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Appendix 1

Resilience trinity: safeguarding ecosystem functioning and services across three different time horizons and decision contexts

Table A1. Resilience mechanisms described in literature and definitions given by the authors.

Mechanism	Reference	Definition
Adaptive capacity	Bernhardt and Leslie 2013	"ability of populations, communities and ecosystems to adapt […] through a combination of phenotypic plasticity, physiological responses, distributional shifts, rapid evolution of traits…"
Adaptive phenotypic plasticity	Oliver et al. 2015	"capacity of individuals to respond to environmental changes through flexible behavioral or physiological strategies […]"

Mechanism	Reference	Definition
Area of natural habitat cover at the landscape scale	Oliver et al. 2015	"larger areas of natural or seminatural habitat tend to provide a greater range and amount of resources, which promote higher species richness and larger population sizes […]. This […] is likely to mean greater genetic diversity and functional redundancy […]"
Biodiversity	Palumbi et al. 2009, Chapin et al. 2010, Griffiths and Philippot 2013, Thompson et al. 2014	"insurance hypothesis […] based on the intuitive idea that the probability of finding species able to adapt to adapt to changing conditions […] is greater in a more diverse ecosystem" (Griffiths and Philippot 2013)
Connectivity	Biggs et al. 2012, Bernhardt and Leslie 2013	"connections that promote stability and recovery at multiple scales of biological organization" (Bernhardt and Leslie 2013)
Dispersal ability	Bernhardt and Leslie 2013	"A species` ability to expand its range into more […] suitable habitats"
Diversity	Chapin et al. 2010, Biggs et al. 2012, Bernhardt and Leslie 2013, Desjardins et al. 2015	"Diversity among elements contributing to a particular ES can modify the effects of disturbance itself" (Biggs et al. 2012)
Dominant species	Sasaki et al. 2015	"if the dominant species is resilient to disturbances" it will maintain ES functioning despite disturbances
Negative feedbacks	Chapin et al. 2010, Gedan et al. 2011, Biggs et al. 2012, Conversi et al. 2014, Spears et al. 2015	"Negative […] feedbacks mechanisms contribute to maintain ecosystem state" (Conversi et al. 2014)

Mechanism	Reference	Definition
Functional diversity	Chapin et al. 2010	"As with economic systems, an ecosystem whose species have a narrow range of functional properties […] has a limited capacity to adjust to change (response diversity) and to sustain ecosystem services (functional diversity) compared with an ecosystem with greater functional and response diversity."
Functional redundancy	Biggs et al. 2012, Bernhardt and Leslie 2013, Griffiths and Philippot 2013, Desjardins et al. 2015, Oliver et al. 2015, Alexander et al. 2016	"when multiple species perform similar functions (…) the resistance of an ecosystem function will be higher if those species also have differing responses to environmental perturbations" (Oliver et al. 2015)
Genetic diversity	Palumbi et al. 2009, Thompson et al. 2014	"Resilience is an emergent ecosystem property conferred through biodiversity, related to genetic diversity, species diversity (…) and ecosystem diversity" (Thompson et al. 2014)
Genetic variability	Oliver et al. 2015	"Higher adaptive genetic variation increases the likelihood that genotypes that are tolerant to a given environmental perturbation will be present in a population"
Habitat diversity	Palumbi et al. 2009	"via conservation of species richness, genetic diversity,species composition, and habitat diversity – will help to maintain ecosystem integrity and stability."
Individual response	Griffiths and Philippot 2013	"Response of individual cells to disturbance which has consequences for the stability of the total community"

Mechanism	Reference	Definition
Intrinsic rate of population increase	Oliver et al. 2015	"Species with a high intrinsic rate of increase will recover more quickly from environmental perturbations […] or show resistance if this population reinforcement occurs during the perturbation"
Keystone species	Traill et al. 2010, Sasaki et al. 2015	"loss of the keystone species can lead to cascading effects" (Sasaki et al. 2015)
Landscape-heterogeneity	Thompson et al. 2014, Desjardins et al. 2015	"Resilience is an emergent ecosystem property conferred through biodiversity, (…), ecosystem diversity (heterogeneity and beta diversity) across a forest landscape" (Thompson et al 2014)
Landscape-level functional connectivity	Oliver et al. 2015	"Metapopulation theory suggests that populations in well-connected landscapes will persist better or re-colonize more rapidly [….] (the "rescue" effect)."
Learning	Chapin et al. 2010, Biggs et al. 2012	"The process of modifying existing or acquiring new knowledge, behaviors, skills, values, or preferences at individual, group, or societal levels" (Biggs et al. 2012)
Local environmental heterogeneity	Oliver et al. 2015	"spatial heterogeneity can enhance the resistance of ecosystem functions by: (i) facilitating the persistence of individual species under environmental perturbations by providing a range of resources and microclimatic refugia; and (ii) increasing overall species richness and, therefore, functional redundancy."

