EFFECT OF FRESHWATER INFLOW ON MOLLUSK COMMUNITY AND POPULATION DYNAMICS IN TEXAS ESTUARIES

A Thesis

by

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This thesis meets the standards for scope and quality of
Texas A&M University-Corpus Christi and is hereby approved.

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ABSTRACT

Mollusks are an abundant species rich phylum within the animal kingdom. Over 130,00 species have been documented, and the Texas Gulf Coast is home to a large portion of these species. Many of these species reside within Texas Estuaries that experience differing freshwater inflow patterns. Freshwater inflow changes can alter estuarine dynamics such as salinity, nutrients, and some biological communities. Many mollusks species' survival and growth rely on freshwater inflow for nutrients for reproduction and survival and are thus suitable bioindicators of freshwater inflow effects within estuaries. Existing mollusk and salinity data from 1987 - 2019 were used, and estuaries compared include Lavaca-Colorado, Guadalupe, Mission-Aransas, Nueces, and Baffin Bay-Upper Laguna Madre. Current environmental inflow standards were determined using *Rangia cuneata,* a brackish water clam found only in Guadalupe Estuary, as a bioindicator. In addition to *Rangia cuneata*, other dominant species with the highest frequency along all estuaries such as *Mulinia lateralis, Nuculana acuta, Mysella planulata,* and *Macoma mitchelli* were examined. were also examined as bioindicators. There were distinct differences in community structure along the salinity gradient on The Texas Coast. Laguna Madre was greatly different compared to other estuarine systems because of being seagrass habitat in comparison to other systems that were bay-bottom mud habitat. Laguna Madre also has the highest salinity leading to a diverse community of mollusks. High inflow systems, such as Guadalupe and Lavaca-Colorado, resulted in high abundance of opportunistic species such as *Mulinia lateralis*, and in contrast there was a higher mollusk diversity found in estuarine systems with higher salinity. All the dominant species responded to freshwater inflow with reproductive events, that often resulted in a population size decrease after lengths reached ~ 3 mm in size due to predation by bottom feeding species, competition, or inadequate hydrologic conditions such as

salinity. Although *Rangia cuneata* indicates when there is a major inflow event, this species is only found in Guadalupe estuary, and requires a salinity between 5 - 12. Due to the infrequency of these conditions, additional species such as *Mulinia lateralis* who is an opportunist species that can reproduce and grow in a wide range of salinity conditions, would be a reliable bioindicator of estuarine health.

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1. INTRODUCTION

Estuaries serve as a transitional zone between freshwater and saltwater in coastal environments. This basic understanding defines an estuary, but classifying estuaries relies on properties such as climatic regime, river discharge, tidal range, and coastal geomorphology (Palmer et al., 2011, Montagna et al., 2011). These influential characteristics combined create the most productive and unique ecosystems on Earth (Montagna et al., 2013). The water balance within an estuary is the product of the difference between water sources and the water losses (Montagna et al., 2018). The three classes of estuaries based on these hydrological processes include positive estuaries where freshwater quantity is larger than evaporation, neutral estuaries where inflow and evaporation are in balance, and negative estuaries where evaporation exceeds freshwater inflow (Montagna et al., 2018). Biological functionality, survival, and productivity within estuaries are direct results from the quantity and timing of freshwater inflow entering the mixing zone. Identifying the relationship between variables such as inflow, salinity, and other various biological parameter fluctuations were used to determine the effects and requirements for developing inflow standards for estuaries.

The purpose of the current study is to compare infauna mollusk community and population changes over time in estuaries with different inflow regimes. Populations are expected to respond to wet and dry periods. Mollusk infauna data exists from 1987-2019 in five estuaries including the Lavaca, Guadalupe, Mission-Aransas, Nueces, and Baffin Bay-Laguna Madre. Mollusk population characteristics were compared to salinity changes as an indicator for inflow change. By correlating salinity with reproduction events and population size-structure, the information was used to determine which species indicated salinity conditions within the estuaries(Hopkins 1970). From the examined species, data will support chosen bioindicators of influx of freshwater inflow. These prominent species will aid indicating proper environmental flow regulations for water policy changes such as Senate Bill 3.

The Texas coastal zone consists of ~ 600 km of barrier islands from the Louisiana border to the Mexico border. Texas estuaries are in a climatic gradient with decreasing rainfall from the northeast to the southwest, resulting in salinity gradients along the coastline, which drive the distribution of estuarine organisms (Montagna et al., 2013). Within Texas estuaries, the salinity gradient serves as a dependable measurement for freshwater inflow. Salinity is a reliable variable to determine the inflow of both the salt water from the oceans and freshwater from inland rivers within an estuary, and historical documentation of salinity can help classify an estuary. (Orlando et al., 1993). Salinity variability in each estuary differs due to differences in inflow, astronomical tides, coastal shelf processes, brine discharges, and evaporation (Orlando et al., 1993). Most organisms found within estuaries are euryhaline and can tolerate a wide range of salinity levels while other organisms are unable to endure these ranges (Montagna et al., 2013). Texas estuaries have large variations within these bounds, resulting in fresh to hypersaline salinity levels caused by disturbances such as floods and droughts (Powell et al., 2002). Abrupt changes of inflow patterns directly affect flora and fauna within estuaries, which were evaluated to determine how water quality characteristics affect living marine resources in Texas estuaries.

Mollusks are an abundant and species rich phyla within the animal kingdom, with over 130,000 documented species. Bivalves compose 15% of species within the seven Mollusca classes (Oehlmann and Schulte-Oehlmann, 2003; Gruner, 1993). Bivalves have been used as bioindicators due to their vast populations as key species for ecosystem functioning, prey, habitat creation, and biomass composition within aquatic ecosystems (Oehlmann and Schulte-Oehlmann, 2003). Mollusk populations are primarily a product of the water they live in, in contrast to the sediment in which they live on (Montagna et al., 2008). Salinity levels serve as a proxy for freshwater inflow and has proved to be the most crucial variable regulating mollusk communities (Montagna et al., 2008). Inflow events cause salinity change, and abrupt salinity changes can trigger spawning and reproduction events within these populations (Montagna and Kalke, 1995). In contrast, low inflow can result in unviable conditions due high salinity caused by evaporation levels exceeding inflow rate. Many mollusks species' survival and growth rely on freshwater inflow for nutrients that promote primary production to feed larvae and young spat (Pollack et al. 2012). Bivalves are persistent and abundant in marine and freshwater ecosystems, and because they are limited in mobility, changes in salinity regimes will be revealed in population abundance (Montagna and Kalke, 1992; Oehlmann and Schulte-Oehlmann, 2003). In contrast to other invertebrates, the mollusk life cycle can be longer, integrating water quality over longer time scales (Oehlmann and Schulte-Oehlmann, 2003). It has been determined that approximately 40% of marine bivalves' species and 20% marine prosobranchs have life spans over 14 years (Heller, 1990). Pollution levels and their impacts will be revealed in mollusks found in marine and freshwater because many mollusks are key species with low mobility within their environments. Many mollusks live in direct contact with their habitats through diet and respiratory organs (Oehlmann and Schulte-Oehlmann, 2003). Due to freshwater being essential for mollusk survival, they are suitable organisms for bioindicators of the effects of freshwater inflow within estuaries. It has been largely accepted that monitoring mollusks as bioindicators is quantifiable for determining inflow needs to maintain health of estuarine and freshwater ecosystems (Bunzan et al., 2009; Black and Heany, 2015).

Two common species of bivalves, *Rangia cuneata* and *Mulinia lateralis,* found in the Texas coast have been identified as indicators for freshwater inflow effects. The distribution of these species has been determined to have a link to environmental conditions such as salinity (Montagna, 1989). *Rangia cuneata* in the family Mactridae is a stenohaline brackish water clam that can be found in areas with 0 – 15 practical salinity units (psu) during juvenile stage of their life cycles. In contrast, when *Rangia cuneata* enter the adult life stage, they can survive over a large salinity range of 0 - 38 psu . Spawning of this species will not take place if salinity levels are not maintained in the 0 – 15 psu range (Hopkins et al., 1973). *Rangia cuneata* can commonly be found in coastal areas along the Gulf of Mexico, and the Atlantic coast from Georgia to Maryland (Andrews, 1992). *Rangia cuneata* are most abundant in areas upstream in tidal rivers where salinities are consistently ~ 1 psu for long periods of time. During drought events, this species will diminish in population size. *Mulinia lateralis,* also from the family Mactridae can tolerate high salinity levels in contrast to *Rangia cuneata. Mulinia lateralis* are found in salinities ranging from 5 psu – 80 psu (Parker, 1975), geographically they are in areas ranging from Prince Edward Island, Canada to Yucatan, Mexico. *Mulinia lateralis* larvae develop in salinity ranges of 15 - 35 psu and successfully spawns at ~ 3 mm in length. Both species are part of the infauna community.

2. METHODS

2.1 Study Area

Along the Texas coast, there are seven major estuaries, which all share similar geomorphic structure. They are parallel to the mainland and contain lagoons between the mainland and barrier islands (Montagna et al., 2013). These lagoons are affected by rivers delivering freshwater inflow from inland watershed systems, and Gulf inlets that deliver seawater through the outer barrier islands. These lagoons are composed of primary and secondary bay systems. The primary bay is larger and experiences a greater influence of seawater. In contrast, secondary bays are smaller with greater influence of freshwater inflow.

The Texas Gulf physical placement falls along a climatic and salinity gradient that experiences gradual patterns through longitudinal placement The seven systems in Texas include: Sabine-Neches Estuary, Trinity San Jacinto Estuary, Lavaca Colorado Estuary, Guadalupe Estuary, Mission Aransas Estuary, Nueces Estuary, and Laguna Madre Estuary (Montagna et al., 2013). For the present study, infauna samples were collected from five of these estuaries including: Lavaca Estuary, Guadalupe Estuary, Mission-Aransas Estuary, Nueces Estuary, and Upper Laguna Madre Estuary. In all estuaries in this study, 4 - 8 stations were sampled. This sampling design has been utilized in previous studies of Texas estuaries (Montagna and Kalke, 1992). Throughout all estuaries, stations A and B were placed near areas with the greatest freshwater inflow in secondary bays. Following these, stations C and D were placed in the primary bays, with a greater seawater influence. Two stations in each bay component are necessary to replicate at the treatment level. Additional stations have been created to address the effects of the Gulf of Mexico's gradient or other river sources. In Matagorda Bay, the Colorado River flows into this system in the eastern sections, resulting in the placement of stations E, F, and 15. The Mission-Aransas has an additional station E at the mouth of St. Charles Bay. Nueces Estuary has an additional station near the Corpus Christi Ship Channel. Laguna Madre contains stations 6, 24,189, and 155 closely related to the other stations placement strategy. Stations 6 and 24 are placed within Baffin Bay, where there is uniquely no river mouth allowing direct freshwater inflow, and stations 189 and 155 are found in Laguna Madre in seagrass bed areas. There is a seagrass (189G and 155G) and sandy, non-seagrass (189S and 155S) stations in each site.

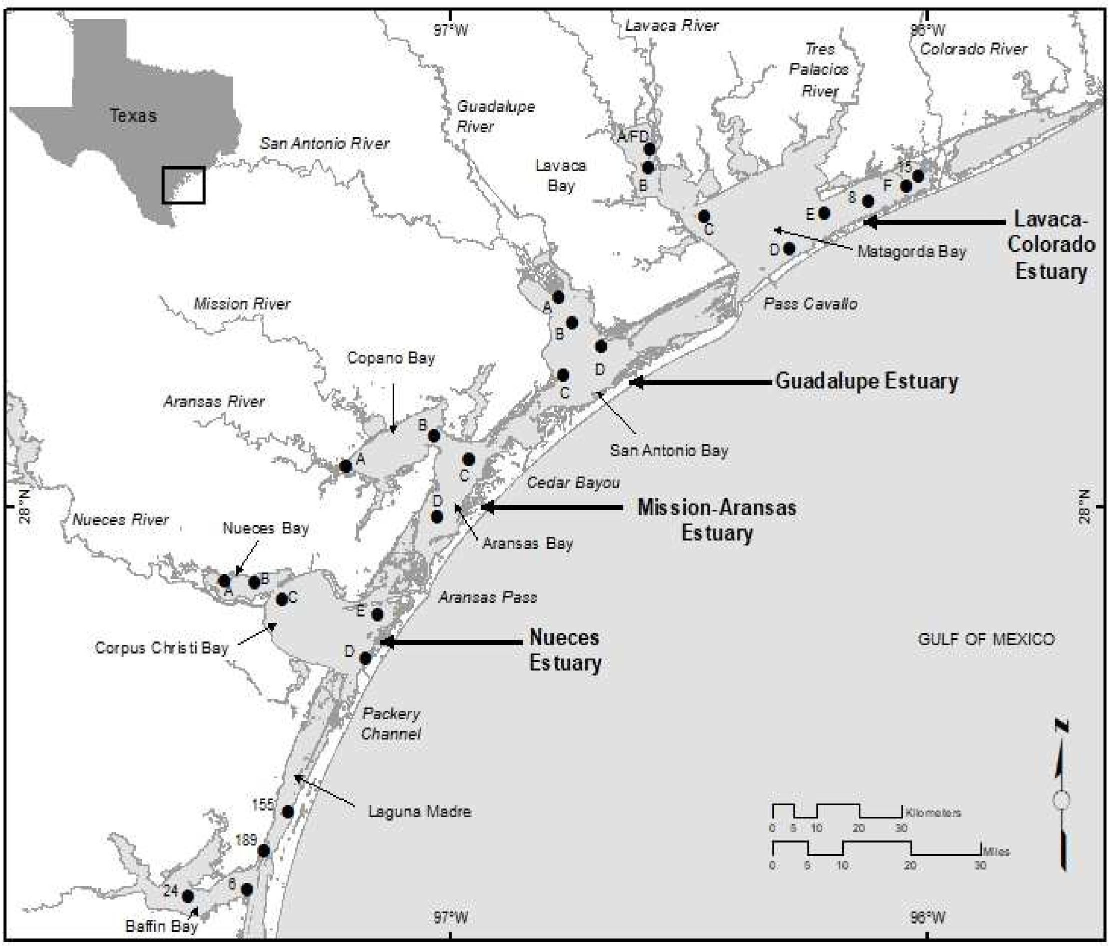


Figure 1. Station locations in the study area.

2.2 Data

This project uses existing benthic infauna data sets from the Harte Research Institute for Gulf of Mexico Studies collected since 1987 or 1988 (Table 1). Data includes water quality characteristics such as salinity, temperature, dissolved oxygen, pH, turbidity, nutrients, and chlorophyll.

Table 1. Estuaries with start and end dates and number of samples collected.

Abbreviation	**Estuary**	**Start Date**	**End Date**	**Samples**
LC	Lavaca-Colorado	JUL1988	JUL2019	2415
GE	Guadalupe	APR1988	JUL2019	1392
MA	Mission-Aransas	AUG1988	APR2003	144
NC	Nueces	OCT1987	JUL2019	1823
LM	Laguna Madre	APR1988	JUL2000	687

Samples for the benthic infauna were collected quarterly each year in the months of January, April, July, and October from 1987-2019 (Table 1). In the Mission Aransas estuary, sampling occurred only once per year. The infauna sampling regime was established in 1987 and numerous studies (Kalke and Montagna, 1991; Montagna and Kalke, 1992; Palmer et al., 2011; Kim and Montagna, 2012; Van Diggelen and Montagna, 2016) have demonstrated the efficacy of quarterly sampling for capturing temporal benthic dynamics in Texas estuaries. Three replicate sediment cores are collected with a 6.7-cm diameter coring tube (35.4 cm^2 area) within a 2-meter radius at each station. Benthic macrofauna are preserved in the field using 5% buffered formalin, and then extracted with a gentle wash on 0.5 mm mesh screens. Biota are then sorted, counted, and identified to the lowest taxonomic level. Only the mollusk data will be used in the current study.

2.3 Estuary and Climatic Condition Data

Lavaca Estuary, Guadalupe Estuary, Mission Aransas Estuary, Nueces Estuary, and Baffin Bay/Upper Laguna Madre all contain different inflow dynamics and salinity regimes (Table 2). Identifying wet and dry periods within these estuaries based on salinity data is crucial for determining mollusk population responses and shell length. When river flows are reduced during a drought, the freshwater entering estuaries is reduced, resulting in elevated salinities, as well as reduction in sediment loads, and nutrient loads (Palmer and Montagna, 2015). Salinity also varies from year-to-year. A common method to classify temporal salinity periods is by determining an upper and lower bound at the 25th and 75th percentiles (Powell et al., 2002). To analyze these effects, time periods will be divided into drought, normal, and wet periods based on the existing data collected in the given timeframe (Table 1). Means are calculated to determine if estuaries monthly salinities are within the upper quartile, interquartile, or lower quartile of salinity ranges. Drought periods are classified in the upper quartile, normal conditions in the interquartile, and wet periods within the lower quartile of the salinity ranges (Palmer and Montagna, 2015). These quartiles serve as the indicator of quantity of inflow within each estuary.

Table 2. Texas coastal estuarine gradient (Van Diggelen and Montagna 2016). Estuaries are listed from northeast to southwest. Area at mean low tide.

	Area	**Rainfall**	**Inflow Balance**	**Salinity (psu)**	
Estuary	**(km^2)**	**(cm yr^{-1})**	**(10^6 m^3 yr^{-1})**	**Mean**	**Variance**
Lavaca-Colorado	1,158	102	3,801	22.25	34.40
Guadalupe	551	91	2,664	15.06	30.44
Mission-Aransas	453	81	265	17.66	24.43
Nueces	433	76	298	30.25	24.15
Laguna Madre	1,139	69	-893	37.66	11.70

2.4 Mollusk Population Structure

The majority of mollusks used in this study are micromollusks, whose greatest dimension is less than 10 mm. Bivalve shell lengths are determined by measuring the longest dimension of the shell. Shell lengths were measured under a Wild M5A APO stereomicroscope, with an ocular micrometer using a unit scale at a magnification of 6x or 12x oculars. If shell lengths exceed the range of view, then a caliper was used to measure the length. The conversions from ocular micrometer units to mm is: 1.2 units = 1 mm.

The size structure of the populations was created with size frequency diagrams. To determine size structures and shell length frequencies, size-frequency bins were created, and the square root of these data points determine the number of bins.

$$\text{Number of bins} = \sqrt{\text{Number of data points}}$$

The quotient of the lower and upper shell length range, and number of bins provide the bin width.

$$\text{Species shell length range} = \text{upper length limit} - \text{lower length limit}$$

$$\text{Bin width} = \text{Species shell length range} \div \text{number of bins}$$

2.5 Community Analysis

Community structure is analyzed using Primer software to create a cluster and nonmetric Multidimensional scaling (nMDS) analysis to describe similarity patterns (Clark and Gorley, 2014; Clark et al., 2015). Prior to analysis, the average count of species per sample over time for each location was calculated. With this average a non-parametric multivariate technique was used to create a resemblance matrix of computed coefficients disclosing similarities between every sample. Each location is then represented by a dendrogram revealing similarity by cluster. Each cluster was computed between each pair of samples, and the similarities of abundance per mollusk species, followed by averaging of all mollusk species, then placed on a scale of 0% complete dissimilarity and 100% similarity on the Bray Curtis similarity index. The clustering technique used for this study followed the hierarchical agglomerative method, merging samples into groups layering larger hierarchy clusters, beginning with the highest similarity level. The cluster analysis can produce multiple contexts of similarities of the data. The cluster results display the difference between composition based off sites. The nMDS plot displays the rank order corresponding to the (dis)similarities found in the triangular matrix. This method displays a configuration of the samples by creating a map of the results by satisfying conditions. The original values were transformed by computing the square root prior to computing the resemblance matrix. The purpose of this transformation is to highlight the species with the highest abundance patterns. The nMDS was visualized with an 2D ordination plot, to check for consistency with the cluster graph by outlining groups from similarity.

