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Aeglidae

Life History and Conservation Status of Unique Freshwater Anomuran Decapods

Edited by
Sandro Santos
Sergio Luiz de Siqueira Bueno

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Contents

Preface

A preface to a unique taxon: *Aegla* Leach, 1820, a crown jewel among South American freshwater decapods.

This book is about one single taxon: *Aegla* Leach, 1820. And what a remarkable taxon it is! Those who had—and those who are having—the experience of studying these unique freshwater decapods could not agree more with Schmitt's remarks written down on the first page (Schmitt, 1942; p. 431) in his seminal monography on aeglids: "There are no freshwater Crustacea at all like *Aegla* anywhere else in the world."

The production of this book comes in a special moment because we find ourselves at the brink of celebrating 200 years since the first taxonomic entry of an extant aeglid, as *Galathea laevis*, in the scientific literature. Over these two centuries, hundreds of investigations on *Aegla* have been published. A brief search for Aeglidae on Google Scholar, for example, retrieves more than 1,600 entries.

Aegla is the only taxon within the Anomura whose representatives are entirely adapted to the freshwater environment. As of 2018, there are now 87 known valid species, all endemic to subtropical and temperate South America. This figure makes *Aegla* the most species-rich genus of all true freshwater decapods in this subcontinent. The tally is certainly bound to go up considerably as putative new species are being recognized and still waiting for the necessary formal description (Chapter 1), and as unexplored or poorly explored areas within the known range of distribution continues to be systematically investigated. It is only reasonable to expect that the number of valid species may soon surpass the barrier of 100 species within the next few years ahead.

This book is also about perhaps the most endangered freshwater decapod in the Neotropical Region (Chapter 9). About 70% of the 87 known species are currently threatened with extinction, having been assessed as critically endangered, endangered, or vulnerable threatened categories, as defined by the International Union for Nature Conservation. The main threats to aeglids include the removal of riparian forest, habitat fragmentation and destruction, industrial, agricultural, livestock, and domestic pollution of the water bodies.

One unique feature about *Aegla* is the fact that its evolutionary history can be told based on sound scientific evidence, starting from marine fossil representatives to the successful adaptation of *Aegla* to freshwater habitats and the subsequent dispersal routes through paleobasins of continental South America that neatly explain the distributional pattern we see today (Chapter 1). The successful adaptation to freshwater environments demanded the acquisition of adaptive life history strategies, most importantly those regarding physiological ecology (Chapter 8), postembryonic development and parental care (Chapter 6).

Morphological studies have been a strong line of investigation starting right from the beginning. Schmitt's monography (1942) may still be the most revered landmark publication on the taxonomy of *Aegla*, but other South American leading investigators have published several equally important papers on this topic since the 1980s (see Chapters 1 and 2 for references therein). Together, this bulk of publications on aeglid taxonomy has provided a great contribution to the knowledge of *Aegla* distribution and diversity. More recently, molecular analyses have made a huge impact in systematic studies of aeglids, providing valuable insights and hypotheses regarding the phylogenetic relationships among *Aegla* species as well as the phylogenetic position of the family Aeglidae within the Anomura (Chapter 1).

Throughout the pages of this book, the reader will also have the opportunity to check out fine compilations on topics such as population structure and maturity (Chapter 3), trophic ecology (Chapter 4) as well as reproduction and gonadal development (Chapter 5) and behavior (Chapter 7). Finally, Chapter 10 deals with sampling techniques, handling procedures, and provides a discussion on analytical treatments of data obtained under field working conditions.

For us, the editing experience involved in the production of this book has been a quite extraordinary one. We are really grateful to our colleagues Dr. Ingo Wehrtmann and Dr. Célio Magalhães for having invited us to carry out this task, which we humbly accepted without hesitation. Also, we wish to demonstrate our gratitude to all who have directly or indirectly contributed to this book. We thank all authors of the chapters: Alexandre V. Palaoro, Bianca Laís Zimmermann, Carlos G. Jara, Carolina Sokolowicz, Georgina Bond-Buckup, Harry Boos, John Campbell McNamara, Juliana Cristina Bertacini Moraes, Keith A. Crandall, Marcelo A. A. Pinheiro, Marcelo M. Dalosto, Marcos Pérez-Losada, Marlise Ladvocat Bartholomei-Santos, Pablo Collins, Paula Guimarães Salge, Roberto Munehisa Shimizu, Samuel Coelho Faria, and Setuko Masunari. We are also especially grateful to the researchers who kindly collaborated with us reviewing the chapters: Antônio Leão Castilho, Christopher Tudge, Ingo Wehrtmann, Marlise L. Bartholomei-Santos, Marcos Tavares, Neil Cumberlidge, Roberto Shimizu, and Rodney Feldmann.

Sandro Santos and Sérgio Bueno
May 2019

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Editors

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Sérgio Luiz de Siqueira Bueno is associate professor at the Department of Zoology, Institute of Bioscience, University of São Paulo, Brazil. He has dedicated the past 15 years of his research career to the study of aeglids. These studies are focused on the relative growth, reproduction, life cycle, postembryonic development, taxonomy, estimation of population size, and conservation of these remarkable freshwater decapods.

CHAPTER 9

Conservation Status and Threats of Aeglidae: Beyond the Assessment

Harry Boos, Paula Guimarães Salge, and Marcelo A. A. Pinheiro

CONTENTS

9.1 WHY CONSERVE?

The need to prevent the extinction of species dates back to the environmental movements of the 1960s, when the first reports of widespread pollution, ecosystem disruption, and species loss began to appear. Today, as these trends have worsened on a global scale, the arguments to justify conservation actions have expanded to include the economic usefulness of species and ecosystems to society (Mace 2014). Nonetheless, assessing the risk of species extinction remains a crucial step in guiding efforts towards biodiversity conservation.

9.2 WHAT TO CONSERVE?

The protocols developed by the International Union for Conservation of Nature (IUCN) to produce the global Red Lists of endangered species in "Red Books," date back to the 1960s. Since then the categories and criteria that make up the IUCN

Red List protocols have been continuously refined (Mace et al. 2008). The result of these efforts is the most recent IUCN Red List protocols published in March 2017 (IUCN 2017a).

The IUCN Red List protocols have been adopted by governments of several countries seeking to protect species from extinction, including Brazil. Brazil stands out because its large geographical area includes species-rich tropical and subtropical ecosystems and biodiversity hotspots such as the Atlantic Forests and the Cerrado (Myers et al. 2000; Mittermeyer et al. 2004; Oliveira et al. 2017). Conservation attention has been primarily focused on endemic species that have a restricted area of occurrence, because these are typically the ones most threatened by expanding human populations (Malcolm et al. 2006; Devictor et al. 2008; Pandit et al. 2009).

