Appendix P

Comprehensive Bivalve Shellfish Survey Results

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The Bivalve Work Group polled bivalve experts on the relative vulnerability of different types of bivalves to five climate change parameters that are expected to change in the Delaware Estuary watershed. See Section 5.4 in Chapter 5 for an explanation of the survey method and Section 5.6 for interpretation of survey results. This appendix includes all major survey data collected.

Table P.1. The sample size for the survey was eleven people, and eight agreed to be listed.

Barb St. John White	USGS
Glen Nelson	USGS
John Kraeuter	Rutgers Haskin Shellfish Research Lab
William Lellis	USGS
Jeffrey Cole	USGS
Gregory F. Zimmerman	EnviroScience, Inc.
Angela Padeletti	PDE
Danielle Kreeger	PDE

P.1 Vulnerability Examined by Bivalve Group. Relative levels of vulnerability concern and response confidence are shown in bar plots for how five climate change drivers (x-axis) could affect six different aspects of bivalve fitness, and for three different bivalve groupings (non-tidal freshwater mussels, freshwater tidal bivalves, brackish/saltwater bivalves). For all plots, the y-axis is the relative weight derived from the risk assessment calculation. As explained in Section 5.5, each of the 18 plots (6 fitness metrics x 3 bivalve types) depicts relative vulnerability in blue bars and relative confidence in the projections in paired red bars.

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P.2 Vulnerability Contrasted Among Bivalve Groups. Relative levels of vulnerability and confidence were integrated (multiplied together) to derive a composite weighted vulnerability index, a unitless metric. For each of the six aspects of bivalve fitness, this vulnerability index is compared among the three bivalve groups in triplicate sets of bars. The five climate drivers are shown on the x-axes.

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P.3 Comparison of Effectiveness of Adaptation Options. For each of the five climate drivers, the projected feasibility and effectiveness of various adaptation tactics was evaluated for alleviating expected impacts. The three different groups of bivalves were compared in the three columns in each table.

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P.4 **Comparison of Ecosystem Service Changes.** For each of the five climate drivers, the projected ecosystem services changes were evaluated. The responses represent the net ecosystem gains or losses to each vulnerability due to the climate drivers. Reponses of 'no net change' or 'not sure' are not represented by these figures.

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P.1 Vulnerability Examined by Bivalve Group

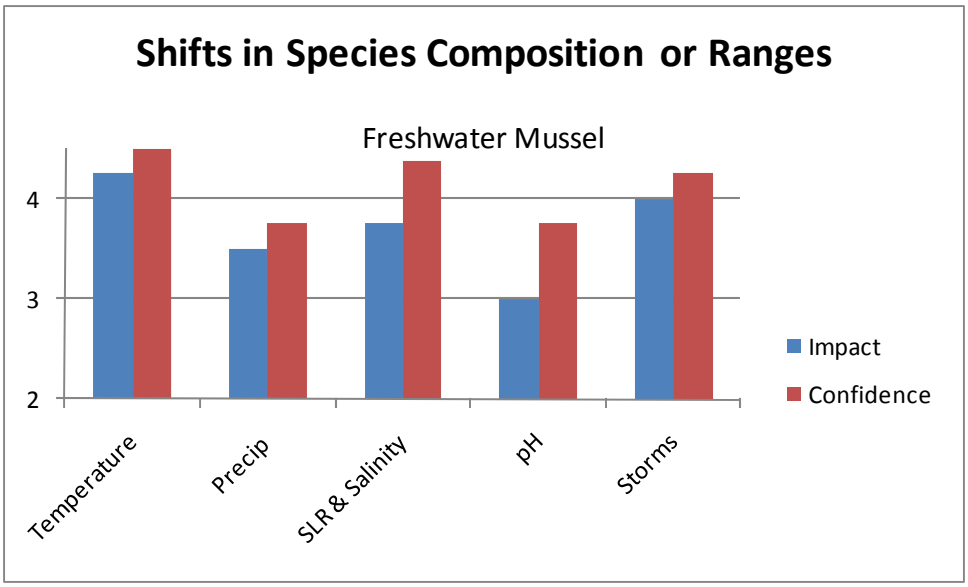

Figure P.1.1. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **shifts in species composition range** of freshwater mussels (blue) and relative confidence in these projections (red.)

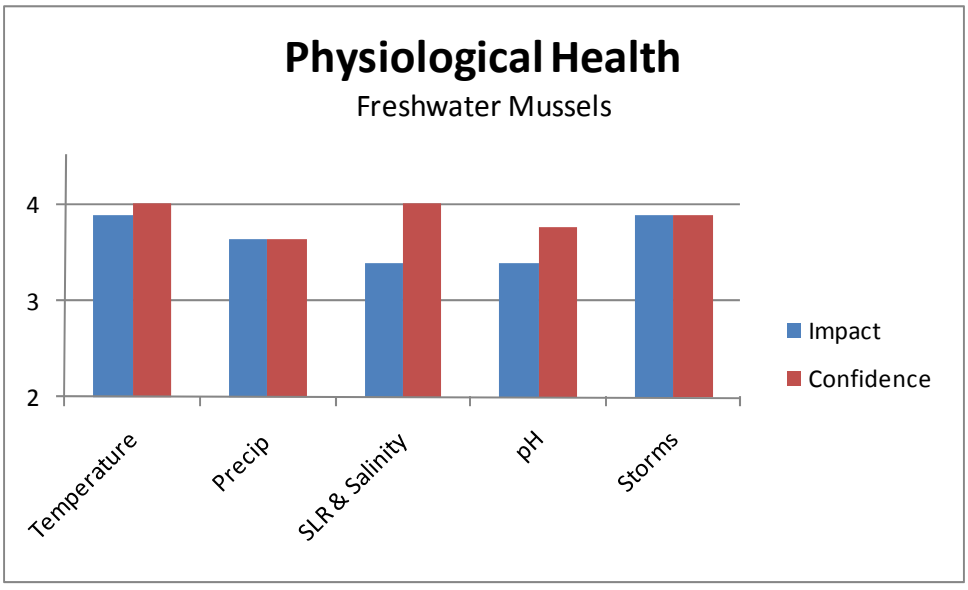

Figure P.1.2. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **physiological health** of freshwater mussels (blue) and relative confidence in these projections (red.)

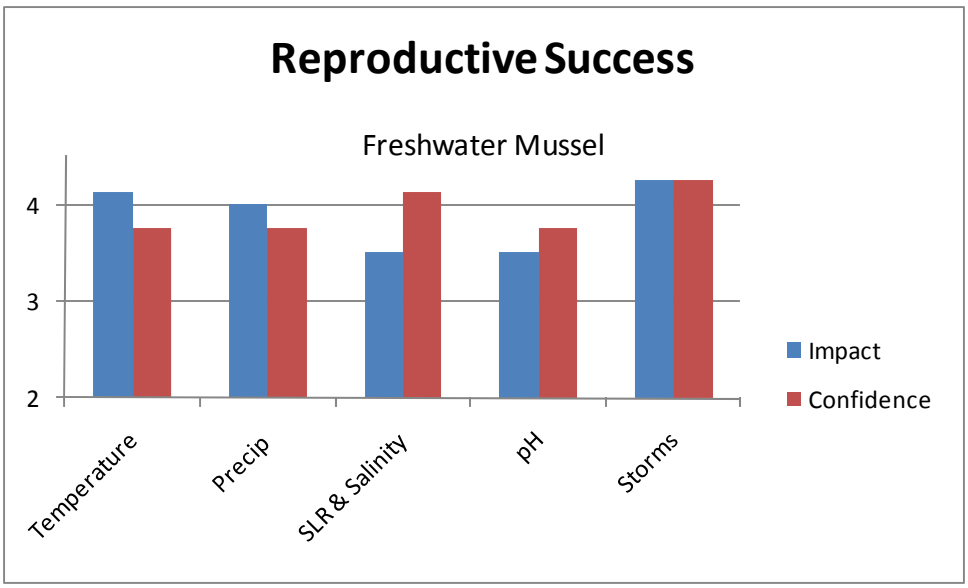

Figure P.1.3 Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **reproductive success** of freshwater mussels (blue) and relative confidence in these projections (red.)

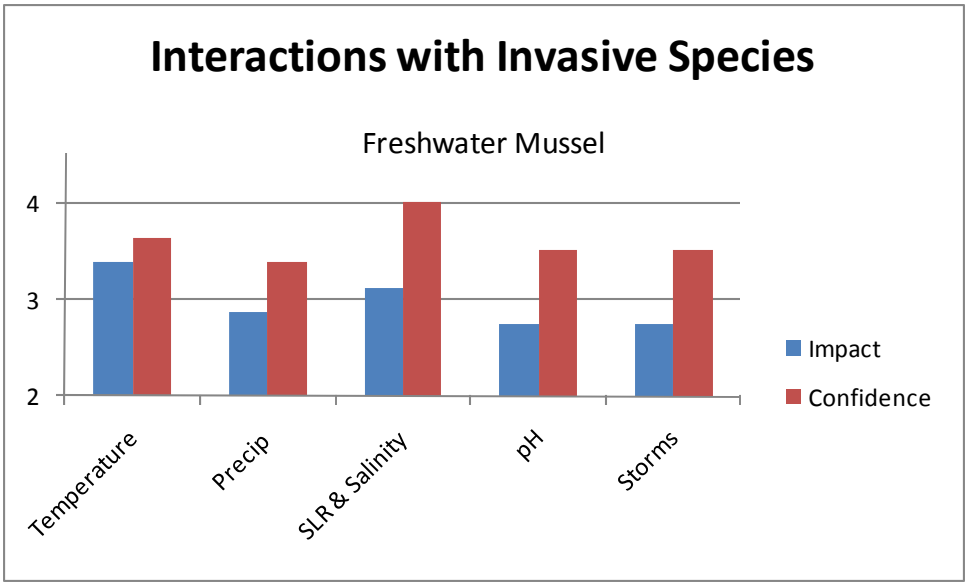

Figure P.1.4. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **interaction with invasive species** of freshwater mussels (blue) and relative confidence in these projections (red.)

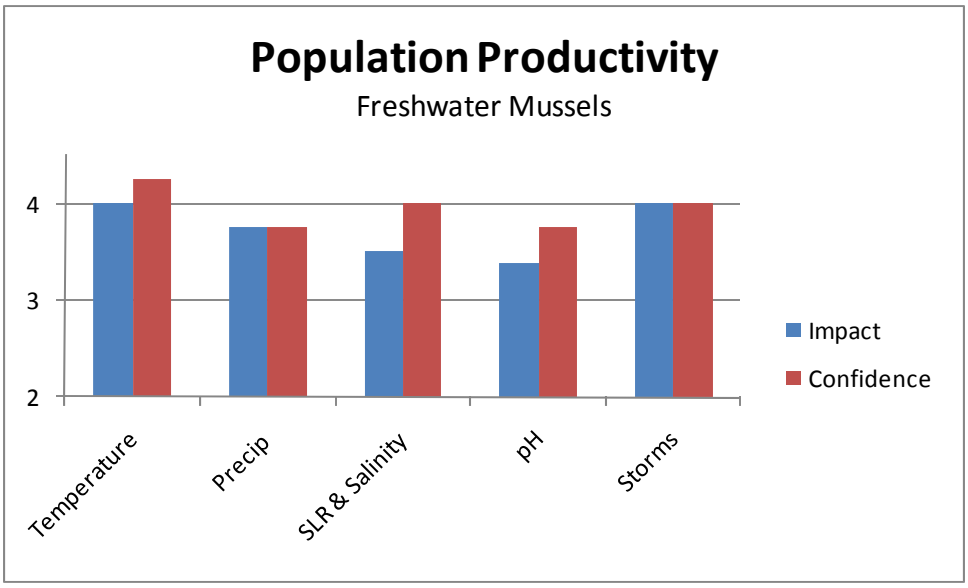

Figure P.1.5. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **physiological health** of freshwater mussels (blue) and relative confidence in these projections (red.)