2.6 Linking Population Structures to Inflow

Within estuaries, salinity reveals the ratio of inflow diluting the seawater. Salinity ranges fluctuate due to season, year, and precipitation. Mollusk populations respond to salinity and are sensitive to abrupt changes in salinity. Within molluscan communities, freshwater inflow drives variability, resulting in salinity patterns revealing zoogeographic patterns within estuaries (Montagna and Kalke, 1995). Thus, mollusk species are controlled more by water quality such as salinity characteristics than other estuarine variables such as sediment composition (Montagna et al., 2008). Along the salinity gradient, mollusk communities experience differences in diversity and abundance patterns due to the differing salinity ranges. In comparison to population dynamics along the salinity gradient, similar patterns are expected because of natural events such as droughts or floods. *Mulinia lateralis* and *Rangia cuneata* both respond to low salinity or wet periods in a recruitment event due to the opportunistic nature and abundancy (Montagna and Palmer 2011, Montagna and Kalke, 1995). Both species are indicators of inflow due to this response to flood conditions resulting in rapid population

The variable that indicates inflow changes within an estuary is salinity fluctuation, so salinity will be linked to abundance patterns and population structure using Spearman correlation coefficients. Wet and dry periods will be classified by using a quartile approach where the lowest 25% of salinities represent wet periods, the middle two quartiles represent average periods, and the highest 25% quartile represents dry periods (Palmer and Montagna. 2015). Analysis of variance will be used to for differences in abundance and population structure among the wet, dry, and average periods. It is expected that a wet period with low salinity will precede recruitment events and growth in abundance will occur subsequently.

3. RESULTS

3.1 Environmental Conditions

Environmental variables such as salinity, dissolved oxygen, turbidity, and temperature were obtained from the Texas Parks and Wildlife Department (TPWD) (Table 3).

Table 3. Hydrological data based on monthly average of estuary-wide values.

Estuary	Salinity (psu)		Temperature (°C)		Dissolved Oxygen (mg/L)		Turbidity (ntu)	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
LC	20.6	6.8	22.8	6.2	7.4	1.3	28.8	14.5
GE	17.4	7.7	22.9	6.1	8.1	1.3	22.7	14.0
MA	19.0	7.9	23.0	6.0	7.8	1.4	20.6	10.8
NC	29.7	5.1	23.5	5.8	7.3	1.1	15.9	7.2
LM	37.0	9.4	24.5	5.5	7.2	1.2	20.2	10.3

Salinity trends follow wet and dry years over time (Figure 2). Salinity was different in each estuary (Tukey test, $P < 0.05$). Estuaries with higher salinities are found southwest along the salinity gradient such as Upper Laguna Madre and Corpus Christi Bay. In contrast, estuarine systems found northeast have lower salinities, such as San Antonio Bay and Matagorda Bay.

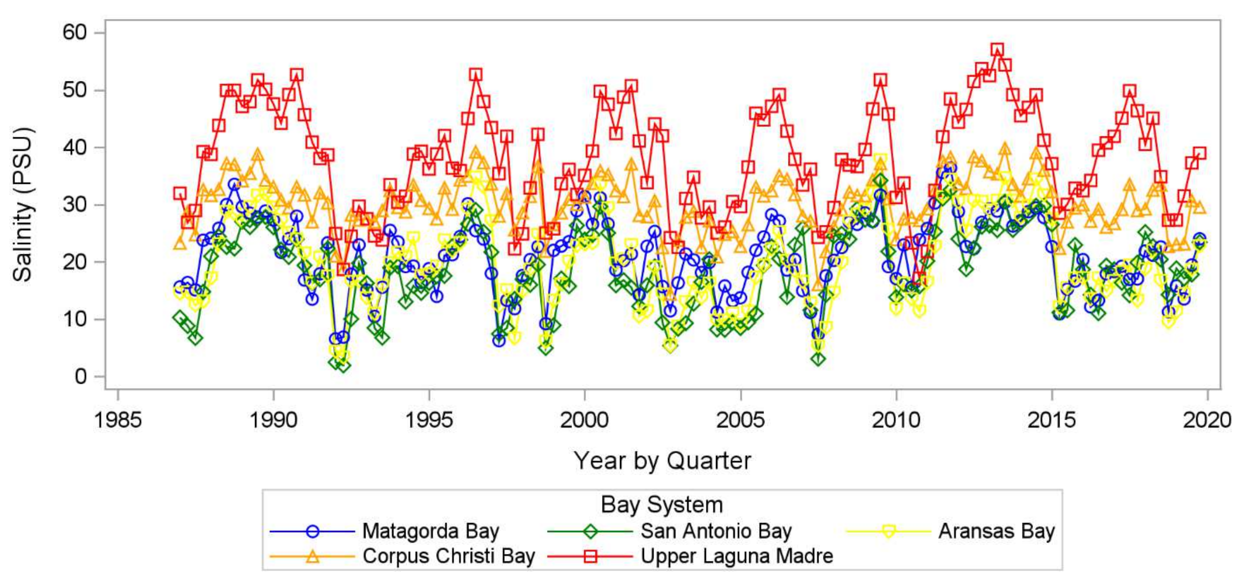


Figure 2. Estuary-wide average salinity by quarter.

Turbidity patterns changed similarly among the five estuaries over time (Figure 3). However turbidity was inversely correlated with salinity (r = -0.38, P < 0.0001). Lower turbidity in the higher salinity estuaries and higher turbidity in the lower salinity estuaries. LC had the highest turbidity, which was different from the rest (Tukey test, P < 0.05). GE and MA were similar, and MA was similar to LM. NC had the lowest turbidity, which was different from the other estuaries.

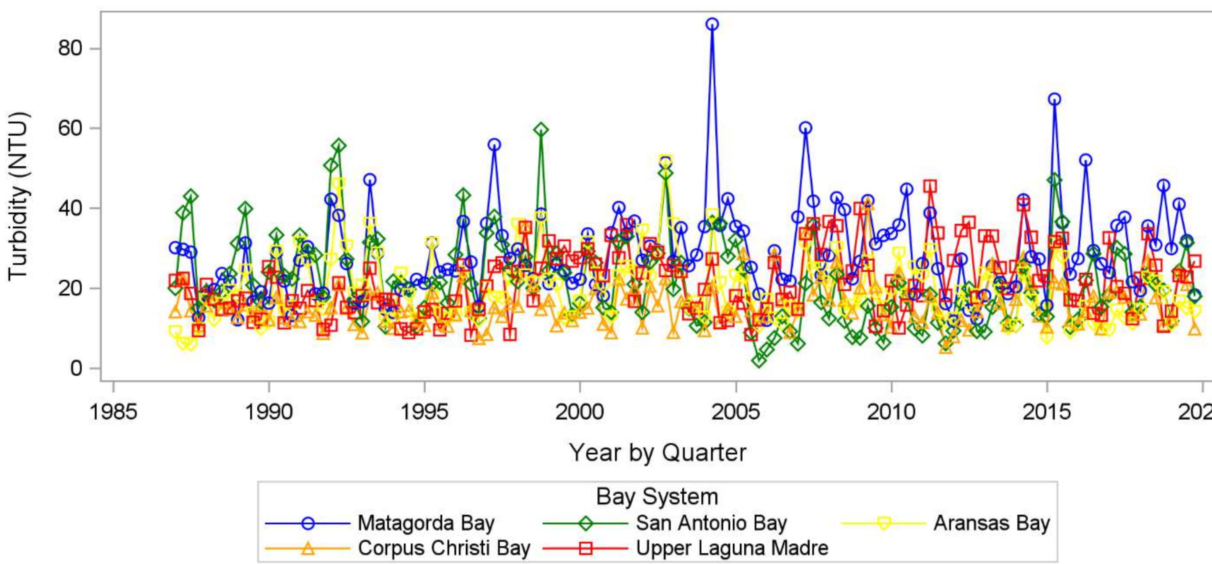


Figure 3. Estuary-wide average turbidity by quarter.

Temperature was highly seasonal (Figure 4). Temperature increased from the northern to southern estuaries, but MA and GE were similar, and GE was similar to LC (Tukey test, P < 0.05)

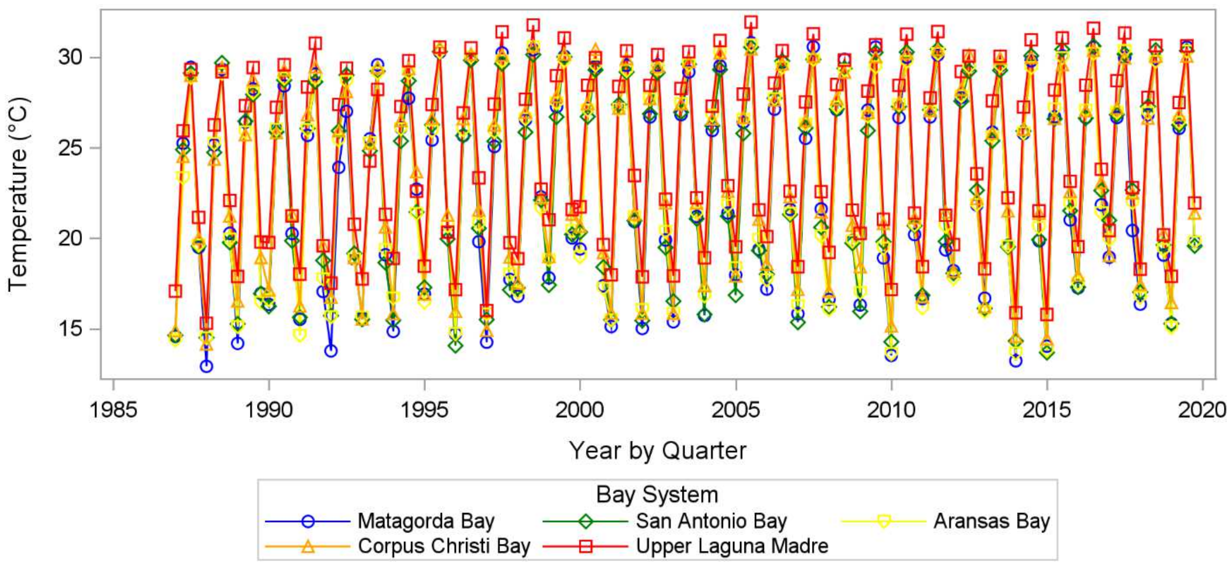


Figure 5. Estuary wide temperature by quarter.

Dissolved oxygen (DO) concentration was higher in winter and lower in summer (Figure 5). DO was inversely correlated with temperature ($r = -0.91$, $P < 0.0001$). DO was lowest in the NC and LM southern estuaries (Tukey test, $P < 0.05$), but LC was similar to NC. The GE and MA had the highest DO, and they were different from one another (Tukey test, $P < 0.05$).

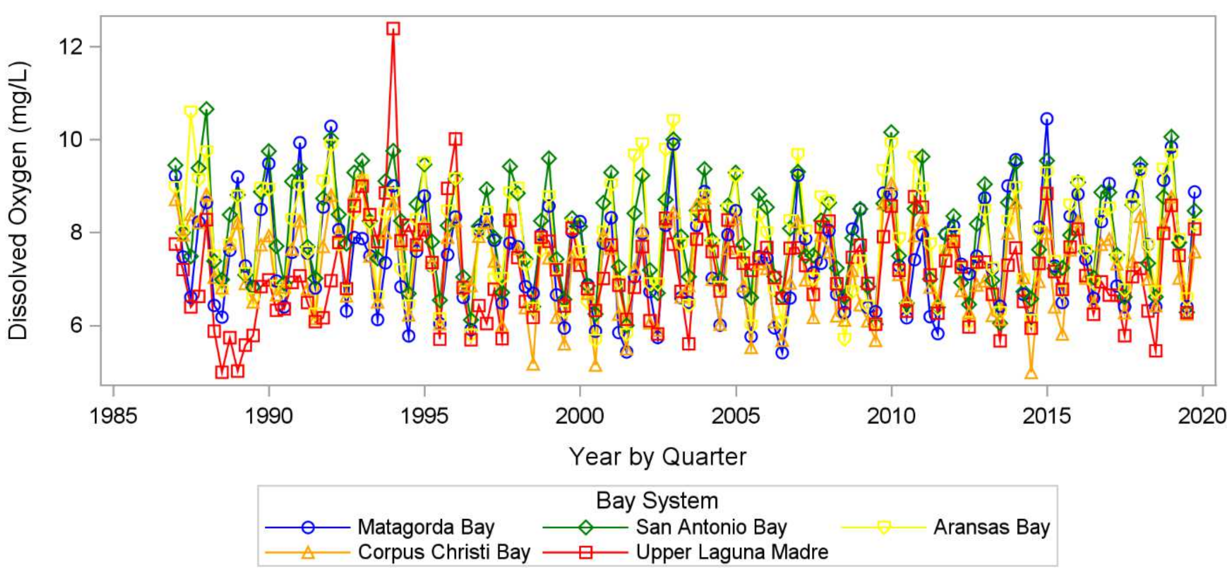


Figure 4. Estuary-wide average dissolved oxygen concentration by quarter.

3.2 Community Structure

A total of 105 of mollusk species were found in total across all estuaries (Table 4 and Table 5).

Table 4 Infaunal molluscan abundance (n/m^2) in Lavaca-Colorado and Guadalupe estuaries. Species distributions of mollusk communities within each estuary are listed by species count and split into two separate tables due to size of the tables. If a zero value is listed for the estuary or station, then the species did not appear in the station. Abbreviations: P = phylum, C = Class, O = order, F = Family, and GS = genus and species.

Taxa Name	Lavaca-Colorado									Guadalupe			
P C O F GS	FD	A	B	C	D	8	E	F	15	A	B	C	D
Mollusca													
Mollusca (unidentified)	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda													
Gastropoda (unidentified)	0	1	1	2	0	0	4	1	4	108	0	1	3
Heterostropha													
Pyramidellidae													
Boonea impressa	0	0	0	0	0	0	0	0	0	0	0	6	0
Eulimastoma sp.	0	7	24	21	0	7	30	21	7	2	7	7	6
Eulimastoma teres	0	0	0	0	0	0	0	0	0	0	0	0	0
Fargoa gibbosa	0	0	0	0	0	0	0	0	0	0	0	0	2
Odostomia canaliculata	0	3	0	0	0	0	0	0	0	0	0	0	0
Odostomia sp.	0	3	2	0	0	0	0	1	0	2	0	1	0
Pyramidella crenulata	0	0	0	0	0	0	0	0	0	2	1	4	2
Pyramidella sp.	0	0	0	0	0	0	0	0	0	5	1	0	3
Sayella crosseana	0	0	0	0	0	0	0	0	0	0	0	0	0
Turbonilla portoricana	0	0	0	0	0	0	0	0	0	0	0	0	0
Turbonilla sp.	0	0	3	35	3	7	1	0	21	0	0	7	31
Acteonidae													
Rictaxis punctostriatus	0	2	2	1	0	3	0	5	0	3	2	3	10
Murchisonelliidae													
Henrya goldmani	0	0	0	0	0	0	0	0	0	0	0	0	0
Neotaeniogloassa													
Littorinidae													
Littorina ziczac	0	0	0	0	0	0	0	0	0	0	0	0	0
Assimineidae													
Assiminea succinea	0	1	0	0	0	0	0	0	0	0	0	0	1
Truncatellidae													
Truncatella caribaeensis	0	0	0	0	0	0	0	0	0	0	0	0	0
Vitrinellidae													
Vitrinellidae (unidentified)	0	0	0	0	0	0	3	3	0	0	0	0	5
Teinostoma biscaynense	0	0	0	0	0	0	0	0	0	0	0	0	2
Vitrinella floridana	0	0	0	0	0	0	1	4	0	0	0	0	8
Caecidae													
Caecum pulchellum	0	0	0	0	0	0	0	1	0	0	1	0	1
Caecum glabrum	0	0	0	0	0	0	0	0	0	0	0	0	0
Caecum johnsoni	0	1	0	12	4	3	18	24	0	0	0	2	17
Epitoniidae													
Epitonium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Epitonium rupicola	0	0	0	0	0	0	0	0	0	0	0	0	0
Calyptraeidae													
Crepidula fornicata	0	0	0	0	3	0	0	0	0	0	0	1	0
Crepidula plana	0	0	0	0	0	0	0	0	0	3	0	66	1
Crepidula sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Naticidae													
Natica pusilla	0	0	0	0	0	0	0	0	0	0	0	0	0

Taxa Name	Lavaca-Colorado									Guadalupe			
P C O F GS	FD	A	B	C	D	8	E	F	15	A	B	C	D
Polinices duplicatus	0	0	1	3	0	0	0	0	0	0	0	0	0
Hydrobiidae													
	11	11								442	119	37	10
Texadina sphinctostoma	4	8	4	0	0	0	0	0	0	6	4	7	0
Texadina barretti	0	0	0	0	0	0	0	0	0	1	0	0	4
Cerithiidae													
Cerithium lutosum	0	0	0	0	0	0	0	0	0	0	0	0	0
Cephalaspidea													
Bullidae													
Bulla striata	0	0	0	1	0	0	0	4	0	0	0	0	1
Cylichnidae													
Acteocina canaliculata	47	44	51	54	4	95	69	90	252	24	29	35	88
Haminoeidae													
Haminoea succinea	0	0	0	0	0	0	3	0	0	0	0	0	0
Haminoea antillarum	0	0	0	0	0	0	0	0	0	0	0	0	0
Nudibranchia													
Nudibranchia (unidentified)	0	0	0	0	0	0	1	1	0	1	2	1	2
Corambidae													
Doridella obscura	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesogastropoda													
Diastomidae													
Diastoma varium	0	0	0	0	0	0	0	0	0	0	0	0	0
Neogastropoda													
Buccinidae													
Cantharus cancellarius	0	0	0	0	0	0	0	0	0	0	0	0	0
Nassariidae													
Nassarius acutus	3	6	8	12	11	17	8	11	53	0	0	6	4
Nassarius vibex	0	0	2	0	3	0	3	1	4	0	0	0	1
Nassarius sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Melongenidae													
Busycon contrarium	0	0	0	0	0	0	0	0	0	0	0	0	0
Columbellidae													
Anachis semiplicata	0	0	0	0	0	0	0	0	0	0	0	0	0
Anachis obesa	0	0	0	0	0	0	0	0	0	0	0	0	0
Mitrella lunata	0	1	0	1	0	0	0	0	0	0	0	1	1
Bivalvia													
Bivalvia (unidentified)	3	4	1	3	4	0	3	4	0	1	1	2	8
Myoida													
Myidae													
Paramya subovata	0	0	0	0	4	0	0	0	0	0	0	0	0
Corbulidae													
					42								
Corbula contracta	0	0	0	0	5	0	3	0	0	0	0	0	1
Corbula dietziana	0	0	0	0	1	0	0	0	0	0	0	0	0
Hiatellidae													
Hiatella arctica	0	0	0	0	4	0	0	0	0	0	0	0	0
Pholadidae													
Cyrtopleura costata	0	0	0	0	1	0	0	0	0	0	0	0	0
Martesia sp.	0	0	0	0	1	0	0	0	0	0	0	0	0
Nuculoida													
Nuculanidae													
						19	15						
Nuculana acuta	0	3	2	81	26	9	4	16	4	1	11	24	26
Nuculana concentrica	0	3	5	15	8	0	39	0	0	0	0	0	7
Pholadomyoida													
Pandoridae													
Pandora trilineata	3	1	5	17	3	14	3	3	11	1	2	6	11
Lyonsiidae													
Lyonsia hyalina floridana	11	2	3	4	1	0	0	0	0	6	1	2	3
Periplomatidae													

