

Review of Draft Lungfish Scientific Report 4 July 2001

Ecology and demographics of lungfish (*Neoceratodus forsteri*) and general fish communities in the Burnett River, Queensland with reference to the impacts of Walla Weir and future water infrastructure development

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August 2001

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Introduction

The purpose of this report is to critically review the draft lungfish scientific report dated 4 July 2001, comment on appropriateness and/or deficiencies of methodologies employed, and to gauge success in achieving research results in terms of the proposed aims.

The study on lungfish in the Burnett River carried out by Brooks and Kind from January 1997 to February 2000 was commissioned to address conditions imposed by the Federal Minister of the Environment. The conditions were in reaction to impact assessments, independent reviews and recommendations in relation to the construction of the Walla Weir. The Boardman review (1996) encompassed the full range of inputs, including all relevant IASs, submissions, scientific literature, letters and discussions with interested parties and a short term study of lungfish in the Burnett by Brooks (1995).

Boardman's review expressed concerns about the potential effects on lungfish of further water infrastructure development on the Burnett River post construction of the Walla Weir, and made recommendations that a series of studies be undertaken over several years to accumulate long term baseline data to assist in evaluation of future proposals. Conclusions from the review, and several additional recommendations outlined by the Commonwealth EPA and QDoE for additional studies, were approved by the Minister as conditional for Commonwealth funding for the Walla Weir. The requirements pertaining to fisheries and lungfish were formed into a research plan by officers of QDNR, QDoE and QDPI Fisheries and a steering committee was established to objectively oversee progress.

Research Proposed

The proposed research aims were:

1. Determine the distribution and relative abundance of lungfish in the Burnett River.
2. Determine the population structure of lungfish throughout its range in the Burnett system.
3. Develop methods for determining the age structure of lungfish populations in the Burnett River.
4. Quantify the characteristics of lungfish spawning sites in the Burnett River.
5. Compare hatching rates between habitats (riverine and impounded).
6. Compare recruitment of juveniles between habitats.
7. Determine habitat requirements of juvenile lungfish.
8. Determine the potential effects of fluctuating flow/water levels on the habitat and hence juvenile lungfish.

9. Determine the normal home range of lungfish.

10. Determine the extent, timing and significance of any migration/movement.

Additional recommendations following from the Boardman review, on analysis of genetic diversity in lungfish populations and survival of macrophytes and semi-aquatic plants in the Burnett River system (impounded and riverine), are addressed in separate reports, and thus are not discussed or reviewed here. Monitoring of the Walla Weir fishlock has been reported on separately by Berghuis et al. (2000). Despite the title of the draft report there is no data or discussion of 'general fish communities' in the report.

Changes to Original Project Proposal

Some modifications to the original research proposal were instituted after consideration by the steering committee:

- Addition of Jones Weir to baseline sampling after the first sampling period, to include an impounded site removed from the impacts of Walla Weir.
- Tagging of lungfish at all nine sampling sites instead of only two, by August 1997.
- Movement patterns were assessed by radio telemetry techniques as well by the originally proposed tag/recapture methods from July 1998.
- Ageing studies were modified to exclude the use of otoliths and teeth after trials proved them to be impractical and of little value in determining age of lungfish. A 'scale bank' and the marking of scales of released lungfish with oxytetracycline was implemented, showing promising indications as an ongoing, longer term method.
- Reproductive biology of lungfish was not originally planned to be examined. Sex and breeding status was assessed by non-threatening internal examination, and gonadal biopsy. Apart from improving description of population structure, this was utilised as an alternate method of modelling possible recruitment levels, after difficulties with very low capture rates of juvenile lungfish.
- Juvenile sampling proved exceedingly problematic and various refinements were made to the originally planned techniques, to maximise efficiency.

These changes were sensible and practical, given the lack of proven techniques applicable to lungfish and problems caused by unforeseen stream flow events, and were instituted in a relatively timely fashion.

Existing information

Some aspects of lungfish anatomy, physiology and embryology are reasonably well researched, however details of behaviour, ecology, demography and recruitment are poorly known. There are studies on spawning that provide some useful information on courtship and the timing, possible stimulus, method and requirements for oviposition (Kemp, 1984, 1987, 1993; Brooks, 1995), however most were limited to particular sites or limited temporally. Kemp (1981) describes methodologies successfully employed to hatch and rear juvenile lungfish in captivity from eggs collected in the wild. There are no reports of lungfish successfully spawning in captivity. Lungfish dietary preferences are known primarily by behaviour in captivity (eg. Kemp, 1977, 1981), although there is also limited data available from faecal remains of wild caught specimens (Kemp, 1987) and anecdotal field observations (eg Semon, 1899).