Brazil hosts a significant number of species of aeglids, and most of them already receive protection under the law, since it is illegal to intentionally capture an animal threatened with extinction, and violators can face 9 to 18 months in prison and a fine of US$ 1,400 (Brazil 2008). Brazil has recently updated its list of endangered species, which now includes species of invertebrates, as well as vertebrates. The delay in including invertebrates has been attributed to a perceived lack of charisma, a point of view that included the freshwater aeglids (Bueno et al. 2016). The inclusion of aquatic invertebrates in the list of endangered species, which are targets of commercial and artisanal fisheries, has generated a series of challenges in the fishing community (Di Dario et al. 2015; Pinheiro et al. 2015). The legal disputes arising from this show that legal protection is still not extended to some threatened species of invertebrates, including the aeglids, even though they are not commonly used as a food resource.

In Brazil, the first official list of endangered animals (vertebrates) was published in 1968 (Brazil 1968). It took another 36 years for the list of endangered Brazilian fauna to include aquatic invertebrates (Brazil 2004; Pinheiro et al. 2015) such as three troglobitic species of aeglids: *Aegla cavernicola*, *A. leptochela*, and *A. microphthalma*. Pérez-Losada et al. (2002, 2009) took an alternative approach to prioritize conservation efforts and included phylogenetic methods that considered the evolutionary component of biodiversity to conserve genetically distant species.

9.3 HOW IS THE EXTINCTION RISK ASSESSED?

The IUCN Red List protocols aim to include all species found in a region, or globally, and assign each assessed species to one of eight categories, three of which are threatened categories indicating an increasingly high risk of extinction: Vulnerable (VU), Endangered (EN), and Critically Endangered (CR). The assignment to a category involves the compilation of data on population levels and trends, geographical distribution, habitat requirements, and threats, derived from the literature and first-hand field studies. These data are used to evaluate species against five criteria (A–E; see the following paragraph for explanation), depending on the quality of the available data; as a result of this evaluation a Red List category will be assigned for the species. This stage typically involves Red List Workshops that bring together group specialists pooling together their expertise to apply the criteria and assign a category, taking into account current knowledge about the biology, distribution, population trends, and current or projected threats (Mace et al. 2008).

The criteria used by IUCN (2001, 2017a) are as follows: **(A) population reduction** (past, present, and/or projected for the future); **(B) geographical distribution** (restricted and showing fragmentation, decline, or population fluctuations); **(C) small population** (and with fragmentation, decline, or fluctuations); **(D) very small population** (or very restricted distribution); and **(E) quantitative analysis of extinction risk.** Species could be assigned one of eight categories, as follows:

- **Data Deficient (DD)**: When there is insufficient or inadequate information on populations, habitat, distribution, and threats to assess the risk of extinction; it indicates that more information is needed.
- **Least Concern (LC)**: The probability of extinction is lowest when the data indicate that the species has a wide distribution, abundant and stable population levels, and without significant threats. A species with restricted distribution may be assessed as LC, as long as there are no significant direct threats.
- **Near Threatened (NT)**: When the geographical range and/or population levels of a species are declining, but these levels are still above the threshold for any of the threatened categories. A species may be assessed as NT if it is likely to fall into a threat category in the near future.
- **Vulnerable (VU)**: When all available information indicates that a species meets any of the thresholds for VU under criteria A to E listed above, the species is assessed as being at risk of extinction in nature.
- **Endangered (EN)**: When all available information indicates that a species meets any of the thresholds for EN under criteria A to E listed above, a species is assessed as being at serious risk of extinction in nature.
- **Critically Endangered (CR)**: When all available information indicates that a species meets any of the thresholds for CR under criteria A to E listed above, a species is assessed as being at extremely high risk of extinction in nature.
- **Extinct in the Wild (EW)**: A species is considered to be EW when it is extirpated from all parts of its natural habitat, and the only living individuals are either kept in captivity, or exist as a naturalized population outside its historic range.
- **Extinct (EX)**: A species is considered to be EX when the last existing member dies and it is no longer found in any part of its known range, despite searches of suitable habitat at appropriate times of the year.

The correct application of the method should be a constant concern during the extinction risk assessment, indicating the category (ies) and justification (s) for each of the criteria used. For this, it is not enough to know the taxonomy, distribution, and biology of the species. It is necessary to know and accurately quantify the threats that in fact impact the evaluated species.

The evaluation of the risk of extinction of newly described species can be problematic due to a lack of data, and many of these taxa have been listed in threatened categories (Santos et al. 2012; Moraes et al. 2016; Pinheiro and Santana 2016; Ribeiro et al. 2016, 2017; Bueno et al. 2017). New species are often described based on a few specimens from either few localities, or only a single location, and have a small extent of occurrence (EOO) and area of occupancy (AOO), that might reflect the initial sampling effort rather than the true state of affairs (IUCN 2017a).

Misunderstandings also occur in the application of "B" criteria (restricted geographical distribution, with fragmentation, decline, or population fluctuations) and "D" (very small population or very restricted distribution). In criterion "B," the categorization of a species at risk of extinction, either by subcriterion "B1" (extension of occurrence—EOO) or "B2" (area of occupation of species—AOO), must follow at least two of the following conditions (IUCN 2017a): **(a) Population severely fragmented** (or in few locations); **(b) Continued decline in at least one of the items**: (i) Extent of occurrence; (ii) area of occupation; (iii) area, extent, and/or habitat quality; (iv) number of locations or subpopulations; (v) number of mature individuals; and **(c) Extreme fluctuations**, in at least one of the items: (i) Extent of occurrence; (ii) area of occupancy; (iii) number of locations or subpopulations; (iv) number of mature individuals.

It is essential to apply the Red List protocols correctly to avoid inaccurate extinction risk assessments. For example, Moraes et al. (2016) and Santos et al. (2017) evaluated four species of *Aegla* (*A. japi*, *A. jundiai*, *A. paulensis*, and *A. vanini*) as Vulnerable (VU), according to the criteria VU B2aD2, but used only one subcriterion (a), whereas criterion B2 (EOO) requires at least two subcriteria.

The EOO calculation must be based on the presence of individuals in basins and/or microbasins. It is important to note that the EOO is not meant to represent the actual range of the species; instead the EOO represents how easily threats to a taxon may spread. A species with a small EOO that is low enough to meet the thresholds for one of the three threat categories is at a higher risk of extinction because a threat at one location may easily spread and reach individuals in other locations in the range. Contrarily, a species with a large EOO is at lower risk of extinction because a threat on one side of the range has to spread a lot further to reach individuals on the other side of the range.

The area of occupancy (AOO) of a species is the area within its EOO, which is actually occupied by the species and reflects the fact that a taxon will not usually occur throughout its EOO area because there may be numerous unsuitable or unoccupied habitats, especially in the case of freshwater organisms. The AOO can be estimated by summing the area around the point localities (e.g., 4 km^2 per locality), or it can be estimated using distribution or habitat maps (perhaps derived from remote imagery and/or analyses of spatial environmental data). The calculation of AOO is especially useful for species (such as aeglids) that may have a wide geographic distribution, but which occupy very specific habitats (IUCN 2017b).

The adoption of the hydrographic basin as a spatial unit, either to map the occurrence of species or to analyze the threats that impact them, is useful because basins are a management unit appropriate to species found in inland waters. In the case of freshwater species, geographical point localities based on field collections, scientific publications, and museum records are used to indicate in which sub-basins a species occurs (IUCN 2017b).

It is important to note that the restricted distribution of a species, as happens with most aeglids, is not enough to fit them into a category of extinction risk (criterion B).