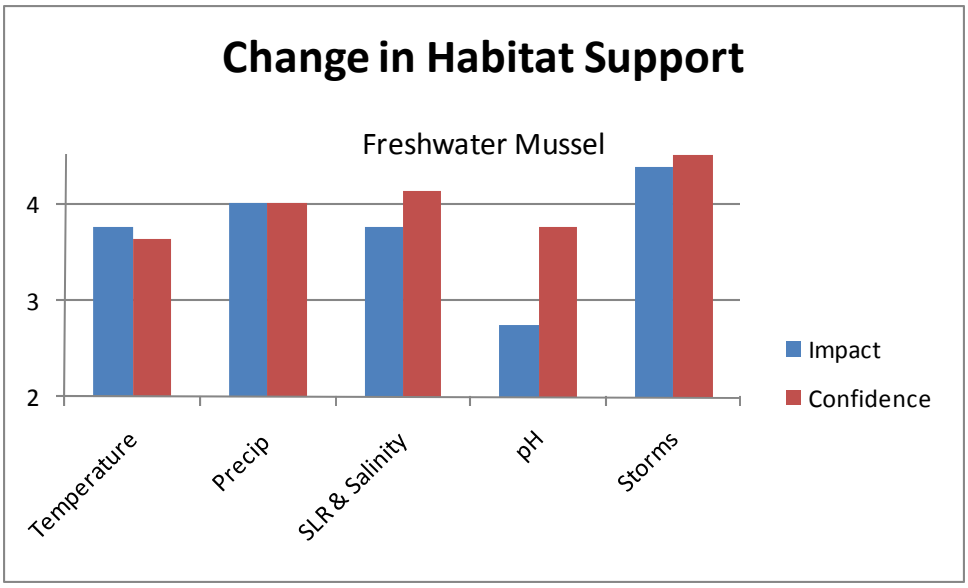

Figure P.1.6. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **change in habitat support** of freshwater mussels (blue) and relative confidence in these projections (red.)

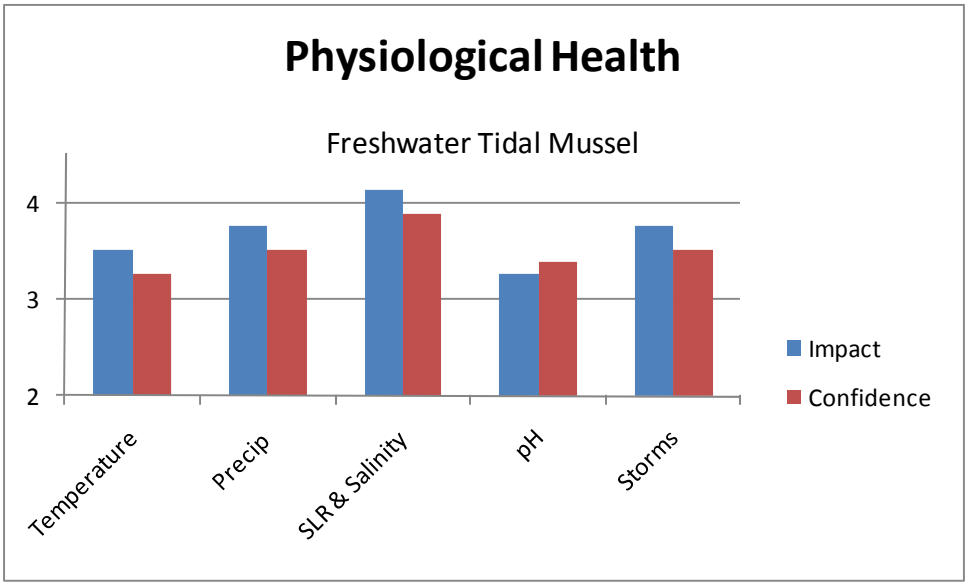

Figure P.1.7. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **physiological health** of freshwater mussels (blue) and relative confidence in these projections (red.)

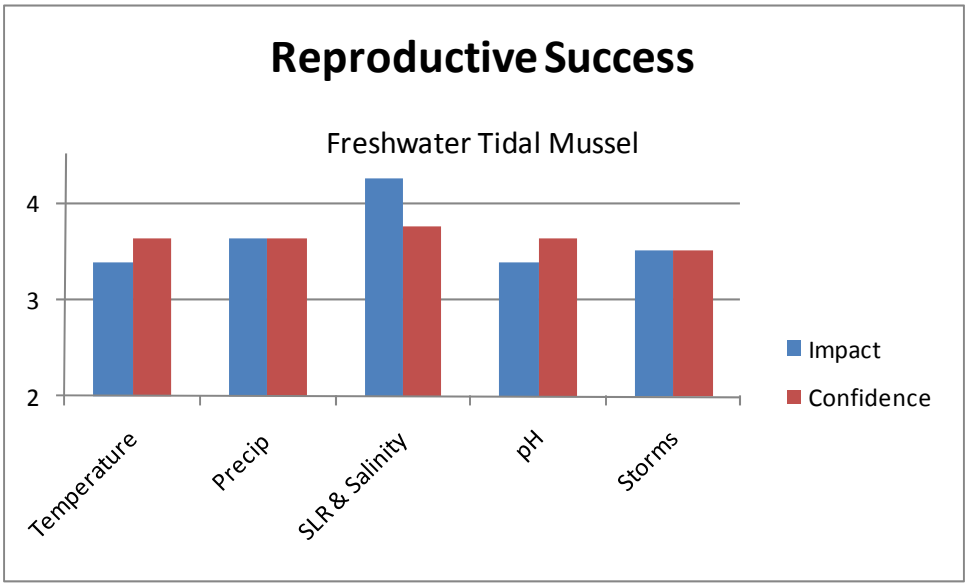

Figure P.1.8. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **reproductive success** of freshwater mussels (blue) and relative confidence in these projections (red.)

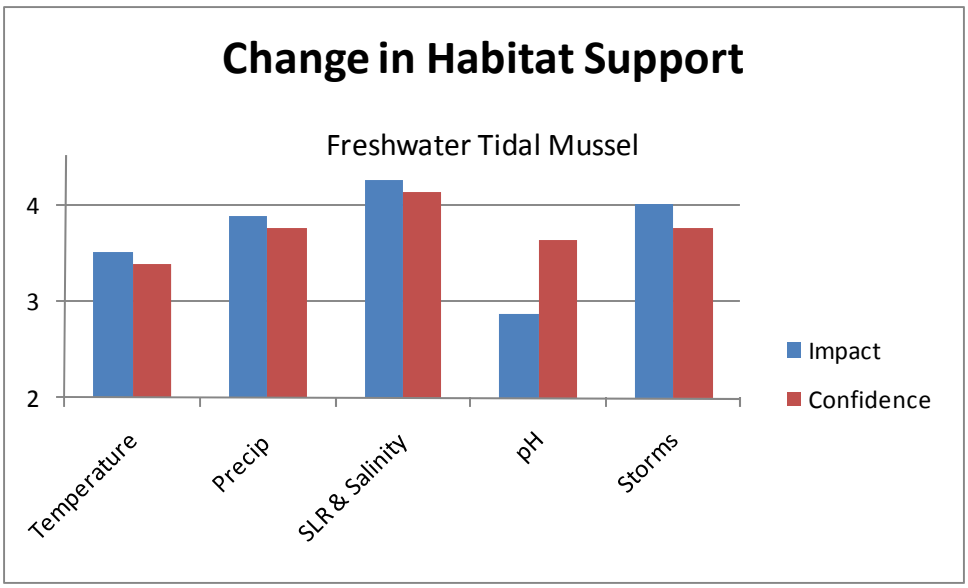

Figure P.1.9. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **change in habitat support** of freshwater mussels (blue) and relative confidence in these projections (red.)

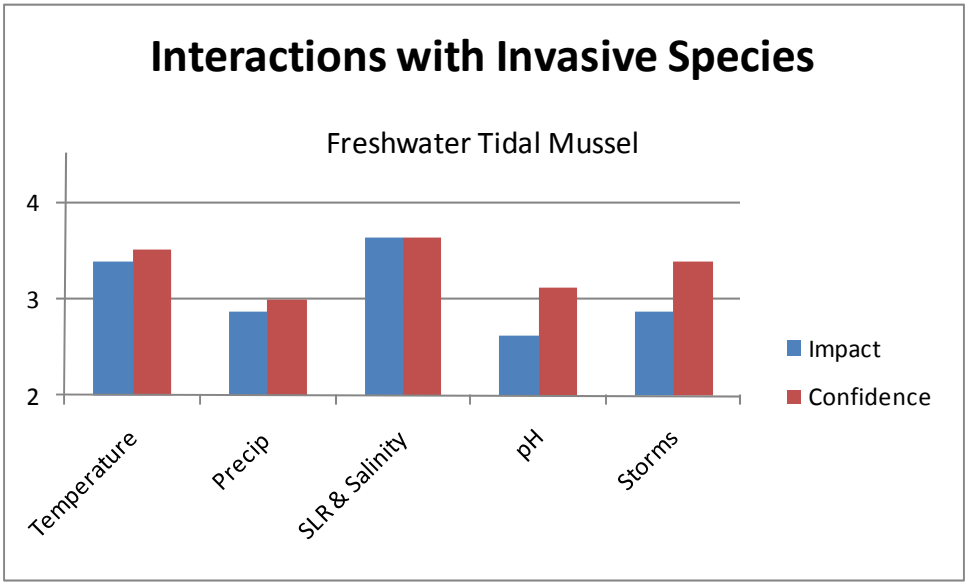

Figure P.1.10. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **interactions with invasive species** of freshwater mussels (blue) and relative confidence in these projections (red.)

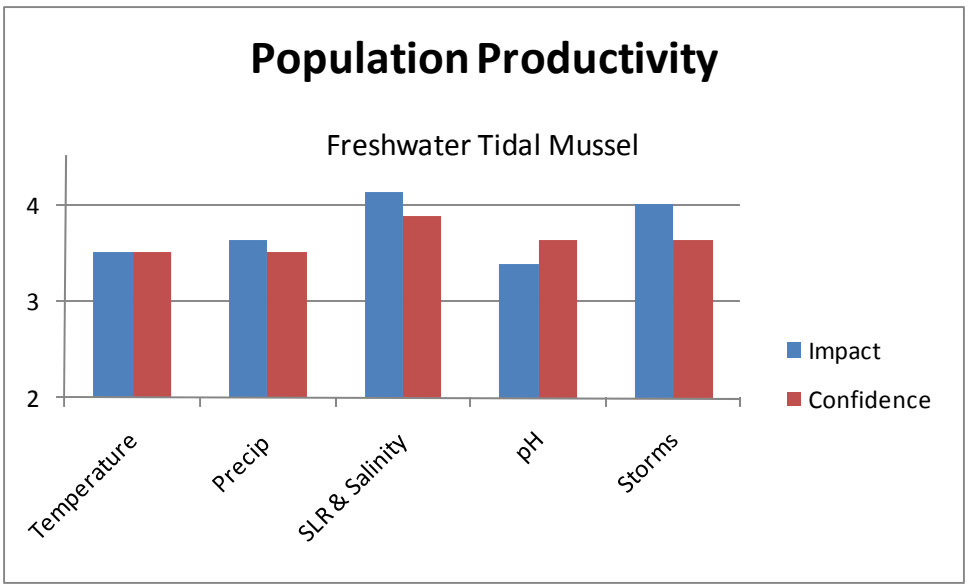

Figure P.1.11. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **population productivity** of freshwater mussels (blue) and relative confidence in these projections (red.)