Summary and review of results

1. Determine the distribution and relative abundance of lungfish in the Burnett River.

Distribution of lungfish was extended upstream from that reported in Brooks (1995) to the wall of Boondooma Dam on the Boyne River arm. Abundance data indicates that the core lungfish population occurs from the Ben Anderson Barrage to about AMTD 275, and the lower Boyne River. Extensive surveys failed to record lungfish above the Barambah Gorge on Barambah Creek. It appears that little sampling effort was expended in the area between the Auburn River junction and Ceratodus, and further upstream in the Burnett arm. Despite this, it is unlikely that significant populations of lungfish inhabit this area, or the upper reaches of Three Moon Creek (above Mulgildie), due the lack of adequate permanent pools.

A total of 2770 individual lungfish were captured, and of these 118 were subsequently recaptured. Spatial abundance was directly related to presence of permanent water and complex instream habitat such as woody debris, dense macrophyte beds or undercut banks. Not surprisingly, catch per unit effort increased markedly for targeted electrofishing in the winter and spring when spawning aggregations were located. Although retention of PIT tags was superior to that of dart tags, both had good results and showed no evidence of biasing data through altering the behaviour of lungfish. Abundance data will provide useful baseline information for comparison with future years, but given the age structure of the population, gross changes other than large scale mortality or instream migration may take decades to detect.

Targeted and standard electrofishing and panel netting proved complementary and efficient methods of sampling lungfish populations (at least in the subadult and above size classes) for distribution and abundance studies. Recaptures from the first large scale tagging exercise on lungfish showed excellent retention rates for both tag types and provides the ongoing opportunity to obtain additional information from future monitoring. As recommended in the scientific report, PIT tag readers should be installed in the Walla fishlock and other fishways to monitor lungfish throughput.

2, 3. Determine the population structure of lungfish throughout its range in the Burnett system. Develop methods for determining the age structure of lungfish populations in the Burnett River.

Boardman recommendation: Determine the size distribution of the lungfish population; Investigate population dynamics of lungfish; Initiate work towards developing an index of lungfish age.

Aims: Describe the population structure of lungfish in the Burnett catchment; Develop methods for determining the age structure of lungfish populations.

Lungfish collected by regular sampling ranged from 345 to 1420mm, with a mean of 906mm. Females dominated size classes above 1200mm. There was no significant difference in condition or growth rates between riverine and impounded sites. Of 586 specimens sexed, the overall sex ratio was almost 1:1. Length at maturity varied widely for both sexes, however a range of 738-790mm and mean of 767mm for males and a range of 814-854mm and mean of 834mm for females, was calculated using a 95% confidence interval. Difficulties were experienced with field recognition of the sex of immature fish and the maturity status of males. Length data was taken for 2665 lungfish, but annual length frequency distributions indicated very low recruitment to the population from 1997-2000. The bimodal nature of overall male/female length frequency histograms indicates the likelihood that recruitment levels in the past have also been irregular. In a similar vein, Kemp (1987) speculates from her (sparse) data that successful recruitment of juveniles may occur in long-term cycles, dictated by the occasional incidence of good spawning seasons followed by favourable conditions for the growth and survival of the newly hatched young.

The usual methods of ageing bony fishes are shown to be poorly applicable to the long-lived and relatively slow-growing lungfish. Scale increments are visible but their periodicity has not been validated. Simple counts of 'annual' increments are likely to significantly underestimate age, particularly of larger fish, while the growth curves modelled in the scientific report appear to moderately overestimate age, particularly at the left hand side of the curve. Attempts to validate the periodicity of scales using OTC marking and tag/recapture show little short-term promise, but may be useful in a 5-10 year perspective.

Data from 118 tag/recaptures with a period at liberty of 71-916 days (mean 366 days) was used to model growth rates. The growth curves produced predict an asymptotic mean length of 925-937mm and an average age at sexual maturity (based on average length at maturity data) of 19 years (17 for males and 22 for females). This may be inaccurate for several reasons. There was no input data from specimens less than 433mm and growth rates of these size classes may be understated. Benchmarks for juvenile growth rates in aquaria determined by Bancroft (1933) and Kemp (1981) are poor guides to what is achievable in captive green water culture, and may also fall well short of actual rates in the wild. Compared with growth rates of captive specimens in green water, and staged captures of same generation juveniles in the wild (Longman, 1928; Kemp, 1987), the growth curves seem to significantly underestimate growth rates of smaller fish. For example, while the predicted age of a 300mm fish is modelled at about 3.5 years, this size has been reached at 12 months in captive fish, and in staged captures no more than 18-24 months. Scale-aged fish estimated to be 3-4 years of age were 711-903mm. The growth curves predict a mean asymptotic length of 931mm, however this is smaller than almost half of all fish

captured, and is only a fraction of the largest fish recorded (1420mm). Capture and tagging stress is almost certainly responsible for temporarily retarding growth rates (growth curves showed significantly higher growth rates for recaptured fish at liberty for more than one year than those up to one year). This, in combination with slower than likely predicted juvenile growth rates, may have flattened the growth curves, lowering predicted asymptotic length and exaggerating age to maturity predictions.

Various estimates are given for (average) age at sexual maturity throughout the scientific report, ranging from 'at least 10 and possibly even 20', 'approximately 19', 'at least 15' and 'several years'. Obtaining more accurate data for juvenile growth rates, and age for both sexes at sexual maturity will be some of the most important and challenging priorities for understanding lungfish reproductive biology. This information will also be integral for conservation management plans.

