

# The Sustainable Management of Giant Salamanders Cryptobranchioidea



The massive size of *Andrias* species is illustrated in this photograph of an adult Japanese giant salamander (*Andrias japonicus*) with large nostrils in the front with tiny eyes to the side.

Image: Michael Ready: <http://michaelready.photoshelter.com>

Robert Browne<sup>1</sup>, Zhenghuan Wang<sup>2</sup>, Sumio Okada<sup>3</sup>, Dale McGinnity<sup>4</sup>, Qinghau Luo<sup>5</sup>, Yuki Taguchi<sup>6</sup>, Douglas Kilpatrick<sup>7</sup>, Rebecca Hardman<sup>8</sup>, Peter Janzen<sup>9</sup>, Zhixin Zhang<sup>10</sup>, Yi Geng<sup>11</sup>.

**1.** Sustainability America, Sarteneja, Corozal District, Belize.; **2.** School of Life Sciences, East China Normal University, 200062, Shanghai, P.R. China.; **3.** Laboratory of Biology, Department of Regional Environment, Tottori University, Tottori 680-8551, Japan.; **4.** Nashville Zoo, Nashville, Tennessee 37189, USA.; **5.** Institute of Chinese giant salamander, Jishou University, P.R. China.; **6.** Hiroshima City Asa Zoological Park, Hiroshima 731-3355, Japan. Japan Hanzaki Institute, Hyogo 679-3341, Japan.; **7.** Douglas Kilpatrick, Umea University, 90736, Sweden.; **8.** Collage of Veterinary Medicine, University of Tennessee, Knoxville, TN, USA.; **9.** Zoodirektoren. Germany, 47119 Duisburg, Landwehrstr, 32.; **10.** Graduate School of Marine Science and Technology, Tokyo University of Marine Science and Technology, Tokyo 108-8477, Japan.; **11.** College of Veterinary Medicine, Sishuan Agricultural University, Wenjiang, Sichuan Province, 611130, P.R. China.

**Citation:** Browne RK, Wang Z, Okada S, McGinnity D, Luo Q, Taguchi Y, Kilpatrick D, Hardman R, Janzen P, Zhang Z, Geng Y. 2020. The Sustainable Management of Giant Salamanders (Cryptobranchioidea). Review. Sustainability America, Belize. Publication 5th November 2020.

**Key words.** Giant salamander, Sustainable management, *Andrias*, *Cryptobranchus*, Hellbender, Zhōngguó dà ní (中国大鲵), Ōsanshōuo (大山椒魚)

**Corresponding author:** Robert Browne, [robert.browne@gmail.com](mailto:robert.browne@gmail.com)

## INDEX

Title/Authors/Citation/Keywords .....	1
Index .....	2
Summary.....	4
Introduction .....	5
Population Genetics and Sustainable Management.....	6
Clades, Species, and Evolutionary Significant Units .....	6
Chinese <i>Andrias</i> clade .....	7
Japanese <i>Andrias</i> clade.....	8
North American <i>Cryptobranchus</i> clade.....	9
Cultural Context .....	10
Vernacular and Scientific Names .....	10
Mythology and Art .....	12
Food and Medicine .....	14
Natural Populations .....	14
Chinese <i>Andrias</i> clade .....	14
Japanese <i>Andrias</i> clade.....	15
North American <i>Cryptobranchus</i> clade .....	15
Threats .....	15
Global Heating.....	15
Bioclimatic Modelling .....	16
Chinese <i>Andrias</i> clade .....	17
Japanese <i>Andrias</i> clade .....	17
North American <i>Cryptobranchus</i> clade .....	17
Global Heating and Global Response.....	18
Ultraviolet B (UVB).....	18
Habitat Loss and Macro-pollutants.....	18
Chinese <i>Andrias</i> clade .....	18
Japanese <i>Andrias</i> clade .....	19
North American <i>Cryptobranchus</i> clade .....	19
Overharvest and Poaching.....	19
Pet Trade.....	19
Incidental Bycatch and Eradication.....	20
Pathogens and Parasites.....	20
Chytrid Fungus.....	20
Ranavirus .....	21
Bacteria .....	22
Internal Parasites.....	22
External Parasites.....	22
Non-infectious Disease and Micro-pollutants .....	23
Anthropogenic Activity and Stress .....	23
Global Heating and Pathogens.....	24
Genetic Impoverishment and Hybridisation .....	24
Exotic Predators and Prey Loss .....	24
Filial Cannibalism.....	25

# Sustainable Management of Giant Salamanders

## INDEX

Sustainable Management.....	26
Law and Policy .....	26
Dedicated Reserves and Programs .....	26
Ecosystem Restoration.....	26
Artificial Breeding Dens and Nest Boxes.....	27
Conservation Breeding Programs .....	27
Genetic Impoverishment.....	27
Sperm Banking .....	28
Chinese <i>Andrias</i> clade .....	28
Japanese <i>Andrias</i> clade .....	29
North American <i>Cryptobranchus</i> clade .....	29
Aquaculture .....	31
Quarantine and Release .....	32
Co-species Sustainable Management .....	32
Monitoring and Surveys .....	34
Cultural Engagement .....	34
Ecotourism, Zoos and Aquariums .....	33
Internet Presence .....	35
Iconic Species .....	35
Flagship Species .....	36
Phylogenetics and Education .....	36
Scientific Meetings and Civil Societies .....	36
Scientific Research .....	36
Community Based Co-management .....	36
Conclusion .....	37
Acknowledgements .....	37
References .....	38
Closing cover.....	46

## SUMMARY

The giant salamanders (Cryptobranchioidea) are iconic species for the sustainable management of freshwater biodiversity, and the initiatives for their sustainable management are much broader in scope than with any other amphibians. They involve three nations that span the Pacific Ocean, working to manage both wild populations and those in conservation breeding programs (CBPs). Governmental, academic, and zoological institutions, along with the public contribute to the sustainable management of giant salamanders through research, CBPs, education, other cultural, and field activities.

Giant salamanders comprise of three clades, or groups of closely related species; the Critically Endangered, Chinese *Andrias* clade comprises five to seven species, the Near Threatened. Japanese *Andrias* clade comprises one species, and the Vulnerable, North American *Cryptobranchus* clade comprises five putative species.

Species in the Chinese *Andrias* clade are only found in nature in relict populations if at all, the Japanese *Andrias* clade is slowly declining, and all species in the endemic North American *Cryptobranchus* clade are declining with some highly endangered. There are also evolutionary significant units within these species that are subject to both conventional and emerging threats.

Conventional threats to all giant salamanders include habitat loss through structural modification or through pollution, and over harvest along with exotic species. Emerging threats include global heating, micro-pollutants, novel diseases, genetic impoverishment, and ecosystem collapse.

The sustainable management of giant salamanders mainly requires population genetic assessment; habitat protection and restoration; disease management; CBPs for threatened populations, genetic resource banks; along with public support and political influence.

The species in the Chinese *Andrias* clade can be recovered through CBPs in concert with focused governance and greater public engagement to interact with and restore giant salamander populations. Working for the sustainable management of giant salamanders builds health and spiritual strength, and fosters regional and national pride. The many giant salamander reserves already established in China can provide for most or all recovered populations, and the needed skills, knowledge, and institutions are available.

The Japanese *Andrias* clade needs the preservation and creation of nest and shelter sites along with ameliorating the effects of dams and channelisation. Some threatened populations need CBPs along with population supplementation because of a lack of recruitment.

North American *Cryptobranchus* suffer from low recruitment in some populations with the causes being identified and ameliorated. Head-starting from eggs taken from nests may help recover some low density populations. Because recruitment may be suffering from the filial cannibalism of eggs. Filial cannibalism increases as population density decreases leading to a cycle of lowering recruitment exacerbated by sedimentation destroying juvenile habitat in riffle banks and burying nest sites.

There are CBPs for the Japanese *Andrias* clade, and CBPs with supplementation projects for the North American *Cryptobranchus* clade. There are many millions of mostly hybrid Chinese *Andrias* in aquaculture in China but only nascent genetically representative CBPs.

Novel pathogens and stochastic events have the potential to decimate the populations of all giant salamanders. In the event of catastrophes, and in support of CBPs, the provision of genetically representative sperm banks will enable the reestablishment of genetic variation in needy populations.

Social networking, the media, and education should be optimised to maximise political influence for the sustainable management of giant salamanders. Public relations should be based on popularising favourable opinions through emphasising the urgency and challenges of environmental sustainability to promote effective private and public engagement. Public engagement should be both knowledge and intuition based.

Social networking, the media, and education need more applied research in respect to audience definition and targeting, message optimisation through audience response, co-marketing with other environmental groups, and ultimately the greatest market impact and benefit for cost.

## INTRODUCTION

Giant salamanders are the worlds largest amphibians with some being the size of a small crocodile. Until the mid-20<sup>th</sup> century all giant salamanders still had high populations, except in some heavily polluted or modified habitats or through localised harvesting. Some species are already extinct, with many highly threatened, and the future survival of all giant salamanders depends on their sustainable management. In a world of ongoing and increasing biodiversity extinctions the sustainable management of giant salamanders is now of global significance [1,2].

Giant salamanders are one of the most ancient amphibian orders, and comprise the most ancient families of salamanders. They derive their scientific name name "Cryptobranchidae" from the Ancient Greek, "kryptos" (hidden) and "branchos" (gill), which refers to the hidden gills in the adults, and are both morphologically and reproductively conservative having changed little in appearance and reproductive strategies over the last 130 million years (Fig. 1., also see review [1]).

The first fossil salamander described was a European giant salamander species that was misidentified in 1726 as a human drowned in the Biblical flood as *Homo diluvii testis* (man drowned in flood [3]). There have now been many other giant salamander like fossils, with taxonomists noting the close similarity between the skeletons of extant giant salamanders and the fossil skeletons of their ancient ancestors [3].

Giant salamanders originated in East Asia ~150 million years ago (MYA) and in the *Andrias* giant salamander clade diverged ~130 MYA between the *Andrias* species now found in China and Japan, and the ancient ancestors of the species in North American *Cryptobranchus* clade [4]. The *Andrias* clade then diverged between 12 [5], 15 MYA [6] into the Chinese *Andrias* clade endemic to China, and the Japanese *Andrias* clade endemic to Japan. The North American *Cryptobranchus* clade then diverged over the last few million years into five putative *Cryptobranchus* species all of which are endemic to central and eastern North America [7].

Giant salamanders are iconic species for conservation in their respective nations, and globally, as they are by far the largest amphibians with *Andrias* species reaching an impressive 1.8 m length and 60 kg weight, and with *Cryptobranchus* species reaching more than 65 cm and 3 kg in weight [1,2].

There are five to seven species in the Chinese *Andrias* clade that only exist, if at all, as relict populations some of which are hybridised through releases (Fig. 3,4,5., [8,5]). Fortunately, some unhybridised individuals still exist in nature, in aquaculture, and in zoos and possibly private collections [8,9]. The Near Threatened, Japanese *Andrias* clade is comprised of one species distributed over western Japan with many populations slowly declining [Fig. 6., [10,11,12,13]. The Vulnerable, endemic North American *Cryptobranchus* clade is comprised of five putative species (Fig. 7., [7]), with most populations

declining and with some at critically low numbers and others possibly extinct [14,15,16,17,18].

In response to the current and looming threat to the survival of giant salamanders, since 2010 there has been growing national and international concern toward their sustainable management, including increased scientific research and practical application, and to much lesser extent research or practice to broaden cultural presence and therefore political influence.

Achievements include:

- The most extensive amphibian survey ever conducted.
- The discovery of four to six novel *Andrias* species and three putative *Cryptobranchus* species.
- The development of biotechnologies for artificial reproduction and gene banking.
- Elucidation of pathology and epidemiology.
- Implementation of CBPs and supplementation programs.

Sustainable management for Japanese *Andrias* and species in the *Cryptobranchus* clade includes the establishment of CBPs and the application of artificial nest boxes, and for Chinese *Andrias* and *Cryptobranchus* supplementation or repopulation projects.

A critical factor in the sustainable management of all giant salamanders is cultural and political engagement. Cultural engagement is generated through direct interactions with species or their environments, and through environmental education, the media, and social activities. To transform these opportunities into effective political strategies requires media presence and public education supported by accurate information and the provision of participatory activities [19,20]. With giant salamanders, marketing research in respect to building public interest and gaining political and financial support, has received less attention than biological and biotechnical studies.

Our first three reviews were biologically focused:

2011 - *Survey techniques for giant salamander and other aquatic Caudata* [21].

2012 - *The giant salamanders (Cryptobranchidae): Paleontology, phylogeny, genetics, and morphology* [1].

2014 - *The giant salamanders (Cryptobranchidae): Biogeography, ecology and reproduction* [22].

Our current review 2020 - *The Sustainable Management of Giant Salamanders*, extends the sustainable management of giant salamanders to a synthesis of scientific and cultural considerations including:

- Population Genetics.
- Cultural Context.
- Natural Populations.
- Conventional and Emerging threats.
- Conservation Breeding Programs.
- Genetic Resource Banking.
- Sustainable Management.
- Public Engagement and Politics.

We anticipate that some of the principles discussed in this review will provide insight for the sustainable management of threatened species in general.



## POPULATION GENETICS and SUSTAINABLE MANAGEMENT

### Clades, Species and Evolutionary Significant Units

Population genetics reveals the phylogenetic history of a clade including the degree of relatedness between the species comprising the clade and the time of their divergence. Recent population genetics assessments of the giant salamanders have yielded surprising results, with the original three known species increased to at least thirteen.

The giant salamander clades are: 1) the endemic Chinese *Andrias* clade that comprises the original species *A. davidianus*, and five or more recently discriminated *Andrias* species [5,8,9]; 2) the endemic Japanese *Andrias* clade comprising one species *A. japonicus* [10]; and 3) the endemic North American *Cryptobranchus* clade comprising the original *Cryptobranchus alleganiensis* and now four other putative species (Fig 1., [7]).

Species of obligate freshwater amphibians are generally confined to a watershed, and within this watershed closely related species and evolutionary significant units (ESUs) may also be found. Each species and ESU has a unique genotype that supports environmental adaptation through inherited, fitness-related traits. These survival traits define each genotypes evolutionary trajectory, with each ESUs considered as distinct management units in the USA [23].

Taxonomic certainty is crucial to the sustainable management of species. Taxonomic uncertainty leads to the miss-targeting the management of both populations in nature and those in conservation breeding programs (CBPs). Taxonomic uncertainty can result in habitat protection that excludes threatened species or ESUs.

Taxonomic uncertainty can also result in founding broodstock from the wrong species or ESU, or from mixed broodstock, resulting in hybridization and consequently the release of genetically inappropriate individuals into natural populations. When any taxonomic uncertainty exists with a target species, a population genetics assessment should be performed across its range before the investing other resources into their sustainable management [6,7].

When a previously described species is shown through genetic assessment to comprise a clade of several species, the original species retains the original scientific name, and the newly identified species are given new scientific names. With morphologically conservative species like giant salamanders the newly identified species are called cryptic species, and are identified by their unique genetic variation specified by the sequence divergence between their genes.

Sequence divergence (SD) in DNA increases between isolated populations over time. Eventually the increased SD shows a significant adaptation to a particular environment through its unique genetic signature as a species or an ESU.

To illustrate, we compare the evolution and morphology of giant salamanders and hominids through DNA sequence divergence (SD). There is a 1.2% SD between modern humans (*Homo sapiens*) and chimps (*Pongo pongo*), which diverged 5-6 MYA (million years ago) [24], and a much lower SD between our close family of many recent *Homo* species from 600,000 year to the present [25]. In contrast there is up to 5.4% SD between *Cryptobranchus* species which are almost indistinguishable by appearance [7].

Hominids evolved from the Australopithecines ~4 MYA [25] a time close to the first divergence within the Chinese *Andrias* clade. Yet what a dramatic difference in appearance is found between our original ancestor the Australopithecines and the at least seven recent *Homo* species including *H. sapiens* (Fig. 2.). In contrast is little obvious difference in appearance between species within the morphologically conservative cryptobranchids [1].

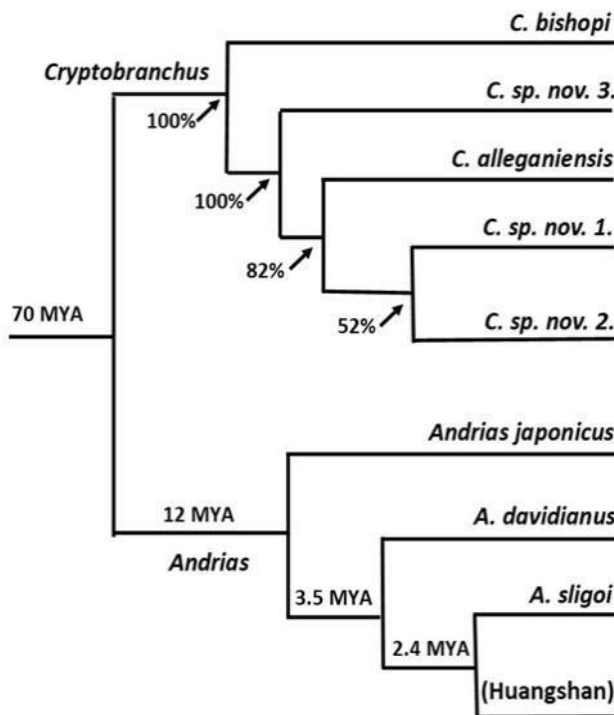


Figure 1. Proposed species divergence in MYA for some *Andrias* species [9], and for *Cryptobranchus* shown as the average posterior probability of a divergence [7].



Figure 2. Lucy was an Australopithecine reaching an adult height of 1 meter. Modern humans (*Homo sapiens*) diverged from Australopithecines ~4 MYA and are very different in morphology and appearance to Lucy. In contrast, *Andrias* and *Cryptobranchus* diverged 70 MYA, and although they vary greatly in size they are morphologically conservative.

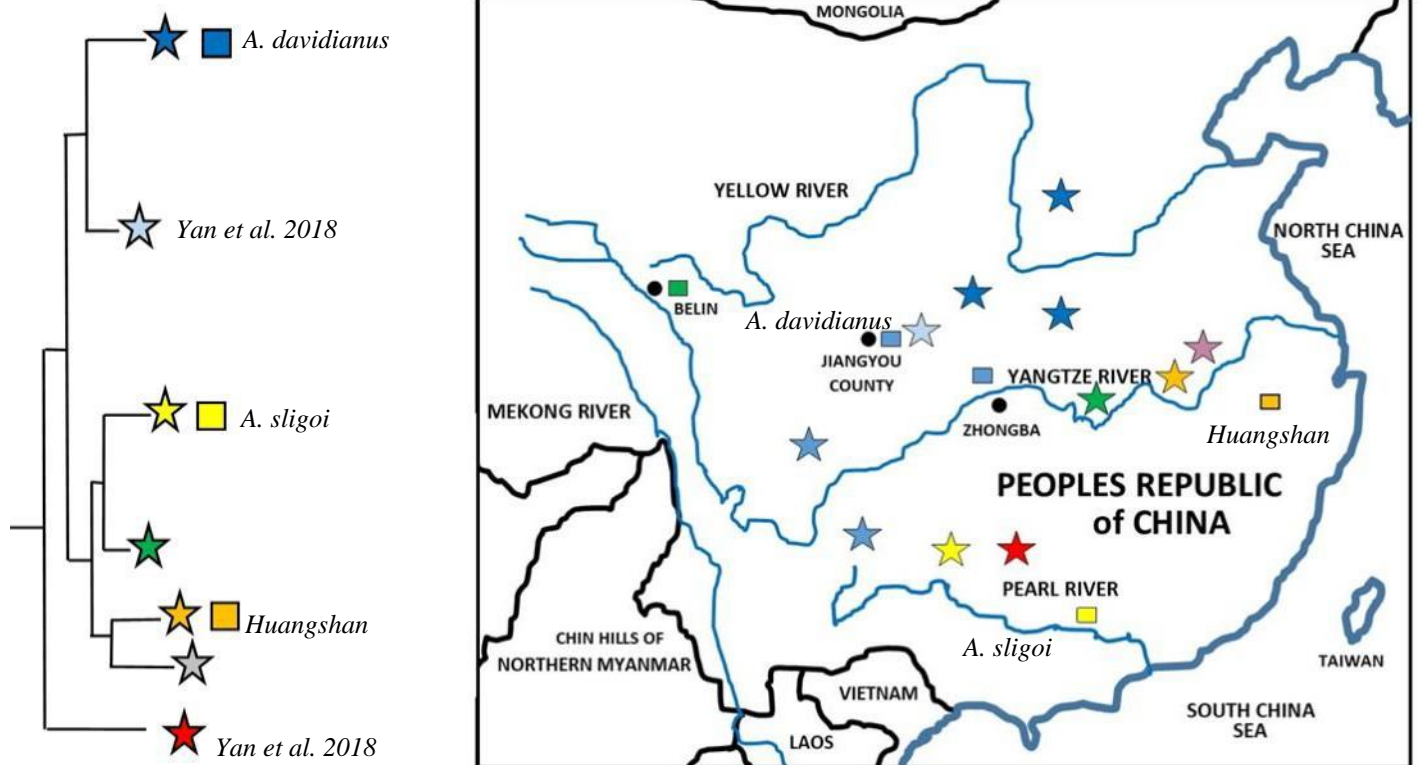


Figure 3. Left: A simplified tree of species in the Chinese giant salamander clade from 2018 [8], shows five distinct species and other possible species. Right: Matching stars show the sampling locations for the Bayesian tree, and squares represent species as identified from archival specimens in 2019 [5], *A. davidianus* blue square at Zhongba, *A. sligoi* yellow square, and *Huangshan* orange square [230]. The blue square in Jiangyou county is the type location of *A. davidianus* (Blanchard 1871), and the blue square in Zhongba the museum sample location in 2019 [5]. The green square is the location of the very high altitude population near Belin.

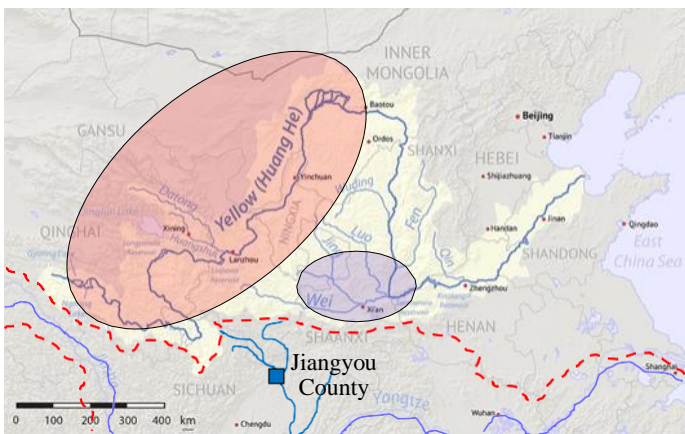


Figure 4. The lower reaches of the Yellow River with genetically assessed individuals (blue ellipse), and the upper reaches (pink ellipse) in need of further surveys. Red dashed line is boundary of the Yellow River and Yangtze River watershed. The location of the originally described *A. davidianus* (blue square; Blanchard 1871).

### Chinese *Andrias* Clade

The Chinese *Andrias* clade ranges across the Yellow River, Yangtze River, and Pearl River watersheds. Speciation between these isolated populations would generally be expected, as these rivers have been separate for millions of years, preventing genetic exchange. However, until 2018 Chinese *Andrias* were regarded as one species, with latitudinal migrations through

unknown mechanisms possibly occurring within the higher altitudes of watersheds [5].

The narrative behind the recognition of many recognised species now comprising the Chinese *Andrias* clade begins at the turn of the 21st Century when current techniques showed little genetic variation over their range. *Andrias* are easily transported for long distances, suggesting that this apparent anomaly could have resulted from hybridization between watersheds through human-mediated translocation over millennia [26]. In 2005 [27]/2006 [28] more refined genetic techniques showed that populations in the Yellow River and Yangtze Rivers were more closely related than to those from the Pearl River. Both articles cautioned that releases should consider these relationships.

The rapidly increasing power of population genetics was evidenced in 2018, through the discovery that five or more species comprise the Chinese *Andrias* clade (Fig. 3. Left., [8 3]). Almost all individuals sampled were hybrids, but human mediated translocation [26] was not apparent until after the recent implementation of supplementation or repopulation programs (Yan pers. comm.). Hybrids in nature were attributed to translocation of broodstock between aquaculture facilities with hybridised individuals then being released to supplement natural populations (Fig. 3., Yan pers. comm.).

In, 2019, genetic analysis of museum specimens from before 1992, that were uncontaminated by later translocations or hybridisation, specified three species in the Chinese *Andrias* clade as *A. davidianus* (Blanchard, 1871) (northern Yangtze/Sichuan), a reinstated *A. sligoi* (Boulenger, 1924) (Pearl/Nanling), and a previously undescribed species from Huangshan, Guangxi province, near Huangshan in the Fujian-Zhejiang hills drainages in SE China (Fig. 3., [5]).

## Sustainable Management of Giant Salamanders

These three species were from regions isolated by either major watersheds or mountain ranges, where the Nanling mountains separate the Yangtze and Pearl River watersheds, and where Huangshan separates the Yangtze and Fujian-Zhejiang hills watersheds. The Yellow River/Nanling clade diverged from the Yangtze/Sichuan and Hangshan clades 3.5 MYA, with a subsequent divergence of the Yangtze/Sichuan and Hangshan clades 2.6 MYA, and is consistent with the rapid uplift of the Qinghai-Tibet Plateau since ~3.6 MYA (Fig. 3.; [5]).

The Yangtze/Sichuan clade was considered the original *A. davidianus* species by [5] because their sample location was close to the site of the holotype as described by [5] as Zhongba, Congqing City, as taken from Liu, 1950 [30].

However, "The exact type location of *Megalobatrachus davidianus* has never been definitely recorded." as Liu wrote about Abbé David, who left Chengdu with it" [30].

Neglected in Liu, 1950, was the site of the holotype according to Blanchard, 1871, as Tchong Pa from the Fowho River, Jiangyou County, Sichuan Province. The Fowho River site is in the Yangtze watershed ~400 river miles from Zhongba, and so the Zhongba samples are probably, but not certainly representative of the type (Fig. 3,4).

Further assessment in 2020 of the phylogeographical patterns of genetic diversity between living *A. davidianus* revealed seven divergent mitochondrial clades, with some watersheds including more than one clade. Watershed partitioning occurred during mountain uplift during the Late Miocene (11.6- 5.5 MYA [6]).

