

Developing population models for informing the sustainable management of the Murray spiny crayfish (*Euastacus armatus*) and the Glenelg spiny crayfish (*E. bispinosus*) in Victoria

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EXTENDED ABSTRACT

Population models can be a useful tool for identifying knowledge gaps to guide future research, ranking different management scenarios, and assessing the risk of extinction and conservation status of a target species. The process involves specifying a set of rules based on the life history of the species that govern how the number and distribution of individuals within the population change over time.

Data availability and quality can be a limiting factor in model development, influencing the estimation of parameters and the understanding of important environmental processes. In such circumstances, uncertainty arises from a plethora of sources: model structure, parameter estimation, intra- and inter-species dependencies, and shape uncertainty about a distribution. Choosing an appropriate model can therefore be problematic, and should be governed by the life history characteristics of the target species, knowledge of environmental processes and the amount of data available.

Here, we describe a conceptual population model for two species of freshwater crayfish, the Murray spiny crayfish (*Euastacus armatus*) and the Glenelg spiny crayfish (*E. bispinosus*). Both species are listed nationally as 'vulnerable'. They are not listed in Victoria despite substantial reductions in range and population abundance that have resulted in local extinctions. Identified threats to both species include overfishing by recreational anglers and habitat modification. Restrictions are currently in place that govern the time of year, number, sex and size of individuals that can be removed. However these regulations have not halted the observed decline in catch size and abundance, as reported by local fisherman.

We found that data on both species were lacking, including vital information about their life history characteristics. In particular, it remains unclear whether moulting impedes the capacity of females to reproduce. Therefore, we propose two stage-based model structures to accommodate this uncertainty. The 'non-moult' model defines two protected stages (ie. below the legal limit): juveniles, that are reproductively immature, and protected adults (that are reproductively mature). There is one un-protected stage (ie. above the legal limit), that contains reproductively mature adults available for harvesting. The final stage contains individuals who have died from harvesting (as distinct from natural mortality). In addition, the 'moult' model contains an additional two stages for moulting females. In each time step, individuals either progress to the next stage, or remain in their current state. Offspring of the reproductive stages enter the juvenile stage. Both model structures are sexually dependent, implying a total of eight stages are required for the 'non-moult' model and ten stages for the 'moult' model.

By fixing some transition rates between stages to equal zero, a variety of model constructs can be obtained from the two species models. We propose five constructs to accommodate species-specific management actions. For example, all female *E. bispinosus* are protected. Therefore, any transitions out of the protected female adult stage (other than natural mortality) equal zero.

Considerable uncertainty remains as to which particular model structure would be most useful for informing management about the efficacy of the current regulations. However these conceptual models offer valuable insight, by highlighting current knowledge gaps. The next stage of the modelling process will be to collect empirical data on the species such that these models can be parameterised.

1. INTRODUCTION

Australia contains approximately 20% of the world's freshwater crayfish species and subspecies (Taylor 2002). Since European settlement, the range and abundance of these species has declined (Barker 1990). Of particular conservation importance are the *Euastacus armatus* (the Murray spiny crayfish) and *E. bispinosus* (the Glenelg spiny crayfish) species which are listed nationally as 'vulnerable' and are protected in South Australia and the ACT (Clarke and Spier-Ashcroft 2002). However neither *E. armatus* and *E. bispinosus* are listed in Victoria, despite having suffered a documented range reduction as well as localised population extinctions (Horwitz 1990).

The main threats to both crayfish species is overfishing by recreational anglers (Horwitz 1990, Lintermans and Rutzou 1991) and habitat modification (Clarke and Spier-Ashcroft 2002). While the occurrence of habitat modification has greatly diminished in recent years, the impacts of recreational angling have not. Recently, the importance of leaving larger individuals in fishery management has become more frequently discussed for its implications in the sustainable harvesting of exploited species (Birkeland and Dayton 2005). Despite this, the removal of larger individuals has been recognised as a threat to the sustainable management of *E. armatus* (Horwitz 1990, Lintermans and Rutzou 1991).

Although the fishery is subject to regulation, there are no measures in place to collect information on the number of crayfish being removed, or to provide information on the efficacy of the current regulations upon the long-term persistence of either species. The aim of this paper is to examine the life history of freshwater crayfish in order to develop conceptual population models for both *E. armatus* and *E. bispinosus*. Once these models have been parameterised through empirical data collection, better informed management decisions can be made by ensuring the process is transparent, explicit and repeatable.

2. POPULATION MODELLING AS AN EXPLORATORY TOOL

Population models are useful within the context of resource management and decision making to assess conservation status, guide future research and rank alternate management strategies, particularly in circumstances of incomplete data or lack of full ecological knowledge (Todd *et al* 2002, Todd *et al* 2004). Modelling can also identify the sensitivities associated with uncertainty about particular mechanisms, and

whether improved knowledge or greater accuracy would change the decision-making process and consequently the management of the resource (Starfield 1997, Bearlin *et al* 2002).