This condition must be added to other aspects such as the number of locations, continued decline in EOO, AOO, habitat quality, and number of locations or number of mature individuals (IUCN 2017a). Likewise, populations with restricted distribution or found only in few locations (criterion D2), are at risk only when they are under plausible present or future threats, in which case they would qualify for Critically Endangered (CR), or CR "Possibly Extinct" (IUCN 2017a).

The number of locations where a species is found reflects the distribution of the species, and if these are declining over time, may also reflect the threats that are impacting it. Under the IUCN Red List terminology, a location corresponds to an area (that may include several nearby point localities) where a single event would rapidly impact all individuals of the species in the location (IUCN 2001, 2017a). The impact must be direct and must occur in the area occupied by the species, and it is essential that the threat is adequately documented. When the most severe threat to the species is habitat loss, for example, a location corresponds to the region where a single agricultural or urban occupation project can eliminate or drastically reduce the population (IUCN 2017a). Thus, the threat must be present in the geographic space under consideration, and when using AOO, the loss of habitat quality [subcriterion b(iii)] must be present in the location, rather than in a diffuse form throughout the EOO.

The reason why the online IUCN Red List is accepted globally as the industry "gold standard" of reliability is because the extinction risk of species listed there have been subjected to rigorous scrutiny at several levels by conservation specialists before publication. The correct assessment of the conservation status of species is, therefore, a fundamental prerequisite so that mitigation measures in form of conservation actions can be taken, aimed at saving threatened species from extinction.

9.4 ASSESSING THE RISK OF EXTINCTION OF AEGLIDS

The assessment of the extinction risk of 82 out of 87 species of aeglids assessed (Bueno, Camargo, and Moraes 2017; Moraes et al. 2017; Santos 2017) revealed that 57 species (67%) were threatened (CR 17, EN 24, VU 16) and at risk of extinction (Table 9.1). *Aegla intermedia* Girard 1855, was not assessed because it has never been found again and its type-series has disappeared (Bond-Buckup and Buckup 1994; Santos et al. 2017). Also, *A. quilombola* Moraes et al. (2017), is a newly described species and has not been assessed.

Bueno et al. (2016) evaluated the extinction risk of 42 species of *Aegla* from Brazil and found that 26 were at risk of extinction (8 CR, 12 EN, 6 VU) and were therefore legally protected in Brazil (Brazil 2014; ICMBio 2018) (Figure 9.1). All these threatened species are endemic and part of the Brazilian carcinofauna and are also the most at-risk group of crustaceans in Brazil (Magris et al. 2010; Boos et al. 2016) (Figure 9.1). Similarly, 11 out of 18 species of *Aegla* (61.1%) in Chile are threatened with extinction (2 CR, 6 EN, 3 VU) (Chile 2014).

There are no official government records of the extinction risk of the aeglid fauna in the other countries where this genus occurs (Argentina, Bolivia, Paraguay, and

Table 9.1 The Extinction Risk of 57 Threatened Species of *Aegla* Derived Using the IUCN (2001, 2017a) Red List Criteria

N°	Species	Red List Threatened Category/Criteria	Reference
1	*Aegla affinis* Schmitt (1942)	CR B1ab(iii)+2ab(iii)	Chile (2014)
2	*Aegla bahamondei* Jara (1982)	EN B1ab(iii)+2ab(iii)	Chile (2014)
3	*Aegla brevipalma* Bond-Buckup and Santos (2012)	CR B2ab(iii)	Brazil (2014)
4	*Aegla camargoi* Buckup and Rossi (1977)	EN B2ab(iii)	Brazil (2014)
5	*Aegla carinata* Bond-Buckup and Gonçalves (2014)	CRB2ab(iii,iv)	Santos et al. (2017)
6	*Aegla cavernicola* Türkay (1972)	CR B2ab(iii,v)	Brazil (2014)
7	*Aegla charon* Bueno et al. (2017)	CR B2ab(iii)	Bueno, Camargo, and Moraes (2017)
8	*Aegla cholchol* Jara and Palacios (1999)	VU B1ab(iii)+2ab(iii)	Chile (2014)
9	*Aegla concepcionensis* Schmitt (1942)	EN B1ab(iii)+2ab(iii)	Chile (2014)
10	*Aegla denticulata lacustris* Jara (1989)	CR B1ab(iii)	Chile (2014)
11	*Aegla expansa* Jara (1992)	EN B1ab(iii)+2ab(iii)	Chile (2014)
12	*Aegla franca* Schmitt (1942)	CR B2ab(iii)	Brazil (2014)
13	*Aegla georginae* Santos and Jara (2013)	CR B2ab(iii)	Santos et al. (2017)
14	*Aegla grisella* Bond-Buckup and Buckup (1994)	VU B1ab(iii)	Brazil (2014)
15	*Aegla humahuaca* Schmitt (1942)	VU B1ab(iii, iv)	Santos et al. (2017)
16	*Aegla inconspicua* Bond-Buckup and Buckup (1994)	VU B1 ab(iii)	Brazil (2014)
17	*Aegla inermis* Bond-Buckup and Buckup (1994)	EN B1ab(iii)	Brazil (2014)
18	*Aegla intercalata* Bond-Buckup and Buckup (1994)	VU B1ab(iii, iv)	Santos et al. (2017)
19	*Aegla itacolomiensis* Bond-Buckup and Buckup (1994)	EN B1 ab(iii)	Brazil (2014)
20	*Aegla japi* Moraes et al. (2016)	VU B2aD2*	Moraes et al. (2016) Santos et al (2017)
21	*Aegla jaragua* Moraes et al. (2016)	CR A4e**	Moraes et al. (2016)
22	*Aegla jundiai* Moraes et al. (2016)	VU B2aD2*	Moraes et al. (2016) Santos et al. (2017)
23	*Aegla laevis* (Latreille 1818)	EN B1ab(iii)+2ab(iii)	Chile (2014)
24	*Aegla lancinhas* Bond-Buckup and Buckup (2015)	EN B2ab(iii)	Santos et al. (2017)
25	*Aegla lata* Bond-Buckup and Buckup (1994)	CR B1ab(i,iii,iv)	Brazil (2014)
26	*Aegla leachi* Boos, Bond-Buckup and Buckup (2012)	EN B1ab(iii)+2ab(iii)	Brasil (2014)
27	*Aegla leptochela* Bond-Buckup and Buckup (1994)	CR B2ab(iii,v)	Brazil (2014)

(Continued)

Table 9.1 (Continued) The Extinction Risk of 57 Threatened Species of *Aegla* Derived Using the IUCN (2001, 2017a) Red List Criteria