4. Quantify the characteristics of lungfish spawning sites in the Burnett River.
Boardman recommendations: Assess the spawning sites, hatching rates and recruitment of lungfish.

Aims: To quantify characteristics of spawning sites in the Burnett River; To compare hatching rates between habitats; To compare recruitment of juveniles between habitats.

Fifteen sampling sites each of 50m length, including 5 from below, within and above the proposed Walla Weir, were chosen to gauge lungfish spawning activity and related site characteristics. Sampling was carried out in 1997 at weekly intervals during the height of the spawning season, as found by various authors and confirmed for the Burnett region by Brooks (1995). Poor environmental conditions precluded sampling in 1998, and in 1999-2000 spot checks only were carried out, in targeted areas. Spawning occurred at 7 sites on both aquatic and terrestrial macrophytes, in low turbidity, broad temperature range, high dissolved oxygen levels, mostly at < 200mm depth in still water, and mostly 400-600mm in flowing conditions.

In still water 2,300 eggs at a rate of 3.1 eggs/m² were collected, as well as 19 juvenile lungfish ranging from 15-40mm. Highest densities of eggs and hatched eggs were found in moderate to high densities of macrophytes, of 160-350mm in height. Preferred spawning media was *Bacopia monniera*, with *Nitella* sp. and *Vallisneria gigantea*, however for late stage and hatched eggs *Paspalum distichum* was heavily utilised.

In flowing conditions 334 eggs at a rate of 3.7eggs/m² and no juveniles were collected. Depths of less than 1m had reasonable densities of eggs and correlation to macrophyte height was similar to still water. *Vallisneria gigantea* was generally the preferred spawning media in flowing conditions. This study and the previous short term study (Brooks, 1995) made many new findings and dispelled various others, markedly broadening the knowledge base on characteristics of spawning sites and the plants used.

During 1997-1998 aquatic macrophyte growth at most sampling sites in the river was rated as 'absent or very sparse' compared to that found in 1995, by reason of loss by scouring and turbid conditions caused by prior flooding. Given the importance of aquatic macrophytes to spawning success as shown in the report, it is reasonable to

assume much lower spawning success during the sampling period than might occur in the absence of recent severe flood events, when the macrophytes would have the opportunity to establish themselves. Accordingly, the results obtained may provide baseline data only for when poor conditions prevail. Although only 7 of the 15 sites sampled in 1997 yielded eggs, neither the breakdown in results nor specific site characteristics are identified to allow comparison.

Unfortunately in 1999 and 2000, following apparently better environmental conditions and the strong build up of aquatic macrophytes above and below the Walla Weir, no quantitative data on spawning was taken. Due to 'time and staff restrictions' spot checks only were undertaken throughout the catchment, with qualitative data noted. At this time lungfish spawning activity reportedly responded favourably to increased macrophyte growth, particularly in the riverine section below Walla Weir. Widespread and prolonged spawning was observed (from mid July to mid December) and running ripe fish were collected from a combination of unregulated and impounded sites. Within the Walla Weir however, where macrophyte growth was poor, only one instance of courtship behaviour was recorded (in 1999).

6, 7, 8. Compare recruitment of juveniles between habitats; Determine habitat requirements of juvenile lungfish; Determine the potential effects of fluctuating flow/water levels on the habitat and hence juvenile lungfish.

Boardman recommendations: The spawning sites of lungfish, hatching rates and recruitment of juveniles should cover several years, both in impounded and riverine sites; The habitat requirements of juvenile lungfish and the effect of fluctuating water levels.

Aims: Determine habitat requirements of juvenile lungfish; Determine potential effects of fluctuating water levels on habitat and therefore juvenile lungfish.

The collection of juvenile lungfish has been notoriously difficult ever since the discovery of the species in 1870, and numerous authors have commented on the scarcity of juveniles. Even in the late 1800's zoologists were so concerned about the perceived lack of recruitment as to commission the translocation of specimens to other catchments in order to prevent its extinction. Various methods were trialed for the study, including electrofishing (boat and backpack), which is highly effective on moderate to large lungfish and most other species of fishes in freshwater. Only 23 juveniles were collected during the study, 19 by push-net and 4 by backpack electrofishing. None were collected in impounded areas, although the dense woody debris found in these areas is likely to provide suitable habitat for larger juveniles. The numbers collected were inadequate to make determinations on present levels of recruitment or fluctuating water levels. All were taken in depths of less than 500mm, among dense macrophyte growth, similar to that favoured for spawning. This and all other available data suggest that juveniles utilise the same type of habitat as for spawning and are slow to disperse after hatching. The reliance on macrophyte beds makes juveniles especially vulnerable to flow events where these beds are removed by scouring, or exposed by rapid decreases in water levels. During these instances small juveniles (especially the largely immotile smaller stages) are likely to suffer high mortality rates through displacement, predation or dessication.