The modelling process characterises the attributes that cause a population to change: a set of logical rules specifying how the number and distribution of individuals within a population change over time (Easterling *et al* 2000). Because modelling explicitly deals with uncertainty, subjective opinion is removed from the management decision making process (Todd *et al* 2004).

Requisite data include state variables that describe the population (i.e. life history characteristics such as rates of birth, growth, maturation, fertility and mortality; immigrations and emigrations) and process variables (i.e. the environmental processes that invoke a response in the population). Process variables include stochastic events that are unpredictable changes in the state of the system. They include demographic stochasticity, reflecting the uncertainty associated with each individual; environmental stochasticity, which are fluctuations in the environment caused by temporal variation of habitat parameters; genetic stochasticity, caused by inbreeding and genetic drift; and catastrophic stochasticity, which are extreme environmental fluctuations (Possingham *et al* 2001). In order to parameterise a population model, the relationship between the process variables and the state variables must be estimated.

In conjunction with these four stochastic processes that are known to affect populations, a variety of different types of uncertainty also exist: structural uncertainty; parameter uncertainty; dependency uncertainty; and shape uncertainty about a distribution (Todd 2001). We can characterise these uncertainties in two ways: epistemic uncertainty resulting from incomplete information about the system in question (ignorance); or the underlying or inherent stochasticity in the system (variability) (Ferson and Ginzburg 1996).

3. BIOLOGY OF THE FRESHWATER SPINY CRAYFISH

E. armatus, *E. bispinosus* and *Astacopsis gouldi* (occurring in Tasmania) are collectively known as large lowland spiny crayfish (Horwitz 1990). The preferred habitat of these species is cool and clean flowing waters with intact riparian vegetation (Barker 1990). *E. armatus* occurs the Murray River throughout most of its length and major tributaries in Victoria and New South Wales, and *E. bispinosus* occurs in the Glenelg River and its tributaries in Western Victoria and a small portion of South Australia (Morgan 1986).

The freshwater crayfish *E. armatus* and *E. bispinosus* share a similar life history: adults produce eggs, eggs hatch to become juveniles that grow and develop into adults. Both species are slow growing and long lived, achieving relatively large sizes: an orbital carapace length (OCL) of 180mm and 2.7kg for *E. armatus* (O'Connor 1984); and an OCL of 130mm and 1.14kg for *E. bispinosus* (Horwitz 1990). Growth rates of crayfish depend on two factors, the frequency of moulting and growth increment at each moult. It has been documented that the estimated age of an *E. armatus* with an OCL of 100mm was between 7 and 14 years old, with a likely age of 9-10 and larger individuals living 20-25 years (O'Connor 1984). *E. bispinosus* have been estimated to take 8-12 years to reach 100mm OCL (Horwitz 1990). Honan and Mitchell (1995b) aged a 130mm OCL crayfish at 25 years.

In *Euastacus* species, sexual maturity is identified by changes in gonospore condition and the presences of eggs (Turvey 1980, Morgan 1986). The length at which sexual maturity is reached varies for both *E. armatus* and *E. bispinosus*. Morgan (1986) states that for *E. armatus* female maturity occurs from 40 to 100mm OCL, and that very large specimens may be immature. Honan and Mitchell (1995a) record sexual maturity to occur between 54.5 to 81mm OCL for *E. bispinosus*. Both species exhibit significant site variation such that individuals from smaller streams reach sexual maturity at smaller sizes.

The clutch size of freshwater spiny crayfish can be estimated from counts of eggs or young, and generally increases with increasing female body size. Clutch sizes for *E. bispinosus* ranged from 63 eggs on a 62mm OCL female to 812 eggs on a 115mm OCL female (Honan 1990). O'Connor (1984) estimated a female *E. armatus* individual with a 90mm OCL to produce 480 eggs and a 125mm OCL individual to produce 1815 eggs.

Clutch sizes are highly variable for several reasons: if food is restricted, ovarian development can be limited; depth, light and temperature affect reproductive success; and damage and disease cause egg mortality. By the end of the incubation period, up to 50% of females may have lost some or all of their brood (Honan 1990)

All *Euastacus* species reproduce sexually, mostly spawning in late summer to autumn. This is followed by winter brooding of the eggs, where females keep the eggs under their tail until they hatch. Eggs hatch in October to November but remain attached to the female parent by a filamentous oosetae. During this period juveniles experience three moulting stages. Individuals are fully independent and eventually resemble the

adult form (despite being sexually immature) by approximately 170 days and are released in spring to summer (O'Connor 1984, Reynolds 2002).