N°	Species	Red List Threatened Category/Criteria	Reference
28	*Aegla leptodactyla* Buckup and Rossi (1977)	VU B1 ab(iii)	Brazil (2014)
29	*Aegla ligulata* Bond-Buckup and Buckup (1994)	VU B1 ab(iii)	Brazil (2014)
30	*Aegla loyolai* Bond-Buckup and Santos (2015)	EN B2ab(iii)	Santos et al. (2017)
31	*Aegla ludwigi* Santos and Jara (2013)	EN B2ab(iii)	Santos et al. (2017)
32	*Aegla manni* Jara (1980)	VU B1ab(iii)+2ab(iii)	Chile (2014)
33	*Aegla manuinflata* Bond-Buckup and Santos (2009)	EN B1ab(iii)+2ab(iii)	Brazil (2014)
34	*Aegla meloi* Bond-Buckup and Santos (2015)	CR B2ab(iii)	Santos et al. (2017)
35	*Aegla microphthalma* Bond-Buckup and Buckup (1994)	CR B2ab(iii,v)	Brazil (2014)
36	*Aegla oblata* Bond-Buckup and Santos (2012)	EN B1 ab(iii)	Brazil (2014)
37	*Aegla obstipa* Bond-Buckup and Buckup (1994)	EN B1ab(iii)	Brazil (2014)
38	*Aegla occidentalis* Jara et al. (2003)	EN B1ab(iii)+2ab(iii)	Chile (2014)
39	*Aegla papudo* Schmitt (1942)	EN A2ce	Chile (2014)
40	*Aegla paulensis* Schmitt (1942)	VU B2aD2*	Moraes et al. (2016) Santos et al. (2017)
41	*Aegla perobae* Hebling and Rodrigues (1977)	CR B2ab(iii)	Brazil (2014)
42	*Aegla plana* Buckup and Rossi (1977)	EN B1 ab(iii)	Brazil (2014)
43	*Aegla pomerana* Bond-Buckup and Buckup (2010)	EN B1 ab(iii)	Brazil (2014)
44	*Aegla renana* Bond-Buckup and Santos (2010)	CR B2ab(iii)	Brazil (2014)
45	*Aegla ringueleti* Bond-Buckup and Buckup (1994)	CR B2ab(iii)	Santos et al. (2017)
46	*Aegla rosanae* Campos Jr. (1998)	CR B2ab(iii)	Moraes et al. (2016)
47	*Aegla rossiana* Bond-Buckup and Buckup (1994)	EN B1 ab(iii)	Brazil (2014)
48	*Aegla saltensis* Bond-Buckup and Jara (2010)	VU B2ab(iii, iv)	Santos et al. (2017)
49	*Aegla sanlorenzo* Schmitt (1942)	EN B2ab(iii)	Santos et al. (2017)
50	*Aegla septentrionalis* Bond-Buckup and Buckup (1994)	EN B1ab(iii, iv)	Santos et al. (2017)
51	*Aegla spectabilis* Jara (1986)	VU B1ab(iii)+2ab(iii)	Chile (2014)
52	*Aegla spinipalma* Bond-Buckup and Buckup (1994)	VU B1 ab(iii)	Brazil (2014)
53	*Aegla spinosa* Bond-Buckup and Buckup (1994)	VU B1 ab(iii)	Brazil (2014)
54	*Aegla strinatii* Türkay (1972)	EN B2ab(iii)	Brazil (2014)

(Continued)

Table 9.1 (Continued) The Extinction Risk of 57 Threatened Species of *Aegla* Derived Using the IUCN (2001, 2017a) Red List Criteria

N°	Species	Red List Threatened Category/Criteria	Reference
55	*Aegla talcahuano* Schmitt (1942)	EN B1ab(iii)+2ab(iii)	Santos et al. (2017)
56	*Aegla vanini* Moraes et al. (2016)	VU B2aD2*	Moraes et al. (2016) Santos et al (2017)
57	*Aegla violacea* Bond-Buckup and Buckup (1994)	EN B1ab(iii,iv)	Brazil (2014)

**Aegla japi, A. jundiai, A. paulensis*, and *A. vanini* were not evaluated correctly, as explained in the text. ***Aegla jaragua* (CR A4e) was evaluated initially as CR A4eB2a, but the subcriterion B2a has now been omitted because it is unnecessary for the categorization of the species as CR.

Uruguay). However, in a recent study of the aeglid fauna in three of these countries, Santos et al. (2017) found seven threatened species of *Aegla* in Argentina (2 CR, 2 EN, 3 VU), one in Bolivia (1 EN), and one in Uruguay (1 CR).

The extinction risk of practically the entire aeglid fauna has been assessed using the IUCN Red List protocols by a team of specialists who have contributed to the taxonomy, distribution, and biology of the aeglids (Bond-Buckup et al. 2009). The results presented indicate alarmingly high numbers of threatened species of aeglids (some of the highest on record). Characteristics such as restricted distribution and unique biology make them particularly vulnerable to habitat destruction and pollution. Bond-Buckup and Buckup (1994) pointed out the need to intensify studies on the aquatic fauna, especially aeglids, considering the advanced process of deterioration of the limnic environments in South America. This aspect is particularly evident in the evaluations of most of the threatened aeglids presented here that use criterion B (restricted distribution), due to rapid environmental degradation in many parts of their geographical distribution range.

9.5 THREATS TO AEGLIDS

The main risks to the 52 threatened species of aeglids (Table 9.1) are associated with the suppression of riparian forests, silting up and pollution of water bodies from agriculture, livestock, and aquaculture (Figure 9.2).

The activities listed in Figure 9.2 are responsible for the continuous decline in the quality of habitats occupied by aeglid crabs [subcriterion b(iii)] and are frequently cited as part of the justification for the extinction risk assessment of these animals. In general, the majority of these threats that impact aeglids are related to economic activities in the regions where each species occurs. Despite differences in landscape and vegetation, anthropogenic threats are well documented for some species of *Aegla* in Brazil and Chile. For example, in the state of Santa Catarina in Brazil, the breeding of cattle and pigs has caused a decline in the water quality in the single locality where *A. brevipalma* has been recorded (Bond-Buckup et al. 2008; Santos et al. 2012) (Figure 9.3). Another example is the increasing habitat degradation of