Taxa Name	Lavaca-Colorado									Guadalupe			
P C O F GS	FD	A	B	C	D	8	E	F	15	A	B	C	D
					27								
Periploma cf. orbiculare	0	0	0	31	9	0	10	0	0	0	0	0	8
Periploma margaritaceum	6	0	0	29	47	0	0	3	7	0	0	2	43
Veneroida													
Cardiidae													
Laevicardium mortoni	0	0	0	0	0	0	0	0	0	0	0	0	0
Crassatellidae													
Crassinella lunulata	0	0	0	0	0	0	0	0	0	0	0	0	0
Lasaeidae													
Aligena texasiana	6	2	0	56	3	0	0	0	0	0	0	2	90
					34								
Lepton sp.	0	1	2	9	1	0	1	4	0	0	0	0	0
Mysella planulata	0	4	4	11	46	3	13	11	7	2	0	2	66
Lucinidae													
Lucina amianta	0	0	0	0	0	0	0	0	0	0	0	0	0
Mactridae													
Mactra fragilis	0	0	0	0	0	0	0	0	0	0	0	0	0
	96	64	47	42		22	72	48	103	191	187	88	40
Mulinia lateralis	2	9	8	6	19	3	4	9	3	2	9	9	6
Rangia cuneata	0	10	0	0	0	0	0	0	0	340	20	4	1
Petricolinae													
Petricolaria pholadiformes	0	0	0	0	0	0	0	0	0	0	0	0	0
Pharidae													
Ensis minor	11	14	0	0	0	0	0	0	11	0	1	2	14
Semelidae													
Abra aequalis	0	0	0	0	27	0	3	0	0	0	0	0	1
Solecurtidae													
Tagelus divisus	14	0	0	0	0	0	0	0	0	0	0	0	0
Tagelus plebeius	0	7	0	0	0	0	0	0	0	0	0	3	5
Solenidae													
Solen viridis	8	0	0	0	0	0	0	1	0	0	0	0	1
Tellinidae													
Macoma brevifrons	0	0	0	0	0	0	0	0	0	0	0	0	0
	10	11						11					
Macoma mitchelli	0	6	78	7	4	3	5	6	74	58	118	80	72
Macoma tenta	0	0	0	0	4	0	0	0	0	0	0	0	2
Macoma sp.	0	0	0	0	2	0	0	0	0	0	0	0	0
Tellidora cristata	0	0	0	1	0	0	0	0	0	0	0	0	0
Tellina tampaensis	0	0	0	0	0	0	0	0	0	0	0	0	0
Tellina texana	0	0	0	0	1	0	0	0	0	3	2	1	21
Tellina versicolor	0	0	0	0	0	0	0	0	0	0	0	0	0
Tellina sp.	6	7	5	2	3	0	0	1	0	0	1	0	2
Veneridae													
Veneridae juvenile	0	0	0	0	0	0	0	0	0	0	0	0	0
Agriopoma texasianum	0	0	0	0	1	0	0	0	0	0	0	0	0
Anomalocardia auberiana	0	0	0	0	0	0	0	0	0	0	0	0	0
Chione cancellata	0	0	0	0	0	0	0	0	0	0	0	0	1
Chione sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclinella tenuis	0	0	0	1	2	0	0	0	0	0	0	0	0
Dosinia discus	0	0	0	0	0	0	0	0	0	0	0	0	1
Dosinia elegans	0	0	0	0	0	0	0	0	0	0	0	0	0
Dosinia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Mercenaria campechiensis	0	0	0	0	1	0	0	0	0	0	0	2	1
Arcoida													
Arcidae													
Anadara ovalis	0	0	0	0	1	0	0	0	0	0	0	0	0
Anadara transversa	0	0	0	0	0	0	0	0	0	0	0	0	0
Anadara sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Limoida													
Limidae													

Taxa Name	Lavaca-Colorado									Guadalupe			
P C O F GS	FD	A	B	C	D	8	E	F	15	A	B	C	D
Lima pellucida	0	0	0	0	0	0	1	0	0	0	0	0	0
Mytiloida													
Mytilidae													
Mytilidae (unidentified)	0	0	0	0	0	0	0	0	0	0	0	0	1
Amygdalum papyrium	8	0	0	0	0	0	0	0	4	1	0	0	1
Brachidontes exustus	0	1	1	0	0	0	0	1	0	0	16	0	0
Ischadium recurvum	*0*	*2*	*0*	*0*	*0*	*0*	*0*	*0*	*4*	*8*	*0*	*2*	*2*
Lioberus castaneus	0	0	0	0	0	0	0	0	0	0	0	0	0
Ostreoida													
Ostreidae													
Crassostrea virginica	0	0	1	0	0	0	0	0	0	0	0	3	1
Pectinidae													
Argopecten irradians amplicostatus	0	0	0	0	0	0	0	0	0	0	0	0	0
Anomiidae													
Anomia simplex	0	0	0	0	0	0	0	0	0	0	0	0	0
Scaphopoda													
Dentaliida													
Dentaliidae													
Dentalium texasianum	0	0	0	1	2	0	0	0	0	0	0	0	0
Dentalium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Gadilinidae													
Episiphon sowerbyi	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5. Infaunal molluscan abundance (n/m^2) in Mission-Aransas, Nueces, and Baffin Bay Laguna Madre estuaries. Species distributions of mollusk communities within each estuary are listed by species count and split into two separate tables due to size of the tables. If a zero value is listed for the estuary or station, then the species did not appear in the station. Abbreviations: P = phylum, C = Class, O = order, F = Family, and GS = genus and species.

	Mission-Aransas				Nueces					Baffin Bay-Laguna Madre					
Taxa Name	A	B	C	D	A	B	C	D	E	24	6	189G	189S	155G	155S
Mollusca															
Mollusca (unidentified)	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0
Gastropoda															
Gastropoda (unidentified)	0	0	0	0	0	12	6	18	16	4	5	26	3	0	0
Heterostropha															
Pyramidellidae															
Boonea impressa	0	0	0	0	0	0	0	0	0	0	0	24	5	0	0
Eulimastoma sp.	0	0	8	8	5	1	2	2	0	0	0	0	0	0	0
Eulimastoma teres	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Fargoa gibbosa	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Odostomia canaliculata	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Odostomia sp.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Pyramidella crenulata	0	0	0	8	0	1	0	0	0	0	0	3	2	0	0
Pyramidella sp.	0	0	0	0	1	2	4	4	7	0	0	0	0	0	0
Sayella crosseana	0	0	0	0	0	0	0	0	0	0	0	7	8	47	0
Turbonilla portoricana	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Turbonilla sp.	0	0	8	8	6	36	58	26	91	0	0	58	37	95	63
Acteonidae															
Rictaxis punctostriatus	0	0	8	0	5	5	0	25	6	93	91	21	5	0	0
Murchisonelliidae															
Henrya goldmani	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Neotaeniogloassa															
Littorinidae															
Littorina ziczac	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Assimineidae															
Assiminea succinea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Truncatellidae															
Truncatella caribaeensis	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Vitrinellidae															
Vitrinellidae (unidentified)	0	0	0	0	6	183	0	6	6	0	0	0	0	0	0
Teinostoma biscaynense	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Vitrinella floridana	0	0	0	0	62	18	1	0	4	0	0	0	0	0	0
Caecidae															
Caecum pulchellum	0	0	0	0	0	0	0	1	0	0	0	985	694	9573	12070
Caecum glabrum	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0
Caecum johnsoni	0	0	0	0	0	2	5	0	14	0	0	0	0	0	0

Taxa Name	Mission-Aransas A	B	C	D	Nueces A	B	C	D	E	Baffin Bay-Laguna Madre 24	6	189G	189S	155G	155S
Epitoniidae															
Epitonium sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Epitonium rupicola	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0
Calyptraeidae															
Crepidula fornicata	8	0	0	0	0	0	0	0	1	0	2	24	5	95	0
Crepidula plana	0	0	0	0	0	23	4	3	10	0	0	17	3	0	0
Crepidula sp.	0	0	0	0	0	12	2	0	6	0	0	0	0	0	0
Naticidae															
Natica pusilla	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Polinices duplicatus	0	0	0	0	0	0	0	1	5	0	0	0	0	0	0
Hydrobiidae															
Texadina sphinctostoma	102	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Texadina barretti	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerithiidae															
Cerithium lutosum	0	0	0	0	0	2	0	0	0	2	0	1272	88	118	0
Cephalaspidea															
Bullidae															
Bulla striata	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Cylichnidae															
Acteocina canaliculata	8	55	16	0	85	115	13	29	20	20	8	0	8	0	0
Haminoeidae															
Haminoea succinea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haminoea antillarum	0	0	0	0	0	0	0	0	0	0	0	101	24	0	0
Nudibranchia															
Nudibranchia (unidentified)	0	0	0	0	0	2	2	2	7	0	0	12	0	0	0
Corambidae															
Doridella obscura	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Mesogastropoda															
Diastomidae															
Diastoma varium	0	0	0	0	0	0	0	0	0	0	0	108	8	780	32
Neogastropoda															
Buccinidae															
Cantharus cancellarius	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0
Nassariidae															
Nassarius acutus	0	0	16	118	1	6	13	2	10	0	0	2	0	0	0
Nassarius vibex	0	0	0	0	0	2	2	0	4	0	0	3	0	24	32
Nassarius sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Melongenidae															
Busycon contrarium	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Columbellidae															
Anachis semiplicata	0	0	0	0	0	0	2	0	0	0	0	9	0	24	0
Anachis obesa	0	0	0	0	0	1	4	0	0	0	0	2	0	0	0
Mitrella lunata	0	0	0	0	0	1	0	0	3	0	0	2	0	0	0

Taxa Name	Mission-Aransas A	B	C	D	Nueces A	B	C	D	E	Baffin Bay-Laguna Madre 24	6	189G	189S	155G	155S
Bivalvia															
Bivalvia (unidentified)	8	0	0	8	2	8	11	8	15	0	0	58	0	0	0
Myoida															
Myidae															
Paramya subovata	0	0	0	0	0	0	0	5	2	0	0	0	0	0	0
Corbulidae															
Corbula contracta	0	0	0	0	0	2	2	0	6	0	0	0	0	0	0
Corbula dietziana	0	0	0	0	0	1	2	0	11	0	0	0	0	0	0
Hiatellidae															
Hiatella arctica	0	0	0	0	0	3	2	3	4	0	0	0	0	0	0
Pholadidae															
Cyrtopleura costata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Martesia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuculoida															
Nuculanidae															
Nuculana acuta	0	0	0	8	218	388	539	38	160	0	0	0	0	0	0
Nuculana concentrica	0	0	24	0	0	0	4	0	2	0	0	0	0	0	0
Pholadomyoida															
Pandoridae															
Pandora trilineata	0	0	0	0	0	4	5	14	3	0	0	0	0	0	0
Lyonsiidae															
Lyonsia hyalina floridana	0	0	0	0	10	158	64	22	42	0	0	0	3	0	0
Periplomatidae															
Periploma cf. orbiculare	0	0	0	0	1	9	132	5	20	0	0	0	0	0	0
Periploma margaritaceum	0	0	0	0	18	57	36	45	29	0	0	0	0	0	0
Veneroida															
Cardiidae															
Laevicardium mortoni	0	0	0	0	0	0	0	0	0	0	0	19	23	47	32
Crassatellidae															
Crassinella lunulata	0	0	0	0	0	0	12	0	1	0	0	0	0	0	0
Lasaeidae															
Aligena texasiana	0	0	8	0	7	140	8	32	84	0	0	0	2	0	0
Lepton sp.	0	0	0	0	0	0	3	0	2	0	0	0	0	0	0
Mysella planulata	0	0	0	0	158	503	17	6	45	0	0	0	3	0	32
Lucinidae															
Lucina amianta	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Mactridae															
Mactra fragilis	0	0	0	0	0	7	0	0	0	0	0	40	2	0	0
Mulinia lateralis	142	0	32	16	1109	868	135	128	40	838	1116	112	178	0	0
Rangia cuneata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petricolinae															
Petricolaria pholadiformes	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Pharidae															

Taxa Name	Mission-Aransas A	B	C	D	Nueces A	B	C	D	E	Baffin Bay-Laguna Madre 24	6	189G	189S	155G	155S
Ensis minor	0	0	0	0	1	2	1	2	1	0	0	0	0	0	0
Semelidae															
Abra aequalis	0	0	0	8	0	3	19	1	16	0	0	0	0	0	0
Solecurtidae															
Tagelus divisus	0	0	0	0	5	19	13	2	7	0	0	0	0	0	0
Tagelus plebeius	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0
Solenidae															
Solen viridis	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0
Tellinidae															
Macoma brevifrons	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Macoma mitchelli	32	102	71	0	101	28	16	7	21	0	0	0	0	0	0
Macoma tenta	0	0	0	0	0	0	2	2	5	0	0	0	0	0	0
Macoma sp.	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Tellidora cristata	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0
Tellina tampaensis	0	0	0	0	0	2	0	0	0	0	0	12	8	0	0
Tellina texana	0	0	0	0	3	0	1	35	0	0	0	60	36	0	32
Tellina versicolor	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0
Tellina sp.	0	0	0	0	0	4	9	11	8	0	0	3	0	0	0
Veneridae															
Veneridae juvenile	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Agriopoma texasianum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anomalocardia auberiana	0	0	0	0	0	0	1	0	0	0	10	411	372	0	0
Chione cancellata	0	0	0	0	0	4	9	0	1	0	0	119	24	47	0
Chione sp.	0	0	0	0	0	0	0	0	0	0	2	34	0	0	0
Cyclinella tenuis	0	0	0	0	1	6	7	0	3	0	0	0	0	0	0
Dosinia discus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dosinia elegans	0	0	0	0	0	1	3	0	7	0	0	0	0	0	0
Dosinia sp.	0	0	0	0	0	2	0	1	6	0	0	0	0	0	0
Mercenaria campechiensis	0	0	0	0	0	3	5	2	1	0	0	0	0	0	0
Arcoida															
Arcidae															
Anadara ovalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anadara transversa	0	0	0	0	0	0	2	0	4	0	0	0	0	0	0
Anadara sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Limoida															
Limidae															
Lima pellucida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mytiloida															
Mytilidae															
Mytilidae (unidentified)	8	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Amygdalum papyrium	0	0	0	0	2	3	0	0	0	2	0	287	46	236	0
Brachidontes exustus	0	0	0	0	0	5	0	0	0	0	0	64	3	425	32
Ischadium recurvum	0	0	0	0	2	8	1	0	3	0	0	0	0	0	0

	Mission-Aransas				Nueces					Baffin Bay-Laguna Madre					
Taxa Name	A	B	C	D	A	B	C	D	E	24	6	189G	189S	155G	155S
Lioberus castaneus	0	0	0	0	0	0	2	0	3	0	0	0	0	0	0
Ostreoida															
Ostreidae															
Crassostrea virginica	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Pectinidae															
Argopecten irradians amplicostatus	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Anomiidae															
Anomia simplex	0	0	8	0	0	1	0	0	0	0	0	0	0	0	0
Scaphopoda															
Dentaliida															
Dentaliidae															
Dentalium texasianum	0	0	0	0	0	2	8	0	12	0	0	0	0	0	0
Dentalium sp.	0	0	0	0	0	0	4	0	1	0	0	0	0	0	0
Gadilinidae															
Episiphon sowerbyi	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0

In Lavaca-Colorado, there is a total of 60 mollusk species (Table 4). From the species found in Lavaca-Colorado, 20 are Gastropoda, 37 Bivalvia, and 1 Scaphopoda classes. From the Bivalvia class, the most abundant species were *Corbula contracta* (13.84/m^2)*, Nuculana acuta* (69.18/m^2)*, Lepton sp.* (11.36/m^2)*, Mulinia lateralis* (494.36/m^2), and *Macoma Mitchelli* (42.35/m^2). The most abundant species found from the Gastropoda class within Lavaca-Colorado include *Texadina sphinctostoma* (228.35/m^2) and *Acteocina canalocilata* (42.35/m^2). All stations within Lavaca-Colorado, excluding station D, share species abundance and diversity similarities. From the Bivalvia class, station D contained a high quantity of *Corbula contracta, Periploma orbiculare,* and *Lepton sp.,* which was not a shared quality with any other station (Table 4).

In Guadalupe Estuary, the Gastropoda class contains 6 species and Bivalvia 28 species (Table 4). Many species found are also documented in nearby estuaries. Bivalvia species in high abundance include *Texadina sphinctostoma, Mulinia lateralis, Macoma mitchelli*, and uniquely *Rangia cuneata*, which is found only in Guadalupe stations. The majority of *Rangia cuneata* are found in station A, which is closest to the Guadalupe River mouth. The Gastropoda, *Texadina sphinctostoma*, has the highest species abundance of all species found within this estuary.

Mission-Aransas Estuary consists of 8 Gastropoda species and 9 Bivalvia (Table 5). Mission-Aransas community structure shared common species found in the other estuarine systems. *Macoma mitchelli* and *Mulinia lateralis* were Bivalves found the most frequent, but not in high abundance compared to other estuaries.

Nueces Estuary contains 36 Gastropoda species and 50 Bivalvia species, resulting in the highest diversity of community structure (Table 5). Abundant Gastropoda species are *Turbonilla sp.* and *Acteocina canaliculata*. Bivalvia species in high abundance are *Nuculana acuta, Lyonsia* *hyaline floridana, Periploma orbiculare, Periploma margaritaceum, Aligena texasiana, Mysella planulata, Mulinia lateralis,* and *Macoma mitchelli.* These species were commonly found in other estuaries, but *Mysella planulata, Periploma margaritaceum,* and *Lyonsia hyalinda floridana* were found in high abundance exclusively in Nueces Estuary.

In total, Baffin Bay-Laguna Madre consists of 24 Gastropoda species and 15 Bivalvia species (Table 5). The species composition varied due to the difference of salinity zones found among the stations. Stations 6 and 24 in Baffin Bay experience higher mean salinity due to the lack of freshwater inflow. Stations 6 and 24 contained Gastropoda species *Rictaxis punctostriatus* and Bivalvia *Mulinia lateralis.* In contrast, stations 189G, 189S, 155G, and 155S in Laguna Madre was found to have Gastropoda species *Turbonilla sp., Caecum pulchellum, Cerithium lutosum,* and *Diastoma varium*. Bivalvia species found in these stations were *Laevicardium mortoni, Aninakicardua auberiana, Cione cancellata, Amygdalum papyrium,* and *Brachidontes exustus.*

The degree in which each Bivalvia species is dominant per estuary is revealed (Table 6). *Mulinia lateralis* was the greatest dominant species in three of the six estuaries, and if it was not most dominant, it was second or third in all estuarine systems except of Laguna Madre. The second most abundant species calculated from the dominant list is even among *Acteocina canalicuata* and *Macoma mitchelli.* *Rangia cuneata* is only listed once, as the third most dominant in Guadalupe Estuary.

Table 6. Dominant three species in estuaries.

Estuary	1st Dominant	2nd Dominant	3rd Dominant
Lavaca-Colorado	*Mulinia lateralis*	*Acteocina canaliculata*	*Macoma mitchelli*
Guadalupe	*Texadina sphinctostoma*	*Mulinia lateralis*	*Rangia cuneata*
Mission-Aransas	*Macoma mitchelli*	*Mulinia lateralis*	*Nassarius acutus*
Nueces	*Mulinia lateralis*	*Nuculana Acuta*	*Mysella planulata*
Baffin Bay	*Mulinia lateralis*	*Rictaxis punctostriatus*	*Acteocina canaliculate*
Laguna Madre	*Caecum pulchellum*	*Cerithium lutosum*	*Diastoma varium*

Shell lengths were measured for the top 9 dominant bivalve species (Table 7). Bivalves that are displayed in both dominant tables include *Mulinia lateralis, Nuculana Acuta, Mysella planulata, Macoma mitchelli,* and *Rangia cuneata.* Out of 9 mollusks listed in Table 6 and Table 7 of the species are within the Bivalvia class. The frequency of *Mulinia lateralis* appeared in this study is dramatically greater than all other abundant Bivalvia species and has the smallest minimum shell size recorded throughout all estuaries. *Rangia cuneata,* was the 9th most abundant Bivalvia species but had the greatest shell size recorded, and the calculated mean was much greater than all other species.

Table 7. Dominant bivalve species with corresponding size calculated by aggregated data from all tested estuaries. Mean(mm), standard deviation, minimum, and maximum size values.