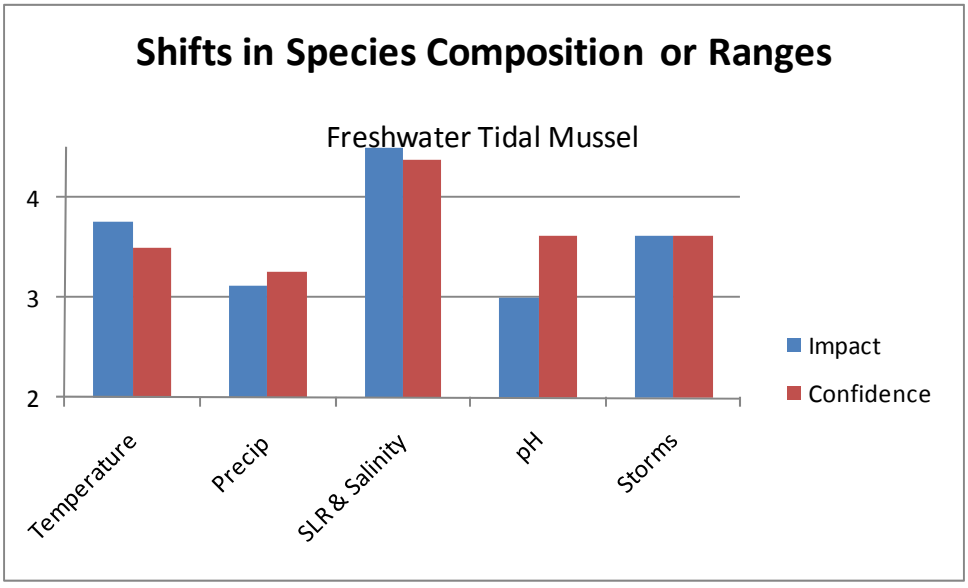

Figure P.1.12. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **shifts in species composition or ranges** of freshwater mussels (blue) and relative confidence in these projections (red.)

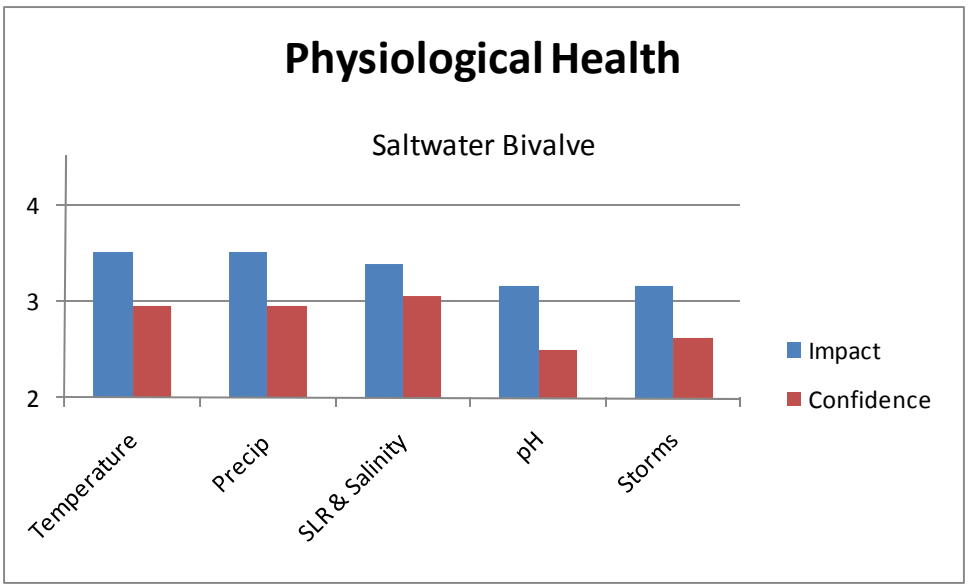

Figure P.1.13. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **physiological health** of freshwater mussels (blue) and relative confidence in these projections (red.)

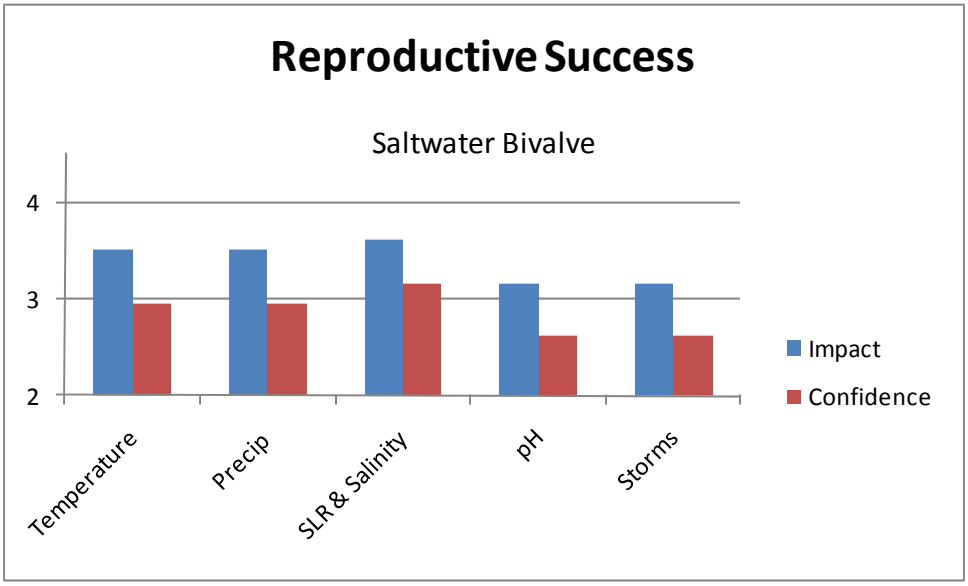

Figure P.1.14. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **reproductive success** of freshwater mussels (blue) and relative confidence in these projections (red.)

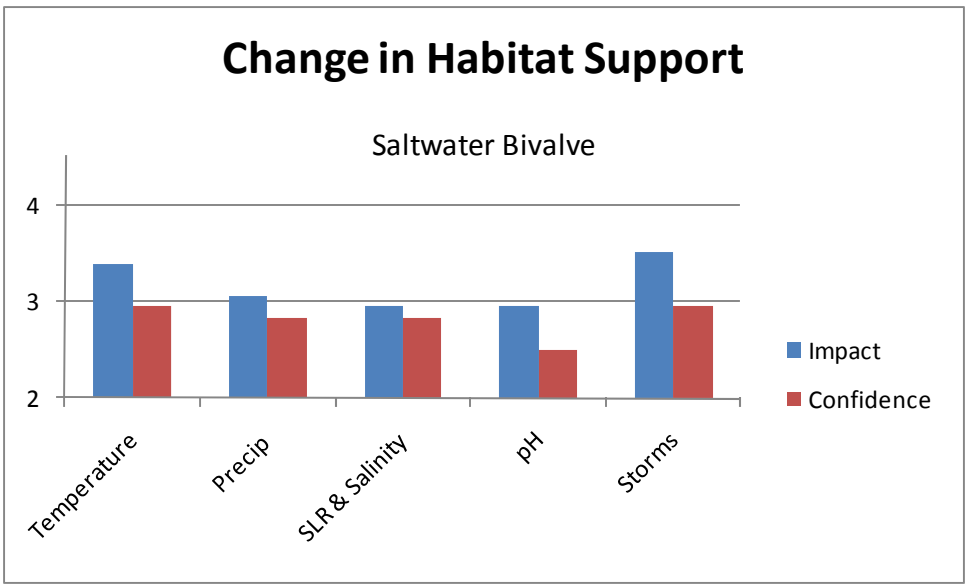

Figure P.1.15. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **change in habitat support** of freshwater mussels (blue) and relative confidence in these projections (red.)

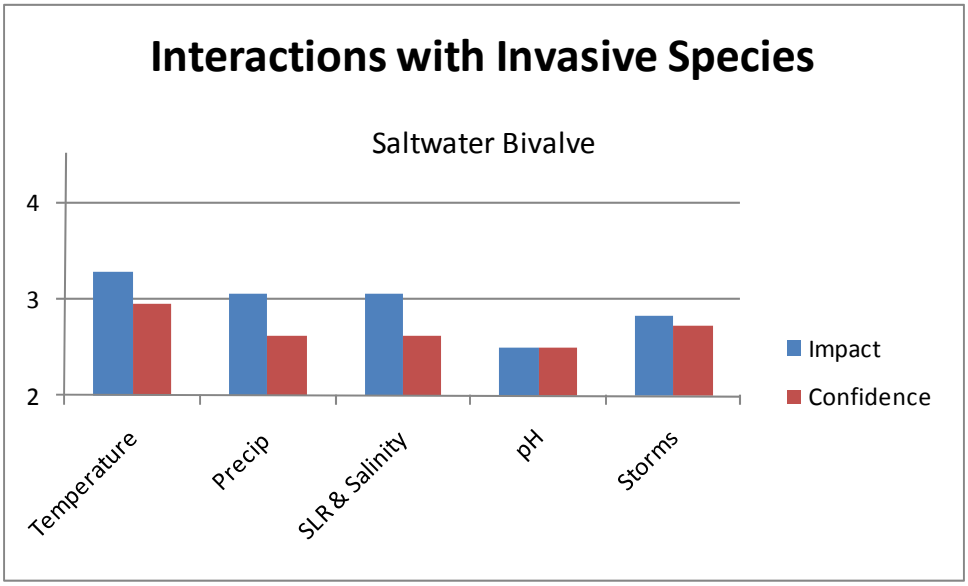

Figure P.1.16. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **interactions with invasive species** of freshwater mussels (blue) and relative confidence in these projections (red.)

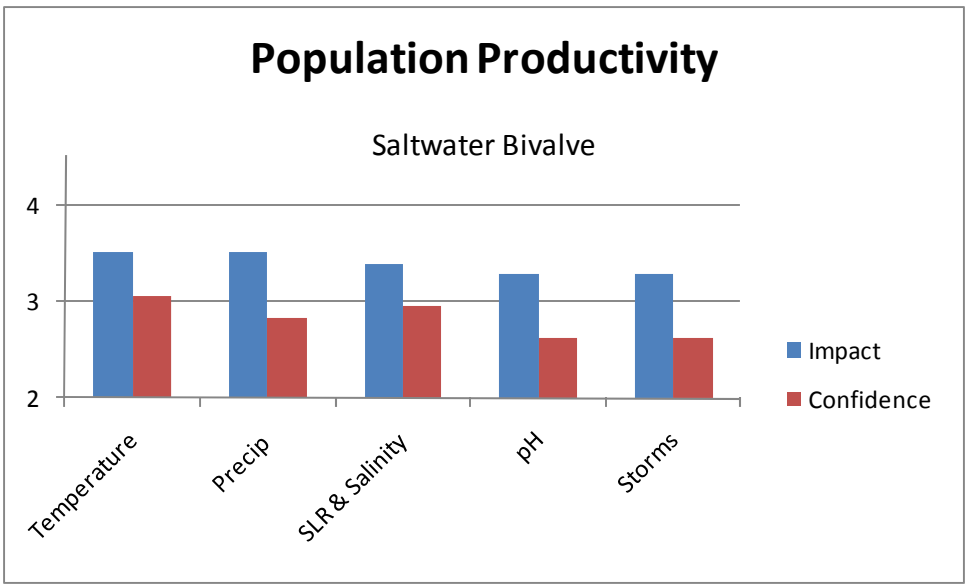

Figure P.1.17. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **population productivity** of freshwater mussels (blue) and relative confidence in these projections (red.)