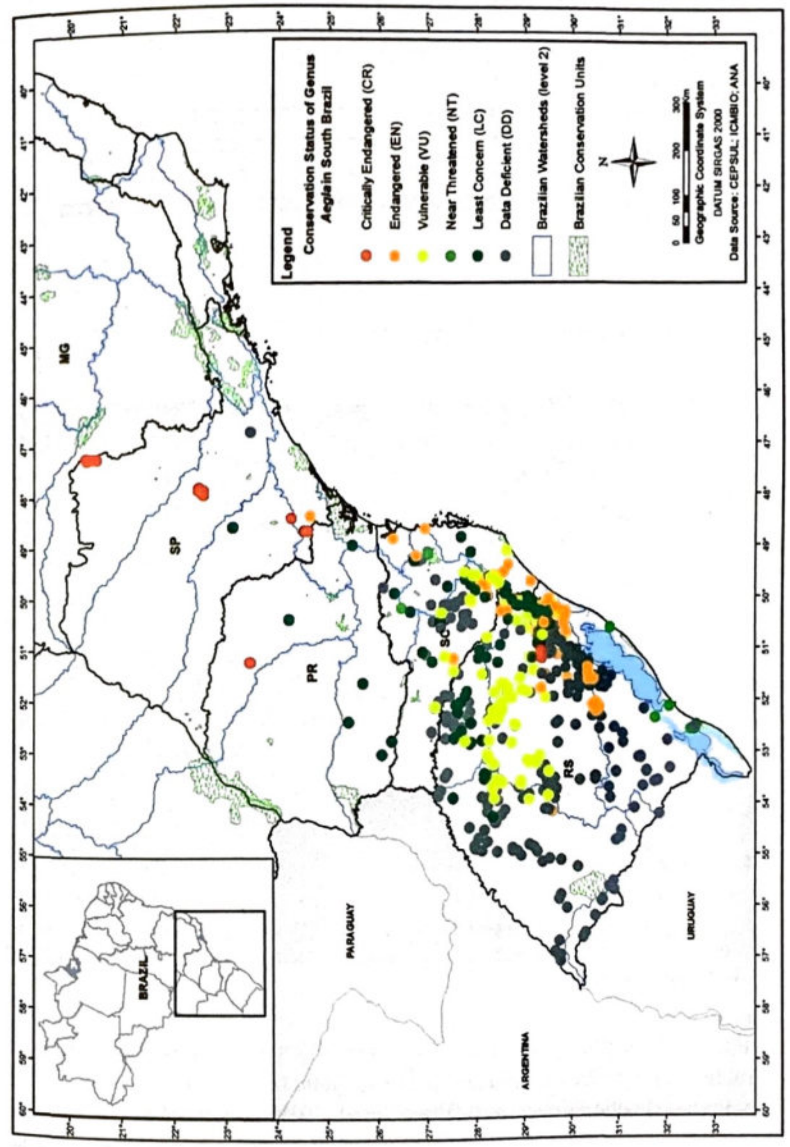

Figure 9.1 Distribution and extinction risk categories of the species assessed in Brazil. In the map the following states are indicated: MG (Minas Gerais), SP (São Paulo), PR (Paraná), SC (Santa Catarina), and RS (RS). Source: Brazil (2014), Bueno et al. (2016), and ICMBio (2018).

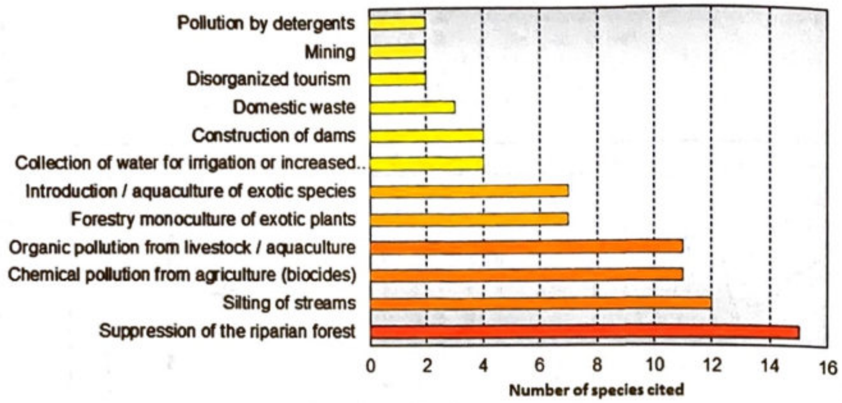

Figure 9.2 Threats indicated for species at risk of extinction.

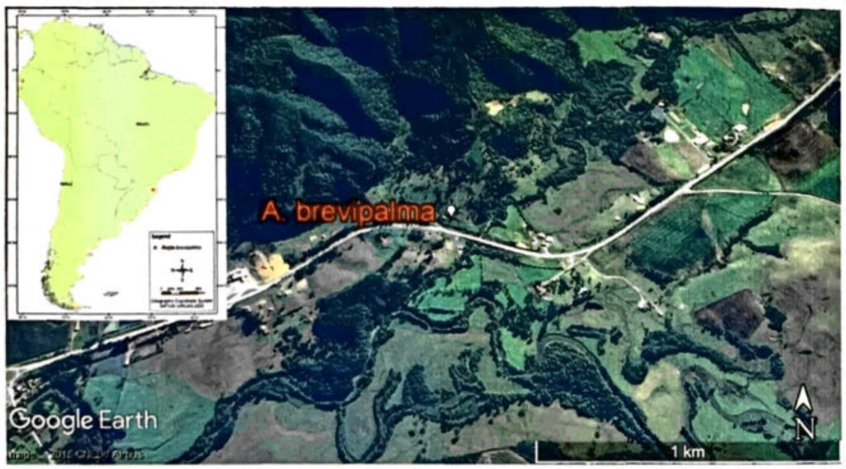

Figure 9.3 The only recorded site for *Aegla brevipalma* in the Matator River in the Uruguay River Basin, Santa Catarina, Brazil (Santos et al. 2012). Source: Modified from Google®Earth.

A. franca due to the suppression of ciliary forest, the sedimentation of streams, road construction, and pollution from significant organic (animal husbandry) and/or industrial pollution (leather processing) (Bueno et al. 2018) (Figure 9.4).

Troglobitic species (such as *A. cavernicola*) are adapted to the relatively stable environmental conditions that characterize the interior of caves and are directly affected by changes of epigean habitats (Trajano 2000; Bueno et al. 2010). The destruction of the riparian forest, the silting of streams, and the pollution of streams by detergents are the main threats to this species (Pacca et al. 2007) (Figure 9.5).

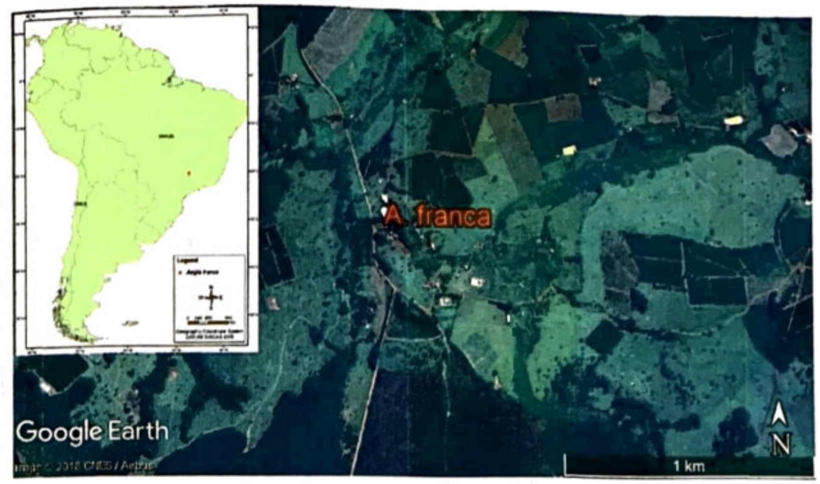

Figure 9.4 One of the localities of *Aegla franca* in the Rio das Canoas in the Paraná River Basin, São Paulo, Brazil (Bueno et al. 2018). Source: modified from Google®Earth.