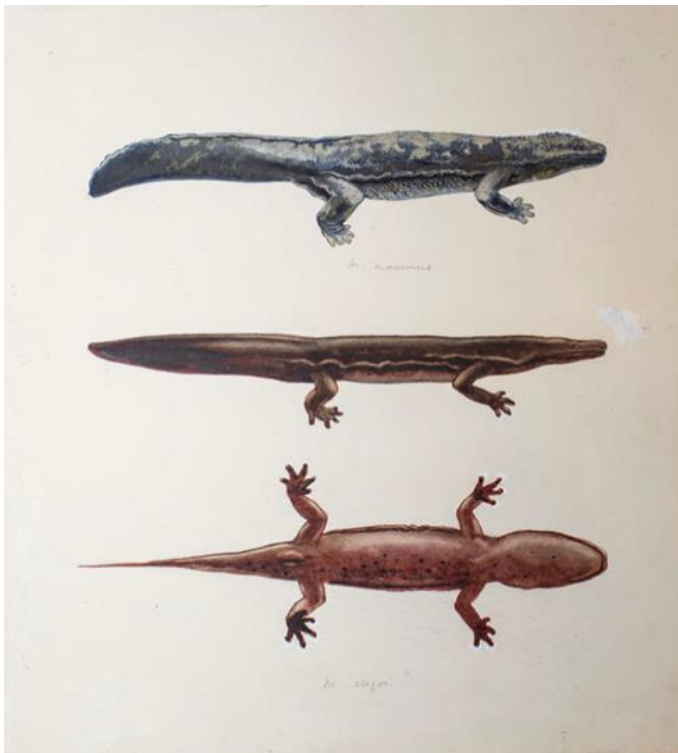


Figure 5. Water colour drawing of *A. sligoi* possibly to accompany Boulenger, 1924. Image: Artist unknown; courtesy of Zoological Society of London library.

The scattered locations sampled in 2019 (Fig. 3.; [5]) along with the genetic assessment in 2018/2019 [6,259], and the possible high altitude species from Belin, show that further species once, and may still, comprise the extant species in the Chinese *Andrias* clade. A single specimen of *Andrias* was collected in the headwaters of the Yangtze River near the town of Belin, Qinghai province, in 1966 at approximately 4,200 m (Fig. 4.)

This location is more than 2,000 m higher than other locations for species in the Chinese *Andrias* clade, and along with the regions biogeographical history providing isolating mechanisms, suggests a likely new species that may be already lost forever [31]. However, DNA could not be extracted from the last museum specimen so taxonomic uncertainty still exists [5]. Other possibilities for unrecognised *Andrias* species are from Taiwan (IUCN, 2018) and the Chin Hills of northern Myanmar [5,32].

A good example of taxonomic uncertainty, before population genetics, is found with the Chinese *Andrias* clade. In 1924, the previously described *A. davidianus* was unknowingly redescribed as a new species, *A. sligoi* by Boulenger who considered a specimen living in London Zoo differed from his impression of *A. japonicus* (Fig. 5.; [33]).

Boulenger's paper was presented at a meeting of the Zoological Society of London (ZSL) and published as "On a new giant salamander, living in the Society's Gardens [33]. The paper was not illustrated and had no reference to the illustration that may have accompanied the paper (Fig. 5.). Serendipity favoured Boulenger and in 2019, the ZSL specimen was shown by genetic assessment to be the recently reestablished species *A. sligoi* [33,5].

### Japanese *Andrias* Clade

The Chinese and Japanese *Andrias* clades were shown by genetics to have diverged ~12 MYA [5]. This divergence time did not coincide with tectonic separation of Japan from mainland Asia ~16 MYA [34]. The distribution of the Japanese *Andrias* clade extends from the south-west in Honshu Island to the northeast in Shikoku Island, and only Kyusyu Island. Their main habitat is in the Chugoku Mountains, Honshu Island, and all habitats are highly fragmented (Fig. 6., [11]).

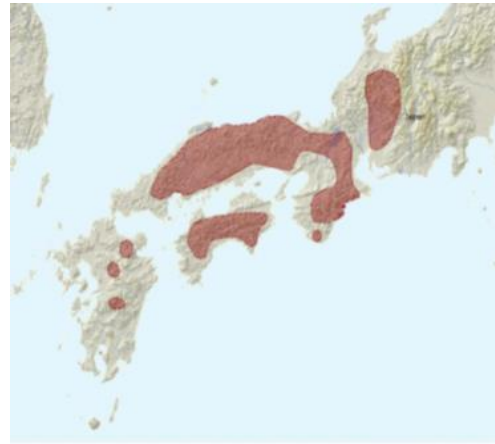


Figure 6. The coloured areas show populations of the Japanese *Andrias* clade. Figure: IUCN Red List.

The Japanese *Andrias* clade has not yet shown the genetic variation found within the Chinese *Andrias* clade or within the North American *Cryptobranchus* clade. Nevertheless, genetic variation within Japanese *Andrias* clade supports the existence of central and western populations and some ESUs [10,11]. The low genetic variability found in the Japanese *Andrias* clade is unexplained, and high genetic variability is found in the Japanese species of the sympatric, closely related, totally aquatic and externally fertilizing sister clade of the cryptobranchids the Hynobiid salamanders [10].



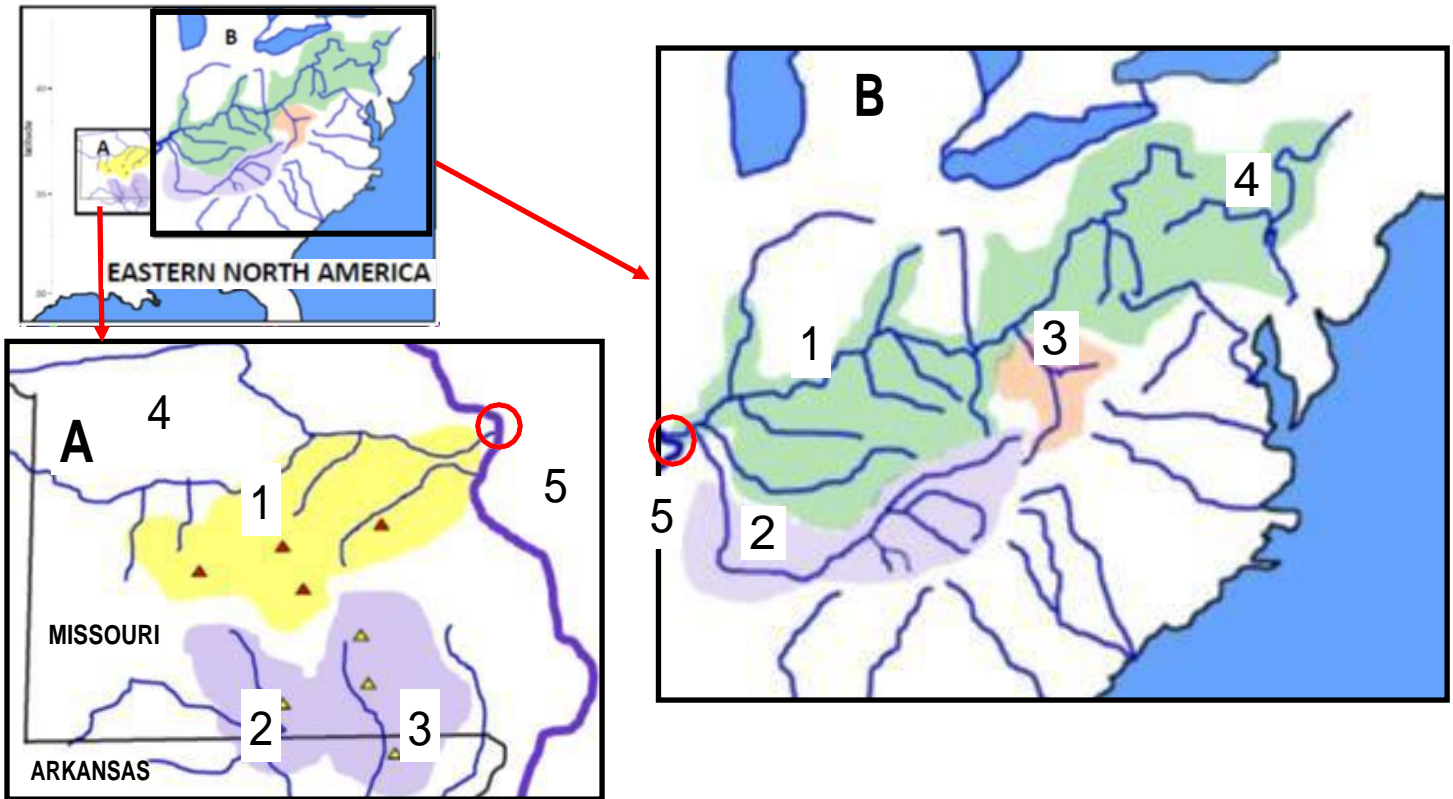


Figure 7. A) Purple area *C. bishopi*, and yellow area *C. sp. nov. 3*. [7]. Watersheds: 1. Ozark River, 2. White River, 3. Black River, 4. Missouri River, and 5. Mississippi River, and B) Purple area *C. alleganiensis*, green area *C. sp. nov. 1.*, and pink area *C. sp. nov. 3*. [7]. Watersheds: Ohio River, 2. Cumberland River, 3. New River, and 4. Potomac River, and 5. Mississippi River Red circle is where Ohio River joins the Mississippi River. Also see Figure 1. for phylogenetic tree.

The low genetic variation Japanese giant salamanders may be due to reproductive traits, such as polygyny by gigantic males, developmental traits such as late sexual maturity and high longevity, adaptive traits such as a high level of adaptation to stable environments, and biogeographical changes causing bottleneck effects including during Quaternary glaciations (1.8 MYA to 20,000 YA., [10]). Low genetic variation could predispose Japanese giant salamanders to increased risk of extinction from threats including exotic pathogens (see Pathogens and Parasites, p 20-22).

#### North American *Cryptobranchus* clade

The North American *Cryptobranchus* clade, now consisting of five species, was once considered as an eastern subspecies *C. alleganiensis alleganiensis*, and a western sub-species *C. a. bishopi*, partitioned by the Mississippi River. However, in 2008 the clade was shown to be eight distinct populations differentiated by a minimum of 0.7 to 5.4% DNA sequence divergence [35]. Further assessment showed that one of the two component populations within the *C. a. bishop* clade [36] is less related to the other population than it is to *C. a. alleganiensis* (Fig. 1., 7A,B; [36,37]).

In 2017, five putative *Cryptobranchus* species were described, two from the former *C. a. bishopi*., *C. bishopi* and *C. sp. nov. 3*. (Fig. 7A.), and three from the former *C. a. alleganiensis*: *C. alleganiensis*, *C. sp. nov. 1.*, and *C. sp. nov. 2.* (Fig. 7B., [7]), with some ESUs discriminated within these species (not figured, [14]).

The phylogeny of the North American *Cryptobranchus* clade has been influenced by both contemporary and ancient river networks. The recent past history of minor watersheds and their river systems in eastern North America are difficult to trace. However, the history of more broad-scale features such as the Mississippi River, Mississippi Embayment, the Teays River are better known [38]. The base topology of the clades phylogeny is best explained by the connection of populations by the Teays River [7]. Genetic assessment showed the possibility of recent introductions of *Cryptobranchus* from the Allegheny into the Susquehanna River drainages [7].

**CULTURAL CONTEXT**

**Vernacular and Scientific names**

**Chinese *Andrias* Clade**

During the mating season, species in the Chinese *Andrias* clade vocalise like a baby crying and have the earliest recorded traditional vernacular name of “wawayu” (baby fish) (*A Chinese Bestiary* circa. 2,200 BC. [39]).

A recently published traditional vernacular name is ‘da ni’ (simplified Chinese 大鲵; [40]. However, the term ‘da ni’ alone means ‘*Andrias*’ and Zhōngguó (meaning Chinese) dà ní (中国大鲵) is the standard Chinese name.

Zhu bu chi, which translates as ‘pig doesn’t eat’ has also recently been presented as a vernacular name “*This name arose during the Cultural Revolution, when food shortages led to pigs being fed Chinese giant salamanders but they refused to eat them.*” [40]. However, it seems unlikely that species in the Chinese *Andrias* clade, an esteemed culinary item for humans with high nutritional value, could be rejected as food by starving pigs.

When genetic assessment of a clade shows previously unrecognised species, the species found in the location of the original species description, by precedence, should retain the regional vernacular name if available, with other species adopting other regional vernacular names (Fig. 1.,2.). Turvey et al., 2019 [5], considered that *A. davidianus* should retain the Westernised vernacular name “Chinese giant salamander”, and coined the vernacular name “South China giant salamander” for the reinstated *Andrias sligoi* (Boulenger, 1924), without reference to a Chinese translation or a traditional regional name.

**Japanese *Andrias* clade**

The most commonly used Japanese vernacular names used for giant salamanders are Ōsanshōu (大山椒魚), ‘Oo-san-shou-uo’; ‘giant’, ‘big’, ‘great’ salamander), and also the widely used ‘hanzaki’, and ‘hajikamiio’, ‘hanzake’, ‘hazako’ and ‘ankou’ (Timothy Johnson pers. comm.)

They are called “hanzaki” in the regional dialect of Okayama, a reminder of an old belief that giant salamanders could survive and regrow to its original form after being sliced into two halves. A CITES review omits the rarely used ‘hajikamio’ but includes ‘hanzake’ [41].

Some Japanese vernacular names for giant salamanders have been erroneously attributed to skin smelling like Japanese pepper traditionally called sansho or hajikami [42]. However, all Japanese salamanders, excluding newts, are also traditionally

called sansho or hajikami but none smell like pepper. A more likely explanation is that these names are derived from the speckled appearance of some Japanese salamanders that make them appear peppered (T. Johnson pers. comm.).

**North American *Cryptobranchus* Clade**

Greater regional pride and community awareness of the species in the North American *Cryptobranchus* clade may be fostered by using their traditional vernacular names (Fig. 8,A,B.). North American *Cryptobranchus* have different regional vernacular names including: Tweeg, Hellbender, Water Dog/Devil Dog/Mud Devil, Mountain Alligator/Alligator of the Mountains, Leverian Water Newt, and Allegheny Alligator (Tab. 1., Fig. 8., Internet sources, [43]).

The first European record of a species of North American *Cryptobranchus*, later described as *C. alleganiensis*, was in 1762 where a journal article mentions the local inhabitants speaking of a small kind of alligator. *Cryptobranchus alleganiensis* was first formally described in 1801 by Sonnini de Manoncourt and Latreille as *Salamandra alleganiensis* from the vicinity of Davenport’s Plantation, North Toe River, 1 mile south of the mouth of the Bushy Creek and 4 miles east-northeast of the Spruce Pine Creek, Mitchell County, North Carolina [44].

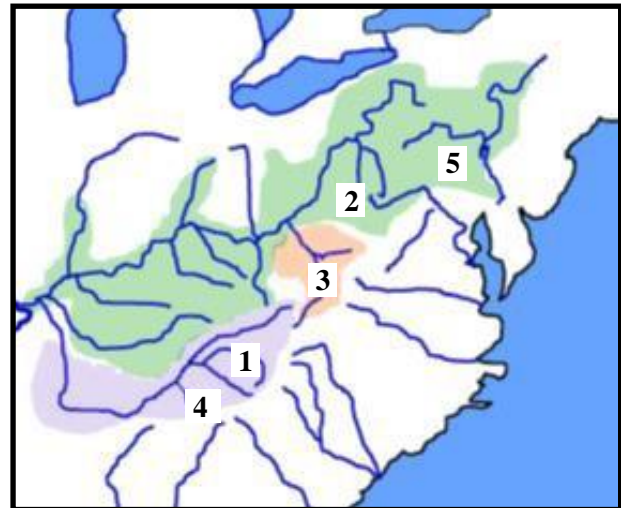


Figure 8. No 1-5, are regional locations for the most verifiable vernacular names (Table 1.). Purple = *C. alleganiensis*, green = *C. sp. nov. 1.*, and pink *C. sp. nov. 3.* [7]. No. 1 the type location of *C. alleganiensis* (Tab. 1.).

<b>1</b>	<b><i>Cryptobranchus alleganiensis</i></b> - type location (Sonnini de Manoncourt and Latreille 1801) Mitchell County, North Carolina. AMNH [44].	<b>5</b>	<b>Snot Otter</b> - St Louis Zoo, for Missouri. North Carolina Zoo Society’s Hellbender ambassador, travels throughout North Carolina, Pennsylvania, Ohio, and Virginia.
<b>2</b>	<b>Tweeg</b> (Delaware Indians) - 60 m below Pittsburg. Barton [ 45].	<b>6</b>	<b>Water Dog, Mud Dog, Mud Devil</b> - St Louis Zoo, for Missouri, [43].
<b>3</b>	<b>Hellbender</b> - (Negroes) Western Virginia, Holsten River. Barton [45].	<b>7</b>	<b>Leverian Water Newt</b> - Specimen in Leverian Museum. [43].
<b>4</b>	<b>Mountain Alligator/Alligator of the Mountains</b> - Doe River, North Carolina or Tennessee [46].	<b>8</b>	<b>Allegheny Alligator</b> - NY, Pennsylvania, Virginia, Winnebago Lake, Illinois River. [43,45]. St Louis Zoo, for Missouri.



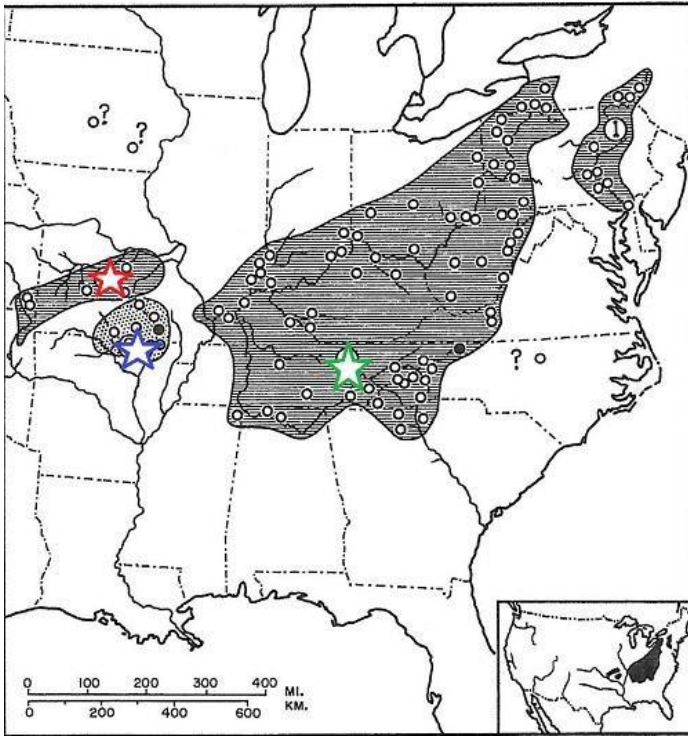


Figure 9. Map from Dundee, 1971, *The Catalogue of American amphibians and Reptiles* [47], with the green star the proposed type locality for *C. alleghaniensis*, the red star for *C. bishopi*, and the blue star *C. sp. nov. 3*. (Fig. 7., [7]).

However, *C. alleghaniensis* is also considered to have been first described by Daudin, 1803, with a type locality as the Allegheny Mountains, which at the time included most of the Appalachians [47]. This description was recognized by the IUCN Red-List 2005, an assessment still current in mid-2019, with the reference given as the American Museum of Natural History archive. For historic taxonomic reviews of species in North American giant salamander clade see [48,49]. The *Catalogue of American amphibians and Reptiles* (Fig. 9., [48]) considers that the type locality should be the location given by Sonnini de Manoncourt and Latreille, 1801 [44], that was generalized as Allegheny Mountains by Daudin, 1803 [47].

*Cryptobranchus alleghaniensis* (as *Salamandra gigantea*) was again described by Barton, 1808, from Ohio River about 60 miles south of Pittsburgh [50]. Barton, 1812, titled his memoir on the *Cryptobranchus* clade ‘A memoir concerning an animal of the class of reptilia, or amphibia, which is known, in the United-States, by the names of Alligator and Hell-bender’. Barton considered Hell-bender a vulgarity but used it, along with Alligator, as one of his two vernacular names in the title [45].

Barton did not include the Delaware Indian name “Tweeg” in the title despite its adoption by Caucasian settlers and its consistent use as the vernacular name throughout the memoir: “Had Linnaeus been acquainted with the Tweeg, he would have no hesitation in considering it as a species”, “the Tweeg ... secretes from different parts of its body, a lactaceous or milky juice”, “The Tweeg has four legs”. “I have collected some of the Indian names of the animal. It is called the Tweeg by the Delaware ... (sic. this name) has been adopted by the white inhabitants in certain parts of North-America (Fig. 9,10.).

The derivation of Hellbender was recorded by Barton, 1812; *By the negroes in the western parts of Virginia, on the waters of Holsten, where it is common, the reptile is often called the Hell-bender, by reason of its slow twisted motions, when moving in*

*the waters, which the slaves compare to the tortuous pangs of the damned in hell. Is it beneath the dignity of natural history to notice such vulgar names, when they serve to throw any light upon the habits or economy of an animal? And does not the moralist perceive, that there is something melancholy and distressing in the condition and reflections of those who impose such names?*

Ironically, in respect to “there is something melancholy and distressing in the condition and reflections of those who impose such names?”, imposing hellbender was exactly what Barton did in the title of his memoir.

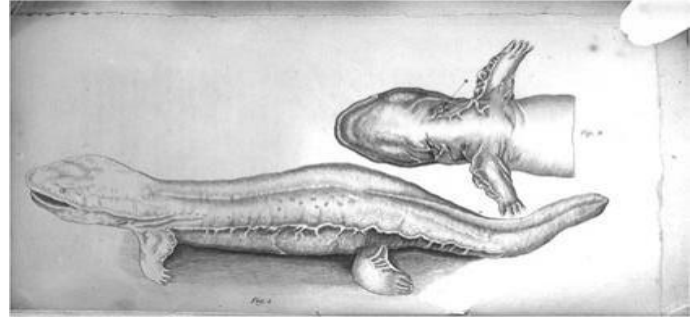


Figure 10. “The annexed figure, ... will certainly give a good general idea of the form .. of the Tweeg”, Barton 1812 [45].

The scientific community rejected the established vernacular of “Tweeg” as in Barton’s scientific description, but used “Hellbender” rather than Alligator” from the book cover, (Fig. 6. [45]). In our previous series of giant salamander reviews we coined the inclusive vernacular name “North American Giant Salamanders” for *Cryptobranchus* species [1,21,22].



Figure 11. A) The vernacular name Snot Otter is used in advertising., and as B) as “Snotty” for the promotion of sustainable management. Image: Courtesy of John, D. Groves.

# Sustainable Management of Giant Salamanders

## Mythology and Art

Mythology and its expression in art are fundamental drivers of both traditional and modern cultures. Both *Andrias* species have a place in mythology, and *Cryptobranchus* were used for medicine and shamanic rituals.

### Chinese *Andrias* Clade

In one particular Chinese myth *Andrias* can live in the hottest of fires. Early travelers to China were shown fireproof garments that were woven from the fictitious wool of species in the Chinese *Andrias* clade that may have been made from asbestos. The association of salamanders with tolerance to fire is also found in Europe and probably derives from salamanders crawling from burning wood.

An *Andrias* is figured on a very early Chinese ceramic from the Middle Kingdom between 3,000 and 4,000 BC (Fig. 12.). The use of *Andrias* oil in lamps is documented (see Food and Medicine p14) and this vessel may have been used for oil storage.



Figure 12. A Chinese giant salamander painted on this ceramic vessel from the Yangshao culture, circa 3,000 to 4,000 BC. Image by Baomi licensed under Creative Commons Attribution-ShareAlike 3.0 Unported license

It has been suggested that the Chinese giant salamander could have inspired, according to legend, the iconic yin-yang motif [51]. However, the basis for this claim is unstated and ubiquitous yin-yang symbol has been foundational to Taoism/Daoism, a Chinese religion and philosophy, at least since the third century BC where it appears on various oracle bones used in China for divination.

### Japanese *Andrias* Clade

The Japanese *Andrias* clade may have contributed to the mythology of the legendary Kappa ([https://en.wikipedia.org/wiki/Kappa\\_\(folklore\)](https://en.wikipedia.org/wiki/Kappa_(folklore))), a water deity that is half human and half monster [52].

Kappa can be malevolent, drowning people or animals, kidnapping children, and raping and impregnating women. Kappa's take their victims for the purpose of drinking their blood, eating their livers, or gaining power by taking a mythical ball located inside the anus that is said to contain the soul.

Kappa's can speak Japanese, and once befriended by gifts can help farmers and are extremely intelligent and highly knowledgeable about medicine. For their survival the top of Kappa's head needs to be submerged in water and so on land they wear a helmet filled with water (Fig. 13,14.).

The origin of the Kappa ('water child.') myth may have been to prevent children venturing too near waterways, lakes, and ponds, without their parents where the Kappa would pull them into the water and drown them, or kidnap them. Children could also be traumatized by seeing the bodies of dead and decaying children as a result of infanticide by the poor in ancient times.



Figure 13. A) Hokusai Kappa. B) 12 types of Kappa [52].

The Kappa often has both human and reptilian characteristics and in many depictions appear to be based on turtles with claws, rather than on the clawless smooth skinned Japanese giant salamander. However, a Japanese giant salamander moving on the stream bed could easily be mistaken for a Kappa and be one foundation for the Kappa myth.

There is an annual Japanese giant salamander festival in Okayama prefecture, Japan (Fig. 15.).

### North American *Cryptobranchus* clade

The native North Americans had mythologies and associated art based on *Cryptobranchus* species. However, we could find no historic records besides Barton, 1812, who wrote that native North American tribes use dried Tweeg (*Cryptobranchus*) for witchcraft (see Food and Medicine p14; [45]). By witchcraft, Barton was referring to the sacred shamanic rituals of the native North Americans that include totemic and fetishistic art.



## Sustainable Management of Giant Salamanders



Figure 14. Art works depicting the Kappa. Left, The samurai Hanagami Danjo no jo Arakage in Izumo stabbing a Kappa with his short sword, by Utagawa Kuniyoshi ; Top middle Kappa by Toriyama Sekien ; Right Kappa being stabbed by a warrior by Utagawa Kuniyoshi.



Figure 15. The Hanzaki matsuri. In Okayama prefecture, Japan, in the village of Yubara Onsen for close to half a century now an annual Hanzaki Festival is held to honor the Japanese giant salamander which is venerated as a god. Given the isolated setting and the strange appearance of these reclusive creatures, it's easy to understand their contribution to local mythology. Images: Timothy Johnson.



## Food and Medicine

China was first inhabited by *Homo* species 2.1 MYA, and by modern humans (*H. sapiens*) by approximately 80,000 BC, with Japan inhabited from 35-40,000 BC, and North America inhabited between 35,000 and 15,000 BC [53].