It is not clear from the literature whether moulting impedes the capacity of females to reproduce. Female *A. gouldi* moult and reproduce in alternate years (Reynolds 2002). Many species of the family Astacidae (including the *Euastacus* genus) have biennial breeding, however *E. bispinosus* has been observed to breed in successive years without moulting (Honan and Mitchell 1995c). O'Connor (1984) states that *E. armatus* reproduces annually, where tagging data confirmed breeding in subsequent years, but they did not indicate whether a moult had occurred in any of the observed females. While it appears that both *E. armatus* and *E. bispinosus* may reproduce annually, it remains unclear if moulting disrupts the reproductive output of females.

4. MODEL STRUCTURE

Choosing an appropriate model structure is determined by the life history of the target species and the associated management objectives. The current management objective for freshwater spiny crayfish species is to maintain the "sustainability of the resource as well as a satisfactory recreational experience for users of the resource" (Barker 1990). We cannot include a 'satisfactory recreational experience' in our model, although this may be achievable depending on a suitable definition. As a result, we will focus on a model structure that will allow questions regarding the sustainable exploitation of *E. armatus* and *E. bispinosus* to be addressed.

Although some information exists regarding the freshwater spiny crayfish (e.g. egg numbers-size relationship) many life history aspects remain poorly understood (e.g. survival rates). At present, the life-history characteristics for both species are poorly known. In order to include uncertainty about the interaction between reproduction and moulting two model structures were developed. They account for *Euastacus* species reproducing every year ('non-moult', Figure 1) or only reproducing in non-moult years ('moult', Figure 2). Parameters in the model include:

- $S_{i,j}$ – Survival (transition from stage i at time t , to stage j at time $t+1$)
- $R_{j,i}$ – Reproduction (number of individuals that contribute to stage i at time $t+1$, from stage j at time t)
- H – Harvesting (transition of individuals into the harvested population)
- Prefixes: F= female and M=male

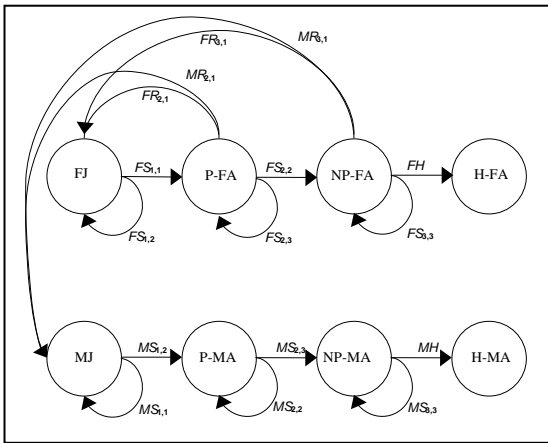


Figure 1. Non-moulting model for the freshwater crayfish: juveniles (J) can remain in the same stage ($S_{1,1}$), grow into reproductive adults that are too small to be harvested (protected adults, P-A) ($S_{1,2}$), or die; protected adults can reproduce to create juveniles ($F_{2,1}$), remain in the same stage ($S_{2,2}$), grow into harvested, non-protected adults (NP-A) ($S_{2,3}$) or die; harvested adults can reproduce to create juveniles ($F_{3,1}$), remain in the same stage ($S_{3,3}$), or die (either from natural causes, or harvesting at rate H). Prefixes: F=female and M=male.

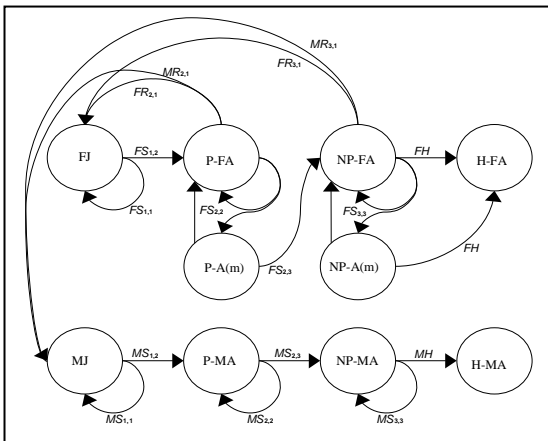


Figure 2. Moulting model for the freshwater crayfish. As per Figure 1, with two additional transitions from protected female adults (P-FA) to protected female adults in a moulting period (P-A(m)) and from non-protected female adults (NP-FA) to non-protected female adults in a moulting period (NP-A(m)). Prefixes: F=female and M=male.

These two model structures are sex dependent. The transition from adult to one year old juveniles, implicitly accommodates fecundity, egg survival (hatching), and survival of juveniles less than one year old.