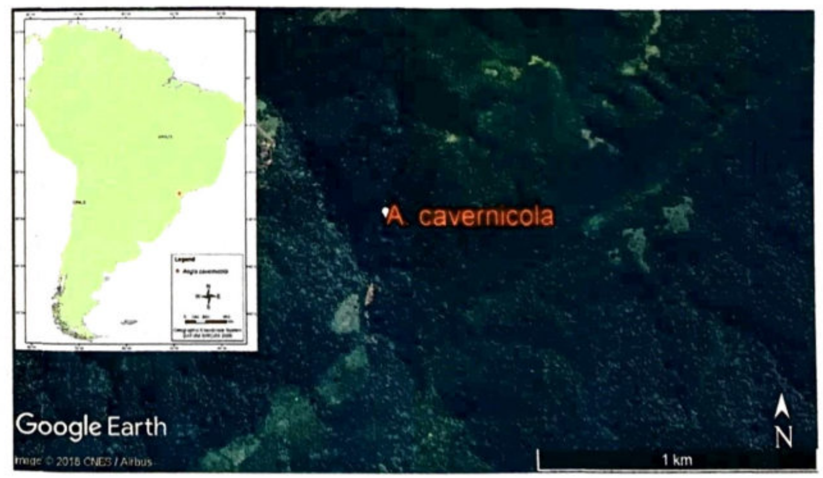

Figure 9.5 The only recorded site for the troglobitic species *Aegla cavernicola*, in the State of São Paulo, Brazil (Bueno et al. 2010). Source: Modified from Google®Earth.

In Chile, environmental degradation occurs mainly through the collection of water for irrigation, silting of streams, and organic and chemical pollution from biocides, and are threats to aeglids such as *A. laevis* (see Chile 2014) found on grape plantations for the wine industry (Bond-Buckup et al. 2008) (Figure 9.6).

Other threatened species of aeglids, such as *A. affinisi* and *A. denticulate*, are impacted by decreased habitat quality and predation by introduced species such as

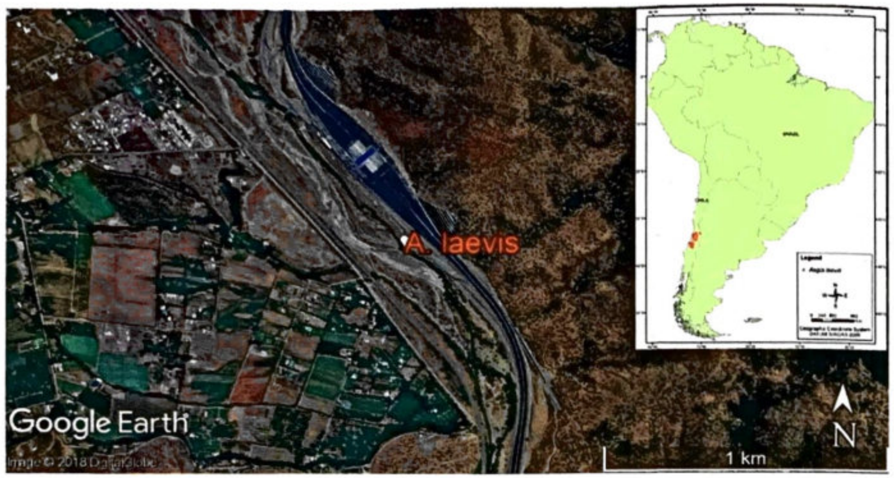

Figure 9.6 Locality of *Aegla laevis* in Angostura, Province of Huasco, Chile (Bahamonde and López 1963). Source: Modified from Google®Earth.

salmonid fish (Bond-Buckup et al. 2008; Chile 2014). The impact of exotic animals has similarly affected aeglids in other regions. For example, Moraes et al. (2016) assessed the extinction risk of *A. jaragua* as Critically Endangered (CR), because of threats from a well-established population of the exotic crayfish *Procambarus clarkii* (Girard 1852).

In Bolivia, the habitat of the endemic species *A. septentrionalis* has been degraded by pollution from organic sewage (domestic and/or livestock and agriculture) and from solid and liquid residues and debris (Flores 2010). Santos et al. (2017) evaluated this species as EN based mainly on similar threats to subpopulations of this species found in Argentina.

Anthropogenic threats to species of *Aegla* originate mostly on land where human populations generate the pollutants that impact freshwater environments (Duarte et al. 2016, 2017). These impacts are intensified along the central river basins whose waters are used for commercial transport, irrigation, animal husbandry, and subsistence farming (Liyanage and Yamada 2017). Humans have used rivers to dispose untreated urban and agricultural wastes (e.g., sewage, herbicides, insecticides) as well as industrial effluents (e.g., heavy metals, HPAs, etc.).

A number of species of aeglids (including threatened species) found in the northern and northeastern State of Rio Grande do Sul (RS) in Brazil (Guaíba watersheds) are likely to be impacted by the expansion of agricultural land used for viticulture (which has doubled in the last 20 years) (EMBRAPA 2017) (Figure 9.7). However, viticulture represents only 1% of the agriculture in this state (Pignati et al. 2017). According to these authors, in the same area, soybean cultivation predominates, accounting for 59% of the crop in RS, and coinciding with a higher human density and intense cattle activity (beef cattle and leather tanning industry).

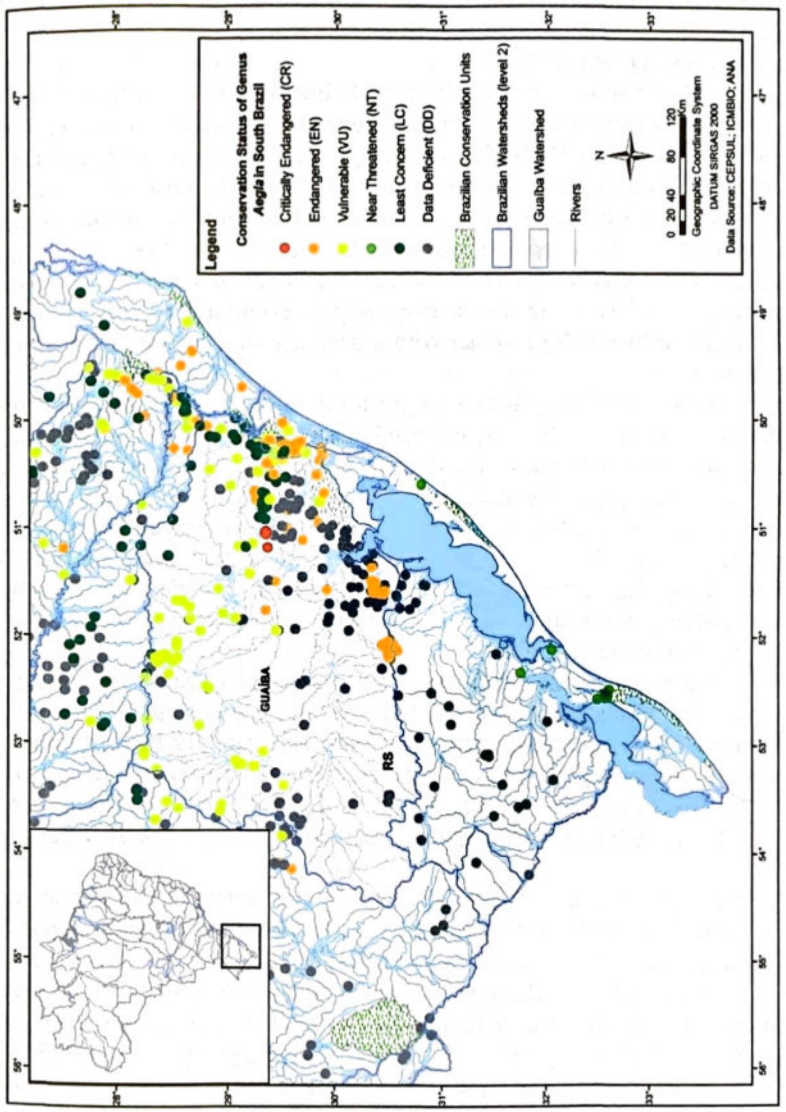

Figure 9.7 Regions with the highest number of aeglid records in Brazil (Guaíba watersheds), indicating the respective categories of extinction risk. Source: Bond-Buckup and Buckup (1994), Boos et al. (2012), Bueno et al. (2016), Santos et al. (2017).