There is a long cultural tradition in the use of species in the Chinese *Andrias* clade for food, and it is difficult to imagine such a large and abundant protein source not having been harvested since prehistoric times. The first harvesting was recorded in ancient Chinese literature in 1,700 BC [54], and later in *The Classic of Mountains and Seas* or *Shan Hai Jing* (<http://totallyhistory.com/shan-hai-jing/>) when in 210 BC “the giant salamander is produced in the rivers Dan and Luo” and “light the candles made by fat of giant salamanders, when the First Emperor of Qin, who was the first emperor of China, was buried”. There are reports that southern, but not northern, Chinese traditionally consumed *Andrias* [40].

include “The mucus, skin, meat and bone of CGS contain many different bioactive substances thereby having various medicinal activities including anti-aging, anti-fatigue, anti-tumor, burn therapy and anti-infection and other physiological functions” [55]. Fortunately, the highly developed aquaculture industry can accommodate any current or anticipated need for giant salamander products [56].

The harvest of Japanese giant salamanders for food appears to have ceased since it was protected as a “Special Natural Monument” in 1952 [57]. However, it is still used as an icon for the advertisement of some foods (Fig. 18.)



Figure 18. The Japanese giant salamander is a popular icon in advertising.

Barton, 1812, reported that Native Americans did not eat Tweeg (*Cryptobranchus*), but that the north-western Indians around Lake Erie dried them for use in witchcraft [45]. Petranka et al. 1998, published that Native Americans traditionally used *Cryptobranchus* as a food source [58].

## NATURAL POPULATIONS

The natural populations of giant salamanders are difficult to accurately assess as they are often found in fragmented populations, are aquatic and cryptic, seek deep shelter, and are mainly nocturnal [21], with many habitats of the Chinese *Andrias* clade consisting of boulder filled rivers in deep ravines [22]. Even surveys for *Cryptobranchus* in streams that appear to provide good survey conditions have shown low recapture rates. Early juveniles are rarely found unless targeted by surveys, and population estimates generally refer to adults [21].

### Chinese *Andrias* Clade

All discriminated species in the Chinese *Andrias* clade are almost extinct and now only exist in nature, if at all, as relict populations [8,9]. There were low to moderate populations until ~2012, with some of these populations possibly increasing, followed by a catastrophic population decline from ~2014 until by 2018 [9].

In 1979, there were approximately 7,000 adult *Andrias* inhabiting the southern part of Qin Lin Mountains [59]. After 1990, when harvesting was made illegal, there was an estimated population of 50,000 adults in all reserves [60].



Figure 16. The aquaculture of the Chinese *Andrias* supplies many licensed restaurants throughout China.

The use of natural medicines is highly esteemed in the China where considerable research is conducted into their use and cultivation. *Andrias* meat is considered to have health benefits, and to be delicious with its soft flesh and unique delicate flavour, and is served in many licenced restaurants throughout the China (Fig. 16,17.).



Figure 17. Japanese giant salamanders are a popular icon for advertising for chocolates, cookies and other sweets.

*Andrias* products traditionally have medicinal benefits including the prevention of greying hair; claims possibly supported by its high nutritional value with 40% of essential amino acids and high component of metal sulfide-proteins, a constituent of hair. Reports of its medical value

# Sustainable Management of Giant Salamanders

Some populations were already declining where three hundred giant salamanders were found in Henan Province in 1991, but by 2003 were undetectable [61], and a 2015 survey failed to find giant salamanders in a national park where some had previously been observed [62]. Some populations were increasing, or originally under surveyed, where a population in 2009 of ~2300 had increased by 2010 to ~3,800 [63,64].

In 2018, an extensive survey over the previous range of the Chinese *Andrias* clade showed only highly fragmented, relict populations remaining, with many of these as hybrids [9]. To guide the management of the Chinese *Andrias* clade with its many species distributed in highly fragmented populations [8,9], more extensive distribution assessments are needed to reveal presently unrecorded and neglected populations.

## Japanese *Andrias* Clade

The 2012, the total population of Japanese *Andrias* in 14 prefectures was well above 9,000 adults, with the total population much higher because the survey only included parts of their distribution [65]. Population densities between two rivers varied between 60 to 100 per km of river length [66].

## North American *Cryptobranchus* Clade

The populations of the three eastern species of the North American *Cryptobranchus* clade are unestimated. Nevertheless, the western species are suffering major declines, with a 2007 population size of *C. bishopi* of ~1,150, and of *C. sp. nov. 3.* of ~600 (Fig. 3., [67]).

Previous populations were much higher where Baker, 1963, observed "The *Cryptobranchus* were collected below a dam in Spring River two miles south of Mammoth Springs, Arkansas. They, are quite abundant here and are picked up at night in shallow water near the shore or from the concrete base of the dam where they are attempting to swim upstream" [68 234].

Survey rates of North American *Cryptobranchus* are now generally less than one record per person hour in good sites. The current populations are unnaturally low, and with our limited knowledge of population viability, species in the North American *Cryptobranchus* clade may be more threatened than their official conservation status recognises.

## THREATS

Threats to giant salamanders can be considered as conventional threats and emerging threats. Conventional threats include: habitat modification and loss, micro- and macro-pollutants including sedimentation, dams, over harvest, hybridisation, exotic vertebrate species, and incidental and malicious harm. Emerging threats include: micro-pollutants including endocrine disruptors, exotic species, loss of genetic variation; pathogens, and loss of public interest and therefore political influence.

However, the overwhelmingly greatest looming threat to giant salamanders and to biodiversity in general is global heating, both through direct environmental effects and through cultural, political, and economic disruption (Fig. 19., [69,70,71]).

## Global Heating

Global heating is the overall increase in the Earth's terrestrial, oceanic, and atmospheric temperatures. Global heating is caused by unnaturally high levels of greenhouse gasses through human industrialisation. Climate catastrophes refer to the current and predicted destructive effects of global heating at a regional level, with climate catastrophes expected to affect all giant salamander clades (Fig. 20., [69,70]).

The effects of global heating are insidious and ubiquitous on ecosystems and biodiversity, and many species cannot adapt to the predicted rates and levels of global heating on rainfall, temperature, and seasonality [71,72]. When combined with other threats, predicted global heating will result in the loss of ecosystem integrity and the extinction of species. Many amphibian species are particularly vulnerable to climate change, as they are thermo-conformers or environmental thermo-regulators, and rely on predictable rainfall and temperature regimes for reproduction and survival [73,74].

Climatic warming due to global heating has been most apparent at higher latitudes in the northern hemisphere, but will soon dramatically affect most regions. Giant salamanders range over northern temperate latitudes [22] that have experienced many cycles of warming and cooling over recent geological periods [75], but cannot now move between watersheds or between some fragmented populations within watersheds.



Figure 19. The threats to giant salamanders include regional and global habitat destruction, exotic pathogens, genetic impoverishment, hybridization, micro-pollutants, and global heating.



# Sustainable Management of Giant Salamanders

**A** Temperature Change in the Last 50 Years  
(2014-2018 Average vs 1951-1980 Baseline)

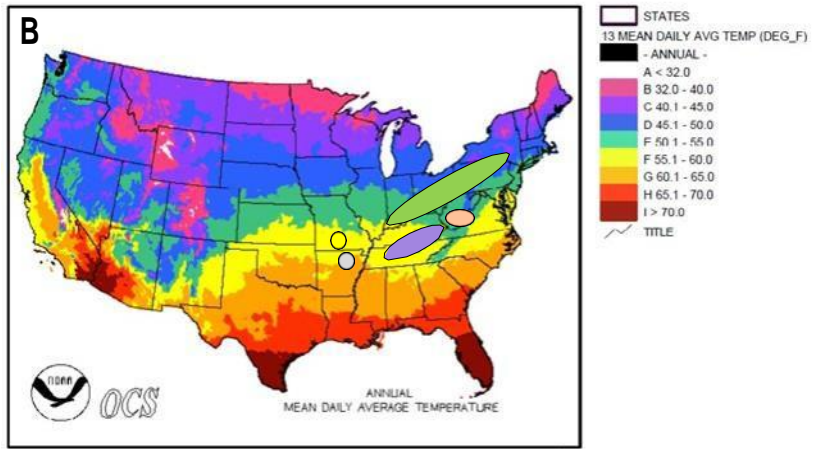
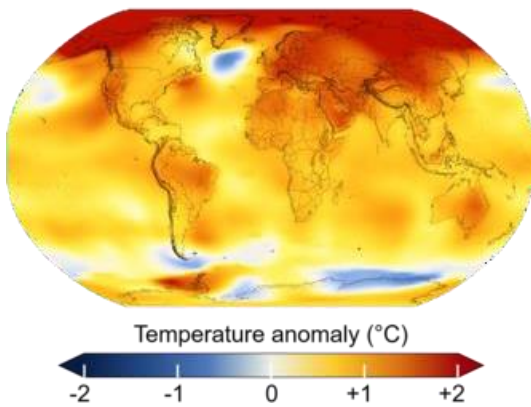


Figure 20. A) The Earth's average temperature (global heating) has already increased on average by  $1^\circ\text{C}$  ( $1.8^\circ\text{F}$ ) with a minimum predicted heating of  $2^\circ\text{C}$  ( $3.6^\circ\text{F}$ ) over the next few decades [source]. Image © Wikipedia commons. B) Global heating will force climate zones to move toward the poles. The climate zones in the USA categorized as differences in average daily temperature of  $2.7^\circ\text{C}$  ( $5.0^\circ\text{F}$ ) in fig. B. show a latitudinal shift north-south caused by  $2^\circ\text{C}$  ( $3.6^\circ\text{F}$ ) heating of  $\sim 90$  miles effectively moving whole regions inhabited by *Cryptobranchus* into hotter climatic zones.. Image © NOAA. The coloured circles/ellipses show the approximate ranges of the five species as described by Hime 2017 (Fig. 7, [7]).

The predicted minimum increase of  $2^\circ\text{C}$  ( $3.6^\circ\text{F}$ ) global heating will extend beyond the watershed habitat of giant salamanders, and will be catastrophic to major global ecosystems reducing productivity of fisheries, agriculture, and forestry. No life on Earth will remain undamaged or untransformed over the next few centuries, and the sustainable management of giant salamanders, and all other life forms, must accommodate these predictions.

Increased regional temperatures due to global heating are most apparent near the polar latitudes, but will soon affect most regions on Earth. Giant salamanders range over northern temperate latitudes [22] that have experienced many cycles of warming and cooling over recent geological periods [75]. However, the high increased temperatures, and even the greater current rates of global heating than in the past, mean that many fragmented giant salamander populations that are adapted to particular climatic regimes will decline to extinction.

Giant salamanders live in deep shelter in perennially flowing watercourses that some what protects them from climate extremes. This habitat is hypothesised to have supported their survival and their evolutionary divergence as a neotonic fully aquatic clade  $\sim 150$  million years ago [22], perhaps at an extreme surviving catastrophic geological events in caves as some Chinese *Andrias* populations did until recently [76].

Nevertheless, due to giant salamanders need for cool well oxygenated water for survival and reproduction [22,77], their populations are vulnerable to global heating through water temperature increase or droughts resulting in watercourse drying and range restrictions [22]. With a  $2^\circ\text{C}$  temperature increase above the summer climate average, North American *Cryptobranchus* decreased immune function, increased physiological stress, and reduced growth (Fig. 20 B, [78]).

Global heating will affect many giant salamander habitats and their associated ecosystems, including higher water temperatures and in particularly altered seasonal stream flows. Global heating could affect reproduction and larval survival [22], with potential biotic changes to riverine ecosystems including reduced prey availability [79], and increased susceptibility to some pathogens and parasites [80,81]. Heavy precipitation can then result in surges in nutrient runoff into

waterways, that when coupled with warm water temperatures, can lead to oxygen depletion through algae blooms [Fig.21., 82]).

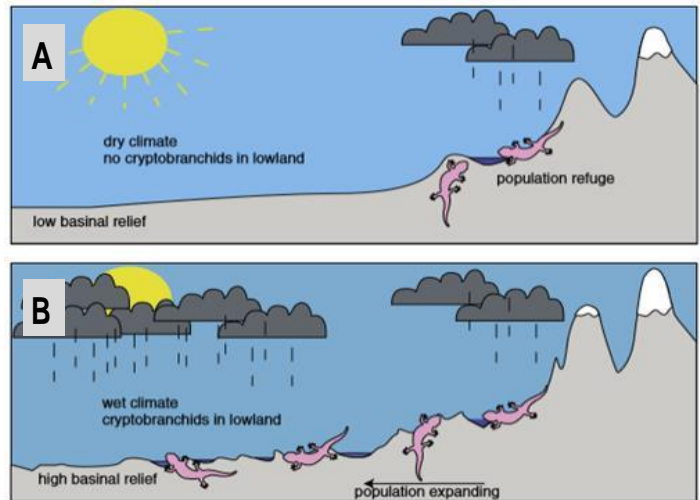


Figure. 21. Habitat tracking during dry and wet climates. A. In unfavourable drier, hotter climates giant salamanders survive in refugia in high mountainous terrain. B. Cooler wetter climates allow giant salamanders to expand into the lower basins. Figure from Bohme et al. 2012 [82].

## Bioclimatic Modelling

Bioclimatic models of giant salamander distributions provide conservationists with a specific and quantified, biogeographical description of where environmentally suitable areas for survival exist under different global heating regimes. Bioclimatic models use representative concentration pathways (RCP) of predicted global heating based on different emission scenarios. A RCP 2.6 is based on our ambitious 2020 plans with a predicted minimum temperature rise of  $2^\circ\text{C}$ , and an RCP 8.5 is based on a continual increase in  $\text{CO}_2$  emissions (Fig. 22., [83,84]).



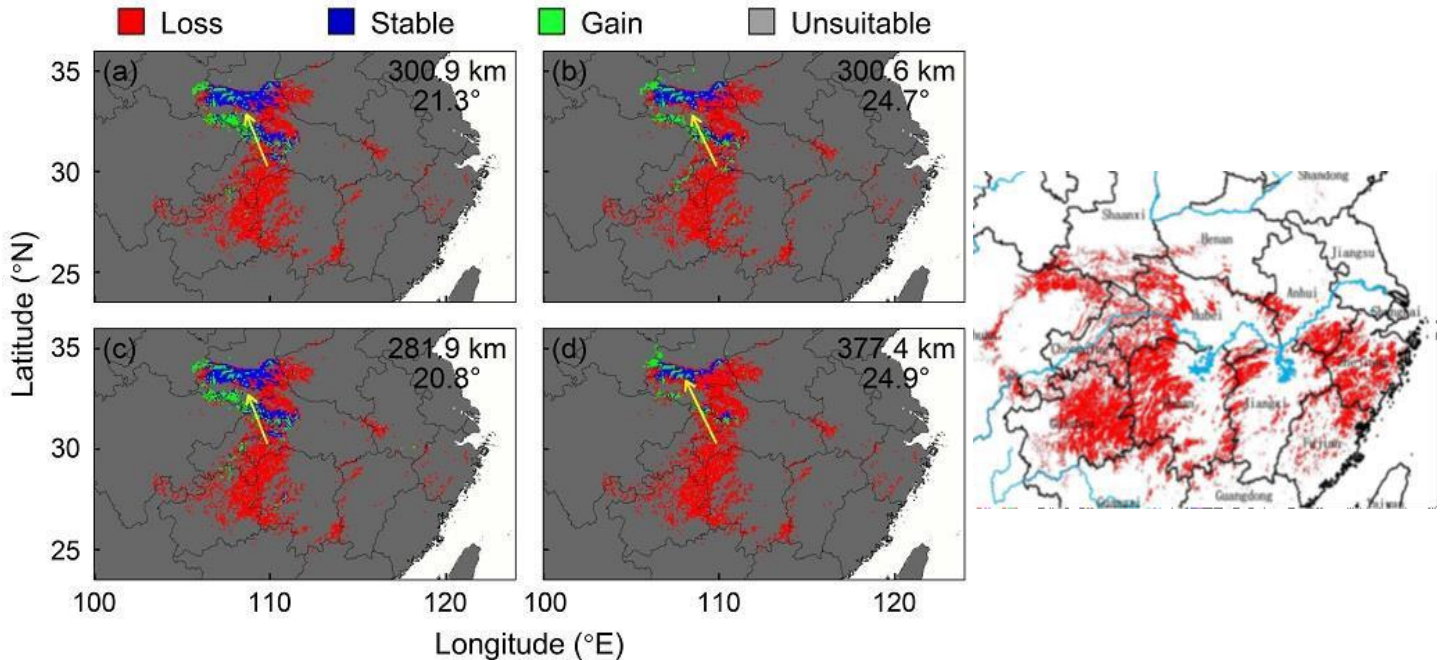


Figure 22. Left: The loss of *Andrias* habitat in central China as predicted by two bioclimatic global heating models for 2050: (a) RCP 2.6, (b) RCP 8.5; and for 2070: (c) RCP 2.6, (d) RCP 8.5. The start of arrows represents the centroid of the projected suitable area of *A. davidianus* habitat under present climate conditions, while the arrows ends represent the position of the centroid under future climate scenarios. Direction is measured in degrees west of north [Figure courtesy of [83]. Right: The historic distribution (red) of suitable Chinese *Andrias* habitat across China according to a bioclimatic based habitat suitability model [85].

Bioclimatic models predict that habitat loss through global heating will greatly reduce, or totally eliminate the populations of many giant salamander species [6,83]. However, regional climate change models do not generally fully include a species physiological and behavioral plasticity's that might buffer species from extinction [84]. Bioclimatic model predictions should be regarded as a guide rather than a mandate.

The ability of giant salamanders to inhabit niches deep in substrate, and to behaviorally, physiologically and reproductively, adapt to warmer aquatic temperature regimes from global heating may enable greater survival than predicted by bioclimatic models alone [85,86,87].

#### Chinese *Andrias* Clade

Biogeographical climate modelling, based on bioclimatic and topographical predictors and field data predicted with a RCP of 2.6, that Chinese *Andrias* will lose most of their range by 2050 and then the contraction will stabilize, with a RCP of 8.5 most range will be lost by 2050. However, in either scenario, eventually only a very small area of suitable habitat remains (Fig. 22., [83]). The models showed that slope, maximum temperature of the warmest month, precipitation of the driest month, and isothermality, are the most influential predictors in determining distribution patterns in Chinese *Andrias*.

Projections showed strong impact of heating with more than two-thirds of the suitable range lost [6,83]. However, phenotypic plasticity along with the retention of habitat niches such as karst caves [76] and niche divergence within ESUs could provide for some populations survival within their lost range. [87a].

Through bioclim modelling with one biotic factor using written or anecdotal evidence, of previous or current presence, a

highly accurate map of the historic distribution of suitable Chinese *Andrias* habitat has been created [76,87].

Global heating poses a serious hindrance to the long-term survival of Chinese *Andrias*, and strict measures are urgently needed to manage Chinese *Andrias*, including the safeguarding of the habitats of its few remaining populations, especially caves in karst landscapes, and the provision of new reserves to mitigate the impacts of climate change [76,83].

#### Japanese *Andrias* Clade

We know of no published bioclimatic model for the Japanese *Andrias* clade.

#### North American *Cryptobranchus* Clade

Climate heating models incorporating niche modeling show that large areas of currently suitable for *Cryptobranchus* habitat may be lost. Conversely, habitat expansion was predicted in small areas. Incorporating phenotypic plasticity can fundamentally altered ecological predictions under Bioclim climate change models for *Cryptobranchus* [85,86].

For instance, in the Appalachian Region, USA, global heating is considered an existential threat to almost 100 salamander species [88]. When added to Bioclim models, the ability of terrestrial salamanders to avoid, or to adapt to, the effects of global heating reduced the predicted extinction risk by ~70%. Juveniles experienced the greatest physiological stress through global heating, and combined with other stressors, increases the probability of local extinctions [86].

A research program at the Smithsonian, Center for Species Survival, Conservation Biology Institute, USA, is dedicated to the physiological effects of temperature change on Appalachian

# Sustainable Management of Giant Salamanders

## Global Heating and Global Consequences

The economic, political and cultural effects of global heating will be devastating and the sustainable management of the environment may receive decreasing support in favour of technological environmental manipulation to maintain condition survivable by humans [89]. Many cities in south Asia and the middle East will become uninhabitable due to intolerable heat. Up to 200 million climate refugees would destabilize politics, and consequently there would be great suffering for those displaced along with the increased chance of economic, political, or military conflict distracting from biodiversity conservation [69,70].

## Ultra Violet B (UVB)

Many studies have focused on the effect of increased levels of UV-B on amphibian survival, particularly of eggs and larvae. However, there is no compelling evidence for any significant effects of increased UV-B on reducing the survival of natural populations of amphibians [90]. Increased levels of UV-B are particularly unlikely to affect the reproduction or health of giant salamanders, which live and reproduced in deep shelter (Fig. 23., [22]).

## Habitat Loss and Macro-pollutants

Modification of terrestrial habitat adjacent to giant salamander habitat can increase soil erosion and stream siltation thereby reducing the number of nest sites, early juvenile habitat, and other critical habitat components. Other threats from macro-pollutants include acidification from mining operations [31,43, 59,60]. Structural threats to giant salamanders habitats are channelisation and dams (Fig. 24.).

The modification of the habitat of species in the Chinese *Andrias* clade began in low altitude areas through intensive land use over many decades and has expanded to the extent that *Andrias* are functionally extinct in most of these habitats [6,76]. Threats to all giant salamander species include bankside damage, industrial and artisanal riverside agriculture, channelisation, dams, gravel and rock extraction, and sedimentation.

Habitat modification caused through deforestation, erosion

and siltation can be reversed, but habitat loss through the construction of dams and other industrialisation is often irreversible (Fig. 24., [59,60,91,92]).



Figure 24. The effect of small dams on altering water flows can be devastating on the populations of giant salamanders by direct damage to habitat and by isolating populations. Small isolated populations are prone to extinction through inbreeding and extreme localized events.

## Chinese *Andrias* Clade

A study in China found that many small dams can pose a greater threat to ecosystems and natural landscapes than a few large dams, where the environmental harm from small dams is often greater by several orders of magnitude than harm from large dams [59,60].

Species in the Chinese *Andrias* clade mainly predate crab larvae and shrimp, and also other invertebrates, fish, frogs, and their own species [93]. Unspecified pollutants affect populations through altering the biotic components of rivers, where populations of once abundant small fish have been decimated. In response some rehabilitation projects for species in the Chinese giant salamander clade have stocked fish prey [94].

A probable new species in the Chinese *Andrias* clade, once found at high altitude on the Qinghai-Tibetan Plateau, appears to be extinct because of the effects of heavy siltation and pollution from mining [31].

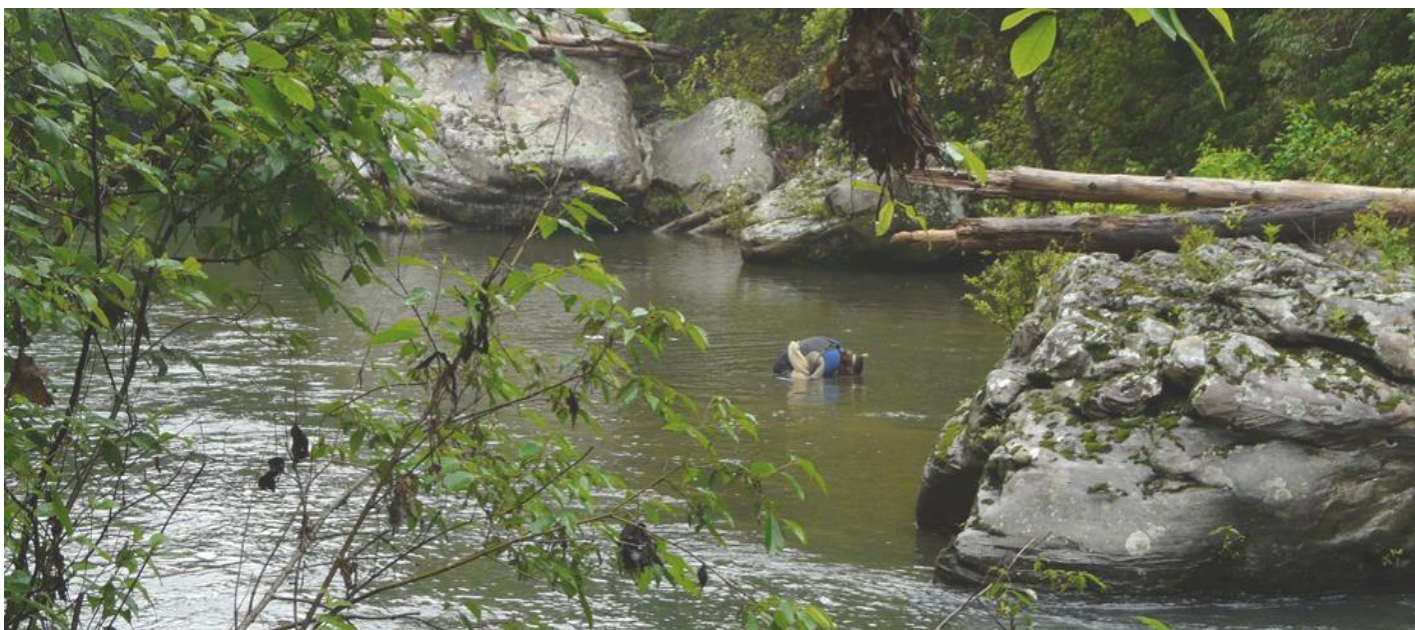


Figure 23. *Cryptobranchus* habitat in eastern North America. Giant salamanders prefer cool highly oxygenated watercourses, surrounded by natural vegetation, and with deep rock shelter. Image: Robert Browne



# Sustainable Management of Giant Salamanders

Karst caves were identified as one of the few remaining refuges for Chinese *Andrias* [76]. In Xiaoyudong Cave, China, a rapid population decline to extinction of giant salamanders occurred either through disease or through pollution of subterranean water systems. These caves were historically a refuge for Chinese *Andrias* because of their unpolluted water and were the source of many larvae [60]. From 2004 to 2009 the number of larva that emerged declined from 3,200 a year to zero.

## Japanese *Andrias* Clade

Japanese *Andrias* are mainly threatened by habitat modification through man-made structures, especially habitat fragmentation by small agricultural dams [91,92,95] that lead to the genetic impoverishment of small fragmented populations and therefore their susceptibility to extinction [91,92]. Dams along with concretisation and other damage to riverbanks, channelization, and the alteration of river courses deprive giant salamanders of their breeding dens [96], reduce daytime shelter and refugia during high water flows [96,97], and limit breeding and feeding opportunities [98].

## North American *Cryptobranchus* Clade

North American *Cryptobranchus* populations are suffering various degrees of decline due to habitat modification, possibly reduced food availability, and seasonal and unseasonal flooding extremes [99]. There are unspecified threats causing a lack of recruitment in some populations, where the siltation of riffles, lower water temperatures, altered seasonal flows, or siltation of caves for nest sites may reduce recruitment [15,16,18,100,101].

Across much of their historic range stream quality has been degraded through sedimentation from vegetation clearance, agriculture, forestry, and mining, with additional stressors including dynamiting of large boulders and riverside cattle and pig pens [15,16,18,101].

