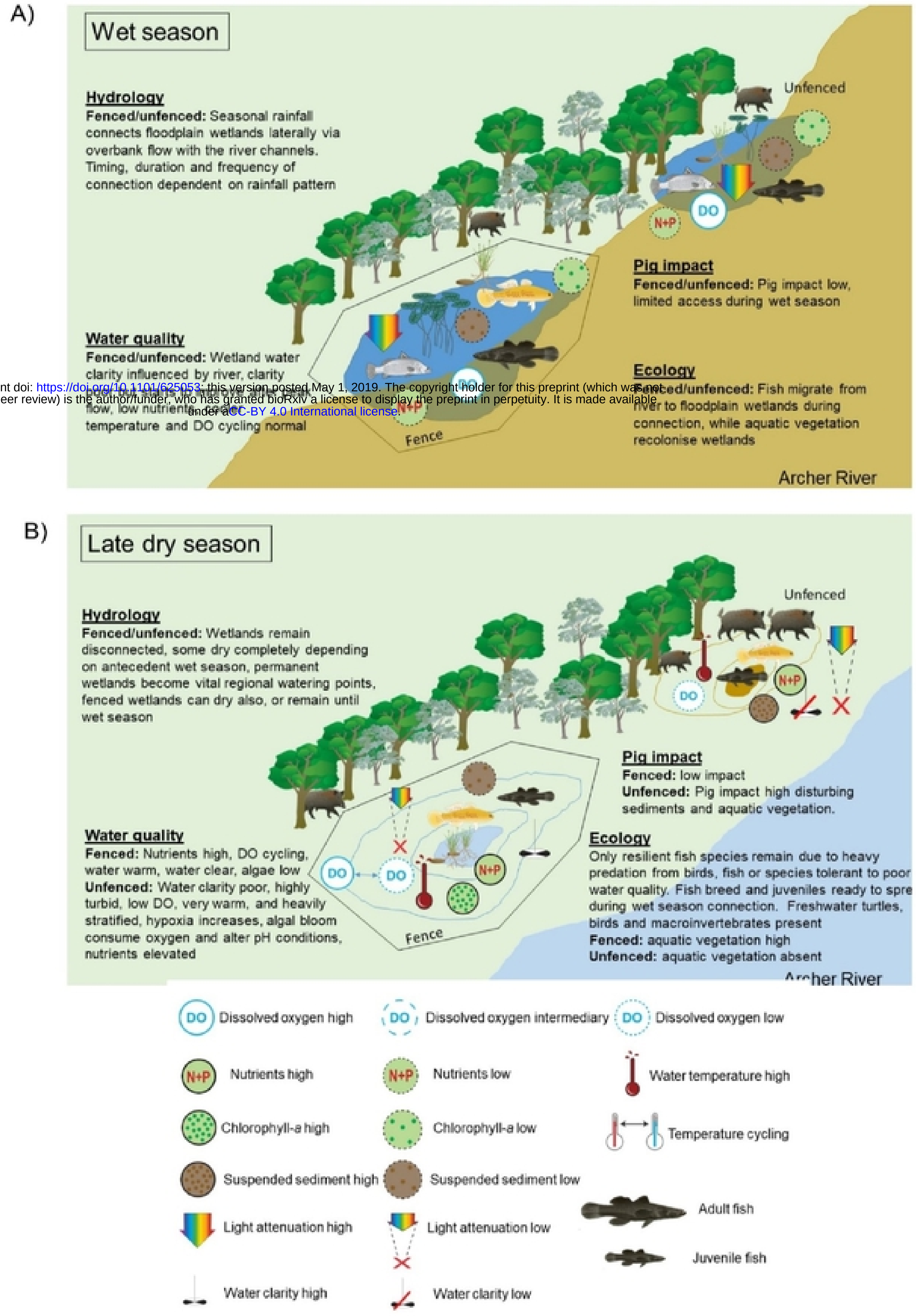

a)
Frequency
Length (SL, mm)
b)
Frequency
Length (SL, mm)
c)
Frequency
Length (SL, mm)
d)
25
20
15
10
5
0
Frequency
20
40
60
80
100
120
Length (SL, mm)
e)
60
40
20
0
Frequency
20
40
60
80
100
Length (SL, mm)

Fig 5.



Hydrology
Fenced/unfenced: Seasonal rainfall connects floodplain wetlands laterally via overbank flow with the river channels. Timing, duration and frequency of connection dependent on rainfall pattern

Water quality
Fenced/unfenced: Wetland water clarity influenced by river, clarity poor but starts to improve after peak flow, low nutrients, cooler temperature and DO cycling normal

Pig impact
Fenced/unfenced: Pig impact low, limited access during wet season

Ecology
Fenced/unfenced: Fish migrate from river to floodplain wetlands during connection, while aquatic vegetation recolonise wetlands

Hydrology
Fenced/unfenced: Wetlands remain disconnected, some dry completely depending on antecedent wet season, permanent wetlands become vital regional watering points, fenced wetlands can dry also, or remain until wet season

Water quality
Fenced: Nutrients high, DO cycling, water warm, water clear, algae low
Unfenced: Water clarity poor, highly turbid, low DO, very warm, and heavily stratified, hypoxia increases, algal bloom consume oxygen and alter pH conditions, nutrients elevated

Pig impact
Fenced: low impact
Unfenced: Pig impact high disturbing sediments and aquatic vegetation.

Ecology
Only resilient fish species remain due to heavy predation from birds, fish or species tolerant to poor water quality. Fish breed and juveniles ready to spre during wet season connection. Freshwater turtles, birds and macroinvertebrates present
Fenced: aquatic vegetation high
Unfenced: aquatic vegetation absent

Fig. 6.