The numbers of juveniles caught, while more than likely indicative of low recruitment, are nonetheless also likely to somewhat understate these size classes in

the overall lungfish population. The moderate to large size classes are likely to have considerably higher catchability than juveniles, especially those < 100mm that still occur in very dense cover. Only 4 juveniles were taken by electrofishing, although several others were sighted, and none (< 100mm) were taken using this method by Brooks (1995). On both these occasions larger numbers were taken by push-nets in the same locations. Other nocturnal fishes, such as small dewfish *Tandanus tandanus*, are often very difficult to catch by electrofishing when in dense beds of aquatic plants, especially when there is no surrounding open water to draw them into. When affected by the electric current they often become caught in the matt of weed or do not move far enough out to become visible to the collector. Similar problems are likely with small juvenile lungfish, and together with a lower visibility factor in turbid conditions, catch per unit effort is thus almost certain to be lower for these fish.

9, 10. Determine the normal home range of lungfish; Determine the extent, timing and significance of any migration/movement.

Boardman recommendations: Study the migration of lungfish in the Burnett River. Radio tracking should be used in conjunction with tagging.

Aims: Determine the normal range of lungfish in the Burnett River; Determine the extent, timing and significance of any migrations/movements.

Lungfish often congregate at stream barriers (or pass over them) during flow events, indicating their willingness to undertake substantial movements at these times. However the reasons for these movements are uncertain. Tag/recapture provided simple start to end point data, while radio telemetry gave more complex regular and ongoing information on movement patterns. Movement data was obtained from 124 tag/recaptured fish of 470-1240mm that were at liberty ranging from 7-928 days. No adverse tagging affects were evidenced. There was no directional trend in movements and despite movements as great as 35,400m, modal movement was nil. Movements in impounded areas were much greater than in riverine sections, where the longest movement was only 2,900m. There were no movements through weirs recorded, although one tagged fish was captured in the fishlock.

Telemetry data was obtained from 28 fish over 354-911 days, and each fish was located on average on 24 separate days. These fish occupied linear ranges of 300-47,900m. Mean total range downstream of Walla Weir was 28,740m compared with 6,450m within the weir and 1,667m for the group well above the Walla impoundment. Fish in the upstream riverine section exhibited strong site fidelity, routinely being found in the same location. Those within the Walla Weir had similar movements and only one fish moved out of the impoundment (upstream). Fish released below the weir were highly mobile and individuals were highly variable. There was some correlation between magnitude of movement and flow rates. The results from tag/recapture and telemetry were complementary, both showing a clear dichotomy between riverine and impounded sections of the river. There is some evidence to suggest that upstream movements, especially from the established impoundments below the Walla Weir, were spawning related.

Achievements in Relation to Boardman Recommendations and Project Aims

The study used best practice methodology and analysis to investigate the questions raised by the Boardman recommendations. While the period allowed to complete the

studies was sufficient to effectively address some the stated objectives, it proved inadequate for others. In general terms, this was mainly due to the extraordinarily long-lived and slow growing nature of the species, but chance environmental conditions were also responsible for significantly hindering the collection of data at critical times, especially during spawning periods. Attempts to answer many of these questions in the past have failed or only been partially successful. However, in contrast to this study, most of those attempts were poorly resourced or critically limited spatially and/or temporally. This study resulted in good baseline and other data on some aspects of the research, including size distribution, population structure, spatial distribution, relative abundance, characterisation and quantification of spawning and spawning sites, movement and migration, and to a lesser extent habitat requirements for juvenile lungfish. It appears that likely spawning habitat in riverine sections may be successfully identified at high confidence levels using the criteria determined in the report, especially depth, macrophyte species and density, and flow rate.

But, as in the past, efforts to obtain meaningful understanding of hatching rates and juvenile recruitment (and their relationship between riverine and impounded sites, to habitat, and fluctuating water levels) was confounded by difficulties in sampling and collecting juvenile lungfish. In the absence of sufficient prior comparative data, it is impossible to say whether recruitment during the study was low in absolute terms, or modal, and merely low relative to that achieved in ideal conditions that are rarely available. It is clear that for a long-lived species with naturally low mortality rates, successful spawning and juvenile recruitment is not essential on an annual basis. There is some anecdotal evidence to suggest that this may only occur irregularly, perhaps in medium to long term cycles, even in unregulated systems. Nonetheless, even if this is indeed correct, it is not reason to ignore persistently low levels of recruitment. The length of these 'cycles' could easily mask potentially deleterious impacts on recruitment, such as the effects of introduced and translocated fish species or dams and weirs, for many years. Large adults could remain common for decades, while the absence of juveniles recruiting to the population could be overlooked for so long as to result in serious consequences for long-term survival of the species. For these reasons, lungfish recruitment studies will necessarily require long time frames to achieve reliable results, and firm commitment to long term monitoring is essential. Techniques employed by the study to sample juvenile lungfish (push-nets and electrofishing) appear to be the best available, however both could probably benefit from further refinement. The large numbers of tagged fish now in the river provide a valuable research tool to answer some of the outstanding problems.