The extinction of a *Cryptobranchus* population was first recorded in 1957 [102]. By 1971 siltation, chemical and thermal pollution had eliminated them from most of the Ohio River drainage and other industrialized regions [103]. Widespread declines due to habitat modification, industrialization, agricultural runoff, and mine wastes were recorded [104,105]. There was also a drastic decline in populations along the Spring River, Arkansas, from over-collection, vegetation clearance, siltation, and from riverside development and recreational use [105]. Other populations have also severely declined [102], from siltation [103], and general habitat destruction [103,104].

Several recent studies have evaluated the effect of adjacent terrestrial forest habitat on *Cryptobranchus* populations. Physiography was shown to be a stronger predictor of occupancy than land use [106], with another study showing that populations tended to be higher when rivers flowed through public rather than private lands [107].

## Overharvest and Poaching

Only the Chinese *Andrias* clade has been subject to recent ecologically significant harvest or poaching. *Andrias* has been subject to harvesting in China since 1,700 BC [54], with legal harvesting continuing until 1998 [40]. Populations were still high in the 1950's, where the industrialised harvest of meat from one region was 50,000 kg, but by 1998 populations had

declined to the extent that harvest declined to only 10,000 kg [108]. During the 1980s, when intense harvesting commenced, 30 to 70 kg of giant salamanders could be caught per person day [40].

Chinese *Andrias* were abundant throughout the Qinling Mountain region until the mid-to-late 1970s but traditionally were not considered palatable [40]. After 1978, southern Chinese who had traditionally eaten *Andrias* migrated to the Qinling Mountain region. They found an abundance of giant salamanders and harvested them for food, and for trade to southern Chinese provinces and to other Asian countries.

In 1998, The Wild Animal Protection Law prohibited harvesting of *Andrias* in China. The unsatisfied market then promoted the development of aquaculture. To some extent the expansion of aquaculture into a highly efficient industry [40], coupled with a dramatic lowering of prices, would limit poaching. However, there is evidence of ongoing poaching even in protected habitat [109,110].

Nevertheless, anecdotal evidence suggests that poaching has declined through a stronger public awareness of the conservation significance of Chinese *Andrias* through public education programs (Lou pers comm.; [40] see Aquaculture). In 2014, before the recent catastrophic decline in populations, reports of giant salamanders showed increases in populations even in areas heavily overharvested in the 1990s [40].

Poaching activities for Chinese *Andrias* can be categorised as:

**Artisanal Poachers** - A survey in 2013 found that ~5% of the local people fished for *Andrias* and consumed 90% of catch [109]. However, there have been reports of locals targeting *Andrias* for sale [40,110].

**Aquacultural Poachers** - There are many small scale Chinese *Andrias* farms operating without licenses [40] even within wildlife reserves [109], where brood stock comes from local populations.

**Professional Poachers** - Many surveys have encountered some poaching for Chinese *Andrias*, either using the traditional technique of bow hooks or electrofishing [109,110]. In 2004 some poaching was industrialised and in one instance used >150 bow-hooks in 3 canoes [39]. This fishing was solely for financial gain, where *Andrias* was poached *en mass* to meet its rising demand from restaurants, the black market trade, and farms.

## Pet trade

Large numbers of captive bred species or hybrids in the Chinese *Andrias* clade have supplied an illegal pet trade especially by overland transport throughout the Eurasian Region. An air shipment of Chinese *Andrias* from China was confiscated in Hong Kong in 2017 [111]. Neither of these routes included quarantine (see *Ranavirus* p21).

## Sustainable Management of Giant Salamanders

Japanese *Andrias* were previously harvested for food but there appears that there is now little if any poaching or trade, although they may occasionally be kept as pets and then released (T. Johnson pers. comm., [41]).

There are anecdotal reports of the collecting of species of the North American *Cryptobranchus* clade for the pet trade [43], and there are anecdotal reports as recently as 2013 of their international sale through Internet sites.

### Incidental Bycatch and Eradication

Incidental bycatch and eradication are not currently considered as significant threats to giant salamander populations. In the past recreational fishers had a major impact on the mortality of the *Cryptobranchus* in Indiana's Blue River [112], and in West Virginia there were eradication attempts [101]. Increased environmental awareness and the scarcity of salamanders has now nullified the threat of intentional eradication.

### Pathogens and Parasites

As with all vertebrate hosts there are a diversity of pathogens and parasites that can infect giant salamanders including fungi, viruses, bacteria, blood parasites, and leeches. However, the most prominent threats are from species and strains of the fungus *Batrachochytrium* and from ranaviruses. Many other yet to be identified diseases may also affect the health of giant salamanders (Fig. 25A,B.)

### Chytrid Fungus

*Batrachochytrium dendrobatidis* (*Bd*) is a fungus that produces an often lethal disease (chytridiomycosis) in many species of anurans (frogs and toads, [113]), caudates (salamanders, sirens, and amphiuma, [114]), and caecilians [115]. In some regions chytridiomycosis caused a 90% extinction rate and a 95% population loss of amphibians (Fig. 25C., [113,116,117]).



Figure 25. A. Swelling and hemorrhage observed in foot of *Cryptobranchus alleganiensis*. B. Toe swelling, toe fusion, and nodule in foot of *C. bishopi*. Image: Sherri Doro Reinsch, Kelly J. Irwin, Bill Sutton. C. *Cryptobranchus alleganiensis* diagnosed with *Bd* along with others in a group tested that day, from a river in east TN. Image: Dale McGinnity.



## Sustainable Management of Giant Salamanders

Endemic Asian strains of *Bd* have shown minimal or no pathology to regional amphibians including *Andrias* species [118,119,120]. The origin of the global panzootic of *Bd* is NE Asia [118], which helps explain the immunity of the two *Andrias* species but not of *Cryptobranchus* where only moderate amounts of sub-clinical infections occur in some populations [121,122,123,124,125,126]. Strains of *Bd* found on *Cryptobranchus* appear to be identical to the global panzootic lineage and are therefore are an exotic pathogen [127].

*Bd* has caused mortality in *Cryptobranchus* in captive populations [128] and after releases [129]. *Bd* is weakly associated with lesion severity in some *Cryptobranchus* populations suffering from disease of unknown origin along with habitat degradation and agricultural run off [130,131]. Signs of this disease include a high prevalence of skin ulceration on the toes and distal limbs (Fig 26., [130,131]).

Novel strains of *Bd* are appearing, with the geographic range of different strains being extended naturally through the movement of water bird [132] and reptile [133] carriers; and through human activities including the amphibian [134], and freshwater fish trade [135], and farmed crayfish [136]. Transmission may also occur through zoospores in unfrozen freshwater, food, and soil [118].

Other exotic or novel *Batrachochytrium* species or strains may threaten giant salamanders. *Batrachochytrium salamandrivorans* (*Bsal*) is a more recently recognized chytrid species also originating from Asia and has not yet been detected in the Americas [137]. However, a *Bsal* epidemic threatens some European salamanders [138,139]. *Bsal* is known to be pathogenic to some western palearctic salamanders [140], and in one clinical trial, maintained infection for at least 45 days in juvenile *Cryptobranchus* [141]. To protect *Cryptobranchus* and other American salamanders from *Batrachochytrium* or other exotic pathogens, no unquarantined international trade of live amphibians or any other means of amphibian pathogen transmission should be tolerated [137].

### Ranavirus

*Ranavirus* has been increasingly implicated as a lethal pathogen in amphibians [142], with its virulence highly dependent upon the host species and the viral strain (Fig. 26,27,28,29., [143]). The first report of *Ranavirus* in giant

salamanders was a sub-clinical infection in *Cryptobranchus* in 2009 [125].

Ranaviruses are sporadically detected in many amphibians, including *Cryptobranchus*, and varies widely in prevalence between years [125,144]. Highly virulent *Ranavirus* strains can be linked to recombination of two or more strains in aquaculture environments [145].

In 2010 there was a lethal outbreak of *Ranavirus* in aquaculture stocks of the Chinese *Andrias* clade [146], that caused high mortality along with lesions including skin ulceration and necrosis of the limbs [147,148,149]. Genetic characterisation placed this *Ranavirus*, known as Chinese giant salamander virus (CGSV-L) or *Andrias davidianus* ranavirus (ADRV), within the common midwife toad virus (CMTV) group and sister to a *Rana catesbeiana* ranavirus (RCV-Z) found in *Lithobates* (*Rana*) *catesbeiana* farms in the United States [145,150]. It is likely that the RCV-Z originated from Europe, was introduced into *L. catesbeiana* facilities, and subsequently spread to China via the amphibian trade.



Figure 27. A *Cryptobranchus alleganiensis* from a creek in middle Tennessee infected by ranivirus. It is emaciated, has lost its feet, and appears near death. An attached leech also proved positive for ranavirus. Image: Sherri Doro Reinsch

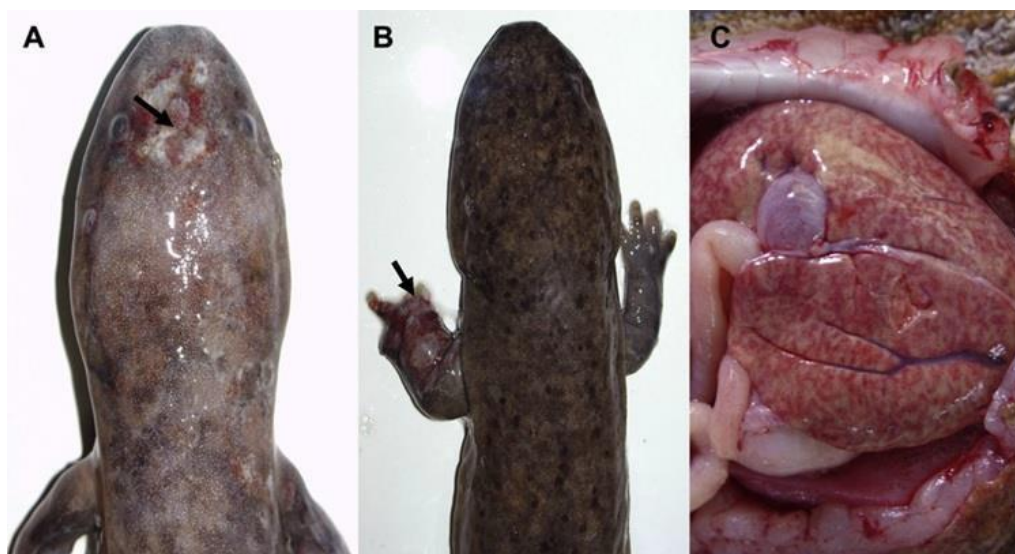


Figure 26. Gross lesions in ranavirus infected Chinese *Andrias*. A. Cutaneous erosion (arrow) and swollen areas on head. B. Ecchymoses, swelling and necrosis on a forelimb. C. The liver was pale and swollen with multifocal haemorrhages. Image: Yi Geng, from [146].

## Sustainable Management of Giant Salamanders

Further mutation is hypothesized to have given rise to the CGSV-L/ADRV [145], decimating Chinese giant salamander stocks. In response to the threat of CGSV-L to the aquaculture of species in the Chinese *Andrias* clade a vaccine was developed that now provides protective immunity to this virus [151].

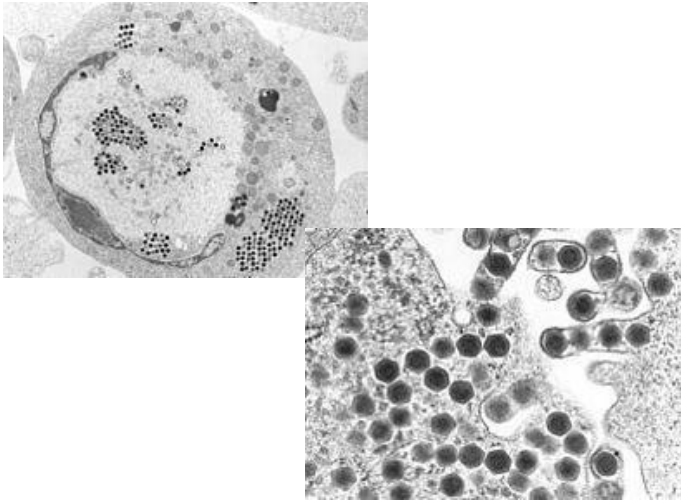


Figure 28. Top: Transmission electron micrograph (TEM) of ranivirus (dark hexagons) gathering at the cell border and leaving the cell in a process called budding. Bottom: TEM of a cell infected with raniviruses, which gather in the cytoplasm and in the assembly bodies next to the contorted nucleus. Images: from 'Ranivirus, WikipediaA'.

The possibility of unquarantined trade of giant salamanders, or other means of animal transport, to North America offers a very serious threat to *Cryptobranchus* through the possible introduction of CGSV-L, especially when considering 100% lethality of at least one *Ranavirus* strain to juvenile *Cryptobranchus* [152]. In 2017, juveniles of species or hybrids of Chinese *Andrias* destined for the pet trade were confiscated in Hong Kong [111].

The unquarantined international trade of giant salamanders, or other amphibians, to North America could at any time result in the decimation of *Cryptobranchus* and other salamander populations .

### Bacteria

A wide range of bacteria can cause pathology in species in the Chinese *Andrias* clade including species of *Aeromonas* [153,154], *Pseudomonas* [155,156], *Citrobacter* [157], *Morganella* [158], and *Edwardsiella* [159]. *Mycobacterium* is another important genus of aquatic pathogens and can cause a variety of acute and chronic pathologies in amphibians [160] and fish [161]. There are no known reports of *Mycobacterium* in cryptobranchids but these bacteria should be investigated where any ulcerative or granulomatous lesions are observed (Fig. 29.).

### Internal Parasites

*Balantidium* is a protozoal genus that causes the disease balantidiasis in humans. Two species, *B. sinensis* and *B. andianusis*, have been found in species in the Chinese *Andrias* clade where infection occurs through ingestion of cysts from water contaminated with feces [162].



Figure 29. Gross lesions in ranavirus infected Chinese *Andrias*. A. Systemic swelling and ulcer on ventral surface. B. Necrosis of the anterior limb. C. Necrosis of the posterior limb. Image: Yi Geng, from [146].



## Sustainable Management of Giant Salamanders

Trypanosomes are a group of blood trematodes known to infect *Cryptobranchus* and show highly variable site-dependent prevalence [163,164]. Trypanosome infection in *Cryptobranchus* does not appear associated with anemia or other health consequences and may be transmitted via leech vectors [165]. The intestinal parasite *Liolope copulans* is found in both Chinese and Japanese *Andrias* [166]. Many other intestinal parasites are found in Japanese *Andrias* [167], and many unidentified internal parasites are likely to be found in all giant salamander species. Some parasites can pose a serious health risk, but naturally occurring parasites that have co-evolved host species can contribute positively to ecosystem health and have minimal effects on the host species [168].

### External Parasites

Leeches as external parasites can slow the growth, and decrease the survival rate, of their hosts. Leeches are also vectors for important pathogens including blood parasites and pathogenic fungi [169,170]. The leech, *Desseroella cryptobranchii* is the suspected vector of blood parasites in western but not eastern populations of *Cryptobranchus* (Fig. 30B., [171]). A leech attached to a *Cryptobranchus* was positive for *Ranavirus* and highlights the potential for leeches to be vectors [130]. Other leeches are known to heavily parasitize *Cryptobranchus*, where the leech *Placobdella appalachiensis* parasitized 30% of one population [169], and 70% of another [171].

Leech parasitism does not appear associated with anemia in *Cryptobranchus* [164] but can affect immunocompetency [170]. Conversely, leech infestation may activate certain innate immunity pathways, where *Cryptobranchus* infested with leeches had better performing innate immunity than those that were uninfested [164]. However, heavy leech infestations caused morbidity and mortality in wood frog *Lithobates sylvaticus* tadpoles [172]. In *Cryptobranchus*, leech infestations could also increase the chance of subsequent disease as vectors or parasites.

### Non-infectious Disease and Micro-pollutants

In contrast to macro-pollutants (Fig. 30A.), even at very low concentrations, micro-pollutants can affect reproduction, development, behaviour, or longevity. Micro-pollutants include a range of heavy metals, and organic agricultural, pharmaceutical, industrial, and domestic chemicals. There are several non-infectious diseases in amphibians caused by chemical pollutants, and dependent on species, dose, and exposure period, the effects may vary from chronic disease to acute mortality [173].

The effects of micro-pollutants on cryptobranchids can be assessed through blood chemistry [174,175], changes in tissues

[173], effects on mortality rate, growth and development [163,176] and reproductive metrics such as sperm counts [176] and gonad condition [177].

Because of their aquatic life stage, and highly permeable skin, amphibians were once considered as being more sensitive than other species to both terrestrial and aquatic pollutants. However, in some cases, amphibians are found to be less sensitive than many other aquatic species to chemical exposure from heavy metals, inorganics, phenols, and pesticides [178].

Nevertheless, micro-pollutants in very low doses may significantly decrease giant salamander health over time through synergistic effects with other stressors such as global heating, habitat modification, and exotic pathogens, predators, or other species interactions [173]. In combination, these factors can impact populations through decreased larval survival and lowered adult body condition [174,177].

Atrazine (1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine), a widely used herbicide in agriculture and horticulture, disrupts amphibian physiology [173,178]. Frogs in midwestern North America have increased limb deformities, directly due to atrazine disrupting limb development and indirectly through increased susceptibility to trematode infection of the developing limb bud [179]. Atrazine has also been shown to increase *Ranavirus* infection in tiger salamanders *Ambystoma tigrinum* [180]. Atrazine is present in many watersheds inhabited by *Cryptobranchus* [181], however, there is no research published to date investigating the effect of atrazine on *Cryptobranchus* health.

Glyphosate (N-(phosphonomethyl) glycine) is another widely used herbicide in agricultural regions still inhabited by *Cryptobranchus*. However, it is challenging to study the effect of glyphosate on amphibians in nature because the reliable quantification of glyphosate is difficult due to its highly variable half-life in both the water column and in sediments [182].

Juvenile *Cryptobranchus* experimentally exposed to a one-time dose of glyphosate showed no gross or histopathological changes [152]. Nevertheless, in laboratory studies, commercial glyphosate herbicides at environmentally relevant low concentrations had lethal and genotoxic impacts on tadpoles of the Indian skittering frog, *Euflyctis cyanophlyctis* [183], and glyphosate has been shown to produce negative health effects in other amphibians [182,184]. These effects are highly dependent on dose frequency [185] and may not be evident until over a year post exposure [182].

Therefore, glyphosate has the potential to produce disease in giant salamanders when exposed over long periods, but is difficult to test, especially in these very long-lived species [186].

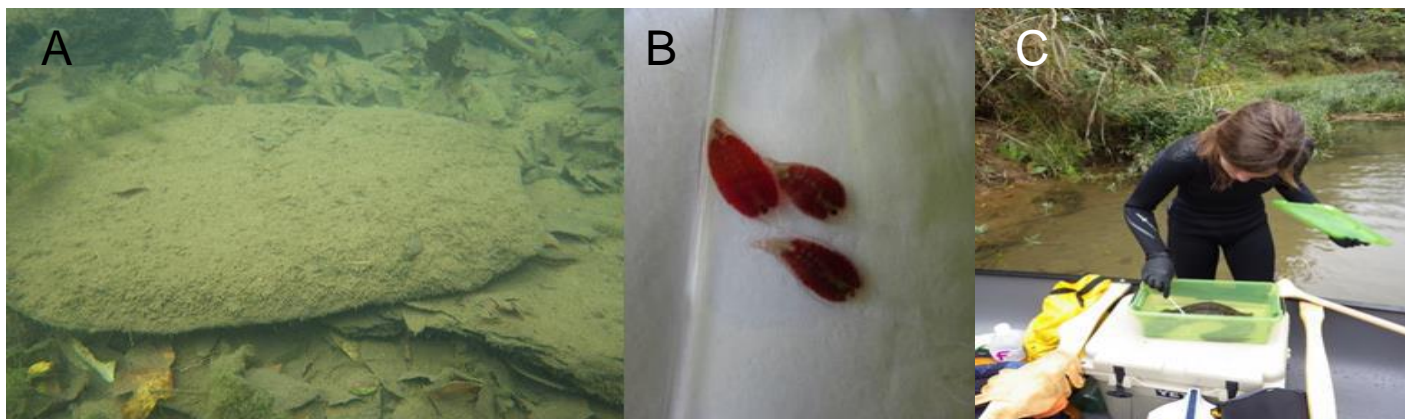


Figure 30. A. Cover rock with thick layer of silt in a stream where *Cryptobranchus bishopi* are declining. B. Leeches removed from a *C. bishopi* adult. C. Swabbing an adult *C. alleganiensis* for later *Bd* analysis. Image: Sherri Reinsch.

Although heavy metals can affect several physiological processes, we still do not understand how they may contribute to pathology or to population declines in cryptobranchids. Heavy metal contamination may be a threat to giant salamander health, where mercury, cobalt, magnesium, and lead were found in the blood of both western and eastern populations of *Cryptobranchus* [174]. Western populations contained significantly greater cobalt levels [174] whereas eastern populations had significantly greater levels of mercury and lead [159]. There are few studies evaluating effects of heavy metals on amphibian physiology, however, the levels of mercury, cadmium, chromium, and cobalt found in *Cryptobranchus* are considered harmless in other vertebrates [174,175].

From 1992-1998, the synthetic pyrethroid insecticide fenpropathrin was used in China when fishing to immobilize *Andrias* for poaching [40]. Pyrethroids are toxic to fish [187] and aquatic invertebrates at low concentrations [188,189], and in invertebrates a single, very low concentration can decrease survival, growth, and development [188]. From 1992-1998 there were declines in both biodiversity and biomass of the fish and invertebrate prey in some riverine systems inhabited by Chinese *Andrias*. Fenpropathrin has a short half-life, and its historical use for fishing is now unlikely to affect aquatic ecosystems. In any case, there are very few fish in the headwaters of some river systems in the Qinling Mountains in southern Shaanxi Province, where small fish were previously abundant (Wu pers. comm.).

Endocrine disruptors have been shown to affect amphibian reproduction [177] and are present in significant amounts in at least some watersheds inhabited by *Cryptobranchus* [190]. Endocrine disruptors may have been partly responsible for the lower sperm concentrations between declining and healthy *Cryptobranchus* populations [176].

### Anthropogenic Activity and Stress Response

The stress response in vertebrates is an adaptive physiological response to different stimuli in order to direct energy toward responding to the threat. Through complex hormonal pathways including the two dominant systems: 1) the hypothalamic-pituitary-adrenal axis (the inter-renal axis in fish and amphibians) that mediates the long-term reallocation of energy, and 2) the sympathetic nervous systemic controlling norepinephrine and epinephrine (the fight-or flight response), a host will respond to stress with systemic changes affecting many organs, and in many cases these responses benefit the organism [191]. However, chronic stress can result in chronic dysfunction of these pathways and lead to decreased allocation of energy into immunity and reproduction resulting in increased disease and decreased fecundity [191,192].

As the world population continues to grow there is ever more anthropogenic stressors and habitat degradation [193]. In response, many wildlife species are now experiencing an increased prevalence of disease due to novel and sometimes exotic pathogens [194].

Three main factors affect disease prevalence in a wildlife population are:

- a pathogen or disease-causing agent,
- an environment conducive to pathogen transmission, infection, and propagation.
- a susceptible host (Fig. 30.).

Anthropogenic activity can affect all three spokes of this triad and result in the decreased health of individuals and population declines with or without mass mortality events. Even without

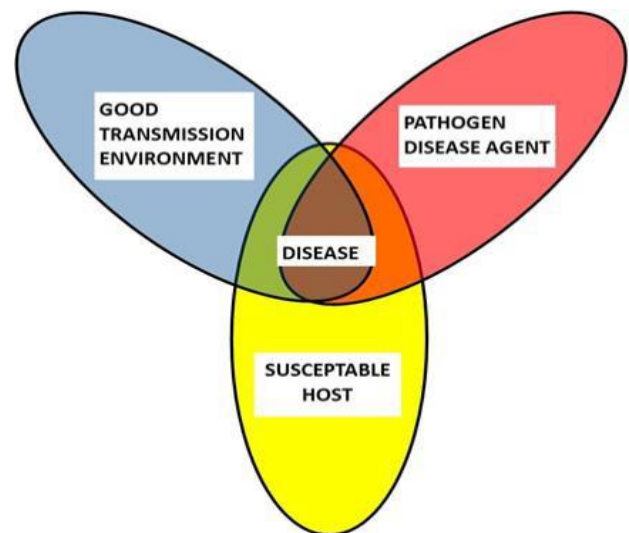


Figure 30. The disease triad.

habitat degradation, increased human activity can increase pathogen transmission through contaminated clothing, boots, and equipment [195].

Giant salamanders are long-lived and rely on semipermeable skin for both electrolyte balance and respiration [192a], where the chronic non-lethal effects of poor water quality could impact health and survival. There are many reports of physical abnormalities in *Cryptobranchus* such as ulcerations, (Fig. 29.), however, the relationship between these abnormalities and the chronic non-lethal effects of poor water quality remain unclear [131,193a,194a].

Western *Cryptobranchus* are suffering a high prevalence of chronic, ulcerative, and non-healing distal limb lesions (Fig. 24., [131,193a,194a]). Lesion severity is associated with *Bd* presence and lesions do become more severe in a given individual over time [194a]. Studies to determine an etiological agent via culture [193a], or microbiome sequencing [195a], have shown changes in the microbial community on skin lesions but no distinct causal agent. The watershed habitats of this *Cryptobranchus* subspecies are highly degraded, and there is little to no recruitment at most historical sites [196,101]. These populations also have a low immunogenic diversity [197]. Similar lesions with much lower frequency are reported in eastern *Cryptobranchus* of Tennessee [125,130,198].

The lesions likely represent a multifactorial cause from habitat, host, and one or more infectious agents. Although the etiology is not definitive, conservation workers should focus on both individual and habitat factors to reduce the incidence of disease.

### Global Heating and Pathogens

Global heating is yet another way humans are influencing complex interactions of host, pathogen, and environment. Temperature changes that alter salamander physiology could lead to direct health and reproductive effects on hosts. How giant salamanders will respond to global heating is uncertain. However, temperature can influence giant salamander reproduction [199], growth, and body condition [200]. Further, *Cryptobranchus* experiencing natural temperature fluctuations had increased innate immunity than those experiencing constant temperatures [201].



Global heating may also change pathogen distribution and virulence, where both *Ranavirus* [202] and *Batrachochytrium* [203], the two most threatening pathogens of giant salamanders, change in virulence when exposed to different temperatures. There are no comprehensive studies of any giant salamander on how global heating will affect both host and pathogen.

## Genetic Impoverishment and Hybridisation

The Chinese *Andrias* clade has been subject to a large number of release programs since 2003, involving ~70,000 individuals produced in aquaculture facilities [8]. However, the genetic variation of these offspring was low through captive selection [204-189] and compromised through hybridisation [8]. Dai et al., 2010, cautioned of the potential of the release of hybrids, or progeny from one local cohort, to reduce the genetic variation of the supplemented wild populations (Fig. 10., [60]). This threat was confirmed in 2017, when most aquacultural and supplemented wild populations were shown to be hybrids [8].