Herbicides such as Paraquat (1,1′-dimethyl-4,4′-bipyridine-dichloride), a toxic product based on ammonium and water-miscible, are used in soybean cultivation, although Paraquat has been under restrictive use by ANVISA (GLOBO 2018). This herbicide promotes toxic and clastogenic effects in aquatic animals (Sartori and Vidrio 2018) and humans (Veríssimo et al. 2017). There are some herbicides and insecticides used in agricultural areas, which quickly reach groundwater, streams, and rivers, and pose a potential threat.

The accumulation of manure from beef cattle breeding causes organic contamination of freshwater habitats, which is worsened by the addition of untreated urban wastewater (Wen et al. 2017). According to the latter authors, the discharge of sewage from livestock and urban areas increase the level of contaminants, which are intensified by the reduction of the volume of rivers by damming and redirecting them, thus decreasing water sustainability. In this sense, precipitation gains importance as one of the leading environmental factors that affect contamination levels, causing the dispersion of pollutants in water bodies (Galloway and Cowling 1978) together with a decrease in the concentration of these pollutants.

Another source of common pollutants originates from the improper disposal and management of solid waste still primarily found in dumps. Over time, this material generates run-off (slurry), which is a dark-colored liquid with a nauseating odor, originating from biological, chemical, and physical processes of organic waste decomposition. According to Schepis et al. (2016), solid waste dumps are responsible for a range of pollutants that contaminate soil, surface, and groundwater with high levels of metal (e.g., mercury, copper, manganese, arsenic, cyanide) and phenolic compounds (polycyclic aromatic hydrocarbons, dioxins, and furans), all detrimental to animals, especially aquatic species.

Most aeglids inhabit streams with clear, well-oxygenated water, with a high flow velocity and a substrate composed by rocks of various sizes (Chiquetto-Machado et al. 2016). Aeglids are generally found in relatively large numbers associated with the most preserved and protected areas of riparian forests with minimal human disturbances (Zimmermann et al. 2016). Although environmental care has been intensifying, sanitary problems from sewage still persist (IBGE 2010).

In this sense, it is fundamental to link records of presence/absence (or abundance) of freshwater species with the quality of the environment they occupy, especially the amount and conservation status of the riparian forests (Arantes et al. 2018). Other studies have correlated physiological and reproductive responses as stress indicators in contaminated environments (Bertrand et al. 2018). Therefore, it is essential to use different approaches and techniques (e.g., genetic, physiological, and ecotoxicological ones) to develop an integrative and reliable evaluation about environmental quality, comprising alternative forms of environmental monitoring (Faria et al. 2018).

The use of alternative techniques to study well-known species was previously mentioned by Larramendi (2017), who cited several species of invertebrates in various environments. Inexpensive, rapid, and simple-to-use techniques, such as genotoxicity (e.g., micronucleus test, MN) and cytotoxicity tests (neutral red retention time, NRRT), have been useful to analyze the response of organisms to environmental quality. The application of these tests does not require the death of the specimens, since it only depends on a hemolymph sample from a few specimens, followed by their subsequent return to the natural environment (Pinheiro et al. 2017). These methods would be especially relevant for studies on aeglids because their populations are small. The simple recording or estimation of the abundance of these specimens in streams and rivers can already indicate the presence of water of excellent quality. Once again, it is crucial to conserve well-structured areas of ciliary forest, protecting streams and rivers, which are the habitat of the aeglids. In addition, the correct shadowing of streams (Gregory et al. 1991), together with biogeochemical and hydrological processes observed in riverine areas regulate the concentration of pollutants and mitigate the impact of sources of contamination from the uplands (McClain et al. 2003; de Sosa et al. 2018).

Despite the potential of aeglids as bioindicators of aquatic environmental quality, little is known about this topic. However, studies (Faria et al. 2018) provide integrative analyses, correlating phylogeny, environmental parameters, and antioxidants, demonstrating that the aeglids are niche specific, although there is some interspecific plasticity. According to these authors, the dosage of metals and analyses involving the antioxidant defense system (ADS) in these decapods can be an alternative for monitoring freshwater environments. The knowledge of such information would have practical applications and would be relevant for the mapping of preservation areas for aeglids as well as the environments habitats they occupy.

However, even if precarious, records about the occurrence and the extinction risk category allow the identification of some priority regions for the conservation of aeglids. The northeast region of the State of Rio Grande do Sul and the watercourses that make up the Guaíba River Basin (Figure 9.8) stand out.

9.6 CONSERVATION OF AEGLIDS

The conservation of aeglids is closely associated with the conservation of their habitats, primarily because the ecological niche is extremely restricted in these endemic species. Therefore, it is fundamental to know more about their distribution, the threats that impact the species, and their origin for the assessment of the extinction risk. Only a joint analysis of the threats versus the distribution of the species will permit the elaboration of public policies that seek to eliminate or mitigate the main threats to aeglids.

The calculation of the extent of occurrence (EOO) of aeglids, as well as for other freshwater species is based on the number of localities where the species has been recorded and represents the area where the main threats to the species operate. Otherwise, there will be only a superficial and generic indication of the threats,