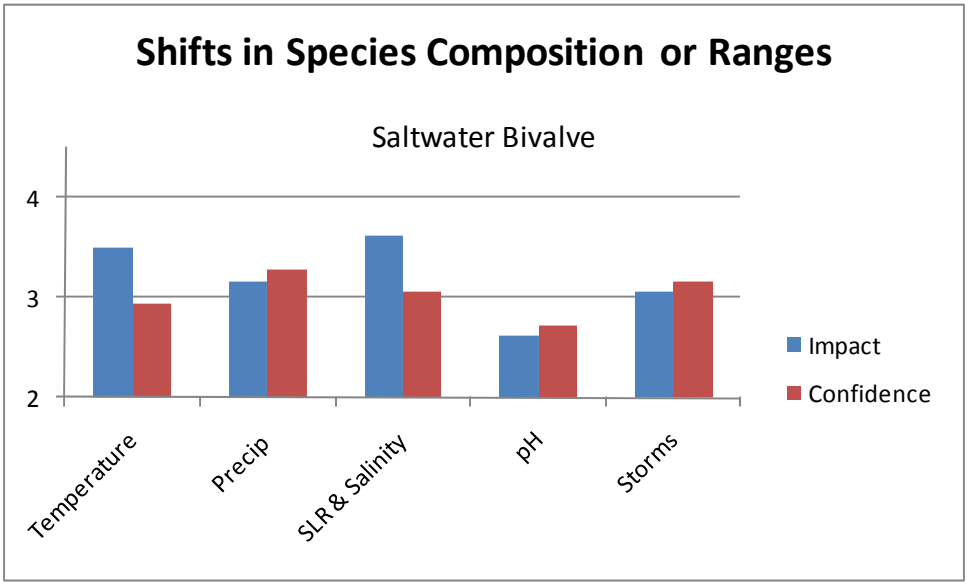

Figure P.1.18. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **shifts in species composition or ranges** of freshwater mussels (blue) and relative confidence in these projections (red.)

P.2 Vulnerability Contrasted Among Bivalve Groups

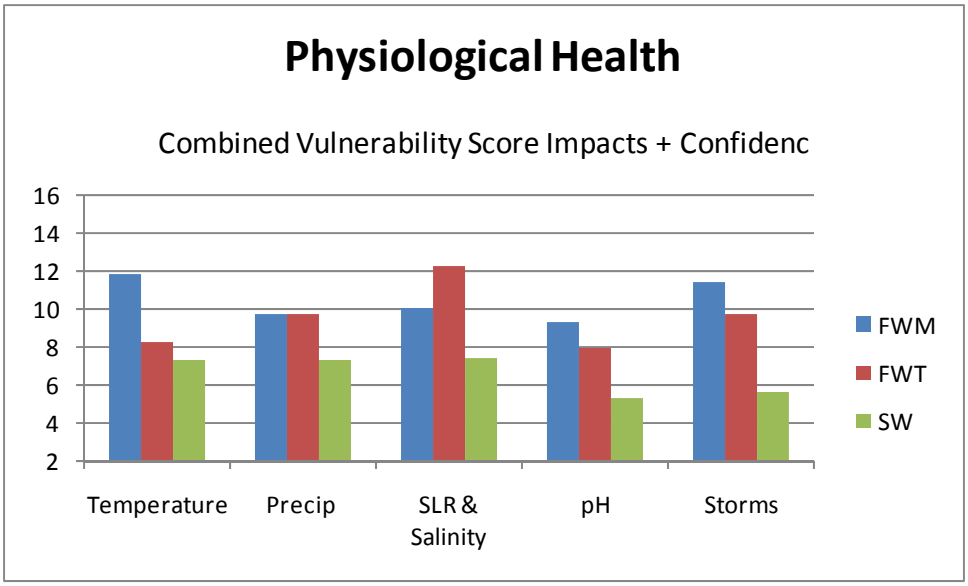

Figure P.2.1. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **physiological health** of freshwater mussels (blue) and relative confidence in these projections (red.)

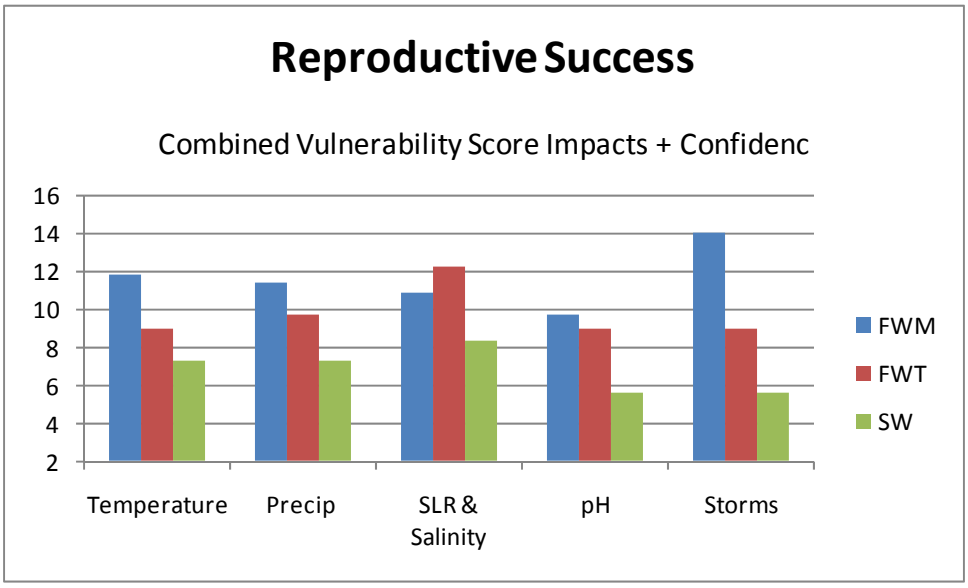

Figure P.2.2. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **reproductive success** of freshwater mussels (blue) and relative confidence in these projections (red.)

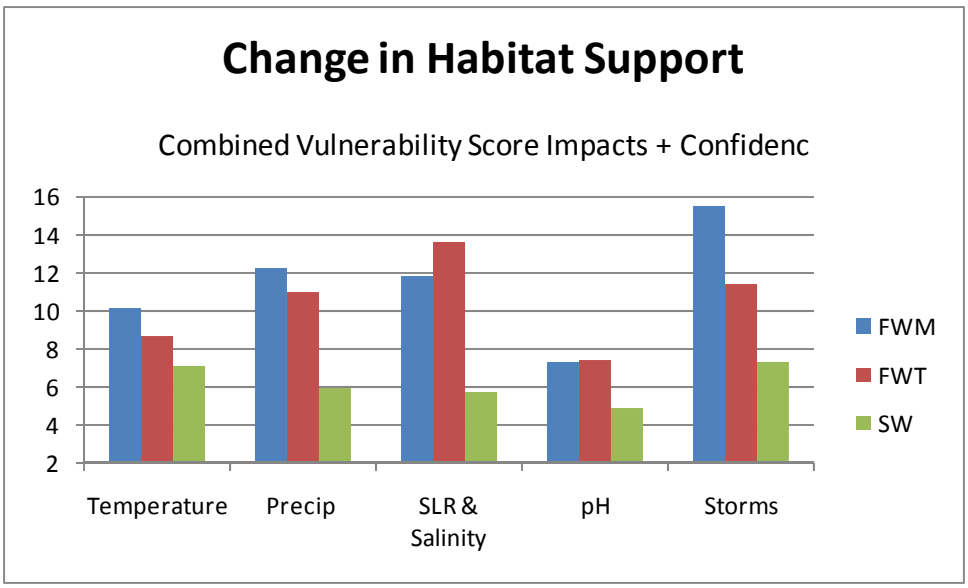

Figure P.2.3. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **change in habitat support** of freshwater mussels (blue) and relative confidence in these projections (red.)

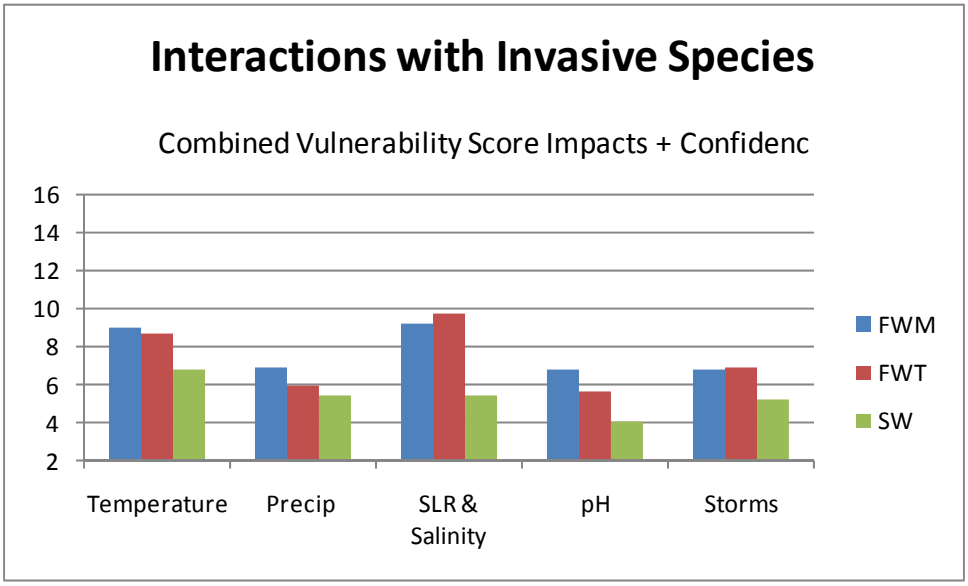

Figure P.2.4. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **interactions with invasive species** of freshwater mussels (blue) and relative confidence in these projections (red.)