Species	Frequency	Mean	Std. Dev	Min.	Max
Mulinia lateralis	13,229	3.47	2.40	0.02	16.25
Nuculana acuta	2,218	2.91	1.87	0.17	11.50
Mysella planulata	1,156	1.82	0.62	0.75	5.00
Macoma mitchelli	810	4.54	4.08	0.42	22.00
Periploma cf. orbiculare	546	3.18	3.07	0.67	23.00
Aligena texasiana	501	2.12	1.07	0.42	5.17
Periploma margaritaceum	462	2.14	1.69	0.42	12.50
Corbula contracta	459	2.81	1.03	0.92	7.00
Rangia cuneata	434	12.71	11.36	0.75	51.00

The cluster analysis dendrogram displays similarity in community structure between each estuary-station combination. There are well defined groups influenced by environmental factors and the diversity found within each estuary (Figure 6). The Y axis defines similarity levels between pairs of samples or groups, which are listed at the end of the dendrogram. Laguna Madre are divided into two areas, one found in Laguna Madre which contains stations 189G, 189S, 155G, and 155S. The other area is found within Baffin Bay with stations 24 and 6. Both

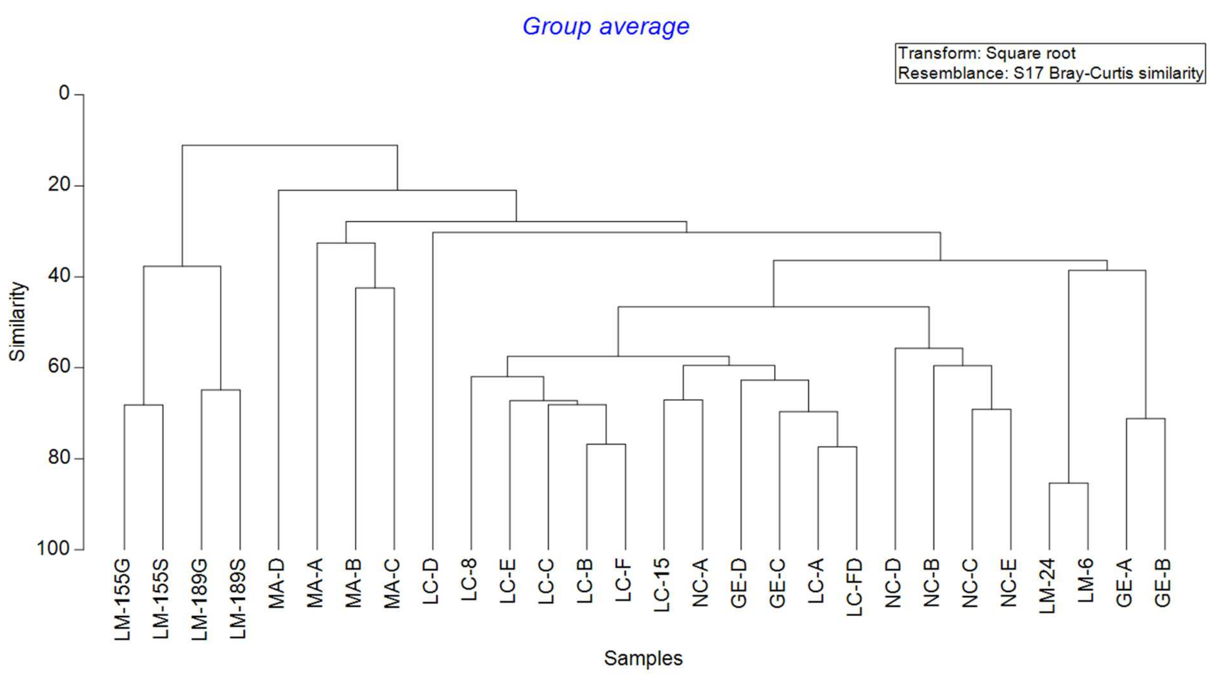


Figure 6. Cluster analysis based on overall station average abundance.

155 stations share 70% similarity, and the 189 stations share 60% similarity as well. Between both locations of 155 and 189, a 40% similarity is shared. A distinguishable difference between stations found in Laguna Madre compared to Baffin Bay. The stations found in laguna Madre, only share a similarity a 10% similarity to the stations found in Baffin Bay. LM 24 and LM 6 have almost a 90% similarity. Mission Aransas stations do not have high similarities to other estuarine stations, but MA-A, MA-B, and MA-C have a 40% similarity (Figure 6). MA-D has a lowest similarity to the other Mission-Aransas stations at 20% similarity. MA-D is found more near the barrier islands in Aransas Bay, while other stations in Mission-Aransas are closer to Copano Bay that are directly influenced by inflow from Mission River and Aransas River. All Lavaca Colorado stations excluding LC-A and LC-FD share a minimum of 60% similarity LC-A an LC-FD are outliers of this estuarine system due the placement near the Lavaca River mouth. The salinity differs greatly form the freshwater run off. Guadalupe has two clear divisions in station similarities. Station GE-D and GE-C share 70% similarity being near the Gulf inlet, while they share a 35% to stations GE-A and GE-B near the Guadalupe River mouth. Majority of stations excluding NC-A in Nueces Estuary are at least ~40% similar to all NC stations. NC-A differs due to the influx of inflow from being at the mouth of the Nueces River. NC-A is found closest to the Nueces River compared to the rest of the stations.

Distinct clusters of stations are mapped on the nMDS based on count of species per sample averaged by station over time (Figure 7). There are two sperate 20% similarity clusters, one containing 4 stations from Laguna Madre stations. On the left, stations 115G, 155S, 189G, and 189S are all found in where Laguna Madre. These stations are also distinct because they are placed in direct grass or sand areas. In contrast to the other Laguna Madre stations on the right side, there is no direct source of inflow for these four stations. The other two Laguna Madre stations can be found in Baffin Bay, where there is freshwater inflow from small creeks. Unlike other stations that are parallel to the barrier islands in other estuaries, there is no gulf inlets or freshwater sources. There are geophysical and water quality differences between the Laguna Madre stations, because there are distinctive abundance patterns in mollusks populations and salinity zones. Despite the 155 and 189 stations being clustered in 20% bounds, the Euclidean distance is large. They do not share a bound greater than 20% and do not share a 40% or 60% similarity despite the stations being near each other in the study area. All other stations are clustered to at least 20% similarity.

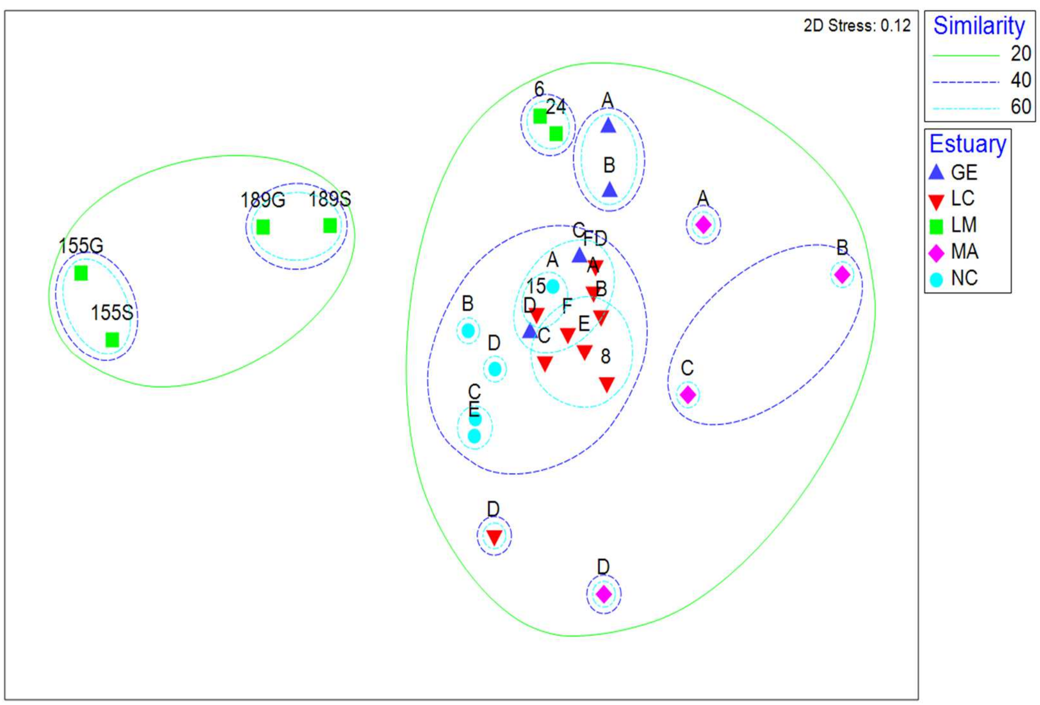


Figure 7. Communmunity structure visualized usiusing nMDS overlayed with the similarity analvsis.

The largest cluster on the right side in the MDS shows a 20% similarity and contains stations from the majority of Lavaca-Colorado, Nueces Estuary, and half of Guadalupe Estuary's stations. Lavaca-Colorado receives freshwater from Tres Palacios River and Lavaca River, and the mollusk community here share closely related population dynamics illustrating a distinguished salinity zone. All the Lavaca-Colorado stations are found in this cluster expect LC-D, and LC-D has a great Euclidean distance from the other Lavaca-Colorado stations. Station LC-D experiences higher levels of salt water due to being the most near to a Gulf inlet and is no more than 20% like any other station. Stations found in Nueces Estuary have a low Euclidean distance and are clustered near one another. Guadalupe Estuary's secondary bay stations, A and B, are 60% similar and are distinct from all other stations, while the primary stations, C and D, are more related to the stations in Lavaca and Nueces Estuary. This relationship between NC and LM explains a salinity zone that is created along these estuary systems when near a freshwater source. Mission Aransas stations resulted stations C and B share 40% similarity with each other. C and B are found near the inlet of fresh and saltwater mixing. While In contrast, stations A and D only share 20%.

3.3 Population Size Structure

Molluscan data of dominant Bivalvia count and length was aggregated for all estuaries to reveal seasonal and size trends over time. The majority of *Mulinia lateralis* found was about 2 mm in length and made up ~15% of its population (Figure 8). There are smaller *Mulinia lateralis's* and fewer large *Mulinia lateralis's.* The boxplots display Mission-Aransas contained the largest *Mulinia lateralis* compared to all other estuaries.

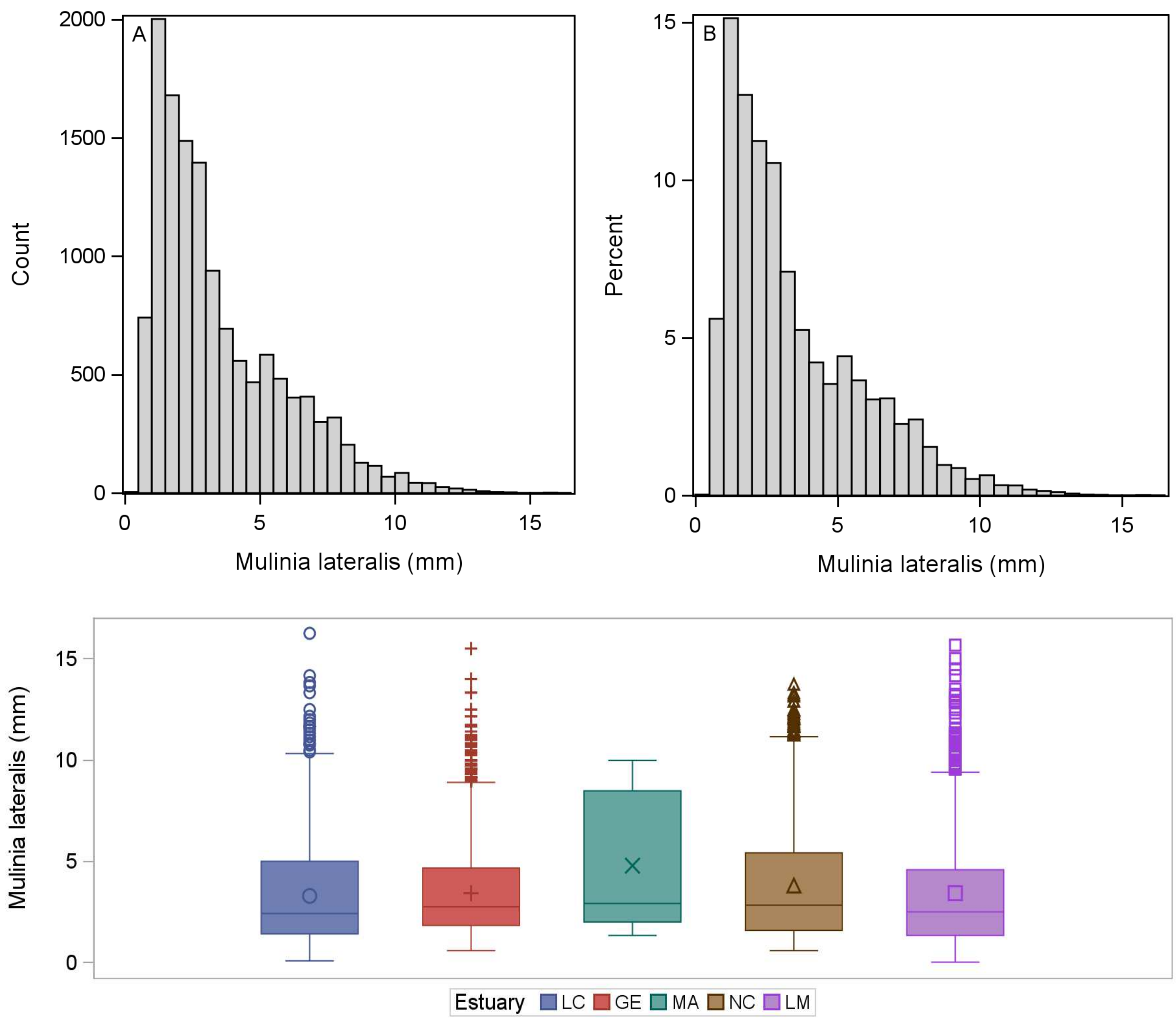


Figure 8. *Mulinia lateralis* shell lengths. Top: Count and percent aggregated throughout LC, GE, MA, NC, and LM. Bottom: Box plots by estuary.

The highest percentage (20%) of shell length resulted in *Mysella planulata* lengths of 2 mm. About 230 individuals *Mysella planulata* were recorded at this peak length (). After 2 mm, a drop off in species count is dramatic in lengths 2 - 5 mm. Boxplots displayed shell lengths were similar in all estuaries, except in Mission-Aransas where no *Mysella planulata* were found.

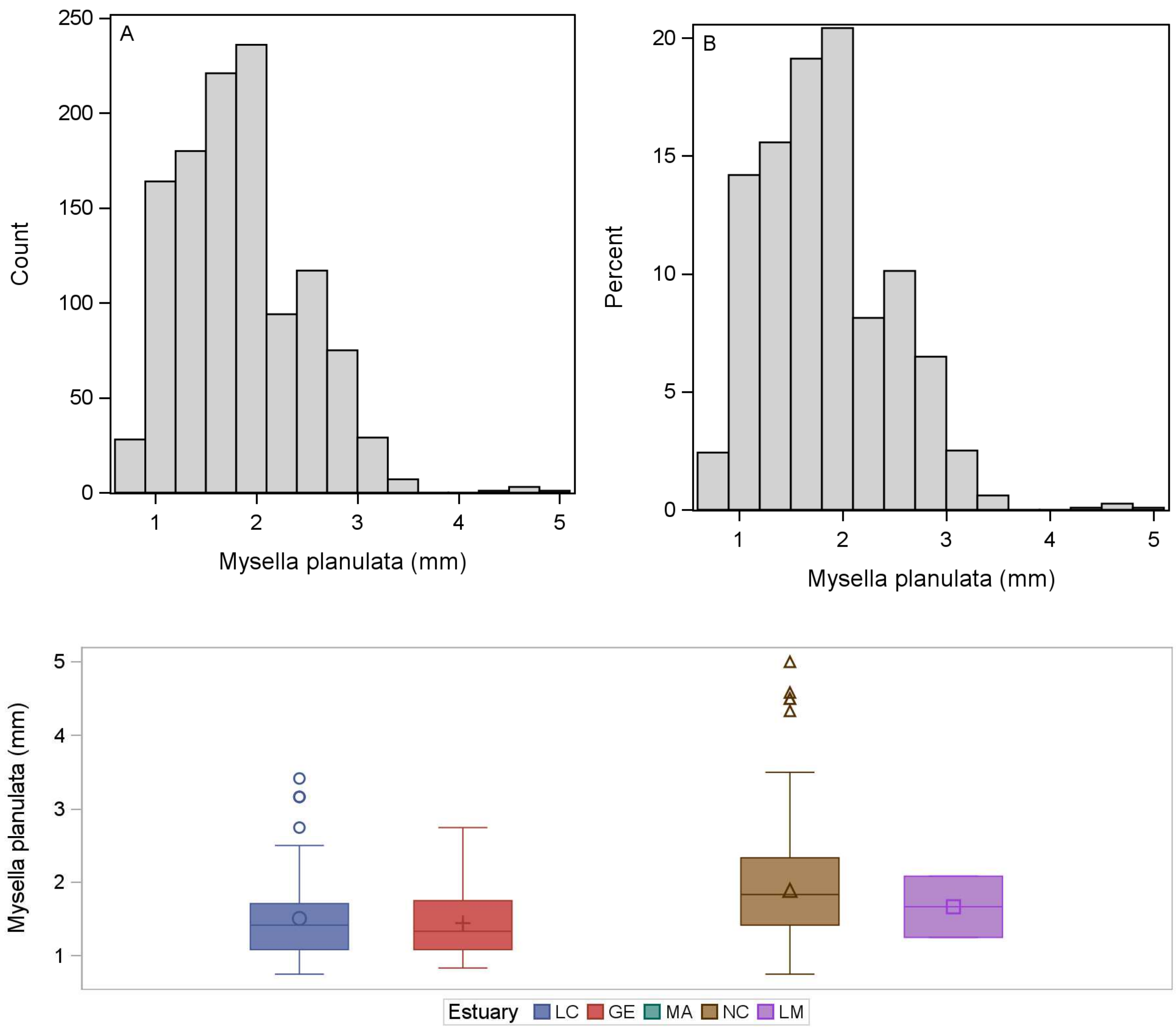


Figure 9. *Mysella planulata* shell lengths. Top: Count and percent aggregated throughout LC, GE, MA, NC, and LM. Bottom: Box plots by estuary.

The majority, 25%, of *Nuculana acuta* is revealed to be 1.5 mm size range and this length had a count of 500 shells (Figure 10). A gradual decline of shell length and count begins at 2 mm and continues to 10 mm. The boxplot displays all estuaries share similar shell lengths, and Mission-Aransas does not have any documented numerous *Nuculana acuta*.

