Pop-GUIDE: Population modeling Guidance, Use, Interpretation, and Development for Ecological Risk Assessment

Decision steps – signal crayfish

To use the dichotomous keys in the following sections starting with Step 2:

1. Start with the first question and answer yes or no. In the box that corresponds to your answer, follow the key to either the number of the next question as indicated, or to the answer in the appropriate box.
2. For sections that include questions that are not numbered, all questions should be asked, following the instructions in the boxes that correspond to the appropriate answer.

Decisions made for signal crayfish model are highlighted in yellow. Changes to questions in decision steps are highlighted in red.

Step 1. Life history representation

Life history most similar to 1.5.D. Invertebrates for which adults reproduce more than once with reproduction rates varying with age of adults. The general life cycle includes eggs (embryos) which remain that stage until they hatch into juveniles. Juveniles remain in the juvenile stage until they mature into the adult life stage. Only adults can reproduce, and reproductive output is size/age dependent. Survival rates within life stages are relatively well known. Adult life stage can be separated to multiple stages due to the size/age dependent reproductive output as well as data availability for survival rates of different life stages.

Step 2. Organism-level processes

2.1. Growth and development

	Question	Yes	No
1	Is there sufficient information to represent growth continuously?	2	No additions to model concept

2	Is there sufficient information to represent growth physiologically?	Physiologically-based (e.g. DEB, other physiological approaches) representation of growth	Simple growth model may be included (Von Bertalanffy, Gompertz, Logistic, other)

2.2. Maturation and reproduction

	Question	Yes	No
1	Is there sufficient information to represent maturation dependent on body size /mass/energy reserves?	Maturation dependent on body size /mass/energy reserves	Maturation dependent on age (constant or distribution)
2	Is there sufficient information to represent fecundity dependent on body size/ mass/ energy reserves or specific age?	Fecundity dependent on body-size/ mass/ energy reserves or age	Fecundity constant or from a distribution

Step 3. Population and spatial Factors

3.1. Population status

	Question	Yes	No
1	Is the estimated species' overall abundance or population size such that it requires a risk assessment (either critically small in the case of native/ vulnerable species vs. recently established or long-established in the case of the invasive species)?	Represent environmental stochasticity as well as variation in demographic rates	2
2	Are data available to demonstrate that populations exhibit high variability between years, i.e. do the population dynamics considerably deviate from stability?	Represent variability through environmental stochasticity and demographic variance (if available)	Variation can be represented by demographic factors alone

We have changed the Question 3.1.1. to make it more inclusive for other applications (i.e. management of invasive or conservation of native species). If Pop-GUIDE is used in the context of invasive species management, relevant questions are whether the population is established or not and how large it is. We

have extended the question so that it is also applicable to conservation of native species (a more general scope is given). The question 3.1.2. is relevant for invasive species management as populations of invasive species such as signal crayfish may be present in the wild at a different stages of the invasion process (i.e. population establishment phase vs. already long established population) and also population viability may be affected by the stressors present in the environment (i.e. pollution, drought, temperature increase, pathogen outbreak; elaborated under 4.2. and 4.3.) which will affect their invasion success as well as the potential success of the chosen management strategy.

3.2. Density dependence

	Question	Yes	No
1	Do populations experience documented resource or space limitation?	2	Negative density dependence does not need to be considered. Continue to 5.
2	Are the factors driving density dependence (e.g., spawning sites, food limitations, shelter) known?	3	Apply ceiling type density dependence
3	Does density affect individuals in the population differently dependent on their life stages or size, or only affect processes unique to a single life stage?	4	Implement a consistent density dependence survival function (e.g., Ricker) across all life stages
4	Does population density affect growth or reproduction?	Implement life-stage specific density dependence, either emergent or imposed, on growth/fecundity	Represent density dependence as survival function for appropriate life stage(s).
5	Are populations reported to experience Allee effects due to low densities?	Include Allee effect, e.g., as function linking fecundity to adult abundance	No additions to model concept