Recent research has shown that the traditional Chinese *Andrias* clade is composed of at least five [8] and possibly seven or more [6] species-level lineages. However, the Chinese *Andrias* clade is officially treated as a single species of conservation and commercial purpose.

China's Ministry of Agriculture has supported the release of farmed individuals into natural habitats, but by not distinguishing the genetic lineages of the released *Andrias*, these releases did not conform to contemporary reintroduction guidelines [8].

The vast and frequent translocation of individuals between farms has resulted in the majority of giant salamanders in farms to be genetic homogenized. Introgression mostly involves the species lineage that originated from the Yellow River in Shaanxi Province, where a genetic analysis of field caught specimens in the Pearl River and Yangtze Rivers, showed mitochondrial haplotypes of the Shaanxi lineage that have apparently completely supplanted indigenous haplotypes [8].

In a survey of 93 counties, *Andrias* were only detected in 19, and Chinese *Andrias* in farms in 18 of these counties had Shaanxi lineage. Only one county had no farms and the populations in nature there were genetically uncontaminated [9]. Therefore, the large numbers of farmed Chinese *Andrias* released into nature have already caused serious genetic contamination of many natural populations, which is a major threat to both currently known and currently unknown populations of Chinese *Andrias* species. Consequently, distribution surveys across the range of Chinese *Andrias* are immediately needed to reveal presently undiscovered genetically distinct populations, and any relict populations of all known species.

Species in the Chinese *Andrias* clade are exotic to Japan and their introduction into the Kamo and Kamogawa River led to their hybridization with the endemic Japanese *Andrias* [205-190]. It is uncertain how these Chinese *Andrias* were introduced. However, in the early 1970's many Chinese *Andrias* were imported to Japan from China and probably some were released. The titles of these Asahi Shimbun news articles give some idea of the giant salamander trade between China and Japan: November 22nd, 1972, "Japan and China Resume Diplomatic Ties--Unexpected Fruit: Salamanders"; November 25th, 1972, "1,300 Rampant Chinese Salamanders Arrive in Okayama"; and January 11th, 1973, "Fuss over Bon Appétit".

## Exotic Predators and Prey Loss

Exotic fish may be a threat to giant salamander populations as predators, competitors for food, or vectors of pathogens or parasites. They may also be a prey item.

Many mountain streams throughout the range of the Chinese *Andrias* clade have been stocked with rainbow trout, *Oncorhynchus mykiss* (Wu pers comm). However, we could find no studies of the negative effect of exotic fish on these *Andrias*.

A range of exotic fish species, some regularly stocked by fisheries or wildlife agencies, as direct or competing predators may affect North American *Cryptobranchus* populations, however, there is no compelling evidence of even the large scale stocking of many exotic fish species affecting *Cryptobranchus* populations [206].

Nevertheless, the lower defensive response of *Cryptobranchus* larvae to chemical cues from exotic fish, than those from native fish, shows the potential for increased predation [207] that is considered as a threat to the western two species [208].

Exotic crustaceans found over parts of the range of *Cryptobranchus* may threaten the viability of populations by reducing predation efficiency, where predation of an invasive crayfish species was shown to be less efficient than of the native crayfish that provide a major part of *Cryptobranchus* diet (Fig. 31., [79]).



Figure 31. Exotic crayfish such as the Kentucky River Crayfish, *Faxonius juvenilis*, that is widespread in eastern Tennessee replace native crayfish species and reduce prey availability. Similarly, exotic *F. viridis* infest cooler streams in the more eastern parts of *Cryptobranchus* habitat Image: Carl E. Williams.

## Filial Cannibalism

Filial cannibalism, the cannibalism of an individual's own young, is found in *Cryptobranchus* where brooding males eat some of the thousands of eggs deposited by many females in the one nest, to provide nutrition for the days of brooding and to invest in future reproduction. Increased filial cannibalism can be due to behavioural stress or to low nutrition, factors often found in declining populations. If the natural degree of filial cannibalism remain similar, or even increases, little or no recruitment may occur in unnaturally low population densities. To ameliorate the negative effects of filial cannibalism on recruitment in affected populations, egg clutches harvested through the use of artificial nest boxes should be moved to head starting programs [209].

## SUSTAINABLE MANAGEMENT

Environmental sustainability requires the management of species and ecosystems within increasingly modified environments. Regions that had previously supported large human populations, within sustainably managed agrarian ecosystems, for many thousands of years are now being compromised by the excessive demands of industrialization, increasing populations, and excessive consumption driven by materialism and consumerism.

Collapsing ecosystems, loss of species, and changes to the physical environment, increasingly impact biodiversity and the biosphere. The sustainable management of giant salamanders now extends to the recognition that environmental morality, cultural presence, and political influence will determine the fate of much biodiversity including humanity.

### Law and Policy

Species in the Chinese giant salamander clade are listed as critically endangered (IUCN, 2019) and on Appendix I of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora; CITES, 2015). In 1989, giant salamanders were listed as Class II State Major Protected Wildlife Species with the legislation of the Peoples Republic of China Protecting Wild Animals Law". In 1993, the "Peoples Republic of China Practice Regulations to Protect Quadric Wild Animals" that included giant salamanders was implemented. Because of their genetic distinctiveness and critical endangerment the species in the Chinese giant salamander clade have been identified by the EDGE of Existence programme, Zoological Society of London, as the second most important amphibians for sustainable management [2].

The Japanese giant salamander is considered by the IUCN Red List as Near Threatened as its area of occupancy is ~ 2,000 km<sup>2</sup> and the extent and quality of its habitat is declining, and Vulnerable in the Japanese Red List, Ministry of the Environment of Japan, 2006. It is a "Special Natural Monument" under the Law for the Protection of Cultural Properties and also as an "International Endangered Species of Wild Fauna and Flora" under the Law for Conservation of Endangered Species of Wild Fauna and Flora [210].

The Japanese giant salamander is CITES under Appendix I, and controlled by the "the Foreign Exchange and Foreign Trade Control Law" and "Customs Act". Some habitats are protected

as "Giant Salamander Habitats" under the Law for the Protection of Cultural Properties. Between 1979 and 1999, 153 Japanese *Andrias* were exported mainly to zoos [41 28], and in 2010 six were exported to the Smithsonian Zoo, USA [211].

The North American *Cryptobranchus* clade was granted Endangered Species Act protection in 2004, and listing in Appendix III of the Convention on International Trade in Endangered Species (CITES) to prevent their exploitation through the international pet trade. In 2019, they were listed as Near Threatened (IUCN Red List, 2019), and are now protected throughout their range.

### Dedicated Reserves and Programs

By 2010, China had established 22 state, provincial, or county nature reserves dedicated to giant salamanders, and 38 reserves in 13 provinces focus mainly on giant salamanders. For example a dedicated reserve of was established at Sijian Mountain, Guangxi Province where populations were drastically reduced in the 19<sup>th</sup> century. Hunting of any kind is prohibited in reserves and water quality should comply with environmental standards that give state nature reserves the highest protection against water pollution. However, these standards are rarely satisfied [212].

We now know the natural ranges of the different Chinese *Andrias* species and some populations distributions. We also know the anticipated effects of global heating in reducing species ranges, and governance needs. Adaptive management should consider the optimal populations and locations on which to focus conservation efforts, including the designation of new reserves where required [83], to provide effective and efficient conservation strategies with a strong scientific and ethical foundation [6].

### Ecosystem Restoration

Major watershed rehabilitation over the range of the Chinese giant salamander clade includes the establishment of alternative agricultural practices for displaced persons such as mushroom or herb farming, landscaping and tree planting (Fig. 32.). Large areas of mountainous habitat in China were cleared of forest from 1970 to 1995, however, in 1996 large scale flooding promoted the re-afforestation of many of the watersheds inhabited by the Chinese giant salamander clade [212].

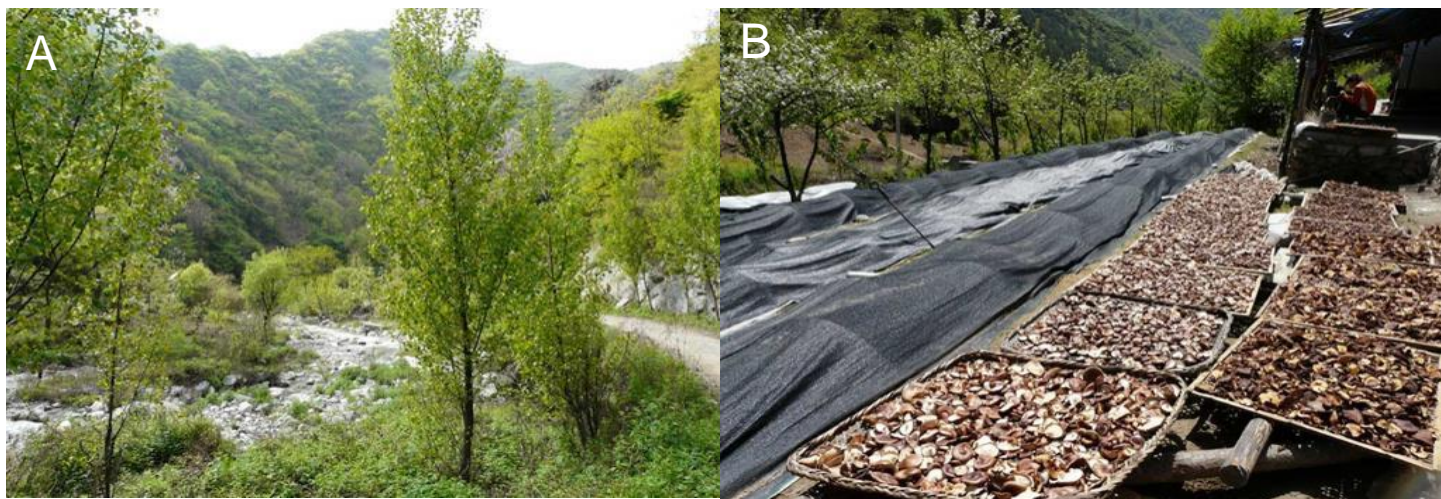


Figure 32. Restoration of previously deforested mountainous habitat of *A. davidianus* in the Qinling Mountains, Shaanxi province. A,B,C. Trees are planted, and D the extraction of natural resources by the traditional community is restricted to the gathering of traditions medicinal plants and fungi. Image: Robert Browne.





Figure 33. Thousands of juveniles of the *Andrias davidianus* migrated up to 2014 from caves in South Taibai Park, China, that are now protected by an artificial counting chamber. Juveniles that were previously collected for aquaculture are now released. The small fish that were very common in this river are no longer apparent. Image. Robert Browne.

### Artificial Breeding Dens and Nest Boxes

Artificial bankside breeding dens have been successfully trialled the aquaculture of species and hybrids in the Chinese *Andrias* clade [213], and the principle of supplying or protecting dens can now be applied in locations where breeding dens are rare, absent or need protection (Fig. 23,24,33., [214]). The Intraregional Breeding Program in Asa Zoological Park established artificial breeding dens for Japanese *Andrias* that produce many larvae annually. Breeding dens for Japanese *Andrias* have been trialled along the banks of one river [96], and manhole-type artificial dens at another [97]. Artificial nest boxes are being trialled for species in North American for *Cryptobranchus* to increase nesting opportunities, provide for studies of reproductive behaviour and larval survival, and to provide oocytes for research and supplementation programs [214].

### Conservation Breeding Programs

In late 18th Century Europe only wildlife species useful for hunting such as deer, pheasants, partridges, or fish such as salmon, or ornamental or culturally significant animals such as birds, monkeys, ornamental fish or snakes were fostered. Exotic animals were kept in private “Menageries”. After the popular uprisings and cultural readjustment of the 19th and early 20th centuries these menageries evolved into the public zoos of Europe, and provided a model for zoos globally [215 Wikipedia -Zoos].

In the mid 20th Century zoos increasingly adopted major roles in species conservation, that now extends from field work to biotechnical research. However, in 2013 the species inventory of zoo collections was still biased toward species considered as high impact for display and still did not proportionally cater for the conservation needs of threatened species [216].

Zoos have provided major support for CBPs and for field conservation of threatened amphibians. These programs have

resulted in the release of thousands of larvae and juveniles in supplementation or rehabilitation programs for *Cryptobranchus*.

### Genetic Impoverishment

Genetic adaptation to captivity depends on the number of generations in captivity, effective population size, founder's genetic variation, and the intensity of selection favourable to captive conditions [217,218]. Selection for captive conditions cannot be eliminated, but can be lessened by raising larvae and early juveniles in simulacrum of their natural environments. Genetic variation can also be maintained through the fragmenting of captive populations. Inbreeding can be controlled by the exchange of individuals, and the supplementation of captive breeding populations with individuals from nature [217,218].

Under ideal conditions a minimum effective population size of 10-20 male and female giant salamanders is needed to maintain a genetic variation of 90% of the founding population for 15 years, and a minimum population size of 50 males and females for 55 years [219].

In captivity, highly fecund species such as giant salamanders, will over a few generations genetically adapt for increased survivorship, more rapid growth, and earlier maturity. Genetic variation will be lost resulting in inbreeding depression, and deleterious alleles will rapidly accumulate in the absence of natural predators, competitors, and diseases [218,219]. Genetic impoverishment will then reduce the survival and reproductive success of releases.

The genetic screening of old specimens of the Chinese giant salamander clade now in farms, zoos, and aquaria globally should be conducted to identify suitable broodstock for CBPs to reestablish each species [6]. The use of cryopreserved sperm could preclude the need for international, or regional, transportation of giant salamander broodstock, and offer greater security and lower costs [220].



# Sustainable Management of Giant Salamanders

## Sperm Banking

The use of cryopreserved sperm (Fig. 34.), to indefinitely provide an effective male generation length of one, offers the most reliable and efficient technique to perpetuate the genetic variation of giant salamanders [220,221]. Sperm banking would similarly support CBPs for fragmented and threatened populations of the Japanese giant salamander clade [10,220]. Progeny of North American giant salamanders have been produced using cryopreserved sperm, with ongoing research of cryopreservation techniques along with the hormonal induction of spawning and maturation in males [222].



Figure 34. *Cryptobranchus* sperm that consist of an elongated head and a long tail for motility. Image: Michael Kirk.

## Chinese *Andrias* Clade

The cost of CBPs needed to re-establish the five or more species in the Chinese *Andrias* clade could be greatly reduced

and have far greater security and flexibility, through the use of cryopreserved sperm from the most genetically significant individuals from within China [220,223], and possibly from international sources as cryopreserved sperm is easily transported. This program could be integrated into a network of regional and national genetic resource banks to perpetuate China's national biological resources, and to indefinitely provide for species conservation, scientific research, and for biotechnological development.

With species in the Chinese *Andrias* clade the foundations for the use of cryopreserved sperm have been established [223,224], large quantities of milt are available [224-204], and techniques are well established for the hormonal induction of sperm and oocytes and their use in artificial fertilisation [225].

The first large scale releases of species or hybrids of Chinese *Andrias* were between 2004 and 2008, when 9,400 larvae from natural egg clutches were raised in captivity then released with some surviving to become juveniles [60]. The survival of 9,400 giant salamanders of varying sizes released in a Chinese nature reserve between 2002 and 2008 were moderate, with mature adults released in spring having the highest survival (Fig. 30., [226]).

From 2008 to 2018 at least 72,000 Chinese giant salamanders have been released from farms [Yan et al., 2018]. In 2009, recommendations to restore populations were made including the strengthening of protective management, improvement in captive breeding techniques, and an increased number of releases. In 2009, the Chinese Ministry of Agriculture selected 28 licensed *Andrias* aquaculture facilities across China to release 13% of their captive-bred offspring when greater than 21cm in total length (Fig. 35.). The sustainable management of the five or more species in the Chinese *Andrias* clade [6,8,9] needs the supplementation of relict populations, and repopulation in some watersheds where they are extinct [6,9]. CBPs to support these programs can acquire pure broodstock from the relict populations in nature, old broodstock in aquaculture facilities, and possibly from global sources.



Figure 35. An aquaculture based facility in China for breeding giant salamanders using channel bankside breeding dens and natural reproduction. Image: Liang Gang.



# Sustainable Management of Giant Salamanders

## Japanese *Andrias* Clade

The Species Survival Commission of the Japanese Association of Zoos and Aquariums created a Giant Salamander Working Group to establish a CBPs for Japanese giant salamanders in four facilities, however, reproduction has only succeeded in Asa Zoological Park, Hiroshima City [227,228]. Since 1992 a pedigree registry (studbook) records the age, body length, body weight, and other details, of the more than hundreds of captive individuals.

Japanese *Andrias* have been a feature of a CBP at Asa Zoo with 100 spawning's from 1979 to 2015 (Fig. 36-40., [227,228,229], along with rescue program focused on degraded habitats [229,230]. Japanese *Andrias* populations in nature that are not reproducing need CBPs to enable survival until the reestablishment of missing critical habitat components, or indefinite CBPs if the habitat needs for their reproduction cannot be provided [227], where without CBPs and supplementation these populations will slowly decline to extinction [231].

## North American *Cryptobranchus* Clade

Conservation breeding programs for each species of North American giant salamanders are needed to provide genetically competent individuals for repopulation, supplementation and research programs. Captive breeding programs were pioneered at the Shepherd of the Hills Hatchery, with eggs collected from nature in 2007. In 2011, the Goellner Center for Hellbender Conservation at St. Louis Zoo first breed North American giant salamanders in large, outdoor simulacrum of a natural stream [233].

The average survival rate over one year of captive reared then released North American giant salamanders was ~50% [234]. Other studies show high survival rates of captive reared and released juveniles and translocated adults, demonstrating the value of both techniques to increase populations [101,235,236]. The survival rates of released juveniles may be increased through longer rearing periods and through environmental conditioning prior to release [101,235,236].



Figure 36. Conservation Breeding Center of the Japanese Giant Salamander in Asa Zoological Park, Hiroshima, Japan., with 60+ tanks that rear hundreds of larvae. Image: Yuki Taguchi.



Figure 37. A. Water supply goes into each tank individually. B. Four connective breeding tanks. C. Stream type breeding tank. Image: Yuki Taguchi.



## Sustainable Management of Giant Salamanders



Figure 38. Japanese giant salamander larvae and juveniles are reared in troughs by Aza Zoo. Image: Yuki Taguchi.



Figure 39. Artificial breeding dens in the wild. Before breeding season Asa Zoo staff and local people clean in and around the den. Under the bank there is a pipe tunnel through to an artificial nest in the house. Image: Yuki Taguchi.



Figure 40. Almost every year breeding succeeds with the den master brooding hundreds of eggs then larvae in the 60 cm diameter artificial nest. Image: Yuki Taguchi.



### Aquaculture

Species and hybrids in the Chinese *Andrias* clade are subject to a large aquaculture industry that may have threatened natural populations through the illegal harvesting of brood stock and larvae, and through the spread of pathogens through waste water or releases [40,94]. However, these threats must be considered within a historical context, and balanced against the benefits of aquaculture (Fig. 35.).

Overharvesting and the high prices for the meat of giant salamanders provided the incentive for the development of aquaculture since the early 1970s [40,94]. Only since 2000 has large scale aquaculture been possible due to the development of reproduction technologies for the hormonal induction of sperm and oocytes that enabled the reliable and cost effective production of large numbers of larvae (Fig. 41,A,B., [94]).

The price of giant salamander meat stayed relatively constant until the mid 1990s (Fig. 42). Protection in 1993 encouraged aquaculture through price increases, but production could not satisfy demand, and the price rapidly increased up to 2000. Aquaculture continued to expand with facilities first licenced in 2004, with most farms in south Shaanxi Province. Aquaculture continued to rapidly expand by 2007 was reducing the price of giant salamanders in spite of increasing demand.

In 2008 the high status of giant salamander meat for banquets and celebrations encouraged very high prices reaching to US\$450/kg for consumption or for broodstock (Fig. 42., [94]). In late 2009 after the global financial collapse, with increasingly efficient production from expanding facilities along with reduced demand resulted in the price dropping to its lowest since 1998. By 2010, survey of aquaculture facilities showed that licenced farms averaged 8,350 adults of which 460 were broodstock, and produced 10,300 larvae [40].

From 2010, major advances in reproduction technologies have greatly increased in efficiency in larval production of 20 per female and have further lowered production costs [237]. A 2011, survey of aquaculture facilities showed that most broodstock were first generation or wild-caught. However, of the 2.6 million giant salamanders in farms 400,000 were young adults being raised as broodstock and 15,350 were breeding adults. Some facilities had more than 200,000 first or second

generation bred in captivity. In 2011 the Qinling Mountain region, Shaanxi province, produced ~500 t, or ~70% of the total output of farmed *Andrias* in China. In one county 6,000 families were farming *Andrias* and 60% of families had smallholder farms, with 70 breeding farms produced 120,000 offspring. In another county the 700 farms were the most profitable industry [40]. By 2015 due to high levels of production and market limitations the price had dropped to US\$40/kg similar to that of high status fish (Fig. 37. Luo pers comm.).

*Andrias* aquaculture is important for some local governments to help improve the economic conditions and livelihoods of residents. Across the Qinling Mountains region, *Andrias* aquaculture is one of the three most important economic activities and tens of thousands of families rely on the industry [40].

By 2015, there were *Andrias* farms in over 17 Chinese provinces, with 12 million adults and juveniles and with an annual production of 12,000 tons. Many of the original broodstock and juveniles for aquaculture were illegally harvested, and even now some poaching for aquaculture may affect the few remaining *Andrias* in nature [39,40]. In any case environmental degradation, poaching of a large slow growing fisheries species, and genetically uniformed releases are the most apparent causes for the immediate loss of Chinese *Andrias* species.

The history and scale of *Andrias* aquaculture in China shows that the industry has not recently been highly reliant on wild caught brood stock. In contrast to the detrimental effect of the poaching of larvae and adults, aquaculture may benefit the sustainable management of species of Chinese *Andrias* by providing the husbandry and reproduction technologies needed for CBPs. Aquaculture facilities may also have provided refuges for some of the last natural broodstock that can be used in CBPs to recover the 5 or more species almost extinct in nature [6,8,9].

The dramatic loss of natural populations between those recorded from 2000-2011, when aquaculture became increasingly self sufficient for brood stock, along with supplementation programs and increased public presence, does not correspond with the subsequent precipitous decline of natural populations.



Figure 41. A. Juvenile Chinese *Andrias* about 8 months old in a flow through aquaculture system. The food source consists of small minnows. B. Five year old aquaculture *A. davidianus* weighing 5 kg and of 70 cm length. Image: Robert Browne.

# Sustainable Management of Giant Salamanders

In 2014, reports of giant salamanders at field sites, through personal communications, focus groups, and newspapers, showed increases in populations even in areas heavily impacted by overharvesting in the 1990s [40]. So what happened between ~2010 and 2018 to the natural populations to bring the species in the Chinese giant salamander clade to near extinction? (Fig. 43).

A possible explanation is that the decimation of the natural recovering populations corresponded with the lethal outbreak of CGSV-L in 2010 that decimated aquaculture stocks through a 90% mortality rate ((Fig. 43. [146,147,148,149]). However, CGSV-L has not yet been recorded in natural populations, and individuals monitored for almost a year after release in 2014 did not show signs of CGSV-L [238]).

## Quarantine and Release

Giant salamanders are threatened by the possible introduction of pathogens or parasites during the release of captive raised stock, or the release of water from aquaculture facilities into natural systems [40]. Giant salamanders for exchange between aquaculture facilities or CBPs, or for release, should be held in quarantine for 15-20 days and screened for pathogens and parasites. The GSIV-L iridovirus shows clinical signs after 5 days with earlier detection possible through microscopy. Chytridiomycosis is reliably detectable using genetic techniques [239].

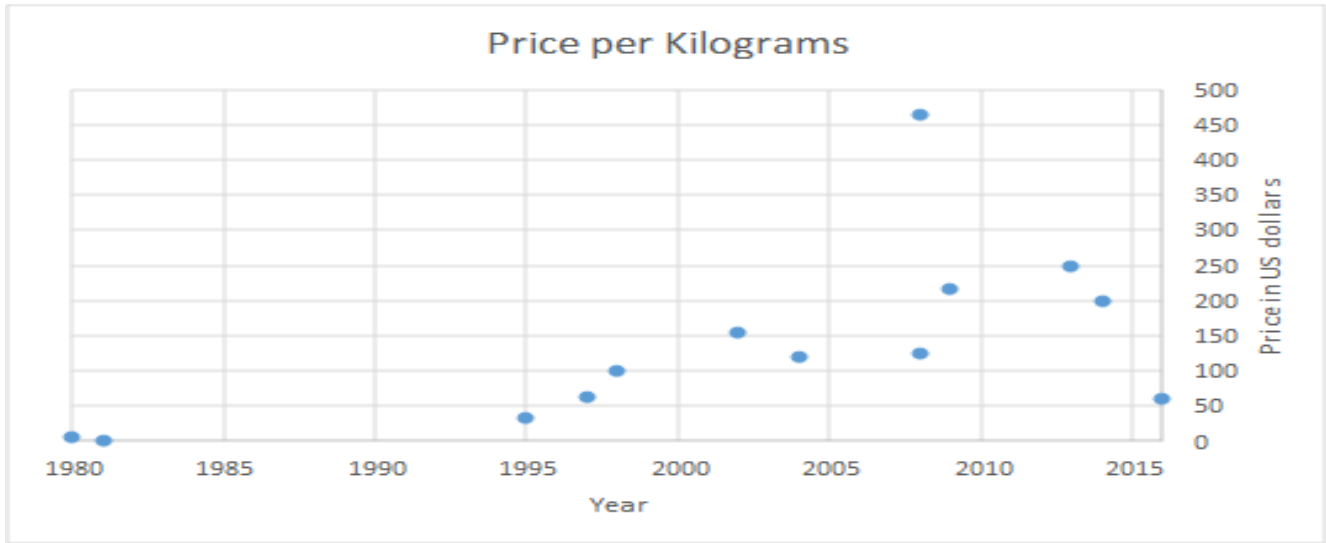


Figure 42. The price of giant salamanders in US\$ exchange rate at time of publication from 1980 until 2015.