Satisfactory indices for lungfish ageing are not yet available from the studies to date, although progress has been made in their development. Traditional anatomical methods used to determine age in fishes were not found to be as successful with lungfish. Methods will need to be refined over time using additional validation data from longer-term tag/recaptures. Good longer term potential of OTC injection technology has been recognised. Growth curves used to mathematically model age appear to require considerable modification in order to achieve more reliable results for lungfish.

Comments on some conclusions of the scientific report

As stated, the scientific report was undertaken due to the absence of information adequate to answer questions posed in the Boardman report. It required the development of some new and unproven techniques, and presents the first quantitative description of a lungfish population in the wild. While questions, especially pertaining to recruitment, ageing and population dynamics remain unresolved, there were many new and valuable findings. Where insufficient data exists, conclusions and subsequent recommendations can only be made on the best available evidence, and in some cases may be the subject of debate and potential future revision. The authors have acknowledged the need for further research, or research over longer time frames, to address these problems. Several other items requiring additional investigation are recommended elsewhere in this review.

Most conclusions made in the report are supportable by the facts as presented, or are suitably qualified so as not to represent unsubstantiated opinion. Outlined below are some areas where statements made are equivocal, require additional information or modification.

- It is claimed that the study coincided with poor recruitment, however it is also acknowledged that environmental conditions leading up to and during much of this period were not conducive to successful spawning. What may represent good or 'normal' rates of recruitment remains unknown. Low rates of recruitment may well be modal for the species. Care should be exercised in linking particular variables with recruitment rates until reliable information is available.
- Further study of overall lungfish dietary requirements are important objectives, however in terms of lungfish conservation and water infrastructure management, comparative data on diet between riverine and impounded systems is more important. In essence, lungfish could prosper on the same, partially different, or entirely different food resources between the two. Until this data is available presence/absence of particular food sources can not be used alone as evidence of relative habitat quality.
- Although the findings of the study indicate that consistently viable spawning grounds are unlikely to occur in impounded areas (between Isis Pumping Station and the Ben Anderson Barrage, within Walla Weir or within Jone's Weir), more research is required to unequivocally determine that significant spawning activity could not develop there. There is an almost total lack of information on water hyacinth provided in the report, with no information on control measures and their frequency in the Burnett, nor whether it was indeed considered, sampled or its microhabitat measured during the studies. The size of water hyacinth rafts, bathymetric profile of the impoundments involved, flow rates, and amount of fluctuation in water levels will be important determinants as to whether sufficient dissolved oxygen levels are likely to exist within the root matts and whether the rafts will be habitually grounded by receding water levels. Given lungfish are known to adapt to its use as a spawning medium elsewhere, with success both in riverine and impounded systems, the possibility of its current or future use can not be ignored and should be investigated. The root systems of floating para grass,

particularly near steeply shelving banks, should also be included in these investigations.

- Construction of impoundments will result in an initial net loss of spawning habitat following inundation. Subsequent regular fluctuations in water levels are likely to mitigate against effective re-establishment of aquatic macrophyte beds used for spawning, unless carefully monitored and regulated. However, the statement that impoundments may represent a total loss of habitat previously available for spawning requires more considered qualification.
- Regulation of the river has clearly decreased the area of *most* suitable spawning habitat, as recognised from the current studies. However, the possibility exists that lungfish may adapt to the use of lesser grade habitats (such as that outlined above) to partially compensate.
- The statement that ‘evidence from this study indicates that even when suitable spawning conditions do arise in the catchment, spawning rarely occurs within the impounded sections’ is mostly supported by assertions that water levels have fluctuated too widely in the impoundments to allow suitable spawning habitat to accumulate and be maintained for adequate periods. No opinion is ventured as to whether it is possible to maintain water levels at suitable levels in any given spawning season, year, or more irregular time frame. If it is indeed possible to achieve the required stability in water levels, then presumably it would only need to happen on an irregular basis to simulate an unregulated environment. It is acknowledged that due to floods, droughts and unseasonal flow events good spawning conditions may only occur occasionally, even in unregulated environments. Responsibility here lies with water resource managers to determine and demonstrate whether it is practical or actually feasible to fine tune water levels to this degree.
- The report provides no site specific break downs of data collected on aquatic or semi-aquatic plants and other potential spawning habitat characteristics between sites above, below and within impounded sections. Data was only presented according to prevalence of observed eggs. Lack of spawning in impounded sections during the study period does not necessarily mean that it could not be facilitated under a different water management regime that fostered the development of aquatic macrophyte communities suitable for spawning. Current habitat data for impounded areas may be valuable in determining whether suitable conditions could be regenerated, given that the maintenance of suitable water levels in these areas is achievable.
- It may not necessarily be the case that lungfish are forced into large spawning aggregations above impoundments through lack of space. There is anecdotal evidence that lungfish sometimes also form spawning aggregations in unregulated sections of the river by choice.
- Concentrating spawning in ‘small’ areas may ‘inevitably lead to increased competition between hatchlings’, however there is no evidence to suggest that either available food or shelter is likely to be a limiting factor for survival of juvenile lungfish.