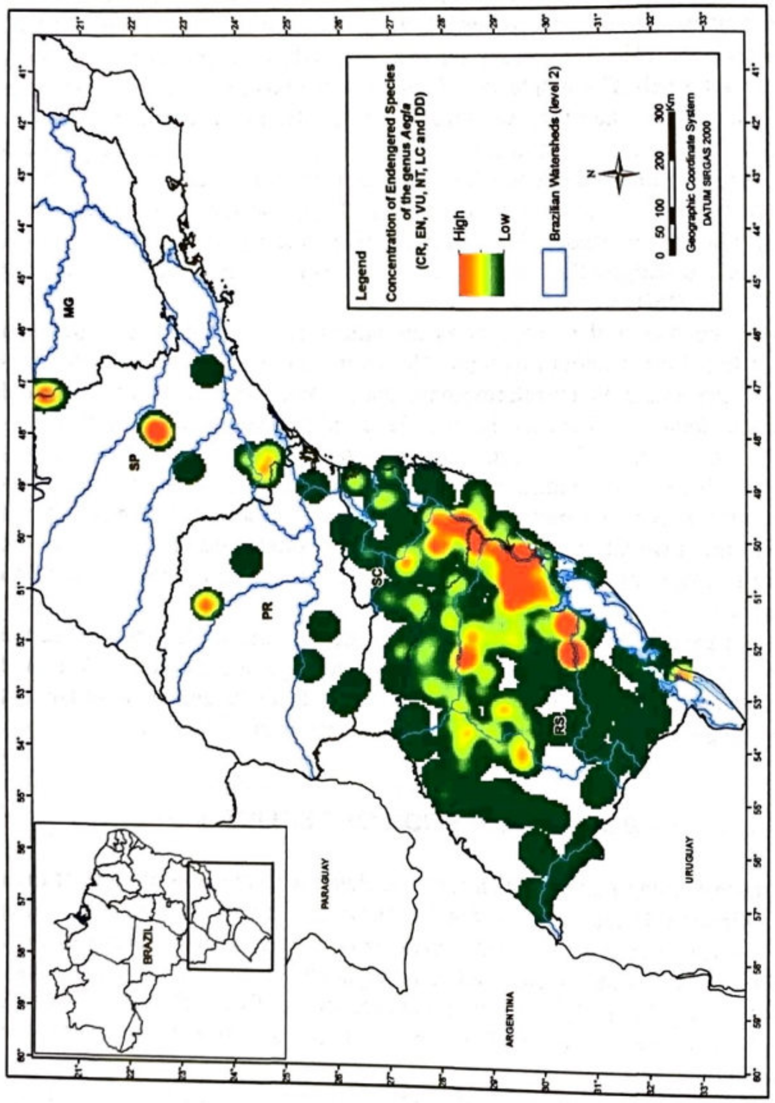

Figure 9.8 Concentration of threatened aeglid species in Brazil, resulting from Kernel density estimation tool by ArcGIS 10.5. The contours indicate the locations where the threatened species (CR, EN, and VU) are more concentrated.

hindering both the identification of cause and effect relationships and the elaboration of effective strategies to revert the extinction risk.

On the other hand, conservation measures should incorporate technological advances, especially genetic evidence. This approach has full adherence to the most recent conservation actions. In this sense, the prioritization of freshwater ecoregions (Abell et al. 2008), which encompasses a greater genetic diversity and number of aeglid species (Pérez-Losada et al. 2009), could help in the decision making for the allocation of resources for the conservation of these animals, which in general is very limited.

There are still no conservation measures for the anomuran freshwater crabs in South America (Magalhães et al. 2016). However, in Brazil, the "National Action Plan for the Conservation of Atlantic Forest Fish and Aeglids" (in prep.) aims to protect 26 endangered species of aeglids (Figure 9.9). Action plans identify and guide priority actions in order to save species at risk of extinction, and the implementation of these plans involve different sectors of society, such as governmental organizations and organized civil society (Brazil 2012).

Environmental education is a crucial part of these priority actions. Following the classic "must-know-to-conserve" idea, conservation initiatives for aeglids will only be supported when these fascinating animals are known not only by researchers but also by most of the society. In this sense, the "Biodiversity of Campos de Cima da Serra: popularizing knowledge" project coordinated by Bond-Buckup (2008a, b) is an example of a valuable initiative. The elaborated books describe educational activities for teachers and students of the cities located in the "Campos de Cima da Serra," within the Atlantic Forest biome in southern Brazil.

The conservation of aeglids represents an important challenge for people and institutions to reverse the extinction risk of these animals. The unique biology and restricted distribution of many aeglid species are a challenge for their conservation, which will only be met if researchers, environmentalists, and decision makers pool their efforts to reverse the trend towards increasing threats for these species.

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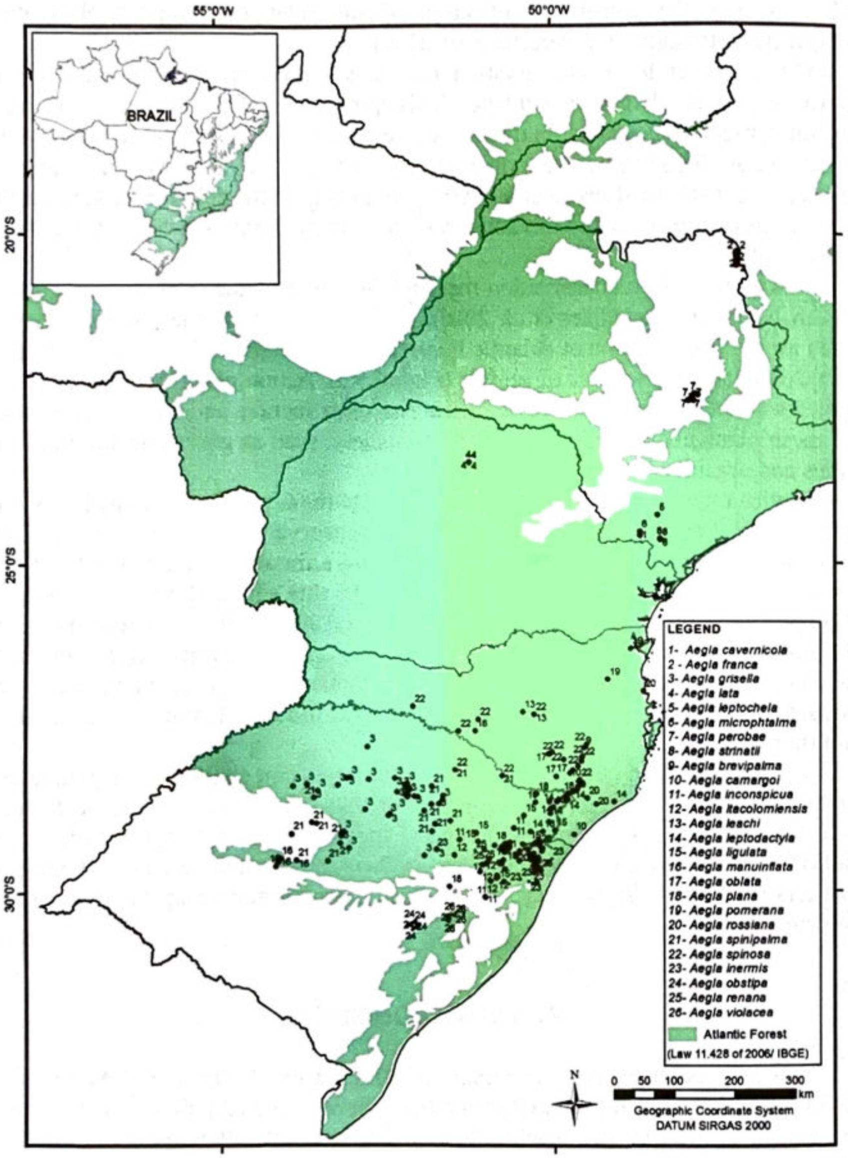

Figure 9.9 Species of *Aegla* that will be included in the "National Action Plan for the Conservation of Atlantic Forest Fish and Aeglids." Source: Bond-Buckup and Buckup (1994), Boos et al. (2012), Bueno et al. (2016), and ICMBio (2018).

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