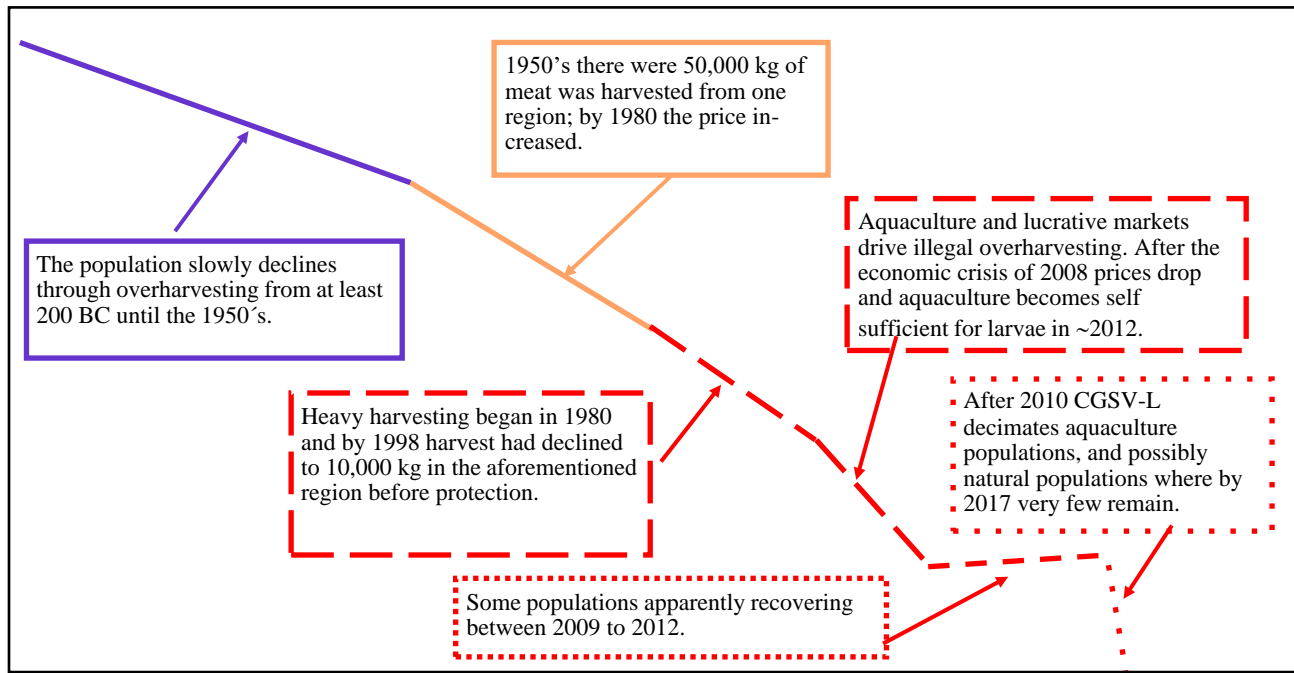


Figure 43. Hypothetical diagram of the stages of the decline of the Chinese giant salamander clade. The apparent recovery of populations after 2009 was followed by a sudden decline to almost extinction that corresponding to the lethal outbreak of Chinese giant salamander iridovirus (CGSV-L) in aquaculture stocks.





**Co-species Management**

The sustainable management of giant salamanders can be linked with that of other threatened species. For example, the QinLin Mountains, China, are of the last remaining strongholds for giant salamanders, is increasingly popular for environmental recreation. This area is geologically and culturally unique and supports giant salamanders and many other threatened and iconic species (Fig. 44,45.).



Figure 44. A) The site of the Ancient Plank Road is prime habitat for *A. davidianus*. B) Tourist information regarding the Ancient Plank Road. “The Ancient Hang Road, named as Tangluo, or Ancient Plank Road, was developed during Han dynasty (206 BC-24 AD). At that time, it was one of the six transportation arteries directed to the south of Shaanxi province and to Sichuan province. Mao Yisheng, a famous architect in China, said that the Ancient Plank Road, the Great Wall, and the Grand Canal were the Three Wonders in ancient China. Here are the relicts of the original construction of bridge for the Ancient Plank Road.” C) Engineering marks in the rocks to the left of the current bridge.. D) The intensity of water flow during floods is shown by the size of this displaced boulder. Images: Robert Browne.





Figure 45. Other threatened species that rely on the same ecosystems as the Chinese *Andrias* clade in their strong hold in the Qinling Mountains, Shanxi Province, include the: Shanxi Takin (*Budorcas taxicolor bedfordi*; J. Patrick Fischer CC BY-SA 3.0), the Qinling Golden Snub-nosed Monkey (*Rhinopithecus roxellana qinlingensis*; [www.flickr.com/photos/giovanmari/72971655367/](http://www.flickr.com/photos/giovanmari/72971655367/)), Crested Ibis (*Nipponia nippon*, Danielinblue), Golden Pheasant (*Budorcas taxicolor bedfordi*; [www.flickr.com/photos/linhdo/5641](http://www.flickr.com/photos/linhdo/5641)), and Qinling Panda (*Ailuropada melanoleuca qinlingensis*).

### Monitoring and Surveys

Although populations of giant salamanders are difficult to survey, their presence during periods of low river discharge can be ascertained using environmental DNA (eDNA). With eDNA and mark recapture combined overall population estimates have been demonstrated for species in the Japanese *Andrias* clade [57,205]. and the North American *Cryptobranchus* clade [240].

### Cultural Engagement

#### Ecotourism, Zoos and Aquariums

Ecotourism and display in aquaria offer the potential to provide education and support for giant salamanders and their riverine environments. The two *Andrias* clades include the world's largest amphibians [5,22] and both are impressive public exhibits in zoos, aquariums, restaurants, and in large home aquariums. It may benefit the global public presence of giant salamanders to enable colour varieties such as with the Chinese *Andrias* clade (Fig. 46.) to be considered as a domestic taxon and be excluded from CITES restrictions (also see Quarantine and Release).

Giant salamanders are a feature of many zoos and aquariums in China., Japanese *Andrias* are a feature of the Hiroshima City

Asa Zoological Park, and in 2010 the National Zoo, USA, imported six from the Hiroshima City Asa Zoological Park [211]. The number of *Andrias* in USA Zoos is increasing, and many zoos in the USA include public displays of North American *Cryptobranchus* along with general education and publicity, and *Andrias* are becoming available internationally. Scientific- and Ecotourism includes volunteering for field research or for habitat restorations and can be incorporated into surveys and general habitat protection [241,242].

Preferred management and facilities for the success of institutional conservation initiatives [242a]:

1. Conservation defines policy decisions.
2. Sufficient organizational funding.
3. A functional conservation department.
4. A vocation for conservation.
5. Conservation education programs for children and adults.
6. Direct contribution to local and global habitat protection.
7. Exhibits that explain and promote conservation.
8. Internal policies and activities for sustainable management.



# Sustainable Management of Giant Salamanders

## Internet Presence

Internet based media and social networking are now the main sources for public presence, and consequently political persuasion and policy [19,20].

Internet search behaviour reflects public interest and is closely tied to the drivers of public policy, and strong public presence in all media is critical to giant salamander conservation. Without strong public presence the expression of pro-conservation opinions by individuals can be suppressed by a lack of social support and a fear of sanctions by peers [19,241].

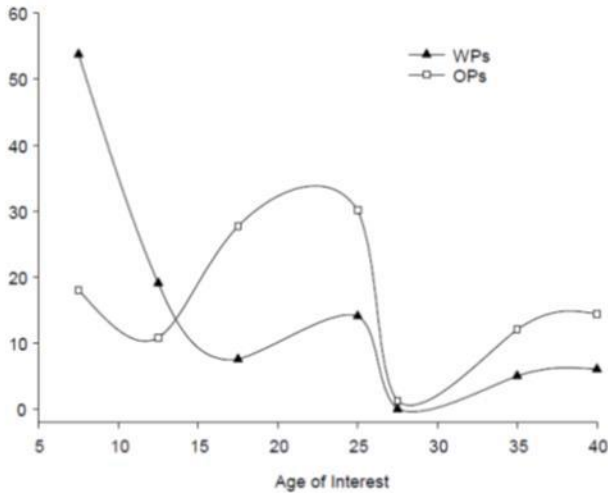


Figure 46. The percentage of respondents in western polities (WP) or other polities (OPs) against their first age of interest in amphibians [242].

There is much to learn, and then to apply, about managing public presence for the sustainability of amphibian biodiversity in general, and for the sustainable management of giant salamanders in particular.

A survey in 2018 was pioneering in its revelations about Internet presence, public perception, and amphibian conservation. A clear message was that amphibian CBPs and field work would benefit by a more culturally and politically inclusive approach to providing for facilities and for research and application [242].

Special attention should be paid to education programs that have been shown to generally bond young children between 3 and 10 years of age in western societies, but in non-western countries bonding mostly occurred between 25-35 years of age [242]. The reasons for these major differences are unknown.

Numerous presentations, educational programs, video games, publications, lesson plans, and websites have been developed to help teach the public about giant salamanders and their sustainable management. To access an excellent example for the North American giant salamander - see [www.helpthehellbender.org](http://www.helpthehellbender.org) at Purdue Extension.

## Iconic Species

Caution must be taken with the publicizing of iconic species as greater public presence does not necessarily mean improved conservation outcomes. For example the ten most charismatic animals are at a high risk of extinction in spite of a high public profile (Figure 47., [243]). The general public largely ignores this tragedy as they are still unaware that these species face imminent extinction and their urgent conservation needs. To increase public perception regarding the conservation needs of giant salamanders, information campaigns need to emphasize the imminent threats they face [243].



Figure 47. The North American giant salamander clade has been widely presented as an flagship species in commercial advertising and in personal websites. Top left by Chloe Rubenstein ; Bottom left by Pia Ravenari ; Top middle by UrpleB3atin; Bottom middle by Center for Biological Diversity's Endangered Species Condoms Project; Right by Hellbender Burritos.

## Flagship Species and ESUs

Flagship species are those species leading campaigns for the sustainable management of their ecosystems. Flagship species can make major contribution to promoting a community awareness of conservation needs and priorities, that result in improvements in sustainable management. The ability of flagship species as umbrella species to raise support for the general sustainable management of the environment comes through flow-on conservation and educational benefits [245].

Giant salamanders are flagship species for the sustainable management of river catchments as they are charismatic, and from an ecological perspective they are keystone, indicator, and umbrella species. They are also iconic species in respect to their global, national, and cultural significance (Fig. 42.).

However, giant salamanders are not included in the world's 20 most charismatic species, which are mainly Endangered or Critically Endangered terrestrial mammals. The 20 most charismatic species studied only included four aquatic species: dolphins, blue whales, crocodiles, and the great white shark [246]. The mammals most generally considered beautiful, beauty is a form of 'charisma', to the general public are carnivores and ungulates with complex fur patterns and body shapes [247].

Giant salamanders are charismatic and visually arresting as ferocious gigantic predators, along with their ancient lineage before the dinosaurs and surviving the great extinction event through the giant meteor, poison slime, ambush predation, physiology, males rearing of young, and sources of medicine, and as a charismatic amphibian species exemplifying the challenges and benefits of sustainable management programs for amphibians [246].

## Phylogenetics and Education

Including phylogenetics in species education offers a means to focus audience interest through genetics and through regional biogeography leading to greater stake holding. Over the past decades, there has been a tendency in zoos and aquaria away from an emphasis on CBPs, and toward education and fund-raising activities to protect and maintain the target species and its habitat. Both field conservation, and zoo based CBPs, have a stronger educational impact when they are coupled with phylogenetic taxonomy. Presentations of zoo based CBPs provide accessibility and immediacy to visitors, and are ideal platforms for information sharing. This education can be couched in the application of genetics to human heredity and forensics; common topics in popular media. Demonstrating the importance of ESUs can convey a strong ethical message against the homogenization of global biodiversity to be directed at global, national and local levels, and has an interesting correlation to the homogenization of human cultures [247a].

## Scientific Meetings and Civil Societies

Symposiums offer opportunities for updating information and creating personal links. To reduce greenhouse gas emissions symposiums can now be conducted through the internet with dedicated Apps disseminating supportive information before the symposium, and enabling immediate and ongoing discussions.

The first International Conservation Workshop for the Chinese Giant Salamander was held in 2010, at Shaanxi Normal University, Xian, China, with the support of the Zoological Society of London, United Kingdom, and included experts from

the PRC, Australia, USA, UK, and Hong Kong [248].

Hellbender Symposiums held every two years in the USA, are fostered by different host institutions and voluntary supporters, and each symposium held in different regions across the range of the North American *Cryptobranchus* clade. Hellbender Symposiums have grown in breadth of subjects, and numbers of attendees and presentations over the years. Since 1998 they have included international guests and have fostered a global fraternity for the sustainable management of giant salamanders.

## Scientific Research

Scientific search engines showed increasing rates of publications since 2010 for all giant salamander clades. Publications for the Chinese *Andrias* clade the North American *Cryptobranchus* clade rapidly increased, and for the Japanese giant salamander slowly increased. However, few of these mentioned the sustainable management of giant salamanders form a cross-disciplinary framework.

Conservation biology has been asserted as being synthetic, eclectic and multi-disciplinary. However, a review of articles in three influential biological conservation journals found that few publications were truly cross-disciplinary. The authors suggested establishing clearer links with other disciplines and research approaches, and with policy management [249].

Conservation biologists working with giant salamanders should put more effort into cross disciplinary approaches in their publications, not only to broaden their subject matter into providing effective conservation outcomes, but also to give greater potential for the achievement of their goals through reaching out for broader support and influence [249].

We anticipate that this current review has helped bridge this gap and that this approach will contribute to similar broadly educational publications for other threatened species.

In order to foster international collaboration we suggest the use of native vernacular names as well as the scientific name for each of the cryptobranchid species within the key word section of publications. This will aid researchers globally in accessing the relevant publications, even when these are republished in a foreign language.

## Community Based Co-Management

Community based co-management by communities local to a species habitat directly engage in education, protection and monitoring of species, both on public or on private lands.

With species of commercial value, community based co-management has proven particularly critical. Without the embedding of environmental morality in every level of the community, practical levels of policing and governance have consistently failed to maintain populations of valuable easily marketable species. The benefits in reliability and cost saving of community based co-management have been consistently demonstrated in fisheries, and with other threatened freshwater aquatic and terrestrial species and ecosystems [249].

Besides providing greater efficiency, community based co-management also builds the skills and social cohesion needed for the transformation to the general sustainable management of the environment. Government, NGOs, and private institutions must work in tandem with community based co-management to assure that community based activities receive adequate support to achieve the sustainable management of their environment.



## CONCLUSION

Giant salamanders are iconic species for their host nations and globally. Natural populations of all species have declined and are now the focus of broad programs for their sustainable management supported by researchers, public institutions, and laypersons. All species have traditionally been harvested for food or medicine. Since the mid-20th Century their natural populations have declined to varying extents, some to probable extinction.

The seven or more original species in the Chinese *Andrias* clade are very rare or functionally extinct in nature, due mainly to overharvest, hybridisation, and possibly disease. The sustainable management of the species in the Chinese *Andrias* clade depends on building genetically viable populations in CBPs, in concert with sperm banking, habitat restoration, releases, and protection. Pathogens offer an increasing threat. However, our genetic discoveries along with habitat and population assessments, provide for highly targeted and efficient conservation strategies supported by a strong scientific and ethical foundation. Community based co-management will be essential to ensure the success of repopulation programs, and can benefit from the experiences of previous release and education campaigns

Japanese *Andrias* populations are slowly declining, with dams isolating many populations and resulting in loss of genetic variation. There are fewer nest sites as bank modifications diminish critical habitat, and in some watersheds hybridisation with Chinese *Andrias*. The CBP at Aza Zoo could be expanded to include the supplementation of populations whose survival is threatened, and the development of reproduction technologies along with sperm banking of the genetic variation of small isolated populations suffering genetic impoverishment.

North American *Cryptobranchus* have largely declined in the western populations, with significant and increasing declines in some of its eastern populations. A wide range of novel management techniques are being applied to assure the survival of the species, ESUs, and populations, in the North American *Cryptobranchus* clade. These include CBPs along with population supplementation, and the refinement of reproduction technologies including sperm cryopreservation. In particular, to focus conservation efforts we need to know why some populations have declined to a greater extent than others with a focus on low levels of larval/juvenile recruitment.

Ultimately, the survival of giant salamanders will depend on proactive strategies that support their sustainable management including greater cooperation between researchers, government and local officials, and the knowledge based building of increased public presence and political influence.

## ACKNOWLEDGEMENTS

We especially appreciate the logistical support of Nashville Zoo, USA; Prof Wu, Shanxi Normal University, PRC; Prof. Xianming Wang, Shaanxi Institute of Zoology, and their research teams. The Royal Zoological Society of London (ZSL), UK, for their EDGE Program, and the enthusiasm of organiser Helen Meredith, and Shanxi Normal University, for hosting the International Conservation Workshop. The Royal Zoological Society of Antwerp for their logistical support, and their expertise and advice in population genetics. The Hellbender Symposiums, USA, provide a valuable resource for research and enthusiasm that has now extended to all Cryptobranchids. The support of David Hendrick and the Lindhurstfoundation.com is greatly appreciated. Timothy Johnson for his wonderful images of the Hanzaki Festival and

advise. This concluding review is based on the work of hundreds or researchers and volunteers, and especially Amy McMillan and those involved in the production of the previous reviews in this series.

## REFERENCES

- Browne RK, Li H, Wang Z, Hime P, McMillan A, Wu M, Diaz R, Hongxing Z, McGinnity D, and Briggler JT. 2012. The giant salamanders (Cryptobranchidae): Part A. palaeontology, phylogeny, genetics, and morphology. *Amphibian and Reptile Conservation*, 5(4):17-29
- Zoological Society of London. Species EDGE of Existence. Chinese Giant Salamander. <http://www.edgeofexistence.org/species/chinese-giant-salamander/> [Accessed: 29th December 2018]
- Meszoely C. 1966. North American fossil cryptobranchid salamanders. *American Midland Naturalist*, 75(2):495-515.
- Milner AR. 2000. Mesozoic and Tertiary Caudata and Albanerpetontidae, Chapter 18 in H. Heatwole and Carroll, R. (eds.), *Amphibian biology*, Vol. 4 Palaeontology, the Evolutionary History of Amphibians. Surrey Beatty and Sons, Chipping Norton, Australia.
- Turvey ST, Marr MM, Barnes I, Brace S, Tapley B, Murphy RW, Zhao E, Cunningham AA. 2019. Historic museum collections clarify the evolutionary history of cryptic species radiation in the world's largest amphibians. *Ecology and Evolution*, DOI: 10.1002/ece3.5257].
- Liang ZQ, Chen WT, Wang DQ, Zhang SH, Wang CR, He SP, Wu YA, He P, Xie J, Li CW, Merilä J, Wei QW. 2019. Phylogeographic patterns and conservation implications of the endangered Chinese giant salamander. *Ecology and Evolution*. 2019;1-12. DOI: 10.1002/ece3.5014
- Hime PM. 2017. Genomic Perspectives on Amphibian Evolution across Multiple Phylogenetic Scales. Doctoral Dissertation. University of Kentucky, USA.
- Yan F, Lu J, Zhang B, Yuan Z, Zhao H, Huang S, Wei F, Wu M, Xiao H, Liang Z, Jin J, Wu S, Xu C, Tapley B, Turvey ST, Papenfuss TJ, Cunningham AA, Murphy RW, Zhang Y, Che J. 2018. The Chinese giant salamander exemplifies the hidden extinction of cryptic species. *Current Biology*, 28:R592-R594.
- Turvey ST, Chen S, Tapley B, Wei G, Xie F, Yan F, Yang j, Liang Z, Tian H, Wu M, Okada S, Wang J, Lu J, Zhou F, Papworth SK, Redbond J, Brown T, Che J, Cunningham AA. 2018. Imminent extinction in the wild of the world's largest amphibian. *Current Biology*, 28:590-592.
- Matsui M, Tominaga A, Wan-zhao L, Tanaka-Ueno T. 2008. Reduced genetic variation in the Japanese giant salamander, *Andrias japonicus* (Amphibia: Caudata). *Molecular Phylogenetics and Evolution*, 49(1):318-326.
- Tochimoto T, Taguchi Y, Onuma H, Kawakami N, Shimizu K, Doi T, Kakinoki S, Natuhara Y, Mitsuhashi H. 2008. Distribution of Japanese giant salamander in Hyogo Prefecture, Western Japan. *Humans and Nature*, 18:51-65.
- Taguchi Y. 2009. Habitat Evaluation and Conservation Planning of the Japanese Giant Salamander (*Andrias japonicus*). Doctoral Dissertation. Kyoto University, Japan.
- Okada S. 2009. Natural History of Japanese Giant Salamander *Andrias japonicus* in Chugoku Area with Conservation Implications. Doctoral Dissertation, Tottori University, Japan.
- Freake M, O'Neill E, Unger S, Spear S, Routman E. 2018. Conservation genetics of eastern hellbenders *Cryptobranchus alleganiensis alleganiensis* in the Tennessee Valley. *Conservation Genetics*, 19(3):571-585.

## Sustainable Management of Giant Salamanders

15. Wheeler BA, Prosen E, Mathis A, Wilkinson RF. 2003. Population declines of a long-lived salamander: a 20+ year study of hellbenders, *Cryptobranchus alleganiensis*. *Biological Conservation*, 109:151-156.
16. Foster RL, McMillan AM, Roblee KJ. 2009. Population status of hellbender salamanders (*Cryptobranchus alleganiensis*) in the Allegheny River drainage of New York State. *Journal of Herpetology*, 43(4):579-588.
17. Nickerson MA, Briggler JT. 2007. Harvesting as a factor in population decline of a long-lived salamander; the Ozark hellbender, *Cryptobranchus alleganiensis bishopi* Grobman. *Applied Herpetology*, 4:207-216.
18. Nickerson MA, Pitt AL, Tavano JJ, K. Hecht KA, Mitchell JC. 2017. Forest removal and the cascade of effects corresponding with an Ozark hellbender population decline. *Bulletin of the Florida Museum of Natural History*, 54 (10):147-164.
19. Mccallum ML, Bury GW. 2013. Google search patterns suggest declining interest in the environment. *Biodiversity Conservation*, 22(6-7):1355-1367.
20. Reilly S, Richey S, Taylor JB. 2012. Using Google search data for state politics research: an empirical validity test using roll-off data. *State Politics Policy Q*, 12:146-159.
21. Browne RK, Hong L, McGinnity D, Okada S, Zhenghuan W, Bodinof CM, Irwin KJ, McMillan A, Briggler JT. 2011. Survey techniques for giant salamanders and other aquatic Caudata. *Amphibian and Reptile Conservation*, 5(4):1-16.
22. Browne RK, Li H, Wang Z, Hime P, McMillan A, Wu M, Diaz R, Hongxing Z, McGinnity D, and Briggler JT. 2014. The giant salamanders (Cryptobranchidae): Part B. biology, ecology and reproduction. *Amphibian and Reptile Conservation*, 5(4):30-50.
23. Distinct Population Segment policy (1996) under the Endangered Species Act, United States. [http://www.eoearth.org/article/Distinct\\_Population\\_Segment\\_policy\\_%281996%29\\_under\\_the\\_Endangered\\_Species\\_Act,\\_United\\_States](http://www.eoearth.org/article/Distinct_Population_Segment_policy_%281996%29_under_the_Endangered_Species_Act,_United_States) [Accessed: 23rd October 2010].
24. Chen F, Li H. 2001. Genomic divergences between humans and other hominids and effective population size of the common ancestor of humans and chimpanzees. *The American Journal of Human Genetics*, 68(2):444-456.
25. Kimbel WH, Villmoare B. 2016. From *Australopithecus* to *Homo*; the transition that wasn't. *Philosophical Transactions of the Royal Society B*. 371(1689), <https://doi.org/10.1098/rstb.2015.0248>
26. Murphy RW, Fu JZ, Upton DE, De Lema T, Zhao EM. 2000. Genetic variability among endangered Chinese giant salamanders, *Andrias davidianus*. *Molecular Ecology*, 9:1539-1547.
27. Tao FY, Wang XM, Zheng HX, Fang SG. 2005. Genetic structure and geographic subdivision of four populations of the Chinese giant salamander (*Andrias davidianus*). *Zoological Research*, 26:162-167.
28. Tao FY, Wang XM, Zheng HX. 2006. Analysis of complete cytochrome B sequences and genetic relationship among Chinese giant salamanders (*Andrias davidianus*) from different areas. *Acta Hydrobiologica Sinica*, 30(5):625-628.
29. Li J, Wei S, Hu M, Luo Z, Zhao M, Wu H. 2018. Reflection of paleoclimate oscillations and tectonic events in the phylogeography of moustache toads in southern China. *Journal of Zoology*, 305:17-26.
30. Liu C. 1950. *Amphibians of Western China*. Chicago, IL: Chicago Natural History Museum.
31. Pierson TW, Yan J, Wang Y, Papenfuss T. 2014. A survey for the Chinese giant salamander (*Andrias davidianus*; Blanchard, 1871) in Qinghai province. *Amphibian and Reptile conservation* 8(1):1-6.
32. Lane WH. 1934. *The home of the Loch Ness monster*. Edinburgh, UK: Grant & Murray.
33. Boulenger EG. 1924. On a new giant salamander, living in the Society's Gardens. *Proceedings of the Zoological Society of London*, 1924, pp. 173-174.
34. Isozaki Y, Aoki K, Nakama T, Yanai S. 2010. New insights into a subduction-related orogeny: A reappraisal of the geotectonic framework and evolution of the Japanese islands. *Gondwana Research*, 18:82-105.
35. Sabatino SJ, Routman EJ. 2009. Phylogeography and conservation genetics of the hellbender salamander (*Cryptobranchus alleganiensis*) *Conservation Genetics*, 10 (5):1235-1246.
36. Crowhurst RS, Faries KM, Collantes J, Briggler JT, Koppelman JB, Eggert LS. 2011. Genetic relationships of hellbenders in the Ozark highlands of Missouri and conservation implications for the Ozark subspecies (*Cryptobranchus alleganiensis bishopi*) *Conservation Genetics*, 12:637-646.
37. Unger SD, Rhodes Jr. OE, Sutton TM, Williams RN. 2013. Population genetics of the eastern hellbender (*Cryptobranchus alleganiensis alleganiensis*) across multiple spatial scales. *PLOS 1*, <https://doi.org/10.1371/journal.pone.0074180>
38. Galloway WE, Whiteaker TL, Ganey-Curry P. 2011. History of Cenozoic North American drainage basin evolution, sediment yield, and accumulation in the Gulf of Mexico basin. *Geosphere*, 7(4):938-973.
39. Wang XM, Zhang K, Wang ZH, Ding YZ, Wu W, Huang S. 2004. The decline of the Chinese giant salamander *Andrias davidianus* and implications for its conservation. *Oryx*, 38 (2):197-202.
40. Cunningham AA, Turvey ST, Zhou F, Meredith HMR, Guan W, Liu X, Sun C, Wang Z, Wu M. 2015. Development of the Chinese giant salamander *Andrias davidianus* farming industry in Shaanxi Province, China: conservation threats and opportunities. *Fauna & Flora International, Oryx*, 2015:1-9.
41. CITES 2009. Convention on International Trade in Endangered Species of Wild Fauna and Flora. Twenty-fourth meeting of the Animals Committee Geneva, (Switzerland), 20-24 April 2009. Periodic review of animal species included in the CITES Appendices. AC24 Doc. 10.2 Annex 2. 2008 December. Review of the status of Japanese Giant Salamander (*Andrias japonicus*). Ministry of the Environment, Japan. <http://www.cites.org/eng/com/AC/24/E24-10-02.pdf>
42. Niwelinski A. 2007. *EAZA Giant Salamanders Husbandry Guidelines*. Compiled by Aleksander Niwelinski, Zoological Garden in Plock, Poland. On behalf of the EAZA Amphibian and Reptile Taxon Advisory Group.
43. Nickerson MA, Mays CE. 1973. A study of the Ozark hellbender, *Cryptobranchus alleganiensis bishopi*. *Ecology*, 54:1164-1165.
44. Sonnini de Manoncourt and Latreille. 1801. *Salamandra alleganiensis* Sonnini de Manoncourt and Latreille, 1801 "An. X", *Hist. Nat. Rept.*, 4: 406. Holotype: animal figured in Sonnini de Manoncourt and Latreille, 1801 "An. X", *Hist. Nat. Rept.*, 2: figure preceding p. 253, of a specimen in the MNHNP, now lost. Type locality: "Virginie sur les montagnes Alléganis"; corrected to "vicinity of Davenport's Plantation", North Toe River, 1 mile south of the mouth of the Bushy Creek and 4 miles east-northeast of the Spruce Pine Creek, Mitchell County, North Carolina", USA.