- The potential mortality rate of adult lungfish, through physical damage when passing over dam and weir walls during flood and by passing into the estuary below Ben Anderson Barrage, should not be underestimated. During very large floods the potential for loss could be in the order of hundreds of individuals, judging on experience in other systems. Mitigating against these problems should be of the highest priority.
- There is no information provided to support the claim that lungfish may be vulnerable to increases in salinity throughout the Burnett (above Ben Anderson Barrage).

Additional research recommended

Adult lungfish have very broad dietary requirements, are quite hardy and adaptable to new environments, are able to utilise some exotic plants (such as water hyacinth and para grass) for both shelter and spawning and have been successfully translocated and established outside their original home range. Further research should be conducted to determine the likely reproductive success of lungfish confined to impoundments within the Burnett system, with emphasis on drawing on experience in other systems.

- Compare characteristics of impoundments lacking an upstream riverine component, but containing viable self-reproducing populations of lungfish, with those on the Burnett. Enoggera Reservoir started with a population of only 18 lungfish in 1896 (O'Connor, 1896). There have been no serious attempts to assess or monitor lungfish numbers there, however there is strong anecdotal evidence that despite numerous periodic losses to Enoggera Creek during overtopping (personal observations and communications, 1978-1999), the population has grown from the original stock and been maintained for over a century. Longman (1928) recorded juveniles that were accidentally captured on several occasions and Kemp (1981, 1984, 1987) reports the collection of eggs and observations of spawning activity. The only stream inflow to the system is through a minor shallow creek that, except for its mouth, is largely unutilised by lungfish. Water levels are prone to significant, albeit gradual, fluctuation, particularly in dry periods. The reservoir has a close to pristine watershed, few human impacts and does not contain introduced exotic or translocated native fishes (except *Gambusia*). Determine strategies employed by lungfish to successfully spawn and recruit in what appears from the scientific report to be less than ideal conditions.
- There is no mention in the scientific report of the presence of water hyacinth in the Burnett, nor of its potential for spawning or shelter for juvenile lungfish. Extensive rafts of the plant are illustrated and are reported as often causing clogging at the entrance of the Ben Anderson fishway (Stuart & Berghuis, 1999). Lungfish are known to actively choose the floats and root systems of the introduced water hyacinth, *Eichornia crassipes*, for oviposition in both the Brisbane River and the Enoggera Reservoir (Kemp, 1982, 1984, 1987) and its use is also mentioned by Grigg (1965). Juveniles are also known to shelter among water hyacinth (Longman, 1928). Eggs laid on floating structures such as water hyacinth (or to a lesser extent para grass) are better equipped to maintain optimum depth and avoid exposure, in spite of fluctuation in water levels, although their

overall value may be limited by low dissolved oxygen levels in many areas. The distribution, abundance, and spatial and temporal variability of water hyacinth growth throughout the Burnett River system, particularly in impounded areas, should be determined. Physical characteristics of the microhabitat available within the root systems should be measured and quantified. Extensive sampling to assess whether lungfish are using water hyacinth as spawning media and juvenile habitat should be carried out.

- Dietary requirements for lungfish are generally considered to be broad. However, no site specific data is available on lungfish dietary preferences. Information suggesting lower macroinvertebrate abundance and diversity in impoundments has been used to infer lower habitat quality in these areas, despite evidence suggesting good condition factor in individuals occupying impounded areas. Data should be obtained to quantify and compare diet between riverine and impounded sections.
- Below the Walla Weir, lungfish are often found in the vicinity of the tailwater pool, and are recorded as abundant immediately below the rock bar, indicating that there may be some intent on upstream migration. Yet few have been shown to use the fishlock (Berghuis, 2000). In the long term it is possible that a 'learned response' may be developed by individuals once they have successfully negotiated the fishlock, however this is by no means certain. In order to further understand these processes, and especially their importance for lungfish reproductive capability, ongoing monitoring of the fishlock and its efficiency over time is essential. Further consideration should be given to the installation of PIT tag readers for efficient gathering of this data.
- Assess those systems from the Calliope River south to the Burrum River, where lungfish do not currently exist, to determine if conditions and habitat of adequate quality exist to potentially support translocation and establishment of viable lungfish populations.

Recommendations on management approaches appropriate to minimise impacts on lungfish in the Burnett River

- Allow sufficient flow from relevant impoundments to preserve aquatic macrophyte beds in riverine habitats used for spawning (eg from Boondooma to the lower Boyne River and from Walla to Isis Pumping Station).
- Spawning and oviposition is shown to occur primarily in depths of < 200mm in still water. Rapid or ill-timed drawdowns within impoundments may cause exposure of aquatic macrophyte beds with associated eggs and juveniles during the spawning season and the time immediately following. Adequate water levels should be maintained during these times.
- Stranding and mortality in at least adult lungfish has been noted for the Walla Weir when water releases are reduced too rapidly (Berghuis et al., 2000). The amount of water released should be staggered over time to prevent this.
- Provide unobstructed passage opportunities for lungfish at causeways, bridges and other crossings.