3.3. Movement

	Question	Yes	No
1	Do individuals migrate/disperse outside the action area to complete their life cycle?	Incorporate function of migration/ dispersal to represent time spent	2

		in action area, as well as important movement within action area	
2	Within the action area, is migration/ dispersal of individuals important, and may interact with planned action area?	3	Migration/dispersal does not need to be represented
3	Do the individuals move across habitat types and/or metapopulation patches in response to resource availability, predation pressure, or migration/dispersal to natal habitat?	Incorporate function of migration/ dispersal in model; represent metapopulation dynamics as appropriate	Migration/dispersal does not need to be represented; model focuses on single habitat type

We have modified Question 3.3.2. which now inquires whether dispersal may interact with planned actions. We defined 'action' as a broader and more general term that could be used to streamline the POP-guide vocabulary and make it applicable to different areas (i.e., exposure risk assessment, species management, intervention planning etc.).

3.4. Behavior

	Question	Yes	No
1	Are aspects of behavior *other than* migration/dispersal known to be affected by planned actions?	2	No additions to model concept
2	Are data available to mechanistically/explicitly represent behaviors potentially affected by existing stressors and/or planned actions?	Include explicit representation of identified behaviors	3
3	Can effects on behavior be linked to submodels (e.g., survival, growth, bioenergetics, fecundity)?	Represent effects on behavior as impacts on appropriate submodel	Categorical or qualitative impacts on behavior could be included to add realism

As in 3.3., we have modified Question 3.4.2. to make it broader and applicable to other types of assessments beyond ERA.

3.5. Habitat features

	Question	Yes	No
1	Does the species occupy more than one habitat type that needs to be represented in the model (e.g., different stressors occurring in the habitats, and is data available to distinguish between habitats)?	2	No explicit representation of space in the model
2	Are data available to distinguish between habitats?	3	Spatially-implicit representation
3	Are spatially explicit interactions with the habitat defined?	Explicitly represent spatial distributions of habitat and/or exposure	Represent habitat(s) implicitly, e.g., along a single axis (e.g., location in the water column, stream section)

We have changed 'exposures' to 'stressors' 3.5.1. to make it broader and applicable to other types of stressors in the habitat beyond exposure to chemicals.

Step 4. External factors

4.1. Diet

	Question	Yes	No
1	Is the species' diet expected to be impacted by the chemical (based on mode of action or available data)?	2	No additions to model concept
2	Are data available to determine how the species' diet may be affected by the chemical exposure (e.g., dose-dependent food reduction)?	3	Categorical or qualitative impacts to diet could be included
3	Can impacts on prey be represented as effects on vital rates (e.g., growth, survival)?	4	Quantitative impacts to diet could be included
4	Is there enough information to represent the species' diet explicitly and/or temporally/spatially varying?	Represent the diet as a time-series of separate or aggregated resource items.	Include indirect effects mediated by diet as impacts on appropriate vital rate estimates

The role of diet has not been taken into account in this conceptual model.

4.2. Other interspecific interactions

	Question	Yes	No
1	Does the species have any known competitors/ predators/ pathogens present in the action area?	2	No additions to model concept
2	Is there sufficient information to represent competitors/predators/pathogens and is that representation relevant for model objectives?	Include indirect effects mediated by obligatory relationship as impacts on appropriate submodel(s)	No additions to model concept
3	Are biota critical to habitat integrity potentially affected by the planned actions?	Consideration of inclusion if indicated that the species is strongly dependent on specific conditions that may be affected by the stressor	No additions to model concept

We have modified questions to make them more applicable to other types of assessments (i.e. invasive species management or native species conservation). We also added a question to clarify if there is sufficient information to represent interspecific interactions and if this is relevant for the model objectives. In many cases these data may not be available and in some, it may not be relevant for the model objectives to include all interspecific interactions. For instance, the success of management interventions can be highly increased if a predator or an interspecific competitor is present, however the role of interspecific interactions has not been currently considered in this conceptual model as we do not have sufficient data to relate specific levels of competition/predation/disease intensity on individual and population growth, in order to support the addition of multiple species which would greatly increase model complexity.