45. Barton BS. 1812. A memoir concerning an animal of the class of reptilia, or amphibia, which is known, in the United-States, by the names of Alligator and Hell-bender. Printed by the author. Griggs and Dickenson Printers, Philadelphia.
46. Michaux FA. 1805. Travels to the west of the Allegheny Mountains, in the states of the Ohio, Kentucky, and Tennessee, in the year 1802. London, Printed for R. Phillips, 1805.
47. Daudon FM. 1803. Histoire Naturelle des Reptiles. V.8. Paris. 493 p. 8 pl.
48. Dundee HA. 1971. Amphibia Caudata Cryptobranchidae. *Cryptobranchus*, and *C. alleganiensis*. Catalogue of American Salamanders and Reptiles, 101.1-101.4.
49. Harper F. 1940. Some works of Bartram, Daudin, LaTrelle, and Sonnini, and their bearing upon North American herpetological nomenclature. Amer. Midland Nat. 23 (3):692.723.
50. Barton BS. 1808. Some accounts of the *Siren lacertian* and other species of the same genus. Privately published in Philadelphia. 34 p., 1 pl.
51. The Ying Yan symbol its meaning, history, and origins. <https://mythology.net/yin-yang-symbol-meaning-origins-history/> [Accessed: 20<sup>th</sup> September 2020]
52. Kappa By Prof. Geller. <https://mythology.net/japanese/japanese-creatures/kappa/> [Accessed: 20<sup>th</sup> September 2020]
53. Atlas of the Human Journey -The Genographic Project. National Geographic Society. 1996-2008. [Accessed: 6<sup>th</sup> October 2009].
54. Efrey PB. 1996. The Cambridge Illustrated History of China. Cambridge University Press, New York, New York, USA.
55. Li X, Chen Y, Lai Y, Yang Q, Hu H, Wang Y. 2015. Sustainable utilization of traditional Chinese medicine resources: Systematic evaluation on different production modes. Evidence Based Complement Alternative Medicine, 2015;2015/218901.
56. He D, Zhu W, Zeng W, Lin J, Ji Y, Wang Y, Zhang C, Lu Y, Zhao D, Su N, Xing X. 2018. Nutritional and medicinal characteristics of Chinese giant salamander (*Andrias davidianus*) for applications in healthcare industry by artificial cultivation: A review. Food Science and Human Wellness, 7(1):1-10.
57. Matsui M. 2005. Habitation confirmation of alien giant salamander species by DNA analysis. <http://www.kasen.or.jp/seibikikin/h18/pdf/rep3-04h.pdf> [in Japanese].
58. Petranka JW. 1998. Salamanders of the United States and Canada. Smithsonian Institution Press, Washington and London.
59. Liu AH, Lu ZX. 2007. A preliminary study on the conservation and management of the giant salamander resource in Shannxi Province. Water Conservancy and Fishery, 27(4):69-71.
60. Dai Q, Wang Y, Liang G. 2010. Conservation Status of Chinese Giant Salamander (*Andrias davidianus*). Chengdu Institute of Biology, Chinese Academy of Sciences, Chengdu, Sichuan Province, Peoples Republic of China.
61. Zheng HX. 2006. The Population Ecology and Ecological Adaptation Characteristic of the Chinese Giant Salamander (*Andrias davidianus*) in Lushi County, Henan Province, China. Doctoral Dissertation. East China Normal University.
62. Tapley B, Okada S, Redbond J, Turvey ST, Chen S, Lu J, Wei G, Wu M, Pan Y, Niu K, Cunningham AA. 2015. Failure to detect the Chinese giant salamander (*Andrias davidianus*) in Fanjingshan National Nature Reserve, Guizhou Province, China. Salamandra, 51(2):206-208.
63. Luo QH, Zhu SH, Xie WH, Wang CQ, Cheng QY, Wang JP. 2011. Planning for resource conservation and industrial development of Chinese giant salamander in Zhangjiajie City. Zhangjiajie Municipal Government, 12:9-14.
64. Luo QH, Liu Y, Zhang LY, Chen JG, Kang LC. 2009. Investigation on resources of Chinese giant salamander in Zhangjiajie County. Sichuan Journal of Zoology, 28:424-426.
65. Shimizu Z, Nakano T. 2012. Results of a questionnaire on the study and protection of the giant salamander. Bulletin of the Herpetological Society of Japan, 2012:117-124.
66. Taguchi Y. 2009b. Seasonal movements of the Japanese giant salamander (*Andrias japonicus*): Evidence for possible breeding migration by this stream-dwelling amphibian. Japanese Journal of Ecology, 59(2):117-128.
67. Briggler J, Utrup J, Davidson C, Humphries J, Groves J, Johnson T, Ettling J, Wanner M, Traylor-Holzer K, Reed D, Lindgren V, Byers O (eds.). 2007. Hellbender Population and Habitat Viability Assessment: Final Report. IUCN/SSC Conservation Breeding Specialist Group, Apple Valley, MN. 118 pp.
68. Baker CL. 1963. Spermatoxoa and spermatogenesis in *Cryptobranchus* and *Necturus*. Report to the Director of Realfoot Lake Biological Station. Tennessee Academy of Science. 38(1):1-9.
69. Intergovernmental Panel on Climate Change (IPCC). 2018. <https://www.ipcc.ch/> [Accessed 29<sup>th</sup> July 2019]
70. National Aeronautics and Space Administration (NASA). 2019. Climate change and global warming. <https://climate.nasa.gov/> [Accessed 1<sup>st</sup> January 2019]
71. Malcolm JR, Liu C, Neilson RP, Hansen L, Hannah LEE., 2006. Global warming and extinctions of endemic species from biodiversity hotspots. Conservation Biology, 20(2):538-548.
72. Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F. 2012. Impacts of climate change on the future of biodiversity. Ecology Letters, 15(4):365-377.
73. Rohr JR, Raffel TR, Romanisc JM. 2009. The missing link: Climate is associated with chytrid-related amphibian declines and affects frog susceptibility to chytridiomycosis. 94<sup>th</sup> Annual Meeting of the Ecological Society of America. August 2-9, 2009. Albuquerque, New Mexico.
74. Rohr JR, Raffel TR, Romansic JM, McCallum H, Hudson PJ. 2009. Evaluating the links between climate, disease spread, and amphibian declines. Proceedings of the National Academy of Sciences of the United States, 105(45):17436-17441.
75. Web T, Bartlein PJ. 1992. Global climate changes during the last 3 million years: Climate controls and biotic responses. Annual Reviews of Ecology and Systematics. 23:141-173.
76. Wang J, Zhang H, Xie F, Wei G, Jiang J. 2017. Genetic bottlenecks of the wild Chinese giant salamander in karst caves. Asian Herpetological Research, 8(3):174-183.
77. Dundee HA, Dundee DS. 1965. Observations on the systematics and ecology of *Cryptobranchus* from the Ozark Plateaus of Missouri and Arkansas. Copeia, 1965(3):369-370.
78. Terrell K, Quintero RP, Murray S, Kleopfer JB, Murphy JB, Evans MJ, Nissen BD, Gratwicke B. 2013. Cryptic impacts of temperature variability on amphibian immune function. Journal of Experimental Biology, 216(22):4204-4211.
79. Cava ZA, McMillan AM, Pennuto CM, Warren II RJ. 2018. Hellbender prey preference is superseded by native and nonnative prey behavior. Journal of Herpetology, 52(2):162-170.

80. Hayes TB, Falso P, Gallipeau S, Stice M. 2010. The cause of global amphibian declines: a developmental endocrinologist's perspective. *Journal of Experimental Biology*, 213:921-933.
81. Hayes TB, Case P, Chui S, Chung D, Haeffele C, Haston K, Lee M, Mai VP, Marjua Y, Parker J, Tsui M. 2006. Pesticide mixtures, endocrine disruption, and amphibian declines: Are we underestimating the impact?. *Environmental Health Perspectives*, 114 (suppl. 1):40-50.
82. Bohme M, Vasilyan D, Winklhofer M. 2012. Habitat tracking, range dynamics and palaeoclimatic significance of Eurasian giant salamanders (Cryptobranchidae) - indications for elevated Central Asian humidity during Cenozoic global warm periods. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 342-343:64-72.
83. Zhang Z, Mammola S, Liang Z, Capinha C, Wei Q, Wu Y, Zhou J, Wang C. 2020. Future climate change will severely reduce habitat suitability of the Critically Endangered Chinese giant salamander. *Freshwater Biology*. 00:1–10.
84. Roark S. 2016. Ecological Niche Modeling of the North American Giant Salamander: Predicting Current and Future Potential Distributions and Examining Environmental Influences. Electronic Theses and Dissertations. Paper 3072. <https://dc.etsu.edu/etd/3072>
85. Riddell EA, Odom JP, Damm JD, Sears MW. Plasticity reveals hidden resistance to extinction under climate change in the global hotspot of salamander diversity. *Science Advances*, 4(7):eaar5471.
86. Huey RB, Kearney MR, Krockenberger AK, Holtum JAM, Jess M, Williams SE. 2012. Predicting organismal vulnerability to climate warming: Roles of behaviour, physiology and adaptation. *Philosophical Transactions of the Royal Society of London. B Biological Sciences*, 367:1665–1679.
87. Chen S, Cunningham A.A, Wei G, Yang J, Liang Z, Wang J, Wu M, Yan F, Xiao H, Harrison X.A, Pettoelli N, Turvey S.T. 2018. Determining threatened species distributions in the face of limited data: Spatial conservation prioritization for the Chinese giant salamander (*Andrias davidianus*). *Ecology and Evolution*. 8:3098-3108.
- 87a. Zhao T, Zhang W, Zhou J, Zhao C, Liu X, Liu Z, Shu G, Wang S, Li C, Xie F, Chen Y, Jiang J. 2020. Niche divergence of evolutionary significant units with implications for repopulation programs of the world largest amphibians. *Science of the Total Environment*, 738:140269-
88. Smithsonian 2016. Will global warming be hell on the hellbender? study aims to find out.” <http://insider.si.edu/2011/07/hellbender/> [Accessed: 29th December 2018]
89. Wikipedia. 2020. Technical Fix [Accessed: 19th September 2020]
90. Antwis RE, Browne RK. 2009. Ultraviolet radiation and Vitamin D3 in amphibian health, behaviour, diet and conservation. *Comparative Biochemistry and Physiology-part B*, 154(2):184-190.
91. Wakabayashi F, Kuwabara K, Ashikaga K, Inoue T, Suzuki N, Kobara J. 1976. The study on the protection of Japanese giant salamander, *Megalobatrachus j. japonicus*, in Hiroshima Prefecture. (3) The Relation between the breeding migration and the weir. *Journal of Japanese Gardens and Aquariums*, 18(2):31-36.
92. Taguchi Y, Natuhara Y. 2009. Requirements for small agricultural dams to allow the Japanese giant salamander (*Andrias japonicus*) to move upstream. *Japanese Journal of Conservation Ecology*, 14 (2):165-172.
93. Song MT. 1994. Research on feeding habits of Chinese giant salamander. *Chinese Journal of Zoology*, 29(4):38-41.
94. Luo Q, Wang C, Xie W. 2012. Existing problems and countermeasures for developing industry of *Andrias davidianus* in Zhangjiajie City. *Hunan Agricultural Sciences*, 2012-19.
95. Matsui M, Tominaga A. 2007. A survey by AFLP of genetic diversity in the Japanese giant salamander aiming conservation of local populations. *Ecology and Civil Engineering*, 10(2):175-184.
96. Tochimoto T, 1995. Ecological studies on the Japanese Giant Salamander, *Andrias japonicus*, in the Ichi River in Hyogo Prefecture. 10. An attempt to rebuild spawning places along the river. *Journal of Japanese Association of Zoological Gardens and Aquariums*, 37:7-12.
97. Tochimoto T. 1996. Ecological studies on the Japanese giant salamander, *Andrias japonicus*, in the Ichi River in Hyogo Prefecture. *Journal of the Japanese Association of Zoos and Aquaria*, 38(2):33-39.
98. Takahashi Y, Rashid MH, Sarkar A, Asaeda T, Isono M, Omura T, Koga K. 2016. Use of ladderways in fragmented habitat to aid the movement of Japanese giant salamander (*Andrias japonicus*). *International Journal of River Basin Management*, 14(2):233-241
99. Humphries WJ. 2005. *Cryptobranchus alleganiensis* displacement by a flood. *Herpetological Review*, 36(4):428.
100. Humphries WF, Pauley TK. 2005. Life History of the Hellbender, *Cryptobranchus alleganiensis*, in a West Virginia stream. *The American Midland Naturalist*, 154(1):135-142.
101. Ettling JA, Wanner MD, Pedigo AS, Kenkel JI, Noble KR, Briggler JT. 2017. Augmentation programme for the endangered Ozark hellbender *Cryptobranchus alleganiensis bishopi* in Missouri. *International Zoo Yearbook*, 51:1-8.
102. Smith PW, Minton Jr. SA. 1957. A distributional summary of the herpetofauna of Indiana and Illinois. *The American Midland Naturalist*, 58:341-351.
103. Nickerson MA, Mays CE. 1973. The hellbenders: North American “giant salamanders”. *Publications in Biology and Geology, Milwaukee Public Museum*, 1:1-106.
104. Williams RD, Gates JE, Hocutt CH, Taylor GJ. 1981. The hellbender: a non-game species in need of management. *Wildlife Society Bulletin*, 9:94-100.
105. Trauth SE, Wilhide JD, Daniel P. 1992. Status of the Ozark hellbender, *Cryptobranchus bishopi* (Urodela: Cryptobranchidae), in the Spring River, Fulton County, Arkansas. *Proceedings of the Arkansas Academy of Science*, 46:83-86.
106. Bodinof Jachowski CM, Millspaugh JJ, Hopkins WA. 2016. Current land use is a poor predictor of hellbender occurrence: why assumptions matter when predicting distributions of data-deficient species. *Diversity and Distributions*, 22(8):865-880.
107. Pugh MW, Hutchins M, Madritch MD, Gangloff MM. 2016. Land-use and local physical and chemical habitat parameters predict site occupancy by hellbender salamander’s water-quality, local habitat, and catchment land-use are informative predictors of hellbender site occupancy. *Hydrobiologia*, 770 (1):105-116.
108. Liu Y. 2006. Resource of Chinese giant salamander in Zhangjiajie and its conservative situation. First proseminar on breeding of Chinese giant salamander in Hunan Province. Changsha, 2006:68-73.
109. Pan Y, Wei G, Cunningham AA, Li S, Chen S, Milner-Gulland EJ, Turvey ST. 2015. Using local ecological knowledge to assess the status of the Chinese giant salamander *Andrias davidianus* in Guizhou Province, China. *Oryx*, [http://dx.doi.org/10,1017/S00306051340008310](http://dx.doi.org/10.1017/S00306051340008310)



110. Pan, Y. 2013. Comparing the status of Chinese giant salamanders between three nature reserves in Guizhou province using local ecological knowledge. MRes Ecology, Evolution and Conservation, Imperial College London (unpublished).
111. Tam KTK, Wong K, Lee FK, Ng M, Young C, Chang A, Gendron S. 2017. Chytrid Fungus and Ranavirus in Chinese Giant Salamanders: Routine Checks, Symptoms and Treatments. Zoological Operations and Conservation Division, Ocean Park Corporation, Hong Kong, China.
112. Kern WH Jr. 1984. The hellbender, *Cryptobranchus alleganiensis*, in Indiana. M.S. Thesis, Indiana State University, Terre Haute, Indiana viii, 48 p.
113. Lips KR, Diffendorfer J, Mendelson III JR, Sears MW. 2008. Riding the wave: Reconciling the roles of disease and climate change in amphibian declines. PLoS Biol, 6(3):e72
114. Cheng TL, Rovito SM, Wake DB, Vredenburg VT. 2011. Coincident mass extirpation of neotropical amphibians with the emergence of the infectious fungal pathogen *Batrachochytrium dendrobatidis*. Proceedings of the National Academy of Sciences of the United States of America 108(23):9502-9507.
115. Doherty-Bone TM, Gonwoue NL, Hirschfeld M, Ohst T, Weldon C, Perkins M, Kouete MT, Browne RK, Loader SP, Gower DJ, Wilkinson MW, Rödel MO, Penner J, Barej MF, Schmitz A, Plötner J, Cunningham AA. 2013. *Batrachochytrium dendrobatidis* in amphibians of Cameroon, including first records for caecilians. Diseases of Aquatic Organisms 102(3):187-104.
116. Lips KR, Burrowes PA, Mendelson III JR, Parra-Olea G. 2005. Amphibian population declines in Latin America: Widespread Population Declines, Extinctions, and Impacts. Biotropica, 37(2):222-226.
117. Scheele BC, Pasmans F, Skerratt LF, Berger L, Martel A, Beukem A, Acevedo AA, Burrowes PA, Carvalho T, Catenazzi A, De la Riva I, Fisher MC, Flechas SV, Foster CN, Frias-Alvarez P, Garner TWJ, Gratwicke B, Guayasamin JM, Hirschfeld M, Kolby JE, Kosch TA, La Marca E, Lindenmayer DB, Lips KR, Longo AV, Maneyro R, McDonald CA, Mendelson III J, Palacios-Rodriguez P, Parra-Olea G, Richards-Zawacki CL, Rodel M-O, Rovito SM, Soto-Azat C, Toledo LF, Voyles J, Weldon C, Whitfield SM, Wilkinson M, Zamudio KR, Canessa S. 2019. Amphibian fungal panzootic causes catastrophic and ongoing loss of biodiversity. Science, 363(6434):1459-1463.
118. O'Hanlon S, Rieux A, Farrer RA, Rosa GM. 2018. Recent Asian origin of chytrid fungi causing global amphibian declines. Science, 360(6389):621-627.
119. Goka K, Yokoyama J, Une Y, Kuroki T, Suzuki K, Nakahara M, Kobayashi A, Inaba S, Mizutani T, Hyatt AD. 2009. Amphibian chytridiomycosis in Japan: distribution, haplotypes and possible route of entry into Japan. Molecular Ecology, 18(23):4757-4774.
120. Zhu W, Bai C, Wang S, Sota-Azat C, Li X, Liu X, Li Y. 2014 Retrospective survey of museum specimens reveals historically widespread presence of *Batrachochytrium dendrobatidis* in China. Ecohealth, 11:241-250.
121. Quillet M, Mikaelian I, Pauli BD, Rodrigue J, Green DM. 2005. Historical evidence of widespread chytrid infection in North American amphibian populations. Conservation Biology, 19(5):1431-1440.
122. Bodinof-Jachowski CM, Briggler J, Duncan MC. 2011. Historic occurrence of the amphibian chytrid fungus *Batrachochytrium dendrobatidis* in hellbender *Cryptobranchus alleganiensis* populations from Missouri. Diseases of Aquatic Organisms, 96(1):1-7.
123. Seeley KE, D'Angelo M, Gowins C, Greathouse J. 2016. Prevalence of *Batrachochytrium dendrobatidis* in Eastern Hellbender (*Cryptobranchus alleganiensis*) populations in West Virginia, USA. Journal of Wildlife Diseases, 52(2):391-394.
124. Briggler JT, Larson KA, Irwin KJ. 2008. Presence of the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*) on hellbenders (*Cryptobranchus alleganiensis*) in the Ozark Highlands. Herpetological Review, 39:443-444.
125. Souza MJ, Gray MJ, Colclough P, Miller DL. 2012. Prevalence of *Batrachochytrium dendrobatidis* and ranavirus in eastern hellbenders (*Cryptobranchus alleganiensis*) in eastern Tennessee. Journal of Wildlife Diseases, 48(3):560-566.
126. Bales EK, Hyman OJ, Loudon AH, Harris RN, Lipps G, Chapman E, Roblee K, Kleopfer JD, Terrell KA. 2015. Pathogenic chytrid fungus *Batrachochytrium dendrobatidis*, but not *B. salamandrivorans*, detected on eastern hellbenders. PLoS ONE, 10:e0116405.
127. Tominaga A, Irwin KJ, Freake MJ, Suzuki K, Goka K. 2013. *Batrachochytrium dendrobatidis* haplotypes on the hellbender *Cryptobranchus alleganiensis* are identical to global strains. Diseases of Aquatic Organisms, 102(3):181-186.
128. Dusick A, Flatland B, Craig L, Ferguson S. 2017. What is your diagnosis? Skin scraping from a hellbender. Veterinary Clinical Pathology, 46(1):183-184.
129. Dean N, Ossiboff R, Bunting E, Schuler K, Rothrock A, Roblee K. 2016. The eastern hellbender and *Batrachochytrium dendrobatidis* (Bd) in western New York. 65th Annual International Conference of the Wildlife Disease Association, Cortland, NY.
130. Hardman RH, Sutton WB, Irwin KJ, McGinnity D, Reinsch SD, Freake MJ, Colclough P, Miller BT, da Silva Neto JG, Souza MJ, Fitzpatrick B, Miller DL. 2020. Geographic and individual determinants of important amphibian pathogens in Ozark and Eastern Hellbenders. Journal of Wildlife Diseases, doi: 10.7589/2019-08-203
131. Hiler WR, Wheeler BA, Trauth SE. 2005. Abnormalities in the Ozark hellbender, (*Cryptobranchus alleganiensis bishopi*) in Arkansas: A comparison between two rivers with a historical perspective. Journal of the Arkansas Academy of Science, 59(13):88-94.
132. Garmyn A, Van Rooij P, Pasmans F, Hellebuyck T, Van Den Broeck W, Haesebrouck F, Martel A. 2012. Waterfowl: potential environmental reservoirs of the chytrid fungus *Batrachochytrium dendrobatidis*. PLoS ONE, 7(4):e35038.
133. Kilburn VL, Ibáñez R, Green DM. 2011. Reptiles as potential vectors and hosts of the amphibian pathogen *Batrachochytrium dendrobatidis* in Panama. Diseases of Aquatic Organisms, 97(2):127-134.
134. Schloegel LM, Picco AM, Kilpatrick AM, Davies AJ, Hyatt AD, Daszak P. 2009. Magnitude of the US trade in amphibians and presence of *Batrachochytrium dendrobatidis* and ranavirus infection in imported North American bullfrogs (*Rana catesbeiana*). Biological Conservation, 12(7):1420-1426.
135. McMahon TA, Brannelly LA, Chatfield MW, Johnson PT, Joseph MB, McKenzie VJ, Richards-Zawacki CL, Venesky MD, Rohr JR. 2013. Chytrid fungus *Batrachochytrium dendrobatidis* has nonamphibian hosts and releases chemicals that cause pathology in the absence of infection. Proceedings of the National Academy of Science USA, 110(1):210-215.