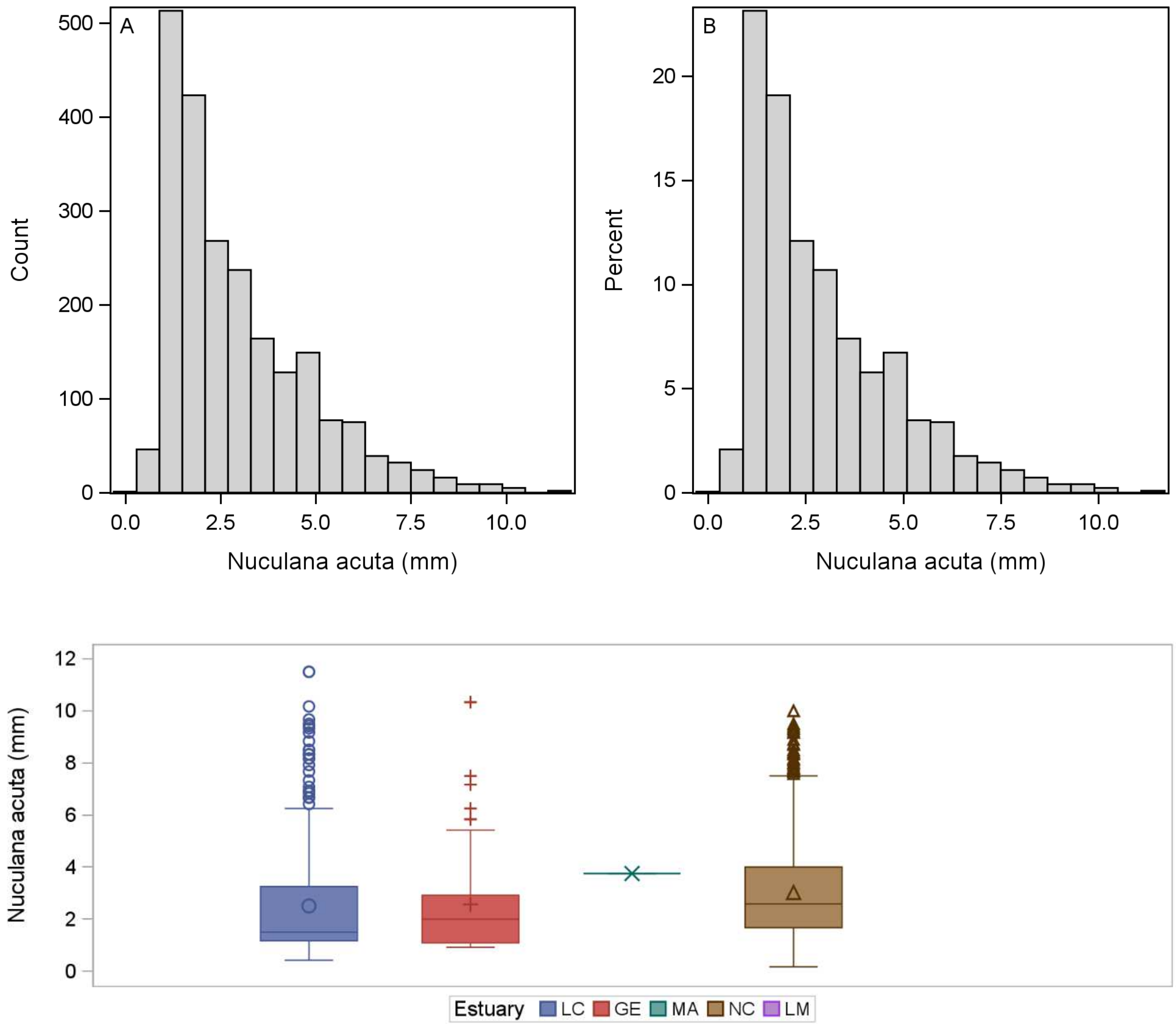


Figure 10. *Nuculana acuta* shell lengths. Top: Count and percent aggregated throughout LC, GE, MA, NC, and LM. Bottom: Box plots by estuary.

Macoma mitchelli's highest abunance at the shell length of 2 mm, with the count of 250 and 30% of overal abudnace. There is a sudden drop of *Macoma mitchelli* abundance following peak length. The estuaries Lavaca-Colorado, Guadalupe, Mission-Aransas, and Nueces Estuary similar shell lengths, displayed on the boxplot. Laguna Madre is absent of *Macoma mitchelli* entirely.

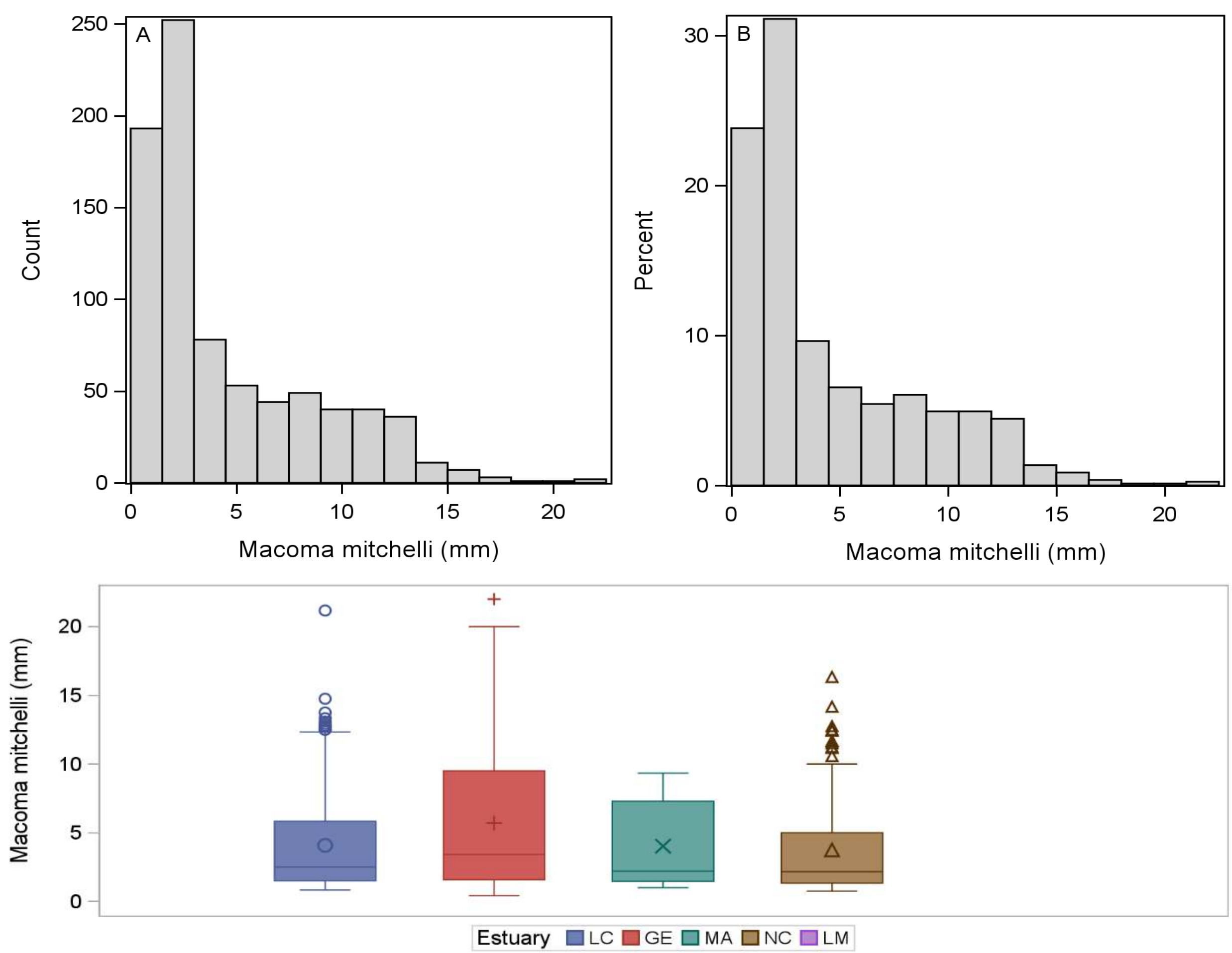


Figure 11. *Macoma mitchelli* shell lengths. Top: Count and percent aggregated throughout LC, GE, MA, NC, and LM. Bottom: Box plots by estuary.

Guadalupe Estuary contained the documented *Rangia cuneata.* From these documented *Rangia cuneata* almost 50% were smaller than 10mm. and 30% of this majority were 10mm. There is a distinct drop off of documented shell length after this size (Figure 12).

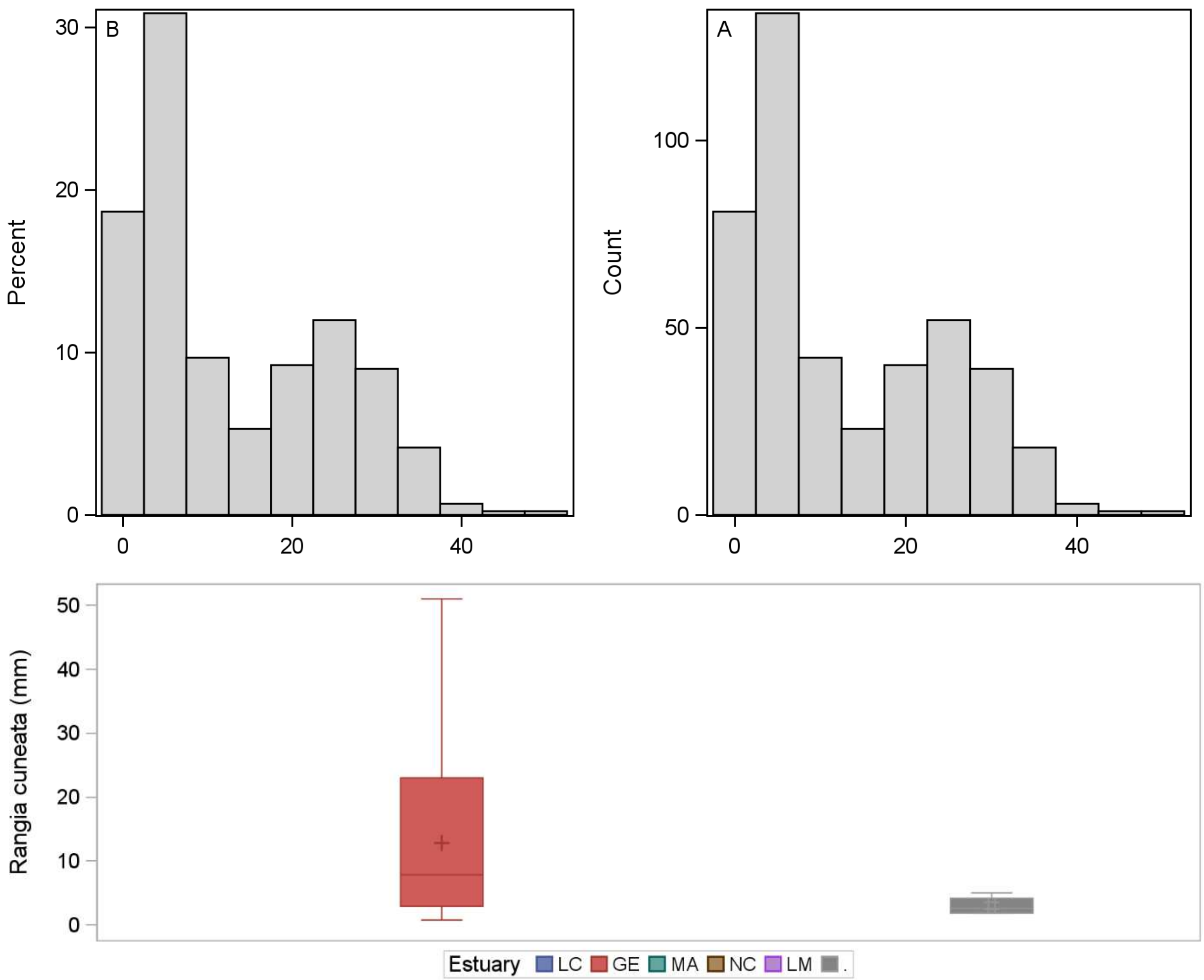


Figure 12. *Rangia cuneata* shell lengths. Top: Count and percent aggregated throughout LC, GE, MA, NC, and LM. Bottom: Box plots by estuary.

3.4 Hurricane Harvey

Hurricane Harvey made landfall on Texas's coastline on August 25, 2017. Hurricane Harvey provides a unique case of the effects on inflow on the most dominant species, *Mulinia lateralis* and the species considering for inflow regulations in Senate Bill 3, *Rangia cuneata* . Guadalupe Estuary received the most freshwater inflow influx from Hurricane Harvey. Lavaca-Colorado's inflow was also affected, but to a lesser extent. In contrast, Nueces Estuary was barley effected by the hurricane. Due to Guadalupe Estuary and Lavaca-Colorado receiving the most inflow, a recruitment even takes place two months after the event, when the estuarine system can return to pre-hurricane conditions.

In Guadalupe estuary. The quantity of *Mulinia lateralis* did not exceed 25 documented shells until April of 2018. During these quarters February 2017 – January 2018, salinities ranged from 5.2 - 22.6, and did not exceed a shell count of more than 25. Salinity levels returned to pre-hurricane conditions 4 months later in October with an average salinity of 22.6. The following quarter, a population recruitment of juvenile shells was recorded. In April 2018, almost 150 shells were found with the shell length of 2.5mm. In the following months of July and October 2018, shell sizes grew within this estuary.

Mulinia lateralis' in Lavaca Colorado February 2017 was documented to have the majority of shell lengths of 2mm, salinity levels were 14.8. In the next quarter in April 2017, the population of *Mulinia lateralis* dispersed into shell lengths ranging from 2 – 8 mm with salinity levels of 16.9 psu. In July 2017, salinity rose to 22.8, and the population of *Mulinia lateralis* was disappeared. October 2017, minimal population density was continued through January of 2018. April of 2018, a peak in *Mulinia lateralis* took place and salinity rose to 22.8 psu. In July and October of 2018, the population count fell dramatically.

Rangia cuneata was found only in Guadalupe Estuary. In April of 2017, with a salinity of 8.2, 25 shells were documented smaller than 10mm. After Hurricane Harvey took place, less than 5 were found in each quarter.

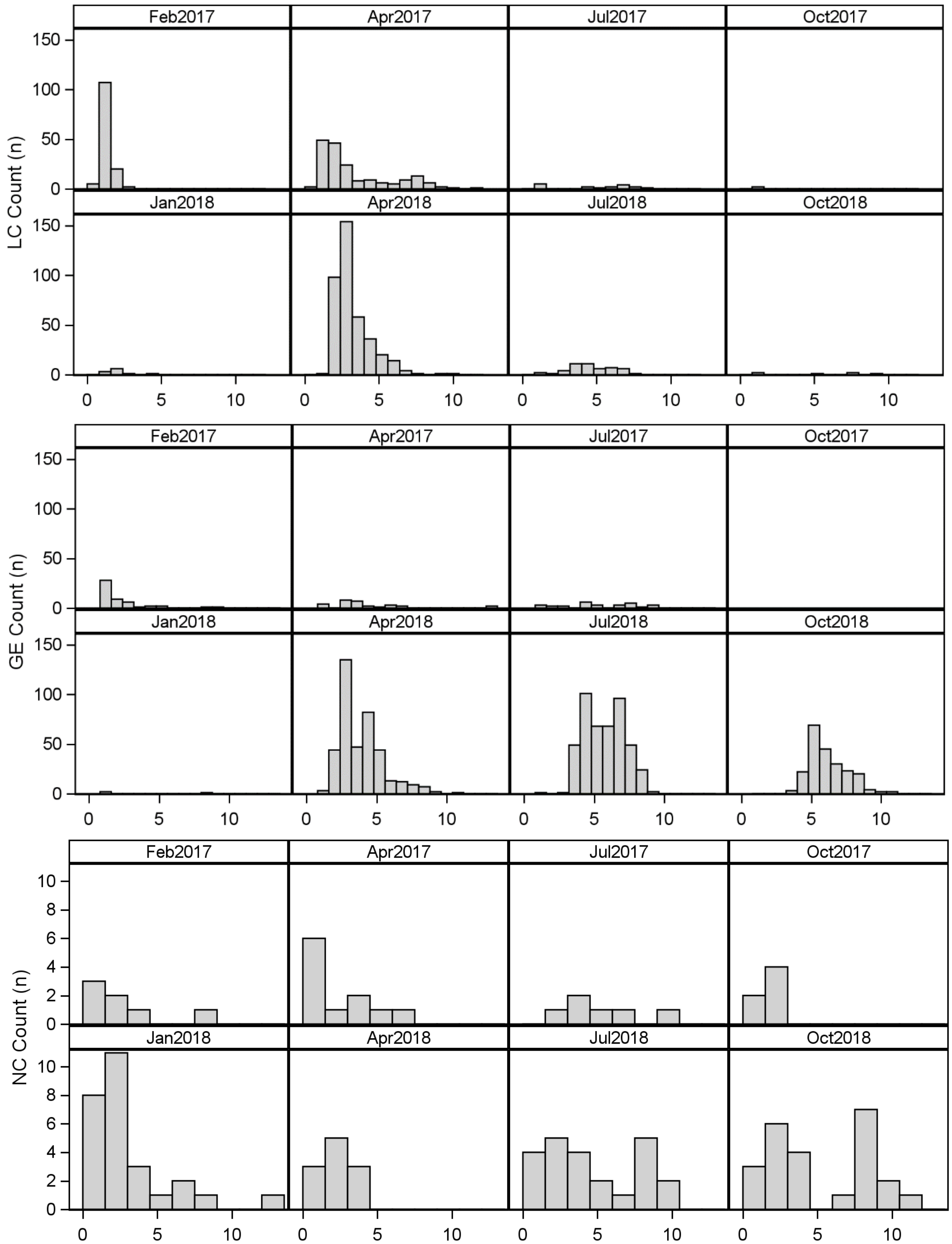


Figure 13. *Mulinia lateralis* abundance count and shell length before and after Hurricane Harvey. Scale of 150 in LC and GE, while NC has a scale of 10.

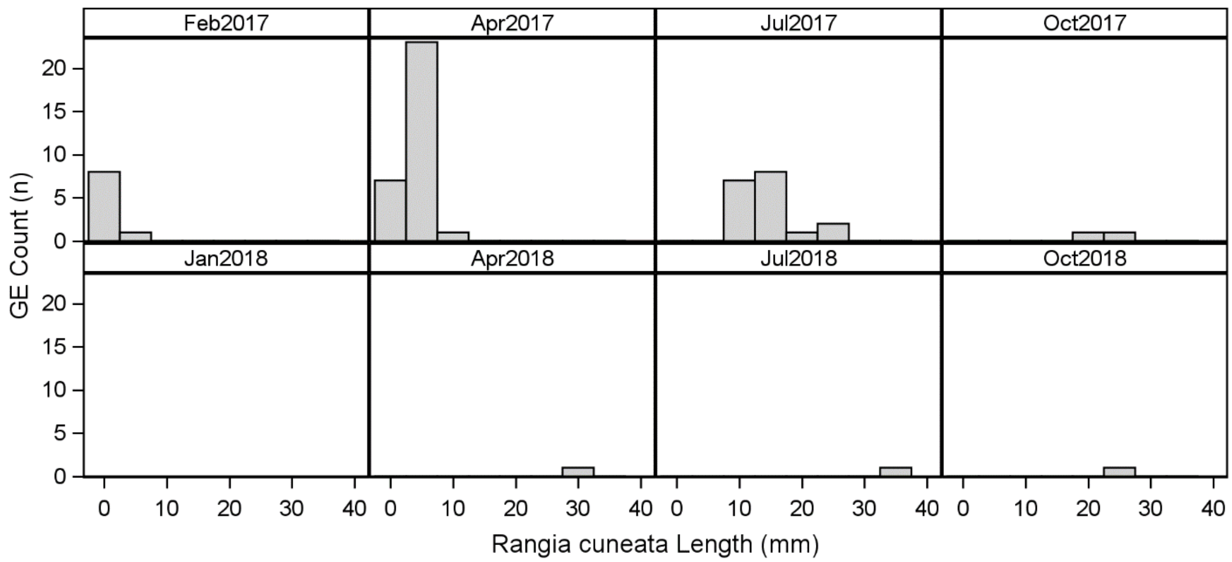


Figure 14. *Rangia cuneata* abundance and shell length in GE before and after Hurricane Harvey.

The size structure of the five dominant bivalve species was examined quarterly over the entire record (Figure 14 – Figure 18). *Mulinia lateralis*'s first peak in population growth took place in spring 1988 (Figure 14), which was the beginning of a multi-year dry season with salinity ranging between 33.7 - 34.2 pp. More than 65% of shells found are below the length of ~2 mm. The following quarter 1988:3, the shells lengths but with a lesser population density. The next influx of *Mulinia lateralis* population occurs during wet year conditions of 1993. Between the quarts 1993:1-1993:3 most shells lengths are below 5 mm. In 1993:4, almost 50% of the population was above 5 mm, but the population density of shell lengths above 5 mm was less. In January of 1993, salinities ranged from 17.5 psu to 30.6 throughout all estuarine systems, and gradually increased to 15.8 psu to 33.8 psu in November of 1993. In 1994, a population increase took place in the first quarter where the salinity average is 24.9, and the majority of *Mulinia lateralis* was below the length of 2.5 mm. Throughout 1994:2-1994:4, the population size distribution grew to 3 - 12.5 mm. In 1995:2, another mini juvenile population bloom occurred, during spring with the salinities averaging of 23.5. Distribution of shell size grew in 1995 following quarters for shells above 5 mm. During the years 1996 - 2000, dry patterns occurred, but minimal recruitment of *Mulinia lateralis* population was found, but the shells that were documented were greatest in the first two quarters of all years. In 2001:1 a slight reproduction event took place with juvenile shell lengths of 2 mm were recorded and were followed by years of low reproduction (2002-2007). In the years 2008 - 2011, a pattern occurred in all first quarterly testing. The majority of *Mulinia lateralis* were documented to be 1-2 mm. Within these years, after the first quarter, shell sizes progressed to adult sizes. Years 2013 - 2016 reveal minimal reproduction events. In 2017, Hurricane Harvey made landfall in Port Aransas and Port O' Connor. This category 4 hurricane influenced a great respawn event of *Mulinia lateralis.* Large amounts of freshwater inflow caused by the hurricane resulted in heavy nutrient loads and lower salinity. In 2018:2, the *Mulinia lateralis* community experienced a recruitment event and population spike. Throughout the year 2018, the quarters exhibit a progressive growth of shell length revealing conditions following Hurricane Harvey were optimal for species growth.