Mechanism	Reference	Definition
Modularity	Bernhardt and Leslie 2013	"It refers to compartimentalization of populations in space and time. (…). For example, where populations are too closely connected, severe disturbances to one population may affect all populations."
Network architecture	Griffiths and Philippot 2013	"A highly connected and nested architecture promotes community stability in mutualistic networks, whereas stability is increased in compartmented and weakly connected architectures in trophic networks. (…) "
Network interaction structure	Oliver et al. 2015	"In general, highly connected nested networks dominated by generalized interactions are less susceptible to cascading extinction effects and provide more resistant ecosystem functions."
Number of links in the food web	Bernhardt and Leslie 2013	"Ecosystems with few links are extremely sensitive to the removal of any given species, and many secondary extinctions may result. (…) in highly connected food webs the onset of secondary extinction is delayed."
Participation	Biggs et al. 2012	"active engagement of relevant stakeholders in SES management and governance" "Participation appears central to facilitating the collective action required to respond to disturbance (…)"

Mechanism	Reference	Definition
Polycentric governance systems	Chapin et al. 2010, Biggs et al. 2012	“a governance system with multiple, nested governing authorities at different scales.” “Polycentric structures confer modularity and functional redundancy”(Biggs et al. 2012)
Response diversity	Chapin et al. 2010, Bernhardt and Leslie 2013, Sasaki et al. 2015	“the diversity of responses to environmental change within and among species contributing to the same ecosystem function" (Elmqvist et al. 2003 cited in Bernhardt and Leslie 2013)
Sensitivity to environmental change	Oliver et al. 2015	“Individuals with [response] traits conferring reduced sensitivity to environmental change will confer higher resistance on ecosystem functions.”
Slow variables	Bennett et al. 2009, Biggs et al. 2012	“slow variables are usually related to regulating ecosystem services, and that the strength of regulating services can attenuate the impact of shocks on ecosystems.” (Bennett et al. 2009)
Species diversity	Traill et al. 2010, Thompson et al. 2014	“As a general rule, ecosystem function is most resilient to change from disturbance where species diversity, or key functional species groups are maintained” (Traill et al. 2010)
Species redundancy	Thompson et al. 2014	“Species in the same functional group often show different responses to disturbances (Laliberté et al. 2010), and hence the value of redundancy”

Mechanism	Reference	Definition
Strength of species interactions	Bernhardt and Leslie 2013	"Weakly interacting species stabilize community dynamics by dampening strong, potentially destabilizing consumer-resource interactions and facilitative interactions."
Tolerance of environmental stress and capacity to acclimate	Bernhardt and Leslie 2013	" (…) phenotypic plasticity may be the most important component of adaptive potential (…). "
Top predators	Thompson et al. 2014	"Loss of keystone predators can have large effects for a system through cascading effects of expansion of herbivore populations"

Table A2. Literature selection.

Source	Step	No. articles
Web of Science Search (05-09-2016)	TS=(review and resilience AND mechanism* AND ecosystem service*)	21
Literature	Excluded	10
	Added	4

Based on our previous literature research we added (Chapin et al. 2010; Biggs et al. 2012; Desjardins et al. 2015; Spears et al. 2015) to our search. We excluded publications that used "mechanism" in a different context than resilience or stated that resilience was an important conservation goal for a specific system but not how it should be conserved.

References

Alexander, S. et al. 2016. The relationship between ecological restoration and the ecosystem services concept. – Ecol. Soc. 21.

Bennett, E. M. et al. 2009. Understanding relationships among multiple ecosystem services. – Ecol. Lett. 12:1394–1404.

Bernhardt, J. R. and Leslie, H. M. 2013. Resilience to climate change in coastal marine ecosystems. – Annu. Rev. Mar. Sci. 5: 371–392.

Biggs, R. et al. 2012. Toward principles for enhancing the resilience of ecosystem services. – Annu. Rev. Environ. Resour. 37: 421–448.

Chapin, F. S. 3rd et al. 2010. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. – Trends Ecol. Evol. 25: 241–249.

Conversi, A. et al. 2014. A holistic view of marine regime shifts. – Phil. Trans. R. Soc. B 370: 20130279.

Desjardins, E. et al. 2015. Promoting resilience. – Q. Rev. Biol. 90: 147–165.

Elmqvist, T. et al. 2003. Response diversity, ecosystem change and resilience. – Front. Ecol. Environ. 1: 488–494.

Gedan, K. B. et al. 2011. Uncertain future of New England salt marshes. – Mar. Ecol. Prog. Ser. 434: 229–237.

Griffiths, B. S. and Philippot, L. 2013. Insights into the resistance and resilience of the soil microbial community. – FEMS Microbiol. Rev. 37: 112–129.

Laliberte, E. et al. 2010. Land-use intensification reduces functional redundancy and response diversity in plant communities. – Ecol. Lett. 13: 76–86.

Oliver, T. H. et al. 2015. Biodiversity and resilience of ecosystem functions. – Trends Ecol. Evol. 30: 673–684.

Palumbi, S. R. et al. 2009. Managing for ocean biodiversity to sustain marine ecosystem services. – Front. Ecol. Environ. 7: 204–211.

Sasaki, T. et al. 2015. Perspectives for ecosystem management based on ecosystem resilience and ecological thresholds against multiple and stochastic disturbances. – Ecol. Indic. 57: 395–408.

Spears, B. M. et al. 2015. Effective management of ecological resilience – are we there yet? – J. Appl. Ecol. 52: 1311–1315.

Thompson, I. D. et al. 2014. Biodiversity and ecosystem services: lessons from nature to improve management of planted forests for REDD-plus. – Biodivers. Conserv. 23: 2613–2635.

Traill, L. W. et al. 2010. Mechanisms driving change: altered species interactions and ecosystem function through global warming. – J. Anim. Ecol. 79: 937–947.