136. Brannelly LA, McMahon TA, Hinton M, Lenger D, Richards-Zawacki CL. 2015. *Batrachochytrium dendrobatidis* in natural and farmed Louisiana crayfish populations: prevalence and implications. *Diseases of Aquatic Organisms*, 112(3):229-235.
137. Klocke B, Becker M, Lewis J, Fleisher RC, Mulet-Wolz CR, Rockwood L, Aguirre AA, Gratwicke B. 2017. *Batrachochytrium salamandrivorans* not detected in U.S. survey of pet salamanders. *Scientific Reports*, 7:13132.
138. Martel A, Spitzen-van der Sluijs A, Blooi M, Bert W, Ducatelle R, Fisher MC, Woeltjes A, Bosman W, Chiers K, Bossuyt F, Pasmans F. 2013. *Batrachochytrium salamandrivorans* sp. nov. causes lethal chytridiomycosis in amphibians. *Proceedings of the National Academy of Science*, 110(38):15325-15329.
139. Fitzpatrick LD, Pasmans F, Martel A, Cunningham AA. 2018. Epidemiological tracing of *Batrachochytrium salamandrivorans* identifies widespread infection and associated mortalities in private amphibian collections. *Scientific Reports*, 8:13845.
140. Martel A, Blooi M, Adriaensen C, Van Rooij P, Beukema W, Fisher MC, Farrer RA, Schmidt BR, Tobler U, Goka K, Lips KR, Mulet C, Zamudio KR, Bosch J, Lotters S, Wombwell E, Garner TW, Cunningham AA, Spitzen-van der Sluijs A, Salvidio S, Ducatelle R, Nishikawa K, Nguyen TT, Kolby JE, Van Bocxlaer I, Bossuyt F, Pasmans F. 2014. Recent introduction of a chytrid fungus endangers western palearctic salamanders. *Science*, 346:630-631.
141. Miller DL, Carter ED, Cusaac JPW, Hardman RH, Reinert LK, Williams LA, Rollins-Smith LA, Gray MJ. 2017. *Batrachochytrium salamandrivorans* pathology in susceptible species. 66th Annual International Conference of the Wildlife Disease Association, San Cristobal, Chiapas, Mexico.
142. Gray MJ, Miller DL, Hoverman JT. 2009. Ecology and pathology of amphibian ranaviruses. *Diseases of Aquatic Organisms*, 87(3):243-266.
143. Echaubard P, Leduc J, Pauli B, Chinchar VG, Robert J, Lesbarrères D. 2014. Environmental dependency of amphibian-ranavirus genotypic interactions: evolutionary perspectives on infectious diseases. *Evolutionary Applications*, 7(7):723-733.
144. Black Y, Meredith A, Price SJ. 2017. Detection and reporting of ranavirus in amphibians: evaluation of the roles of the world organisation for animal health and the published literature. *Journal of Wildlife Diseases* 53(3):509-520.
145. Claytor SC, Subramaniam K, Landrau-Giovannetti N, Chinchar VC, Gray MJ, Miller DL, Mavian C, Salemi M, Wisely S, Waltzek TB. 2017. Ranavirus phylogenomics: Signatures of recombination and inversions among bullfrog ranaculture isolates. *Virology*, 511:330-343.
146. Geng Y, Wang KY, Zhou ZY, Li CW, Wang J, He M, Yin ZQ, Lai WM. 2011. First Report of a Ranavirus associated with morbidity and mortality in farmed Chinese giant salamanders (*Andrias davidianus*). *Journal of Comparative Pathology*. 145(1):96-102.
147. Dong W, Zhang X, Yang C, An J, Qin J, Song F, Zeng W. 2011. Iridovirus infection in Chinese giant salamanders, China, 2010. *Emerging Infectious Diseases*, 17(12):2388-2389.
148. Jiang YL, Zhang M, Jing HL, Gao LY. 2013. Isolation and characterization of an iridovirus from sick giant salamander (*Andrias davidianus*). *Bing Du Xue Bao*, 27(3):274-282.
149. Meng Y, Ma J, Jiang N, Zeng LB, Xiao HB. 2014. Pathological and microbiological findings from mortality of the Chinese giant salamander (*Andrias davidianus*). *Arch Virology*, 159:1403-1412.
150. Zhou ZY, Geng Y, Liu XX, Ren SY, Zhou Y, Wang KY, Huang XL, Chen DF, Peng X, Lai WM. 2013. Characterization of a ranavirus isolated from the Chinese giant salamander (*Andrias davidianus*, Blanchard, 1871) in China. *Aquaculture*, 384-387:66-73.
151. Chen ZY, Li T, Gao XC, Wang CF, Zhang QY. 2018. Protective immunity induced by DNA vaccination against ranavirus infection in Chinese Giant Salamander *Andrias davidianus*. *Viruses*, 10(2):E52.
152. Cusaac JPW, Carter ED, Woodhams DC, Robert J, Spatz JA, Graham AW, Hill RD, McGinnity D, Bemis D, Hardman RH, Miller DL, Gray MJ. 2017. Interactive effects of a pesticide and emerging amphibian pathogen in eastern hellbenders. (*in review* )
153. Wang L, Wei Y, Yuan G, Dai M, Chen, X. 2012. Molecular characterization and virulence genes of *Aeromonas hydrophila* isolated from the Chinese giant salamander (*Andrias davidianus*). 3(4):303-309.
154. Wang Y, AO D, Wu Z. 2008. Empirical study of *Megalobatrachus davidianus* (Blanchard) infected *Aeromonas sobria*. *Acta Academiae Medicinae Zunyi*, 311:6-10.
155. Du Z-J, Duan Y-J, Huang X-L, Wang K-Y, Duan J, Deng Y-Q, Geng Y, Chen D-F. 2017. Pathological lesions of Chinese Giant Salamander (*Andrias davidianus*) infected by *Pseudomonas fluorescens*. *Chinese Journal of Zoology* 52 (3):537-542.
156. Zhao H, Zhang P, Chen JH, Fang S, Zhang HX. 2008. Isolation and identification of *Pseudomonas putida* from Chinese giant salamander. *Henan Fishery*, 4:40-41.
157. Gao Z, Zeng L, Meng Y, Liu X, Zhang B. 2012. Isolation and identification of *Citrobacter* from diseased giant salamander, *Andrias davidianus*. *Acta Microbiologica Sinica*, 52(2):169-176.
158. Wang L, Wei Y, Huang Y. 2013. *Morganella morganii* as a causative agent of disease in the Chinese giant salamander (*Andrias davidianus*). *Asian Herpetological Research*, 4 (3):197-201.
159. Ao D, Wu Z, Wang Y, Zhang D, Li X. 2010. Study on infection in *Andrias davidianus* caused by *Edwardsiella tarda*. *Sichuan Journal of Zoology*, 29(3):411-414.
160. Martinho F, Heatley JJ. 2011. Amphibian mycobacteriosis. *Veterinary Clinics of North America Exotic Animal Practice*, 15(1):113-119.
161. Gauthier DT, Rhodes MW. 2009. Mycobacteriosis in fishes: a review. *Veterinary Journal*, 180(1):33-47.
162. Li M, Wang J, Zhang J, Gu Z, Ling F, Ke X, Gong X. 2008. First report of two *Balantidium* species from the Chinese giant salamander, *Andrias davidianus*: *Balantidium sinensis* Nie 1935 and *Balantidium andianensis* n. sp. *Parasitology Research*, 102(2):605-611.
163. Davis AK, Hopkins WA. 2013. Widespread trypanosome infections in a population of eastern hellbenders (*Cryptobranchus alleganiensis alleganiensis*) in Virginia, USA. *Parasitol Res*, 112:453-456.
164. Hopkins WA, Fallon JA, Beck ML, Coe BH, Jachowski CMB. 2016. Haematological and immunological characteristics of eastern hellbenders (*Cryptobranchus alleganiensis alleganiensis*) infected and co-infected with endo- and ectoparasites. *Conservation Physiology*, 4(1):1-16.
165. Burgmeier NG, Unger SD, Meyer JL, Sutton TM, Williams RN. 2011. Health and habitat quality assessment for the eastern hellbender (*Cryptobranchus alleganiensis alleganiensis*) in Indiana, USA. *Journal of Wildlife Diseases*, 47(4):836-848.



166. Baba T, Hosoi M, Urabe M, Shimazu T, Tochimoto T, Hasegawa H. 2011. *Liolope copulans* (Trematoda: Digenea: Liolopidae) parasitic in *Andrias japonicus* (Amphibia: Caudata: Cryptobranchidae) in Japan: Life cycle and systematic position inferred from morphological and molecular evidence. *Parasitology International*, 60(2):181-192.
167. Hasegawa H, Doi T, Tochimoto T, Myata A. 2002. Parasitic helminths collected from the Japanese Giant Salamander, *Andrias japonicus* (Temminck, 1837) (Amphibia: Cryptobranchidae), in Japan. *Comparative Pathology*, 69 (1):33-42.
168. Hudson PJ, Dobson AP, Lafferty KD. 2006. Is a healthy ecosystem one that is rich in parasites? *Trends in Ecology and Evolution*, 21(7):381-385.
169. Hopkins WA, Moser WE, Garst DW, Richardson DJ, Hammond CI, Lazo-Wasem EA. 2014. Morphological and molecular characterization of a new species of leech (Glossiphoniidae, Hirudinida): Implications for the health of its imperiled amphibian host (*Cryptobranchus alleganiensis*). *ZooKeys*, 378:83-101.
170. DuRant SE, Hopkins WA, Davis AK, Romero LM. 2015. Evidence of ectoparasite-induced endocrine disruption in an imperiled giant salamander, the eastern hellbender (*Cryptobranchus alleganiensis*). *Journal of Experimental Biology*, 218:2297-2304.
171. Moser WE, Richardson DJ, Wheeler BA, Irwin KJ, Daniels BA, Trauth SE, Klemm DJ. 2008. *Placobdella cryptobranchii* (Rhynchobdellida: Glossiphoniidae) on *Cryptobranchus alleganiensis bishopi* (Ozark hellbender) in Arkansas and Missouri. *Comparative Parasitology*, 75(1):98-101.
172. Berven KA, Boltz RS. 2001. Interactive effects of leech (*Desserobdella picta*) infection on Wood Frog (*Rana sylvatica*) tadpole fitness traits. *Copeia*, 2001(4):907-915.
173. Egea-Serrano A, Relyea RA, Tejedo M, Torralva M. 2012. Understanding of the impact of chemicals on amphibians: a meta-analytic review. *Ecology and Evolution*, 2(7):1382-1397.
174. Solis ME, Bandeff JM, Huang YW. 2007. Hematology and serum chemistry of Ozark and eastern hellbenders (*Cryptobranchus alleganiensis*). *Herpetologica*, 63(3):285-292.
175. Huang CC, Xu Y, Briggler JT, McKee M, Nam P, Huang YW. 2010. Heavy metals, hematology, plasma chemistry, and parasites in adult hellbenders (*Cryptobranchus alleganiensis*). *Environmental Toxicology and Chemistry*, 29 (5):1132-1137.
176. Unger DS. 2000. Sperm production and larval development in hellbenders (*Cryptobranchus alleganiensis alleganiensis* and *C. a. bishopi*): a comparison of stable and declining populations. Thesis. Southwest Missouri State University.
177. Lenkowski JR, Reed JM, Deininger L, McLaughlin KA. 2008. Perturbation of organogenesis by the herbicide atrazine in the amphibian *Xenopus laevis*. *Environmental Health Perspectives*, 116(2):223-230.
178. Kerby JL, Richards-Hrdlicka KL, Storfer A, Skelly DK. 2009. An examination of amphibian sensitivity to environmental contaminants: are amphibians poor canaries? *Ecological Letters*, 13(1):60-67.
179. Rohr JR, McCoy KA. 2009. A qualitative meta-analysis reveals consistent effects of atrazine on freshwater fish and amphibians. *Environmental Health Perspectives*, 118(1):20-32.
180. Forson DD, Storfer A. 2006. Atrazine increases ranavirus susceptibility in the tiger salamander, *Ambystoma tigrinum*. *Ecological Applications*, 16(6):2325-2332.
181. Burgmeier NG, Unger SD, Meyer JL, Sutton TM, Williams RN. 2011. Health and habitat quality assessment for the eastern hellbender (*Cryptobranchus alleganiensis alleganiensis*) in Indiana, USA. *Journal of Wildlife Diseases*, 47(4):836-848.
182. Annett R, Habibi HR, Hontela A. 2014. Impact of glyphosate and glyphosate-based herbicides on the freshwater environment. *Journal of Applied Toxicology*, 34 (5):458-479.
183. Yadav SS, Giri S, Singha U, Boro F, Giri A. 2013. Toxic and genotoxic effects of Roundup on tadpoles of the Indian skittering frog (*Euflyctis cyanophlyctis*) in the presence and absence of predator stress. *Aquatic Toxicology*, 132-133 :1-8.
184. Relyea RA. 2011. Amphibians are not ready for Roundup. Pages 267-300 in J. Elliott, C. Bishop, and C. Morrissey, editors. *Wildlife ecotoxicology—forensic approaches*. Springer, New York, New York, USA.
185. Jones DK, Hammond JI, Relyea RA. 2010. Roundup and amphibians: the importance of concentration, application time, and stratification. *Environmental Toxicology and Chemistry*, 29(9):2016-2025.
186. Narayan EJ. 2013. Non-invasive reproductive and stress endocrinology in amphibian conservation physiology. *Conservation Physiology*, 1(1):cot011.
187. Haya K. 1989 Toxicity of pyrethroid insecticides to fish. *Environmental Toxicology and Chemistry*, 8(5):381-391.
188. Mian LS, Mulla MS. 1992. Effects of pyrethroid insecticides on non-target invertebrates in aquatic ecosystems. *Journal of Agricultural Entomology*, 9(2):73-98.
189. Liess M, Schulz R. 1996. Chronic effects of short-term contamination with the pyrethroid insecticide fenvalerate on caddisfly *Limnephilus lunatus*. *Hydrobiologia*, 324:99-106.
190. Solis ME, Liu CC, Nam P, Niyogi DK, Bandeff JM, Huang Y. 2007. Occurrence of organic chemicals in two rivers inhabited by Ozark hellbenders (*Cryptobranchus alleganiensis bishopi*). *Archives of Environmental Contamination and Toxicology*, 53:426-434.
191. Romero LM, Dickens MJ, Cyr NE. 2009. The reactive scope model—A new model integrating homeostasis, allostasis, and stress. *Hormones and Behavior*, 55(3):375-389.
192. Silverman MN, Sternberg EM. 2012. Glucocorticoid regulation of inflammation and its functional correlates: from HPA axis to glucocorticoid receptor dysfunction. *Annals of the New York Academy of Sciences* 1261:55-63.
- 192a. Guimond RW, Hutchison VH. 1973. Aquatic respiration: an unusual strategy in the Hellbender *Cryptobranchus alleganiensis alleganiensis* (Daudin). *Science*, 182 (4118):1263-1265.
193. Caro T, Darwin J, Forrester T, Ledoux-Bloom C, Wells C. 2011. Conservation in the Anthropocene. *Conservation Biology*, 26(1):185-188.
- 193a. Nickerson CA, Ott CM, Castro SL, Garcia VM, Molina TC, Briggler JT, Pitt AL, Tavano JJ, Byram JK, Barrila J, Nickerson MA. 2011. Evaluation of microorganisms cultured from injured and repressed tissue regeneration sites in endangered giant aquatic Ozark Hellbender salamanders. *PLoS ONE*, 6:e28906.
194. Zylberberg M, Lee KA, Klasing KC, Wikelski M. 2013. Variation with land use of immune function and prevalence of avian pox in galapagos finches. *Conservation Biology*, 27:103-112.

- 194a. Hardman RH, Irwin KJ, Sutton WB, Miller DL. 2020. Evaluation of severity and factors contributing to foot lesions in endangered Ozark hellbenders, *Cryptobranchus alleganiensis bishopi*. *Frontiers in Veterinary Science*, 7:34. doi: 10.3389/fvets.2020.00034
195. Lindahl JF, Grace D. 2015. The consequences of human actions on risks for infectious diseases: a review. *Infection Ecology and Epidemiology*, 5:30048.
- 195a. Hernández-Gómez O, Kimble SJ, Briggler JT, Williams RT. 2017. Characterization of the cutaneous bacterial communities of two giant salamander subspecies. *Microbial Ecology*, 73(2):445-454.
196. Hiler WR, Wheeler BA, Trauth SE. 2013. The decline of the Ozark hellbender (*Cryptobranchus alleganiensis bishopi*) in the Spring River, Arkansas, USA. *Herpetological Conservation and Biology*, 8(1):114-121.
197. Hernández-Gómez O, Briggler JT, Williams RT. 2018. Influence of immunogenetics, sex and body condition on the cutaneous microbial communities of two giant salamanders. *Molecular Ecology*, 27(8):1915-1929.
198. Miller BT, Miller JL. 2005. Prevalence of physical abnormalities in eastern hellbender (*Cryptobranchus alleganiensis alleganiensis*) populations of middle Tennessee. *Southeastern Naturalist*, 4(3):513-520.
199. Etling JA, Wanner MD, Schuette CD, Armstrong SL, Pedigo AS, Briggler JT. 2013. Captive reproduction and husbandry of adult Ozark hellbenders, *Cryptobranchus alleganiensis bishopi*. *Herpetological Review*, 44(4), 605–610.
200. Zhang L, Kouba A, Wang Q, Zhao H, Jiang W, Willard S, Zhang H. 2014. The effect of water temperature on the growth of captive chinese giant salamanders (*Andrias davidianus*) reared for reintroduction: a comparison with wild salamander body condition. *Herpetologica*, 70(4):369-377.
201. Terrell KA, Quintero RP, Murray S, Kleopfer JD, Murphy JB, Evans MJ, Nissen BD, Gratwicke B. 2013. Cryptic impacts of temperature variability on amphibian immune function. *Journal of Experimental Biology*, 216(Pt 22):4204-4211.
202. Brand MD, Hill RD, Brenes R, Chaney J, Wilkes RP, Grayfer L, Miller DL, Gray MJ. 2016. Water temperature affects susceptibility to ranavirus. *EcoHealth*, 13(2):350-359
203. Sonn JM, Berman S, Richards-Zawacki CL. 2017. The influence of temperature on chytridiomycosis in vivo. *EcoHealth*, 14(4):762-770.
204. Meng Y, Yang Y, Zhang Y, Xiao H. 2008. A comparison of genetic diversity between wild and cultured populations of the Chinese giant salamander, *Andrias davidianus*, based on microsatellite analyses. *Biodiversity Science*, 16(6):533-538.
205. Fukumoto S, Ushimaru A, Minamoto T. 2015. A basin-scale application of environmental DNA assessment for rare endemic species and closely related exotic species in rivers: a case study of giant salamanders in Japan. *Journal of Applied Ecology*, doi: 10.1111/1365-2664.12392
206. Gall BG. 2008. MSc Thesis. Predator-prey interactions between hellbenders (*Cryptobranchus alleganiensis alleganiensis* and *C. a. bishopi*) and native and non-native fishes. Missouri State University, Missouri, USA.
207. Cava ZA, McMillan AM, Pennuto CM, Warren II RJ. 2018. Hellbender prey preference is superseded by native and nonnative prey behavior. *Journal of Herpetology*, 52(2):162-170.
208. United States Fish Wildlife Service. 2011. Endangered and threatened wildlife and plants; endangered status for the Ozark hellbender salamander. *Federal Register*, 76: 61956–61978.
209. Unger S, Williams RM. 2017. Genetic confirmation of filial cannibalism in North America's giant salamander, the Eastern hellbender *Cryptobranchus alleganiensis alleganiensis*. *Ethology Ecology & Evolution, Forum* 5:1-7. DOI: 10.1080/03949370.2017.1342696
210. Ota H. 2000. Population Ecology. In: Current status of the threatened amphibians and reptiles of Japan. 42:5-9.
211. Purvis K. 2010. New Arrivals at the Zoo: Japanese Giant Salamanders. *SmithsonianMag*. <https://www.smithsonianmag.com/smithsonian-institution/new-arrivals-at-the-zoo-japanese-giant-salamanders-109957/> [Accessed: 28th December 2018]
212. Yu X. 2015. Environmental effects under China's Western Development Strategy: a case study in the Beipan River basin, Guizhou. *International Journal of Environmental Studies*, 72(1):132-145.
213. Liang G. 2007. Chinese giant salamander captive breeding models in Shaanxi Province and primary assessment. *Journal of Economic Animal*, 11(4):234-237.
214. Briggler JT, Ackerson JR. 2012. Construction and use of artificial shelters to supplement habitat for hellbenders (*Cryptobranchus alleganiensis*). *Herpetological Review*, 43(3):412-416.
215. Wikipedia- Zoos [Accessed: 19<sup>th</sup> September 2020]
216. Conde DA, Colchero F, Gusset M, Pearce-Kelly P, Byers O, Flesness N, Browne RK, Jones OR. 2013. Zoos through the lens of the IUCN Red List: A global metapopulation approach to support conservation breeding programs. *PLoS ONE*, 11;8(12):e80311. doi: 10.1371/journal.pone.0080311.
217. Frankham R. 2008. Genetic adaptation to captivity in species conservation programs. *Molecular Ecology*, 17(1):325-333.
218. Williams S.A., Hoffman E.A. 2009. Minimizing genetic adaptation in captive breeding programs: A review. *Biological Conservation*, 142:2388–2400.
219. Schad K. Amphibian population management guidelines. In: Amphibian Ark. Amphibian population management workshop; December 10-11. San Diego, CA, USA: Amphibian Ark; 2007. p. 31.
220. Browne RK, Silla AJ, Upton R, Della-Togna G, Marce-Greaves R, Shishova NV, Uteshev VK, Proano B, Perez OD, Mansour N, Kaurova SA, Gakhova EN, Cosson J, Dzyuba B, Kramarova LI, McGinnity D, Gonzalez M, Clulow J. Clulow S. 2019. Sperm collection and storage for the sustainable management of amphibian biodiversity. *Theriogenology*, 133:187e200
221. Clulow J, Clulow S. 2016. Cryopreservation and other assisted reproductive technologies for the conservation of threatened amphibians and reptiles: bringing the ARTs up to speed. *Reproduction Fertility and Development*, 28(8):1116–1132.
222. Scientific American. 2012. Endangered eastern hellbenders bred in captivity for first time. <https://blogs.scientificamerican.com/running-ponies/endangered-eastern-hellbenders-bred-in-captivity-for-first-time/> [Accessed: 28<sup>th</sup> December 2019]
223. Peng L, Xiao Y, Liu Y. 2011. Effect of cryopreservation and short-term storage of Chinese giant salamander sperm. *Acta Hydrobiologica Sinica*, 2011-02
224. Zhao H, Zhang H, Wang Q, Chen J. 2011. Preliminary study on conservation of *Andrias davidianus* sperm *in vitro*. *Journal of Hydroecology*, 33(1):149-151.
225. Wu W. 2010. Study on technique of artificial propagation of Chinese giant salamander immigrated to the north. *Journal of Anhui Agricultural Sciences*, 2010-2014.
226. Luo QH. 2009. Habitat characteristics of Chinese giant salamander (*Andrias davidianus*) in Zhangjiajie, China. *Chinese Journal of Applied Ecology*, 20(7):1723-1730.



## Sustainable Management of Giant Salamanders

227. Kuwabara K, Inoue T, Wakabayashi F, Ashikaga K, Suzuki N, Kobara J. 1989. The study on the protection of Japanese giant salamander, *Megalobatrachus j. japonicus*, in Hiroshima Prefecture. (4) Observation on the reproductive behavior in the stream of Matsuzai-gawa. *Journal of Japanese Gardens and Aquariums*, 22(3):55-66.
228. Kobara J, Ashikaga K, Inoue T, Wakabayashi F, Kuwabara K, Suzuki N. 1980. The study on the protection of Japanese giant salamander, *Megalobatrachus j. japonicus*, in Hiroshima Prefecture. (5) The egg-laying in aquarium. *Journal of Japanese Gardens and Aquariums*, 22(3):67-71.
229. Kobara J. 1985. Japanese giant salamander. Doubutsu-sha, Tokyo. (in Japanese)
230. Tochimoto T. 2005. Ecology of Japanese giant salamander. In: *Directions in Batrachology*. Editor, Matsui M. Shokabo, Tokyo, Japan. pp 28-29
231. Aichi Prefecture. 2002. Red Data Book Aichi - Animals, Threatened Wildlife of Aichi Prefecture.
232. Okada S, Utsunomiya T, Okada T, Felix IZ, Ito F. 2008. Characteristics of Japanese giant salamander (*Andrias japonicus*) population in two small tributary streams in Hiroshima prefecture, western Honshu, Japan. *Herpetological Conservation and Biology*, 3(2):192-202.
233. In 2011, the Goellner Center for Hellbender Conservation at St. Louis Zoo first breed *Cryptobranchus* in a large, outdoor simulacrum of a natural stream <http://www.stlzoo.org/home/featurednews/hellbenderbreeding> [Accessed : 19th September 2020]
234. Bodinof CM, Briggler JT, Junge RE, Mong T, Beringer J, Wanner MD, Schuette CD, Ettling J, Millsbaugh JJ. 2012. Survival and body condition of captive-reared juvenile Ozark Hellbenders (*Cryptobranchus alleganiensis bishopi*) following translocation to the wild. *Copeia*, 2012:150-159.
235. Kraus BT, McCallen E, Williams RN. 2017. Evaluating the survival of translocated adult and captive-reared, juvenile Eastern Hellbenders (*Cryptobranchus alleganiensis alleganiensis*). *Herpetologica*, 73(4):271-276.
236. Ettling JA, Wanner MD, Pedigo AS, Kenkel JL, Noble KR. 2017. Augmentation programme for the endangered Ozark hellbender *Cryptobranchus alleganiensis bishopi* in Missouri. *International Zoo Yearbook*, (2017) 51: 1-8.
237. Yongjie W, Honglian C, WangFen1, Rao Fujiang W. 2017. Method in breeding and artificial propagation for Chinese giant salamanders (*Andrias davidianus*). *Journal of Marine Biology and Aquaculture*, 3(2):1-5.
238. Zhang L, Jiang W, Wang Q-J, Zhao H, Zhang H-X, Marcec RM, Willard ST, Kouba AJ. 2016. Reintroduction and Post-Release Survival of a Living Fossil: The Chinese Giant Salamander. *PLoS ONE* 11(6):e0156715. doi:10.1371/journal.pone.0156715
239. Doherty-Bone TM, Gonwouo NL, Hirschfeld H T, Ohst T, Weldon C, Perkins M, Kouete MT, Browne RK, Loader SP, Gower DJ, Wilkinson MW, Rödel MO, Penner J, Barej MF, Schmitz A, J. Plötner J, Cunningham AA. 2013. *Batrachochytrium dendrobatidis* in amphibians of Cameroon, including the first records of infected caecilian hosts. *Diseases of Aquatic Organisms*, 102(3):187-194.
240. Olson ZH, Briggler JT, Williams RN. 2013. An eDNA approach to detect eastern hellbenders (*Cryptobranchus a. alleganiensis*) using samples of water. *Wildlife Research*, 39 (7):629-636.
241. Nghiem LTP, Papworth SK, Lim FKS, Carrasco LR. 2016. Analysis of the capacity of Google Trends to measure interest in conservation topics and the role of online news. *PLoS ONE* 11(3): e0152802. doi:10.1371/journal.pone.0152802.
242. Browne RK, Janzen P, Bagaturov MF, van Houte DK. Amphibian keeper conservation breeding programs. *Journal of Zoological Research*, 2(1):29e46.
- 242a. Miller B, Conway W, Reading RP, Wemmer C, Wildt D, Kleiman D, Monfort S, Rabinowitz A. Armstrong B, Hutchins M. 2004. Evaluating the conservation mission of zoos, aquariums, botanical gardens, and natural history museums. *Conservation Biology*, 18(1):1-8.
243. Courchamp F, Jaric I, Albert C, Meinard Y, Ripple WJ, Chapron G. 2018. The paradoxical extinction of the most charismatic animals. *PLoS Biol*, 16(4):e2003997. <https://doi.org/10.1371/journal.pbio.2003997>
244. Lute ML, Attari SZ. 2016. Public preferences for species conservation: choosing between lethal control, habitat protection and no action. *Environmental Conservation*. doi:10.1017/S037689291600045X
245. Schlagloth R, Santamaria Dr.F, Golding B, Thomson H. 2018. Why is it important to use flagship species in community education? The koala as a case study. *Animal Studies Journal*, 7(1):127-148.
246. Albert C, Luque GM, Courchamp F. 2018. The twenty most charismatic species. *PLoS One*, 13(7): e0199149.
247. Landová E, Poláková P, Rádlová S, Janovcová M, Bobek M, Frynta D. 2018. Beauty ranking of mammalian species kept in the Prague Zoo: does beauty of animals increase the respondents' willingness to protect them? *The Science of Nature*, 105:69-73.
- 247a. Gippoliti S. 2019. Conservation breeding programs and refined taxonomy as a political tool for biodiversity conservation: the de Beaux and Durrell legacies. *Journal of Animal Diversity*, 1(1):26-33.
248. Meredith HMR. 2011. International Conservation Workshop for the Chinese Giant Salamander. Workshop Report 2010. Unpublished report to Ocean Park Conservation Foundation, Hong Kong, China.
249. Fazey I, Fischer J, Lindenmayer DB. 2005. What do conservation biologists publish? *Biological Conservation*, 124:63-73.

# Sustainable Management of Giant Salamanders



Chinese education campaigns for the sustainable management of Chinese *Andrias*. Images: Dai Q, Wang Y, Liang G. 2010. Conservation Status of Chinese Giant Salamander (*Andrias davidianus*) [60].