Mysella planulata experienced the first population growth during this study in 1990:3, shell lengths were majority 1-2 mm. In 1991:3, another growth event took place under similar conditions and results. Minimal population changes took place 1992-1996, and in 1997:3 and 1997:4, a major population bloom took place for *Mysella planulata*. During this event salinities were around 15.9 - 22.2 and were the result of years returning to average wetness after a dry period. In the year 1998, the beginning of a continuous population patter begun, with juvenile *Mysella planulata* development in 1998:1, with a salinity of 20.6, size increased throughout 1998. In all quarters of 1999, *Mysella planulata* size ranged between 2 – 4 mm. Similar patterns continued in years 2000 and 2001 with less density within the *Mysella planulata* population. Years 2002-2011 data reveals low abundance of *Mysella planulata.* 2012, a population bloom occurs and reveals shells lengths ranging between 1 – 4 mm. The highest abundance found occurred in 2012:3 quarter. During this year salinities ranged 13.0 - 41.7.

Macoma mitchelli experience low levels of recruitment until the first quarter of 1992. The lengths were found to be under 5 mm. Salinity levels were found lower than the previous years, documented as low as 0.4 in Guadalupe stations. In 1994:1, a large population spike occurred in juvenile *Macoma mitchelli.* 40% were 2 mm, and 20 % were 1 mm in shell length. Lengths during this period did not exceed 10 mm. This recruitment event occurred during an average year of freshwater and had an average salinity of 24.9. The following recruitment occurrence took place in 1998:1, majority of shell lengths were below 5mm with salinity the salinity of 20.. In the year 1988 following the second quarter, Hurricane Gilbert took place as a level 4 hurricane and years 1988 - 1989 were recorded as dry years. In the spring season of 1994 - 2002 *Nuclana acuta* population rose and then dropped in fall and winter season. Until the year 2009, a minimal rise in population took place. 2009:1, the population of *Nuculana acuta* increased primarily with the shells size or 2 mm, throughout the tested quarters in 2009 the shell lengths grew until 9 mm in 2009:4. In years 2012 - 2015, the greatest recruitment in *Nuculana acuta* during this study occurred. These years were documented as average and dry years. Salinity levels in Lavaca Colorado during this period were averaged 27.0, 30.4, 27.7, and 16.7. Guadalupe salinity averages were 19.9, 27.5, 26.3, and 14.8. During these years, a pattern occurred of quarters 1 and 2 displaying high densities of shell lengths ranging from 2 – 7 mm. In the last half of the years, in quarters 3 and 4, dispersion of lengths was found at a much less density with a wide variety of shell lengths.

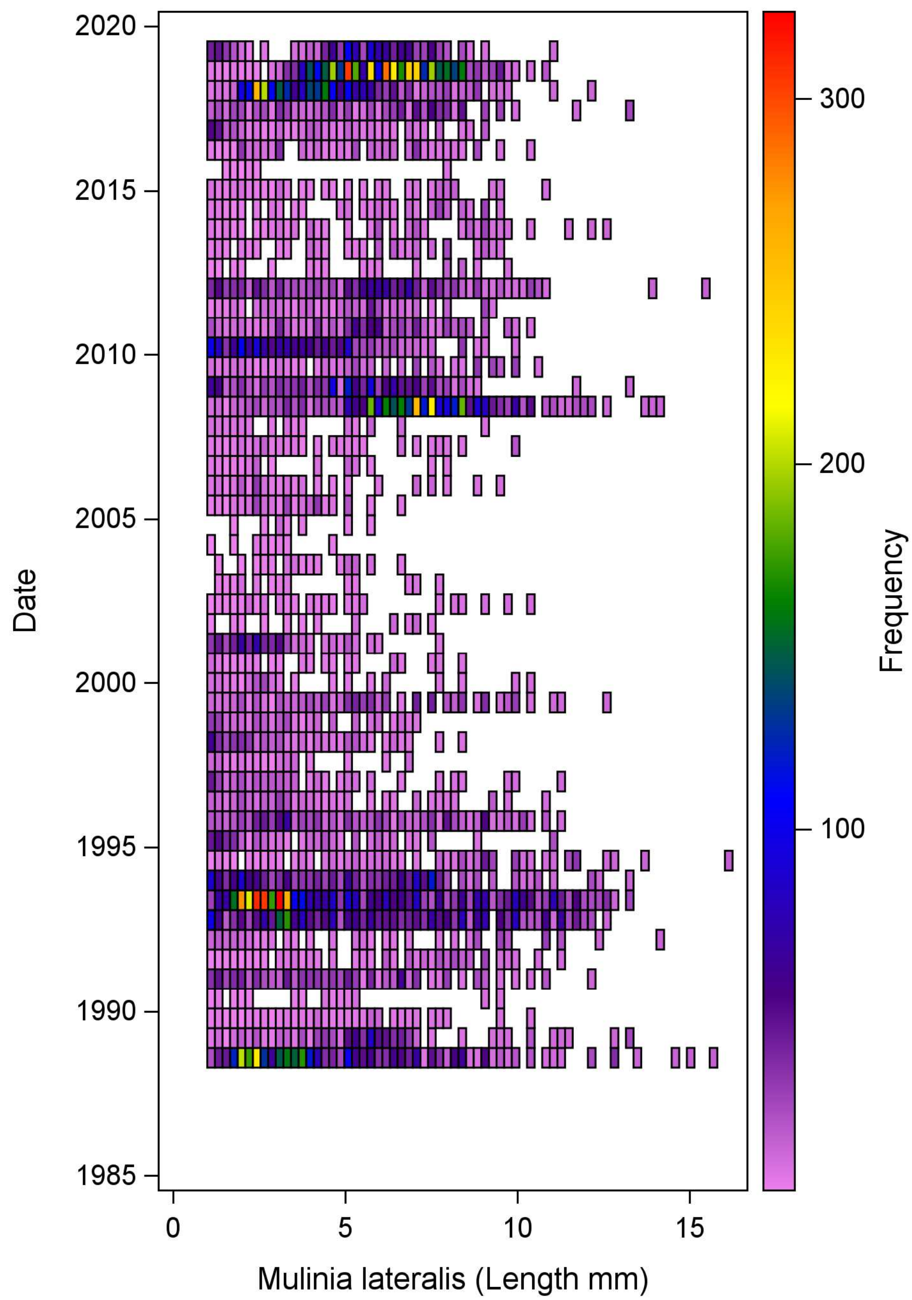


Figure 15. Heat map of *Mulinia lateralis* frequency and shell length by year.

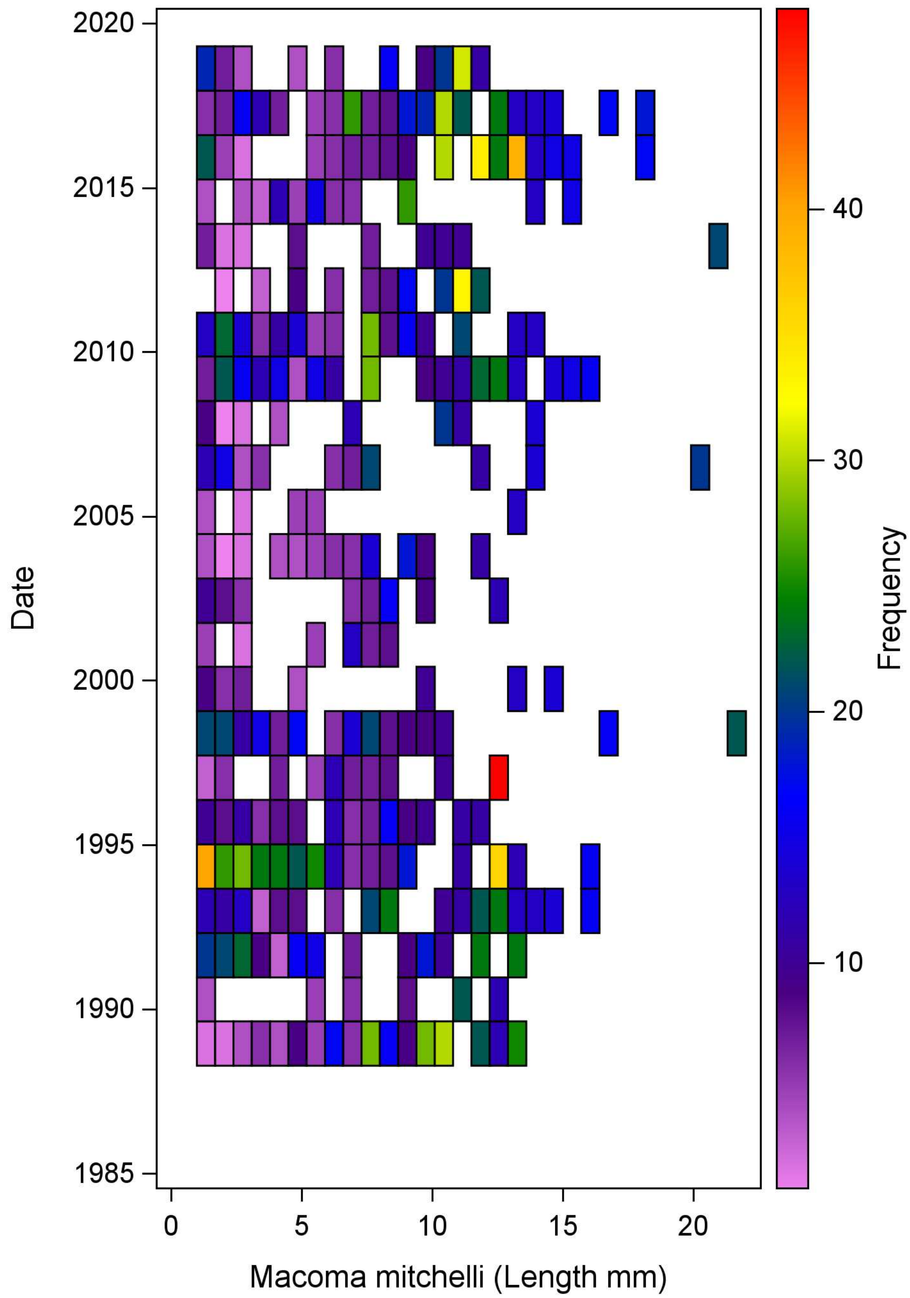


Figure 16. Heat map of *Macoma mitchelli* frequency and shell length by year.

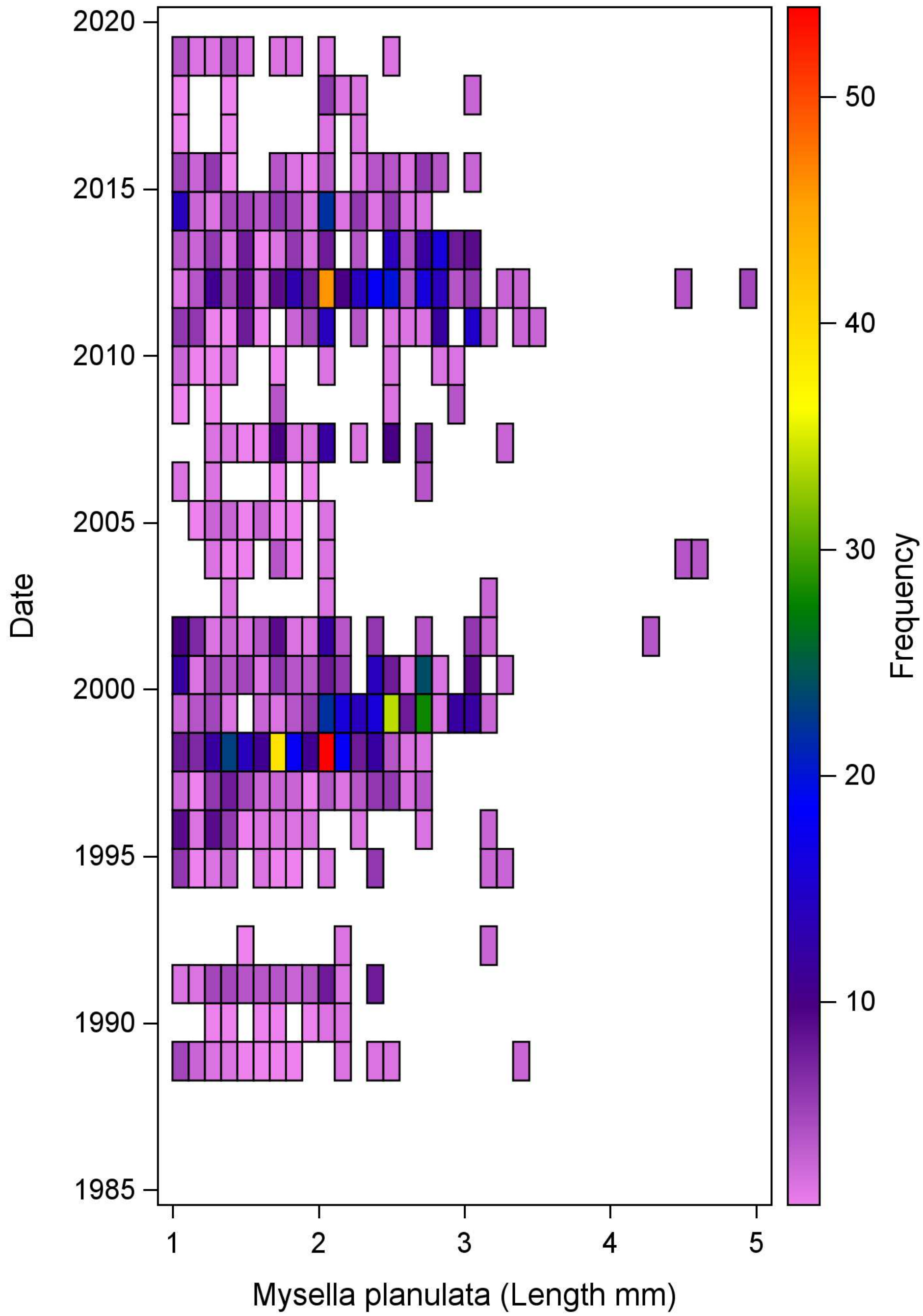


Figure 17. Heat map of *Mysella planulata* frequency and shell length by year.

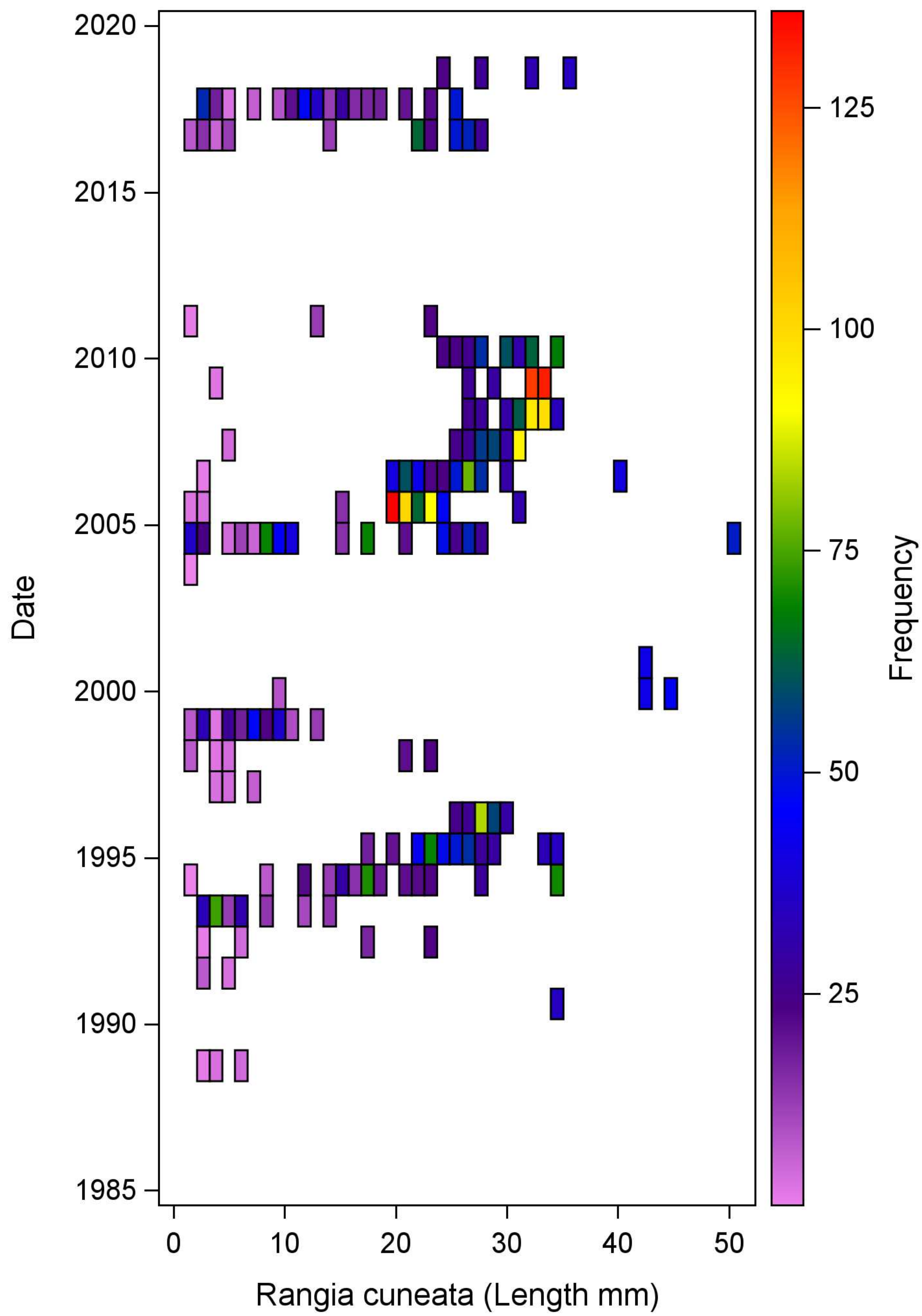


Figure 18. Heat map of *Rangia cuneata* frequency and shell length by quarter.