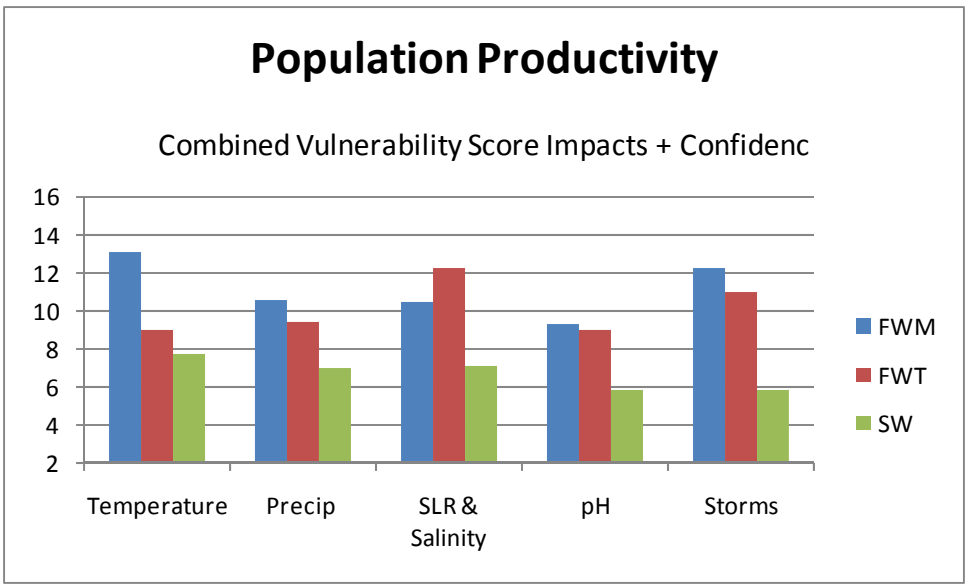

Figure P.2.5. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **population productivity** of freshwater mussels (blue) and relative confidence in these projections (red.)

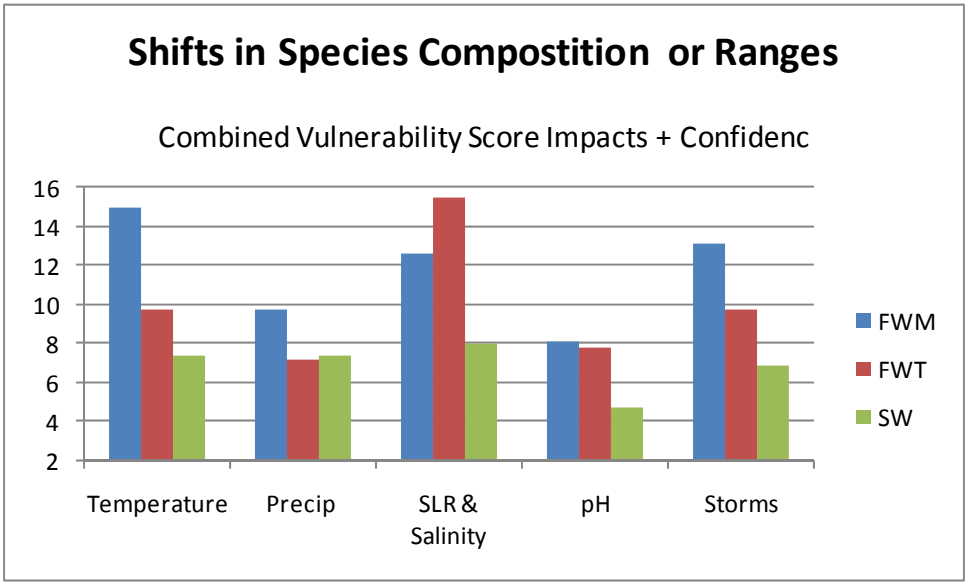

Figure P.2.6. Relative levels of concern regarding the potential impact of changing physical and chemical conditions on **physiological health** of freshwater mussels (blue) and relative confidence in these projections (red.)

P.3 Comparison of Effectiveness of Adaptation Options

Table P.3.1. Effectiveness Index of various adaptation options for offsetting vulnerabilities of freshwater non-tidal mussels (FWM), freshwater tidal bivalves (FWT), and brackish/saltwater bivalves (SW) exposed to projected shifts in **temperature** by 2100.

		Combined Scores - Effectiveness + Feasibility		
		FWM	FWT	SW
Temperature Changes	Monitor/Research Vulnerability Impacts	Highest	Highest	Med-High
	Hatchery Propagation and Restocking of Populations	Med	Med-High	Med-Low
	Transplants of Broodstock to Expand Ranges	Med	Med	Med-High
	Metapopulation Expansion for Common Species	Med	Med-Low	
	Restoration of Extirpated Rare Species	Low	Low	
	Dam Removals to Assist Dispersal on Fish Hosts	Med-High		
	Assisted Migration (of southern species) to Fill Open Niches	Low	Low	
	In-stream and/or Riparian Habitat Enhancements	Highest	Med-High	
	Water Quality Management	Med	Med-High	Med
	Water Quantity (Flow) Management	Med	Med	Med
	Shellplanting on Seed Beds (Oysters)			Highest
	Shellplanting or Living Shorelines Along Marshes/Tributaries			Med-High

Table P.3.2. Effectiveness Index of various adaptation options for offsetting vulnerabilities of freshwater non-tidal mussels (FWM), freshwater tidal bivalves (FWT), and brackish/saltwater bivalves (SW) exposed to projected shifts in **Precipitation Changes** by 2100.

Precip Changes	Monitor/Research Vulnerability Impacts	Highest	Highest	Highest
	Hatchery Propagation and Restocking of Populations	Med-Low	Med-Low	Med-Low
	Transplants of Broodstock to Expand Ranges	Med-Low	Low	Med
	Metapopulation Expansion for Common Species	Med-Low	Low	
	Dam Removals to Assist Dispersal on Fish Hosts	Med		
	Restoration of Extirpated Rare Species	Low	Low	
	Assisted Migration (of southern species) to Fill Open Niches	Med	Low	
	In-stream and/or Riparian Habitat Enhancements	Low	Med-High	
	Water Quality Management	Highest	Med-Low	Med-Low
	Water Quantity (Flow) Management	Med-Low	Med	Med
	Shellplanting on Seed Beds (Oysters)			Med-High
	Shellplanting or Living Shorelines Along Marshes/Tributaries			Med-High

Table P.3.3. Effectiveness Index of various adaptation options for offsetting vulnerabilities of freshwater non-tidal mussels (FWM), freshwater tidal bivalves (FWT), and brackish/saltwater bivalves (SW) exposed to projected shifts in **sea level rise** by 2100.

Sea Level Rise & Salinity	Monitor/Research Vulnerability Impacts	Med-High	Highest	Highest
	Hatchery Propagation and Restocking of Populations	Med-Low	Med-Low	Med-High
	Transplants of Broodstock to Expand Ranges	Med-Low	Med-Low	Med-High
	Metapopulation Expansion for Common Species	Low	Med-Low	
	Restoration of Extirpated Rare Species	Low	Low	
	Dam Removals to Assist Dispersal on Fish Hosts	Med		
	Assisted Migration (of southern species) to Fill Open Niches	Low	Low	
	In-stream and/or Riparian Habitat Enhancements	Med-Low	Med	
	Water Quality Management	Med-Low	Med-Low	Med-Low
	Water Quantity (Flow) Management	Med	Med	Med-Low
	Shellplanting on Seed Beds (Oysters)			Med-High
	Shellplanting or Living Shorelines Along Marshes/Tributaries			Med

Table P.3.4. Effectiveness Index of various adaptation options for offsetting vulnerabilities of freshwater non-tidal mussels (FWM), freshwater tidal bivalves (FWT), and brackish/saltwater bivalves (SW) exposed to projected shifts in **pH Changes** by 2100.

pH Changes	Monitor/Research Vulnerability Impacts	Highest	Highest	Highest
	Hatchery Propagation and Restocking of Populations	Med-Low	Med-Low	Med
	Transplants of Broodstock to Expand Ranges	Med-Low	Med-Low	Med
	Metapopulation Expansion for Common Species	Med-Low	Low	
	Restoration of Extirpated Rare Species	Low	Low	
	Dam Removals to Assist Dispersal on Fish Hosts	Med-Low		
	Assisted Migration (of southern species) to Fill Open Niches	Low	Low	
	In-stream and/or Riparian Habitat Enhancements	Med	Med-Low	
	Water Quality Management	Med-Low	Med	Med-Low
	Water Quantity (Flow) Management	Med	Med-Low	Med-Low
	Shellplanting on Seed Beds (Oysters)			Med-High
	Shellplanting or Living Shorelines Along Marshes/Tributaries			Med

Table P.3.5. Effectiveness Index of various adaptation options for offsetting vulnerabilities of freshwater non-tidal mussels (FWM), freshwater tidal bivalves (FWT), and brackish/saltwater bivalves (SW) exposed to projected shifts in **increased storm intensity and frequency** by 2100.

Increased Storm Intensity & Frequency	Monitor/Research Vulnerability Impacts	Highest	Highest	Med-High
	Hatchery Propagation and Restocking of Populations	Med-Low	Med-Low	Med
	Transplants of Broodstock to Expand Ranges	Med-Low	Med-Low	Med-High
	Metapopulation Expansion for Common Species	Med-Low	Med-Low	
	Restoration of Extirpated Rare Species	Low	Low	
	Dam Removals to Assist Dispersal on Fish Hosts	Med-Low	Low	
	Assisted Migration (of southern species) to Fill Open Niches	Low	Low	
	In-stream and/or Riparian Habitat Enhancements	Highest	Med-High	
	Water Quality Management	Med	Med-Low	Med-Low
	Water Quantity (Flow) Management	Highest	Med-High	Med
	Shellplanting on Seed Beds (Oysters)			Highest
	Shellplanting or Living Shorelines Along Marshes/Tributaries			Highest

P.4 Ecosystem Services Changes

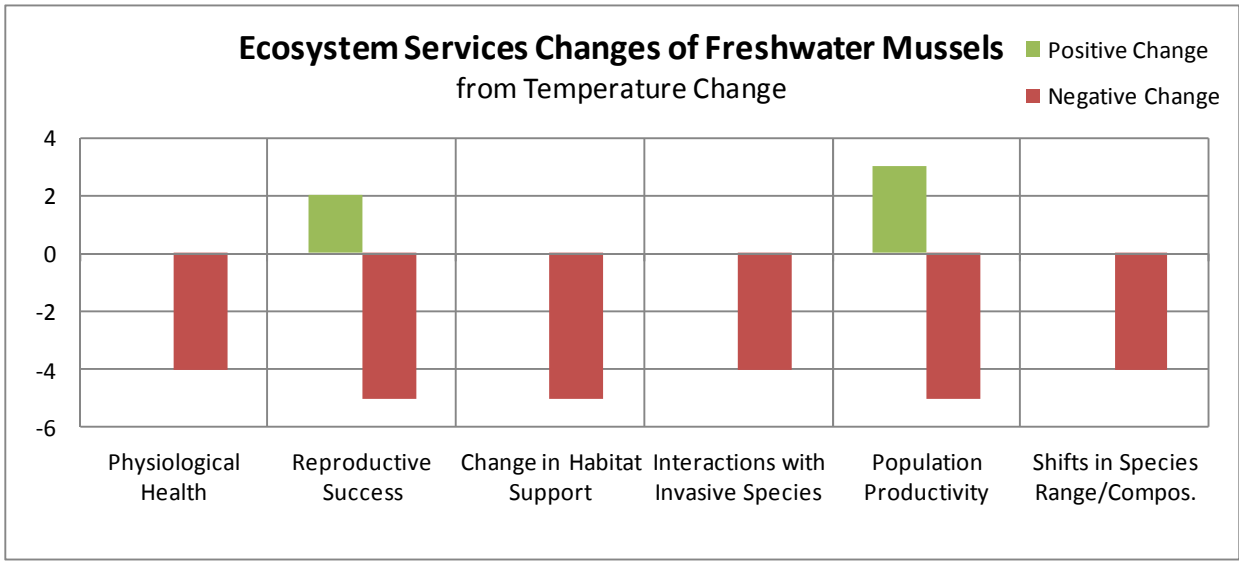

Figure P.4.1 . Ecosystem service changes in FWM, from **temperature** changes by 2100.