4.3. Abiotic factors

	Question	Yes	No
1	Are environmental conditions indicated to be important drivers of the population dynamics (e.g. temperature, precipitation, water depth, stream flow, flood events, habitat connectedness, etc.) and do those drivers differ between years or habitats of the species?	Dependence on environmental condition should be represented; Variation in across-year environmental conditions may be captured by stochasticity in the model	Species-specific environmental conditions do not need to be represented explicitly in the model

2	Is the species impacted by additional stressors not previously discussed that may interact with planned actions?	Include relationships as impacts on appropriate submodel(s)	No additions to model concept
3	Is the species the subject of an existing management plan that may influence the efficacy/ success of planned actions?	Include relevant management scenarios in model, as appropriate	No additions to model concept

Questions within this section have been modified to be more applicable to other types of assessments.

Step 5. Exposure and effects characteristics

5.1. Exposure

	Question	Yes	No
1	Do multiple exposure routes need to be considered, e.g., contact exposure, dietary exposure, exposure via nesting material?	2	Include exposure via primary route as measured in tests
2	Are separate sets of toxicity data available to inform the effects from each exposure route?	Represent each exposure route separately	Combine the exposures from the exposure routes for the effect representation

Since we are not considering any form of chemical control of invasive crayfish species, exposure routes and toxicity data are not included in this conceptual model. Therefore, this whole section has not been considered.

5.2. Mortality effects

	Question	Yes	No
1	Are measured effects on survival available?	2	No direct effects on survival represented in the model
2	Are lethal effects endpoints available from multiple studies with different durations, e.g., acute and chronic studies?	3	If acute data only are available, go to 3; If chronic data only are available, go to 4
3	Can the available acute data be used to fit a time-variable effects model, e.g.	Represent effects of time-variable	4

	toxicokinetic-toxicodynamic model (TKTD / GUTS)?	exposures based on all study data; continue to 4	
4	Are chronic survival data available for all concentrations?	Represent survival effects as dose-response functions or TDTK models	Represent survival effects as a threshold (e.g., NOEC/LOEC)

Since we are not considering any form of chemical control of invasive crayfish species, mortality effects, their endpoints and survival rates are not included in this conceptual model. We are only considering the mortality/survival data falling under chapter 3.2.

5.3. Sublethal effects

	Question	Yes	No
1	Are data on sublethal effects available, e.g., effects on growth, reproductive rate, etc.?	2	Sublethal effects are not represented in the model
2	Can measured sublethal effects be linked with corresponding organism-level processes explicitly represented in the model, e.g., bioenergetics?	Sublethal effects represented affecting the corresponding organism-level process via e.g. dose-response or TKTD models	3
3	Can sublethal effects be expressed as reduction in growth, reproductive, and/or population survival rates?	'Translate' sublethal effects to lethal effects and/or impacts on growth and/or fecundity	Sublethal effects are not represented in the model

As in 5.1. and 5.2., since we are not considering any form of chemical control of invasive crayfish species, sublethal effects on growth, reproduction, metabolism and survival are not included in this conceptual model.

5.4. Temporal representation

	Question	Yes	No
1	Are important toxicological processes represented at fine resolution (e.g., TKTD processes)?	Time step consistent with temporal resolution of process with shortest time step; or nest	*Not applicable*

		functions with shorter time steps within larger time step.	
2	Are seasonal differences important to the species' life cycle and need to be considered to adequately plan and analyze action approaches?	Temporal resolution < 1 year reflecting temporal scale of seasonal changes	Default to annual time step

Since we are not considering any form of chemical control of invasive species, toxicological processes are not included in this conceptual model. Therefore question 5.4.1. is not applicable to our model. Seasonal differences are important for planning an invasive species management strategy, therefore the question 5.4.2. has been reformulated to address this issue. Due to the importance of seasonal changes in crayfish biology and population dynamics, as well as the inclusion of DEB processes which operate at a relatively fine scale, the temporal resolution of the model is set to a day.