- Given the naturally low recruitment levels to lungfish populations, it is vital that unnaturally high mortality rates for mature adults be avoided to maintain the overall population. Investigate most efficient alterations to vertical slot fishway in Ben Anderson Barrage so as to facilitate upstream return of lungfish passing downstream into saline conditions during major flow events. Consider more gradual gradient (eg 1: 18 to 20 as opposed to current 1: 15.8) and wider slot width than current 150mm (to allow passage of specimens of at least 1.4m total length). As an interim measure, have personnel assigned to check for lungfish below the barrage after major flow events and to manually relocate them.
- Determine methods of minimising physical damage and consequent mortality of lungfish over dam and weir walls during overtopping (eg by planning in appropriate adjustments to departure angle of the wall or to energy-dissipating measures at the foot of the wall).
- The concentration of spawning effort in diminishing areas of suitable spawning habitat has been determined in the scientific report to be likely to cause ‘interference competition’ and thus a potential threat to successful spawning and recruitment. Areas in the Burnett with strong competition for spawning sites should be identified and some sexually mature lungfish translocated from these areas to impoundments elsewhere in the drainage that have been identified as devoid of lungfish (eg Boondooma Dam, Bjelke Petersen Dam). Only those impoundments assessed as possessing viable spawning habitat should be chosen to receive these translocations. This may marginally lower interference competition, without significantly lowering overall reproductive capacity, while providing the potential for broadening the distribution and population base of lungfish throughout the system.

Distribution and Status of Lungfish beyond the Burnett River system

Historical distribution of *N. forsteri* was throughout the Mary and Burnett River systems. They were translocated to the North Pine River, Enoggera Reservoir, Brisbane River (Cressbrook), Albert River, Coomera River and Condamine River by O’Connor in 1895-6. Those in the North Pine, Enoggera Reservoir and Brisbane River have resulted in self-reproducing populations and are currently extant. There is some evidence of their current existence in small numbers in the Albert/Logan, but status there is uncertain. Those in the Condamine, and probably the Coomera did not persist. Early reports from the Fitzroy by Castelnau (1876) and Macleay (1870) were not later substantiated and are considered to be erroneous.

Kemp (1987) contends that lungfish were probably originally present in the Brisbane and Pine Rivers. She argues that the ‘five’ specimens translocated on 15th December 1895 to Cressbrook and the ‘three’ specimens translocated on 7th May 1895 to the North Pine (O’Connor (1896) actually reported 8 specimens for each, but later (1902) reported the numbers quoted by Kemp) are unlikely to be responsible for the whole of the lungfish population currently in these systems. However Kemp does not suggest that the population in the Enoggera Reservoir, nor those that she reports as extant in the Logan/Albert and Coomera Rivers were native, despite the only known translocations by O’Connor being of similarly low numbers (18, 5 and 16

respectively). Her suggestion that lungfish are unlikely to have left the small dam at Cressbrook to enter the Brisbane River (and thus establish there) as 'they are not known to migrate' and are 'reluctant to leave dams even in times of flood' can not be supported by current knowledge. The scientific report clearly shows that lungfish regularly migrate large distances within, and at least upstream from, impoundments. They also *often* leave dams during floods, sometimes in large numbers, as evidenced by their passing over the walls at Enoggera Reservoir and North Pine Dam during flood events. Lungfish in the Brisbane River are still today regularly caught by hook and line, and can readily be taken in multifilament gill nets at some sites (monofilament nets are less pliable and do not wrap and secure fishes lacking spines, such as eels and lungfish, as effectively). These were common methods of fishing (along with use of explosives) in the late 1800's and early 1900's and it would be surprising if lungfish were not commonly caught at this time, had they been present.

Genetic studies by QDPI Fisheries using preserved lungfish in the Queensland Museum, that were collected in the early 1900's, are currently under way and may more effectively establish the origins and genetic diversity of lungfish stocks.

Recent information on distribution and status of lungfish populations outside the Burnett River system is sparse and largely anecdotal. There is no good evidence of their occurrence, historical or current, between the Burnett and the Mary Rivers, in streams such as the Isis, Gregory and Burrum Rivers. Streams to the near north of the Burnett, including the Kolan, Boyne and Calliope Rivers and Baffle Creek, apparently have not been occupied by lungfish.

Unpublished studies in the Mary River have been carried out by officers of QDPI Fisheries (referred to, but not detailed in the scientific report) and anecdotal reports indicate that populations in this system are locally healthy. Studies by Pusey et al. (1993) on fish assemblages in the upper Mary River and tributaries do not record the presence of lungfish, however this is not surprising as most of their sites did not contain suitable habitat, and the techniques they employed were not conducive to sampling deep permanent pools likely to be occupied by the species.