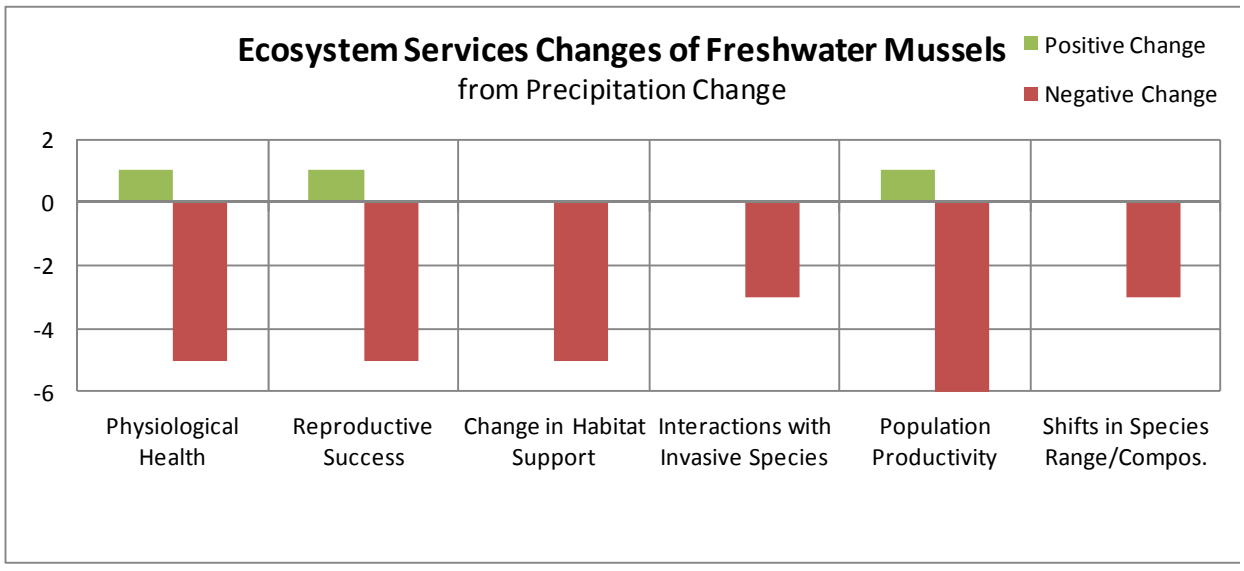

Figure P.4.2 Ecosystem service changes in FWM, from **precipitation** changes by 2100.

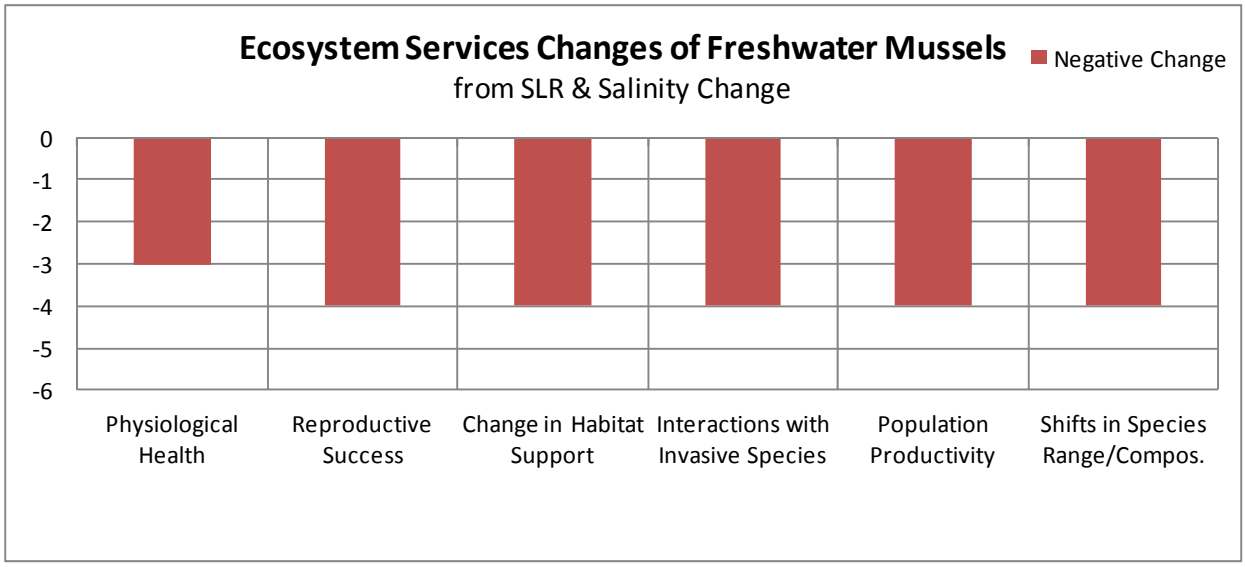

Figure P.4.3 Ecosystem service changes in FWM, from **sea level rise and salinity** changes by 2100.

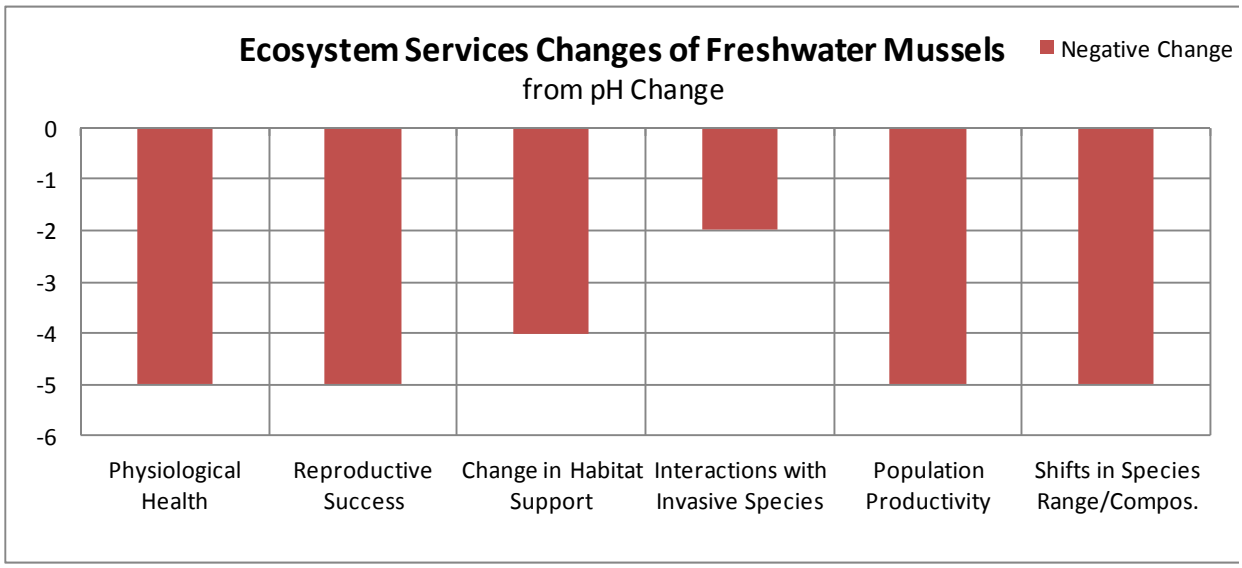

Figure P.4.4 Ecosystem service changes in FWM, from **pH** changes by 2100.

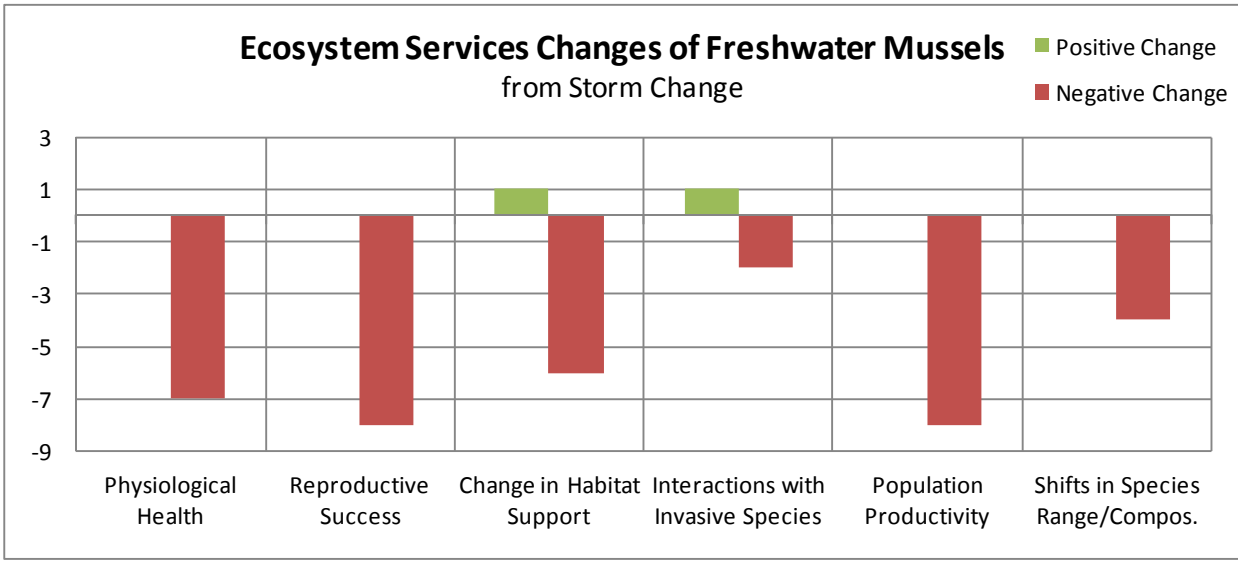

Figure P.4.5 Ecosystem service changes in FWM, from **storm intensity and frequency** changes by 2100.

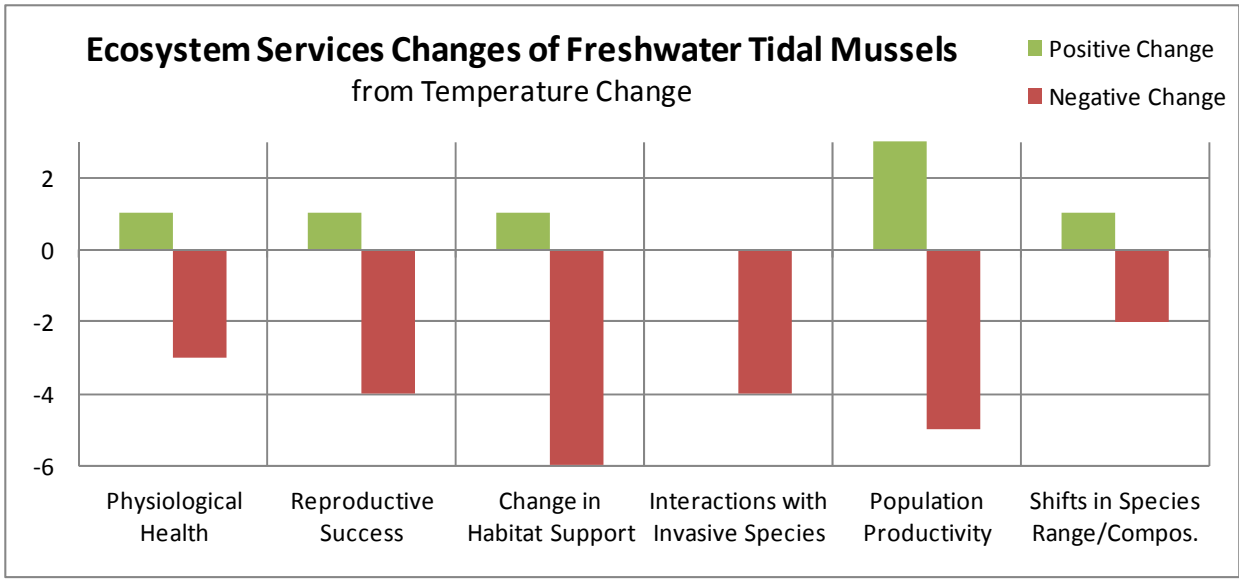

Figure P.4.6 Ecosystem service changes in FWT, from **temperature** changes by 2100.