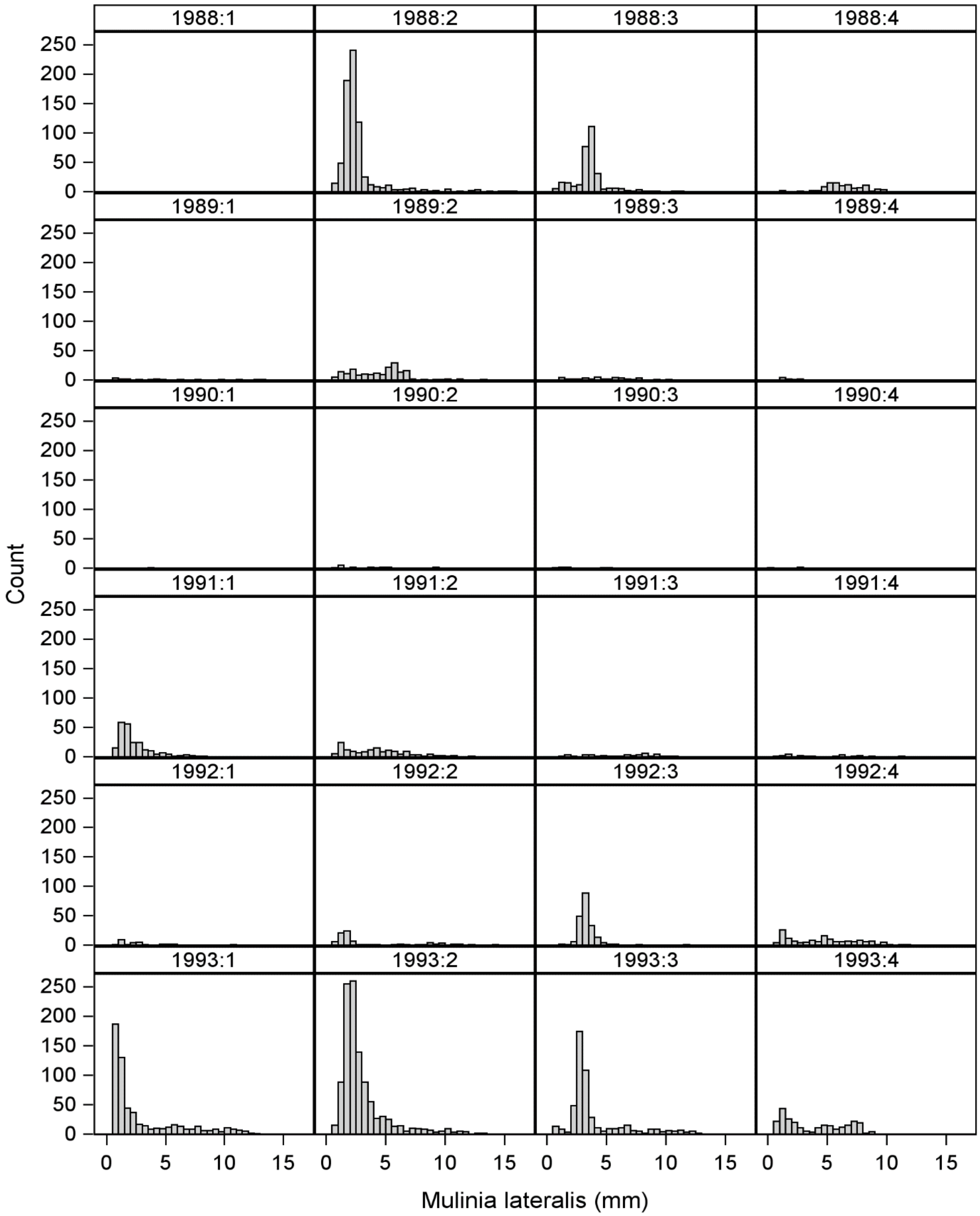
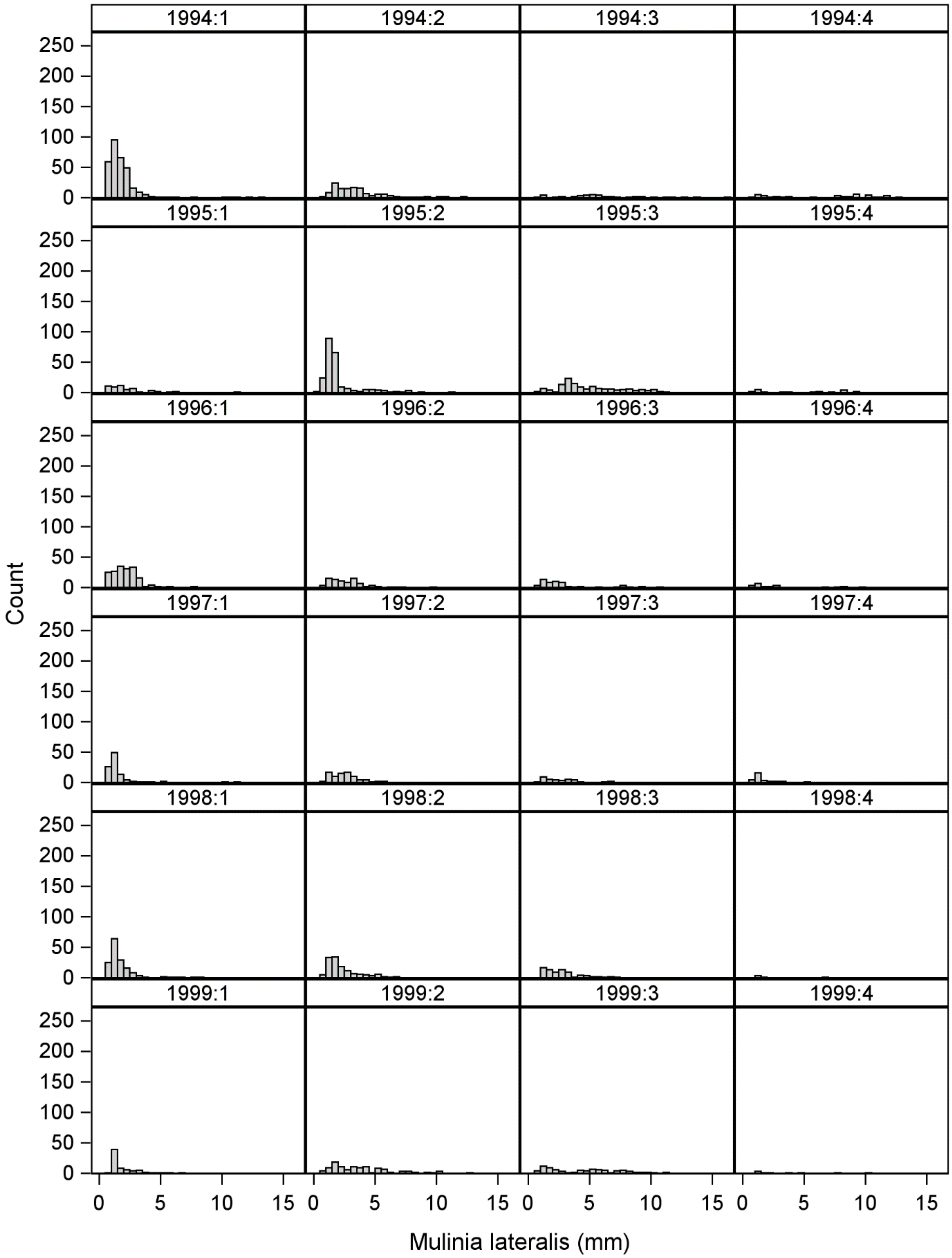


Figure 19. Size structure of *Mulinia lateralis* over time. Each figure displays the count for each size range with years are rows and the four quarters in four columns named :1 for January through March, :2 for April through June, :3 for July through September, and :4 for October through December.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Count
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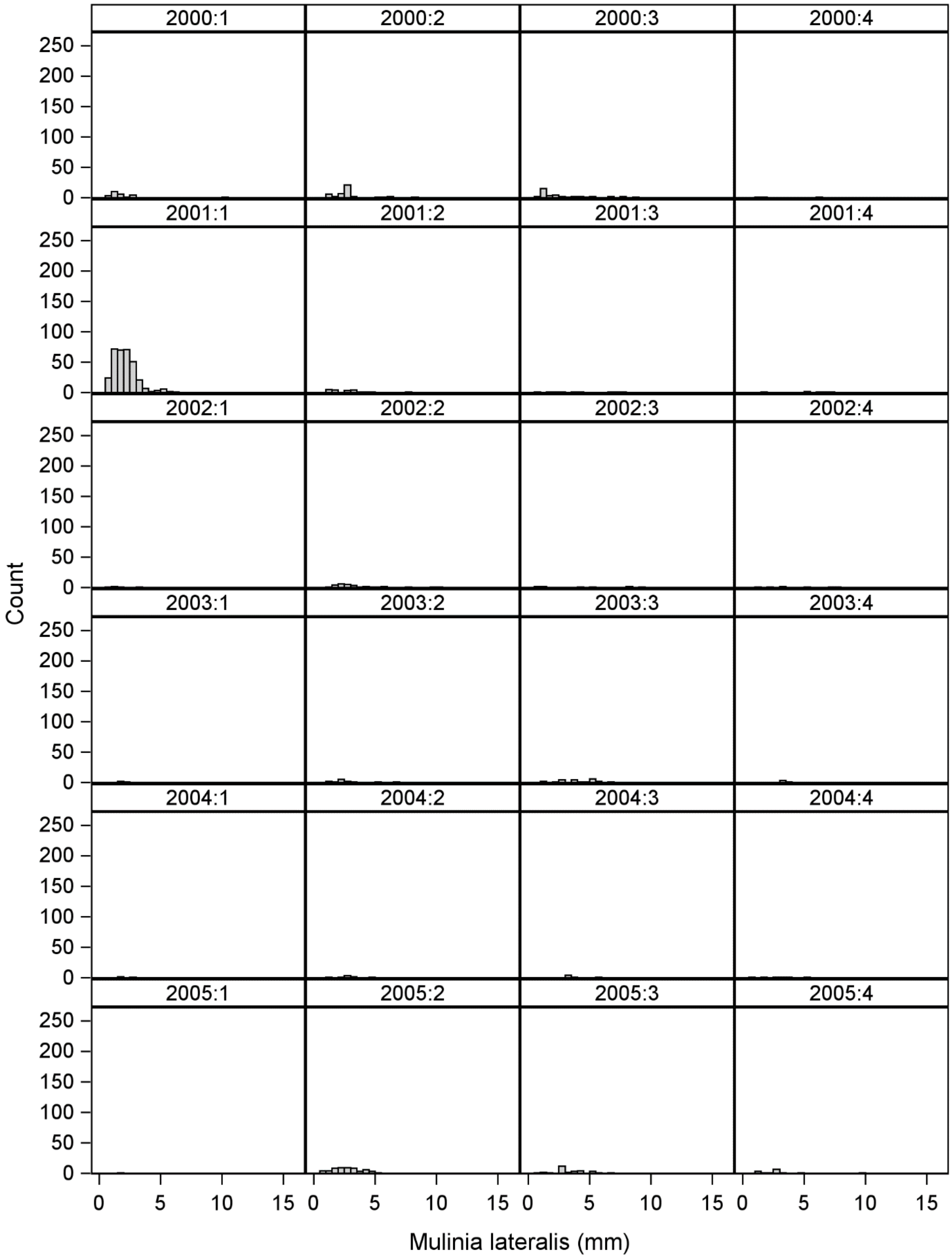
15
Mulinia lateralis (mm)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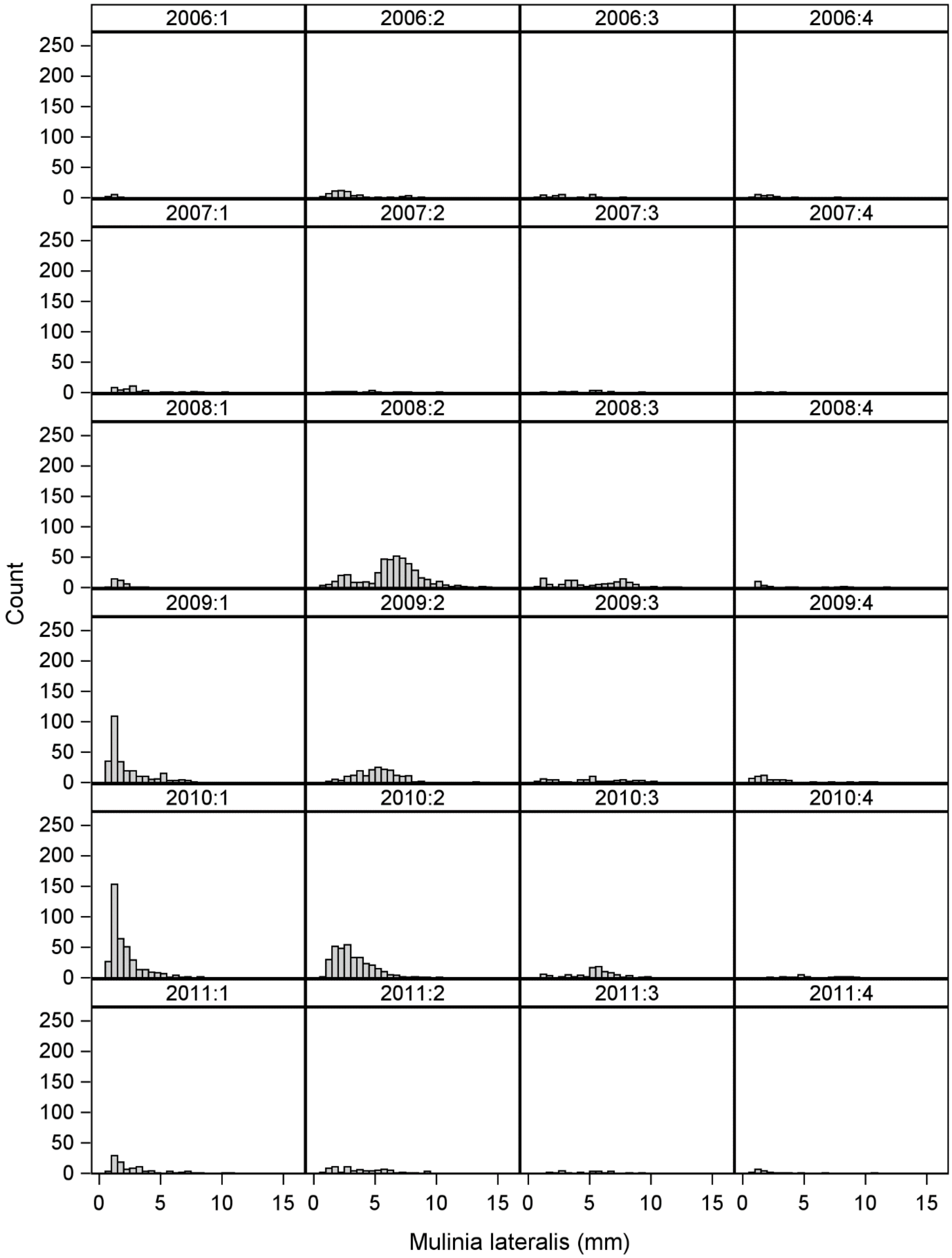
Mulinia lateralis (mm)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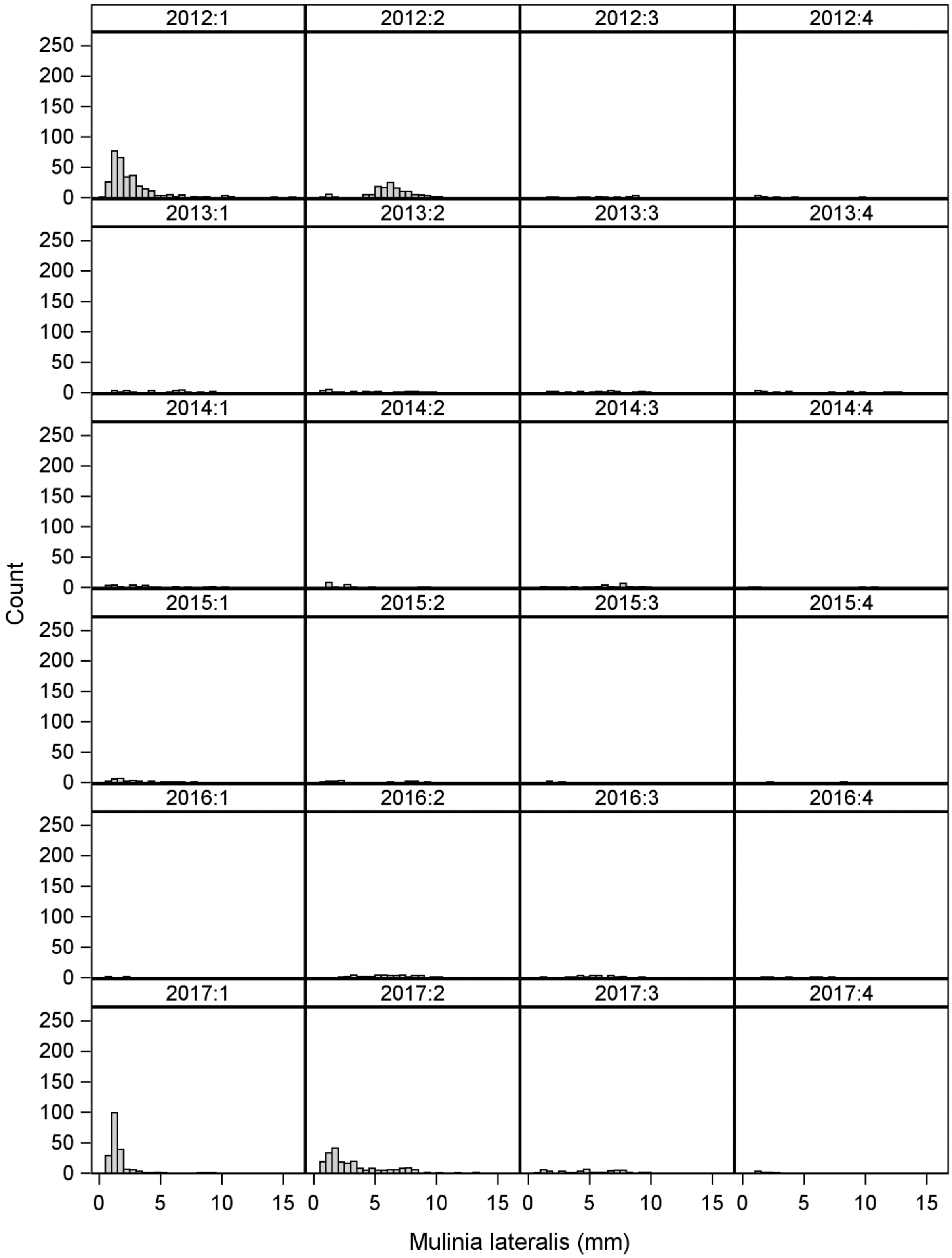
Mulinia lateralis (mm)