Various studies concentrating on the exotic Tilapia, *Oreochromis mossambica* in the North Pine Dam (Lake Samsonvale) unfortunately yielded no incidental data on the occurrence of lungfish. There appear to be significant resident populations though, as there have been several recent mass strandings below the dam wall after flooding forced the rapid release of water through the spillway. There were reported estimates of about 60 individuals found dead or injured in the area immediately below. On several occasions those still living were manually returned to the dam. It is reasonable to assume that many more would have been washed further downstream. Captures by hook and line from the nearby Young's Crossing reach of the North Pine River are frequently reported by members of the public following significant overtopping. Recent electrofishing surveys by DPI Fisheries officers have located moderate numbers of lungfish in the North Pine Dam.

Recent lungfish populations in the Brisbane River system, particularly from the Wivenhoe Dam downstream to the Mt Crosby Weir, appear to be healthy. Numerous large specimens are regularly sighted near the Mt Crosby Weir, while smaller fish between about 300 to 600mm are less common and usually more closely associated

with cover near the river banks. Incidental captures of small numbers of juveniles in the strainer of the water treatment works at Mt Crosby have been a regular event during the 1980's and 1990's, especially during and shortly after significant flow events. There have been none noted however since 1999, due to dry conditions (K. McDougall pers. comm., 2001). Large specimens are also common in the Brisbane River near the mouth of Cabbage Tree Creek (personal observations, 1979-2000) and in the Wivenhoe Dam (D. Charles, pers. comm., 2001).

Longman (1928) and Kemp (1984) report on lungfish in the Enoggera Reservoir, providing various data, especially on the occurrence of juveniles, spawning activity and oviposition. The introduced water hyacinth *Eichornia crassipes* is shown to be valuable as habitat for juvenile lungfish, as well as preferred media for spawning. Kemp (1987) reports that spawning has not been recorded 'since the effective control of hyacinth in 1974', but does not detail the frequency of search in the intervening period. Water hyacinth has never been eradicated from the reservoir, but is treated periodically when rafts become large, or problematic for management and access to the weir infrastructure (T. Heath, personal communication, 2001). During the 1980's and 1990's reports to the Qld Museum of wounded lungfish below the dam wall and further downstream after flood events were commonplace and were often confirmed by personal observations. Officers of the Brisbane Forest Park are required under code of practice to return any incapacitated specimens to the reservoir. Enoggera Creek has very few deep pools suitable as lungfish habitat and only several reports of medium term survival there were noted. Lungfish found in the estuarine conditions of Breakfast Creek, after passing over the small weir near Red Hill, have always been reported as mortalities. There is no available recent quantitative data on lungfish populations from the Enoggera system.

Kemp (1995) records present distribution of lungfish as including the Gold Creek Reservoir and Lake Manchester, both of which are in the Brisbane River drainage. Although upstream migration of freshwater eels *Anguilla reinhardtii* to these dams has been noted, this is not possible for lungfish. There is no data available on current occurrence of lungfish in Gold Creek Reservoir. Several long-time on site caretakers at Lake Manchester could not recall sightings, either from in the lake, or of dead or injured specimens below the spillway after overtopping, despite reporting the mortality of various other species subsequent to the latter (D. Hutchins & N. Kelly, pers. comm., 2001).

O'Connor translocated 5 lungfish to the Albert River (a tributary of the Logan River) in 1895. There have been several unconfirmed reports of lungfish from fishermen over the past 20 years, but if still present the species appears to be uncommon in the system. Despite 40 years fishing experience in the area, and involvement in the local fish stocking and 'carp busters' group, Mr B. Panitz, a Logan river-side resident, reports (2001) no sightings of lungfish in the area. Recent electrofishing efforts in the Logan River have also failed to locate lungfish.

Since the translocation of 16 lungfish to the upper Coomera River in 1896, there have been few records from this system. One was taken in 1917 and lodged at the Qld Museum. A report by a resident from the lower freshwater reaches in 1999 could not be confirmed. Local freshwater fishing guide Mr Des Charles has not sighted lungfish in the Coomera despite actively targeting bass on the Coomera for 20 years. He

reports that deep pools suitable for large fish such as lungfish are sparse. Recent post-stocking surveys in the Hinze Dam, have not turned up lungfish. If lungfish are present in this system, numbers are likely to be very low and the population at risk.

O'Connor (1902) reported the capture of several lungfish in the Condamine River, after his initial translocation of 21 specimens on 31st July 1896. The largest was presumed to be of the original stock, but a second was too small and evidently of a new generation. Kemp (1995) also reports the 'current' occurrence of lungfish in the Condamine River, however the report is third hand, with no detail of the timing, location or number of specimens, and can not be substantiated independently. Numerous surveys in the area using various methods, including electrofishing, have failed to turn up lungfish.

In summary, from available information, reports and personal observations:

- Lungfish maintain large populations, with evidence of successful recruitment, in the Mary and Brisbane River systems.
- There are moderate but viable populations, showing irregular evidence of recruitment, in the North Pine Dam and Enoggera Reservoir.
- Insufficient information exists to speculate on whether populations are still extant in the Logan/Albert and Coomera Rivers, Gold Creek or Lake Manchester.
- Occurrence of lungfish in the Condamine River is highly unlikely.