By modifying transition rates between stages in these two models, species-specific constructs can be developed. This is necessary because current fishing regulations differ for the two species:

- *E. bispinosus* - A minimum carapace length (OCL) of 10cm and only one (male) crayfish per day. There is no closed season.
- *E. armatus* - A minimum carapace length of 9cm, and up to 5 crayfish per day where only one may exceed 12cm. There is a closed season for Victorian waters north of the Great Divide from September to April, all-inclusive.
- *Both species* - No removal of female crayfish that are in 'berry'.

In total, five model constructs are proposed that accommodate these various management actions (Table 1).

4.1. Construct One

This is the simplest model construct that explicitly accounts for harvesting. It is applicable for situations where males are believed to be a non-limiting factor (i.e. response of female population can be assumed to reflect the response of the entire population). For the Murray crayfish, this assumption may be valid, as female individuals are available to harvesting. The model is not applicable to the Glenelg spiny crayfish, as all females are protected under current fishing regulations.

4.2. Construct Two and Three

These models build on the previous construct by explicitly accounting for harvesting in the male and female populations. This is applicable to situations when harvesting rates of both sexes may differ. In populations of freshwater crayfish, this may occur as regulations prohibit the removal of female crayfish that are in 'berry'.

Construct two is appropriate for *E. armatus* as it allows for harvesting of the female population. Given current fishing regulations protect all *E. bispinosus* females, construct three is required that does not account for the removal of females from the population via harvesting.

Table 1. Construct definitions. If boxed is ticked, that parameter is included in the construct. For example, $FS_{1,1}$ is needed in construct 1.

Construct	$FS_{1,1}$	$FS_{1,2}$	$FS_{2,2}$	$FS_{2,3}$	$FS_{3,3}$	$MS_{1,1}$	$MS_{1,2}$	$MS_{2,2}$	$MS_{2,3}$	$MS_{3,3}$	$FR_{2,1}$	$FR_{3,1}$	$MR_{2,1}$	$MR_{3,1}$	FH	MH
1	✓	✓	✓	✓	✓	–	–	–	–	–	✓	✓	–	–	✓	–
2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	–	✓
4	✓	✓	✓	✓	✓	–	–	–	–	–	✓	✓	–	–	–	–
5	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	–	–

4.3. Construct Four and Five

These models do not explicitly account for harvesting, instead assume that estimates of survival incorporate the affect of harvesting. They will be easier to parameterise than the other models because less transition estimates are required, however they cannot explicitly investigate management questions related to harvesting pressure. Construct four is a female only model (e.g. *E. armatus*), and construct five is a sex-dependent model (e.g. *E. bispinosus*).

5. DISCUSSION

Considerable uncertainty remains as to which particular structure would be most useful for informing management about the efficacy of the current regulations and whether management is meeting stated objectives. In order to assess any of the structures identified in this study, parameters need to be estimated from data. Very little data has been collected on the either *E. armatus* or *E. bispinosus*, and no data has been collected in the past decade. Inadequate amounts of data have been problematic in attempts at building models for solving real-world problems (Akçakaya and Burgman 1995, Burgman and Possingham 2000).

Advances in tagging technology means that freshwater spiny crayfish could be individually marked and the tag retained through the moulting process (M. Lintermans, pers. com., Montgomery and Brett 1996). Consequently, data that directly lend itself to being used in population modelling could be collected in the future through a comprehensive mark-recapture program.

This study has also identified the need for further research to understand the influence of moulting on the reproductive process. We do not believe that it would be difficult to establish whether moulting influences the reproductive process.

There are at least two numerical approaches to modelling the exploited populations of these species, a conservation/population viability approach (Todd *et al* 2001, Todd *et al* 2002) and a fisheries/exploitation approach (Punt and Kennedy 1997). The structures identified in this study are most suited to being modelled in the conservation/population viability approach as fishing is explicitly modelled. This approach also incorporates demographic stochasticity. These structures can be easily modified to suit the fisheries/exploitation approach by implicitly accounting for fishing through adjusting survival in the unprotected adult stage by the rate of removal. Neither approach incorporates genetic stochasticity, which has not been identified as a management priority to date.

6. CONCLUSION

The population models developed are a reasonable summary of the life history of the species and could be used as an exploratory management tool. For the model to be of most benefit to management, this would require the parameters to be estimated through further research. The construction of the model highlights where the knowledge gaps are that would most usefully inform management about the impacts from recreational fishing. These were identified as estimation of transition rates, reproductive rates, harvesting rates, size at sexual maturity, and growth/age relationships. By identifying knowledge gaps, this may contribute to an efficient allocation of resources, as funding can

now be spent on areas where data are most required.

The inherent stochastic nature of the environment implies it is difficult to parameterise models accurately. As such, models will always include uncertainty and this must be considered when using models to draw management conclusions. All models should be used in an iterative and adaptive framework, such that as new knowledge becomes available, it should be incorporated into the model and new simulations be determined.

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