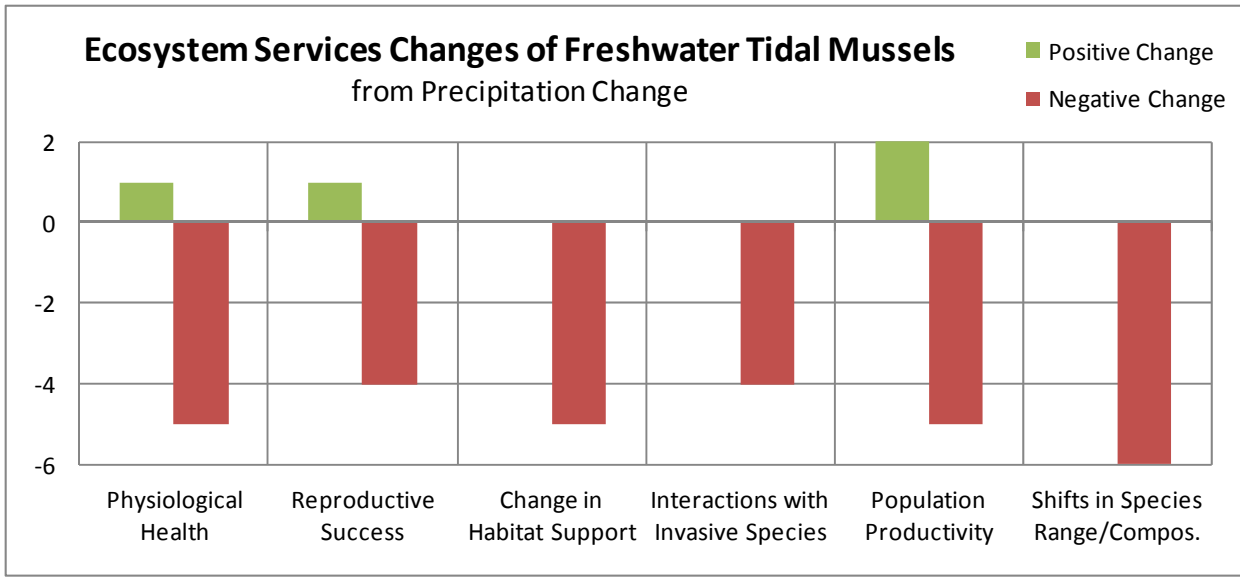

Figure P.4.7 Ecosystem service changes in FWT, from **precipitation** changes by 2100.

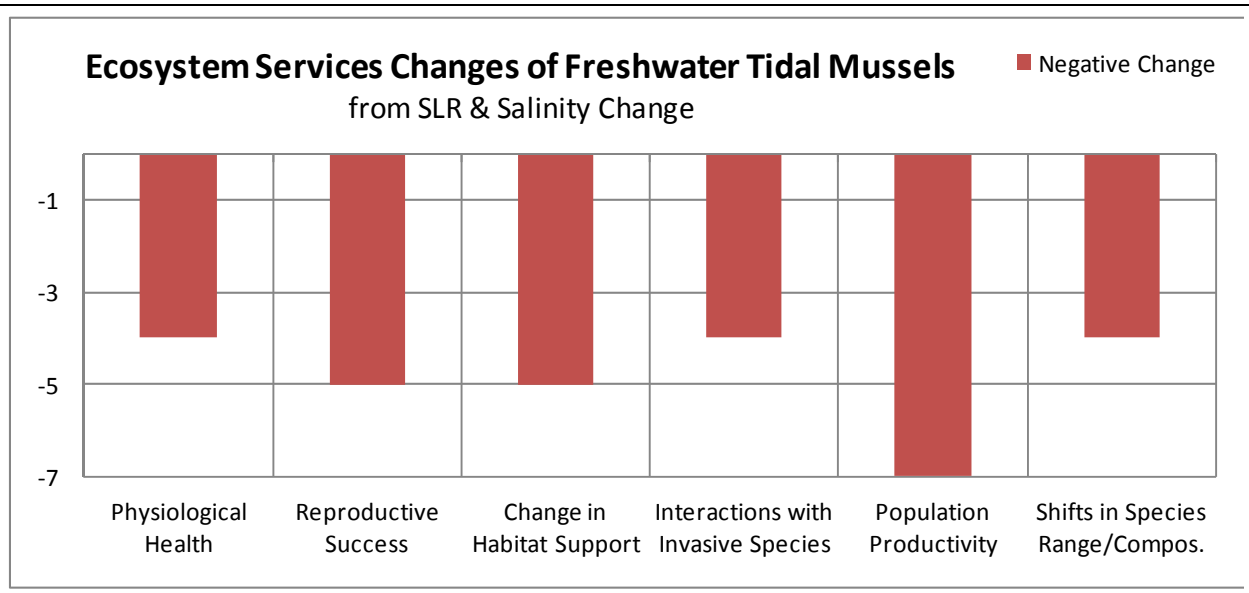

Figure P.4.8 Ecosystem service changes in FWT, from **sea level rise and salinity** changes by 2100.

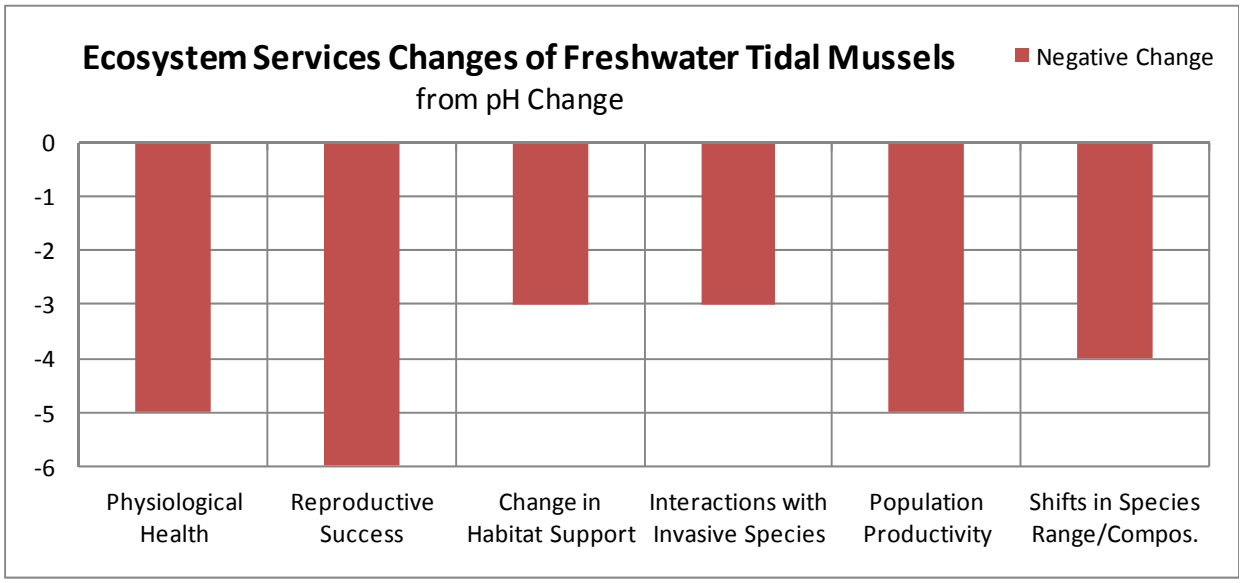

Figure 5.4.9 Ecosystem service changes in FWT, from **pH** changes by 2100.

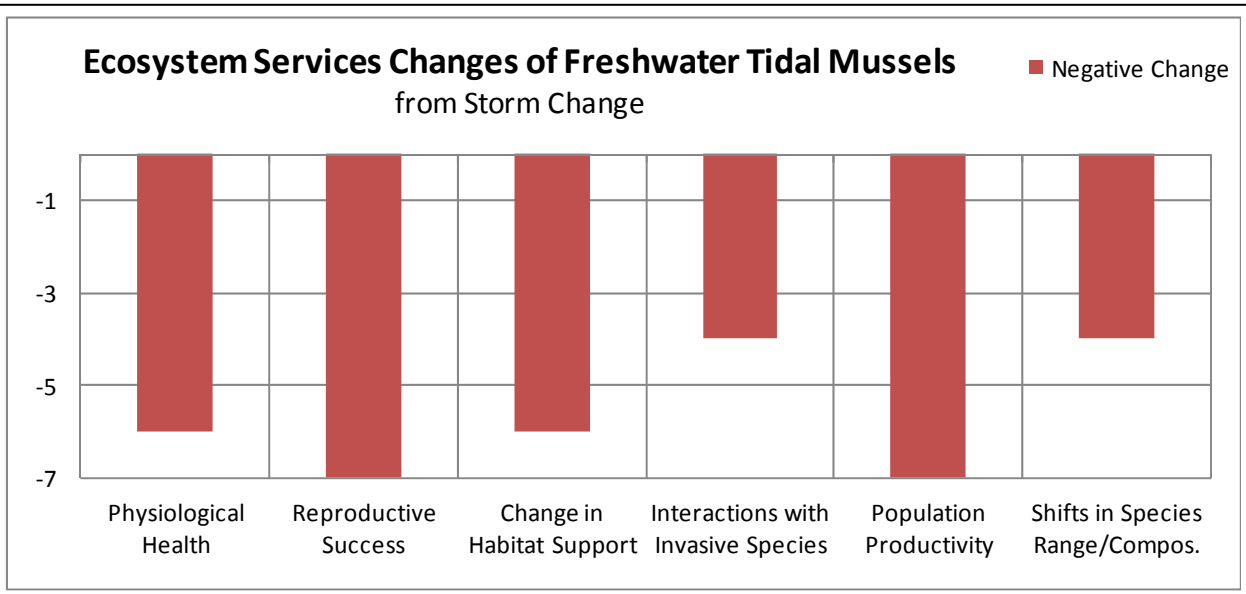

Figure 5.4.10 Ecosystem service changes in FWT, from **storm intensity and frequency** changes by 2100.

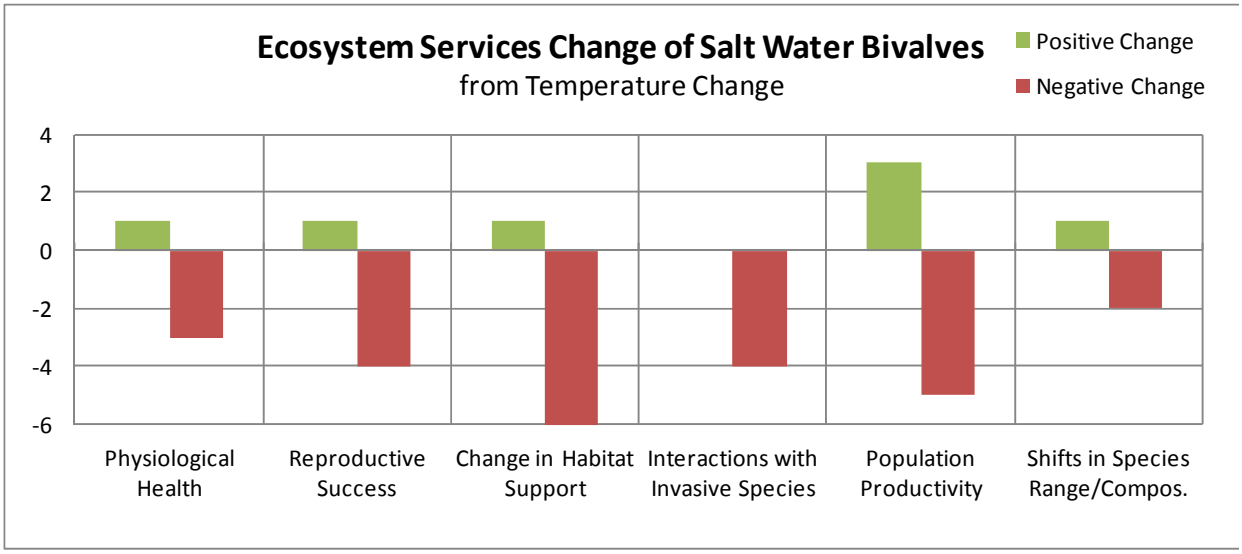

Figure P.4.11 Ecosystem service changes in SW, from **temperature** changes by 2100.

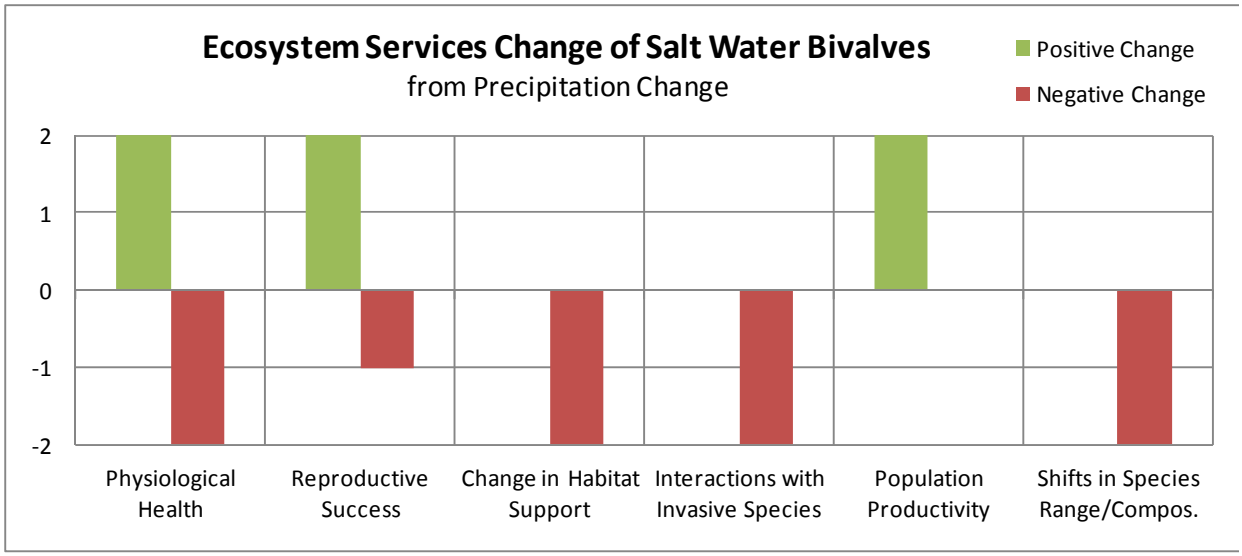

Figure P.4.12 Ecosystem service changes in SW, from **precipitation** changes by 2100.

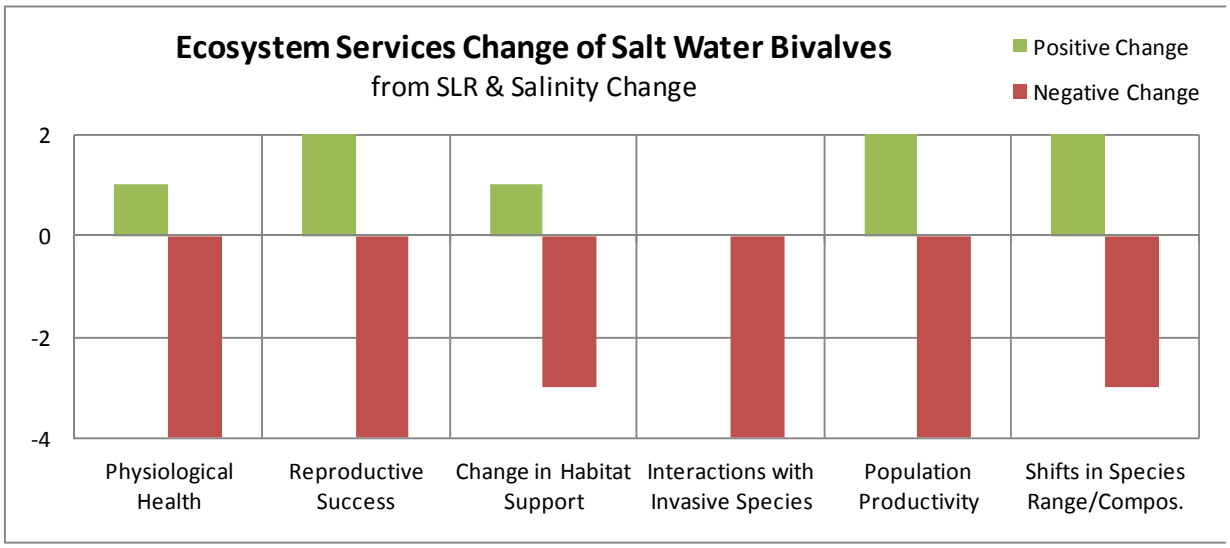

Figure P.4.13 Ecosystem service changes in SW, from **sea level rise and salinty** changes by 2100.

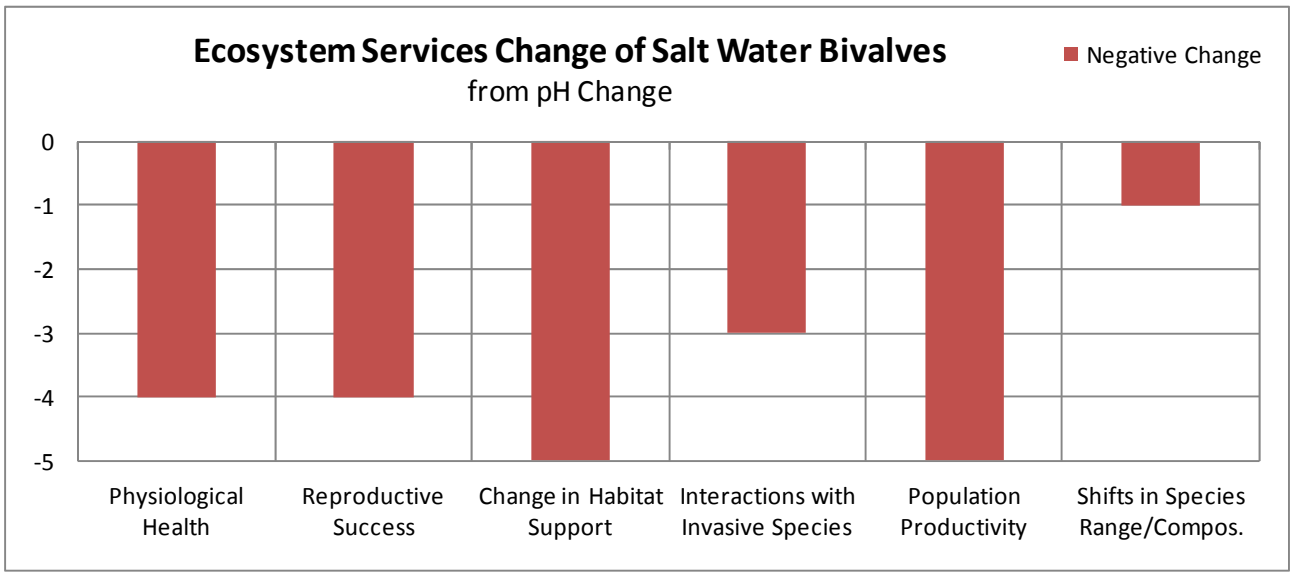

Figure P.4.14 Ecosystem service changes in SW, from **pH** changes by 2100.

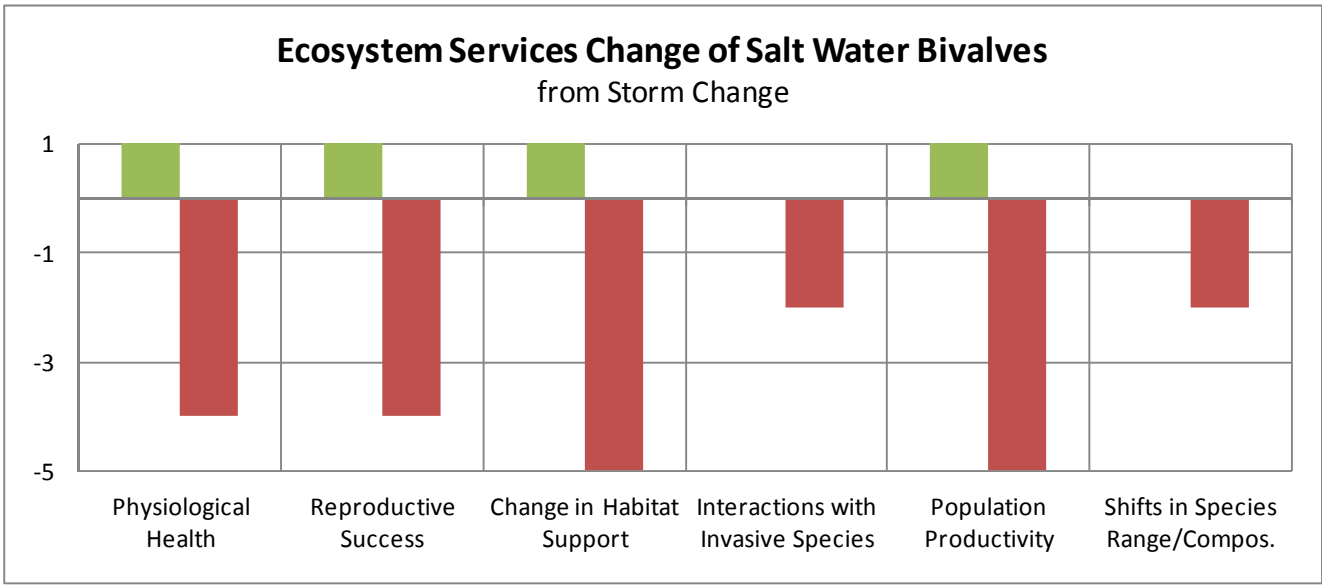

Figure P.4.15 Ecosystem service changes in SW, from **storm intensity and frequency** changes by 2100.