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2015:3
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2016:4
2017:1
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2017:4
Count
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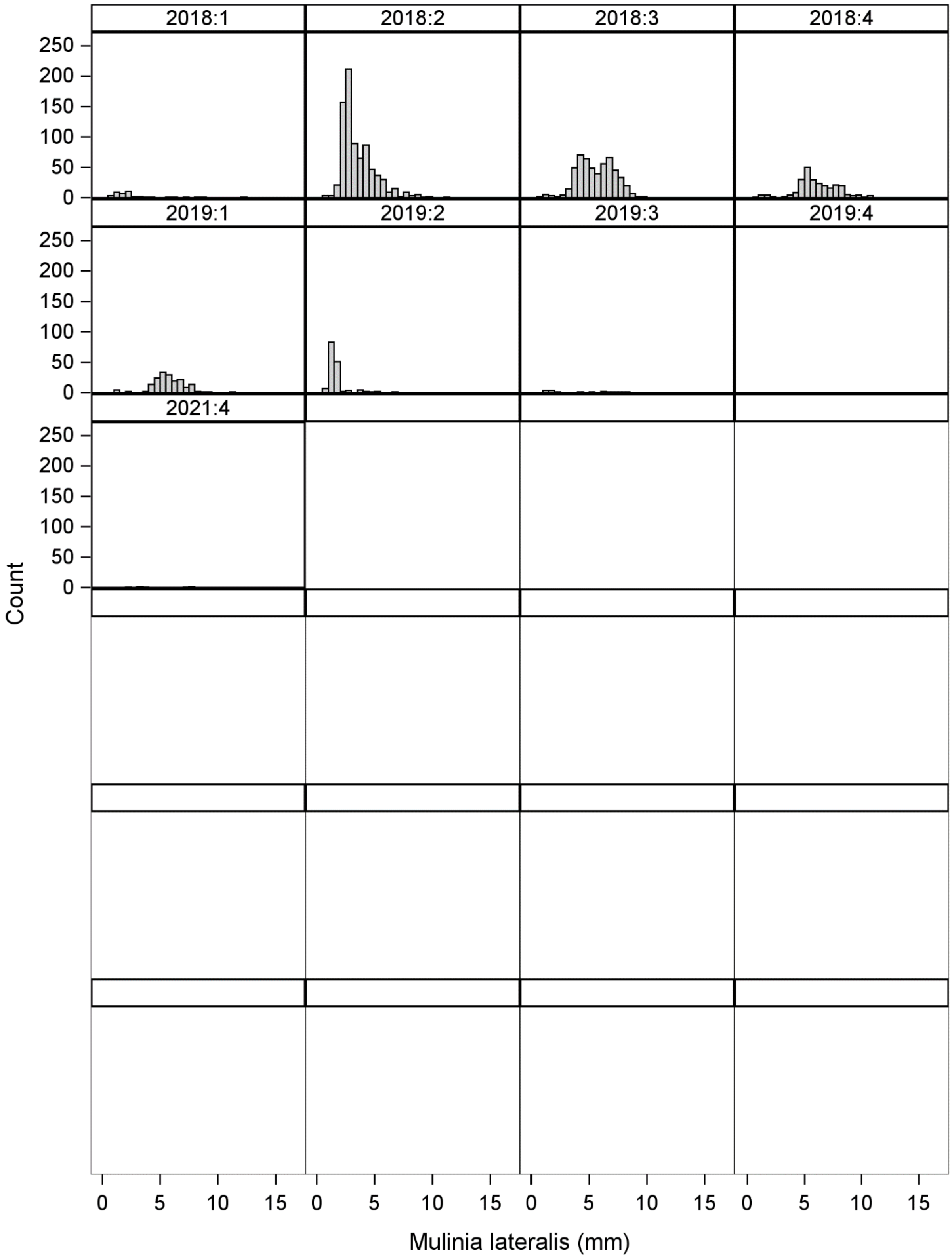
Mulinia lateralis (mm)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Count
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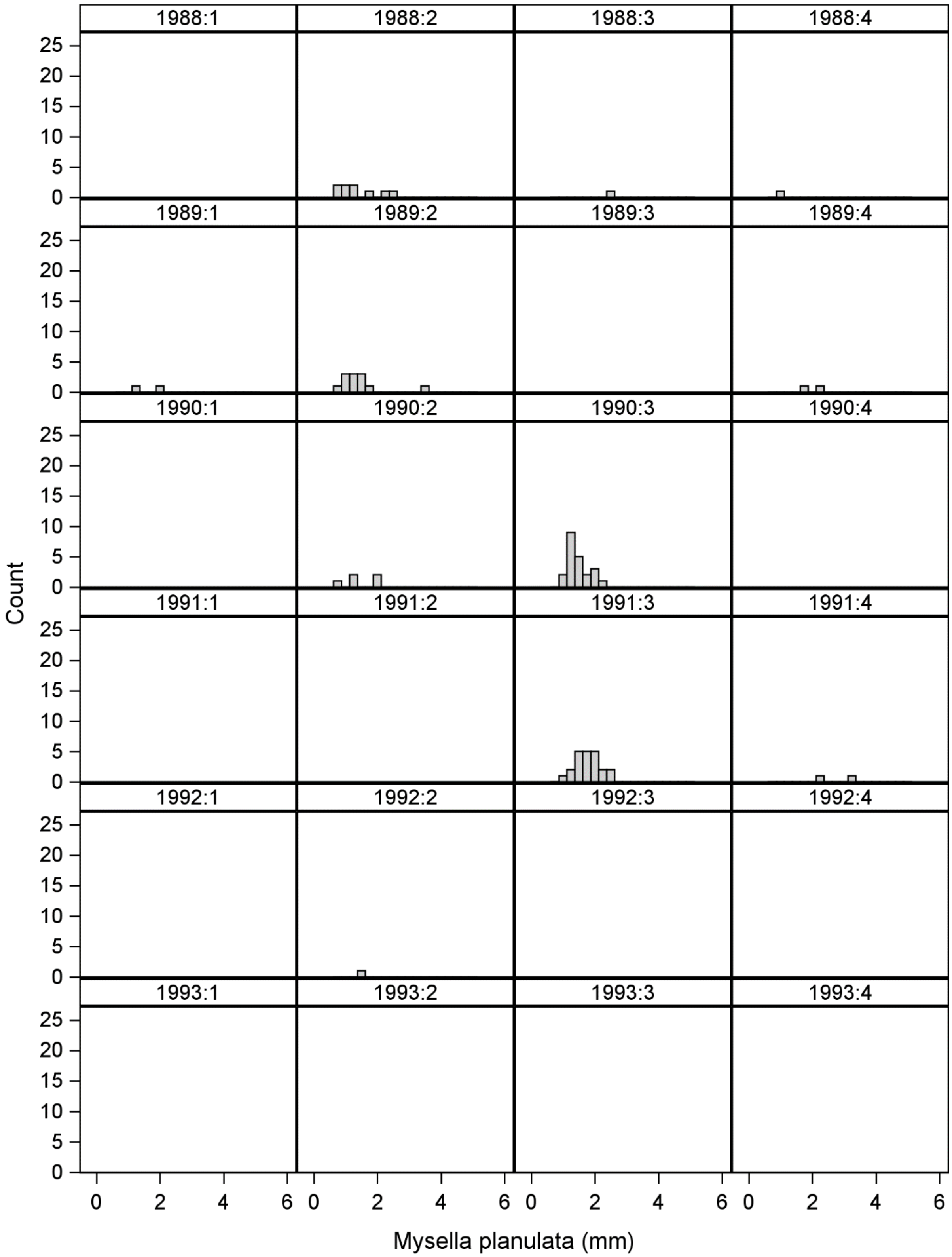
Mulinia lateralis (mm)



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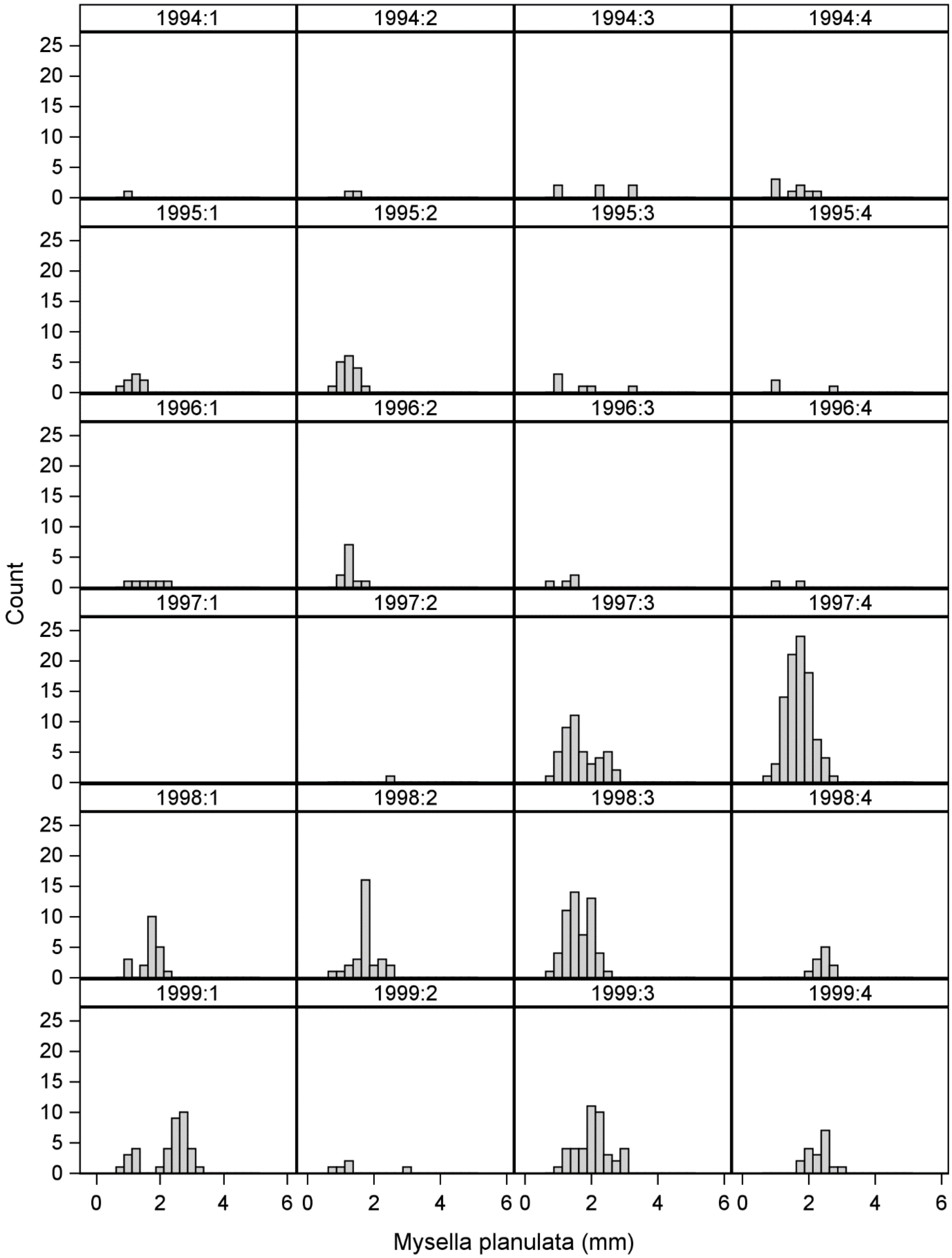
Mysella planulata (mm)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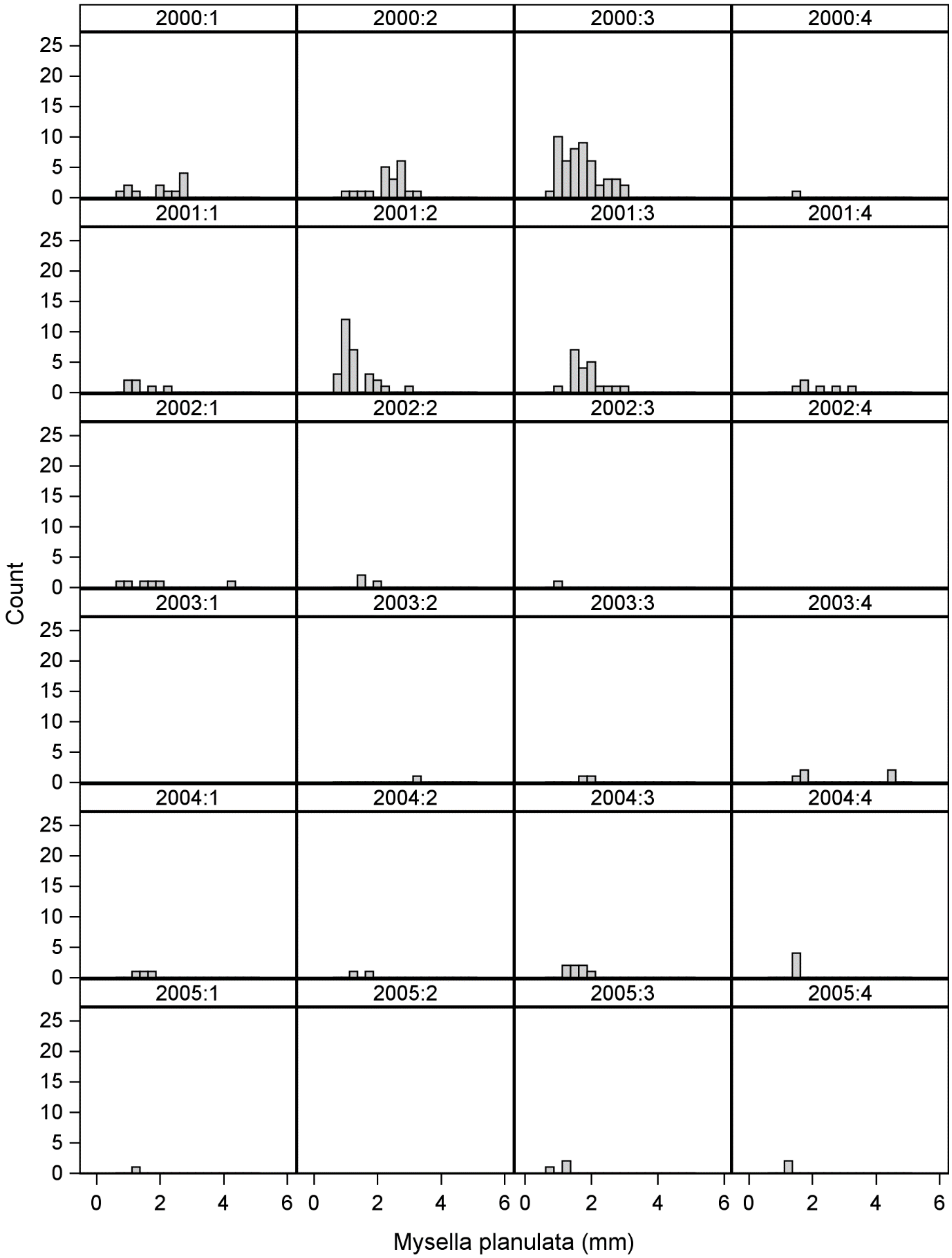
Mysella planulata (mm)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Count
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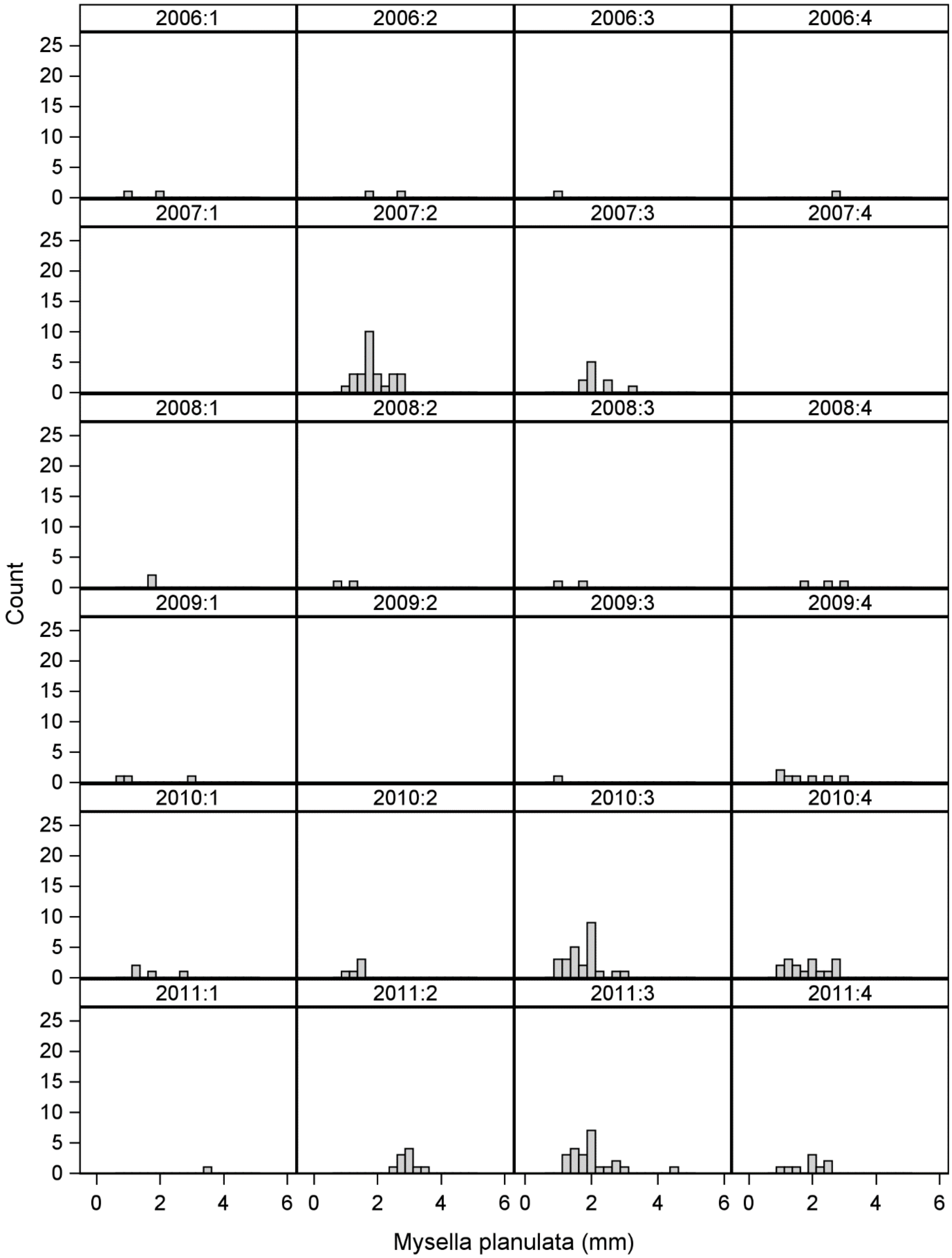
Mysella planulata (mm)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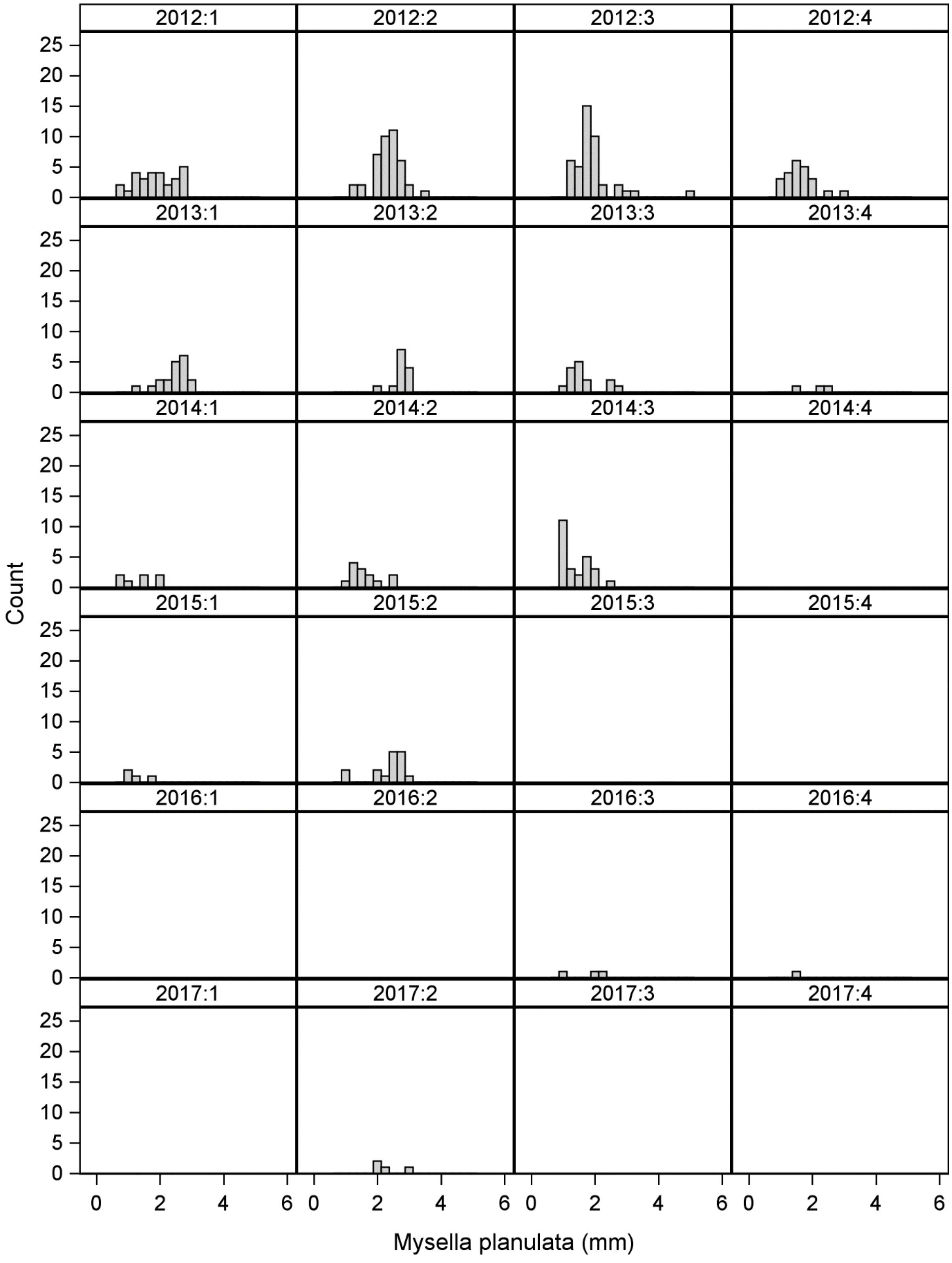
Mysella planulata (mm)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Mysella planulata (mm)

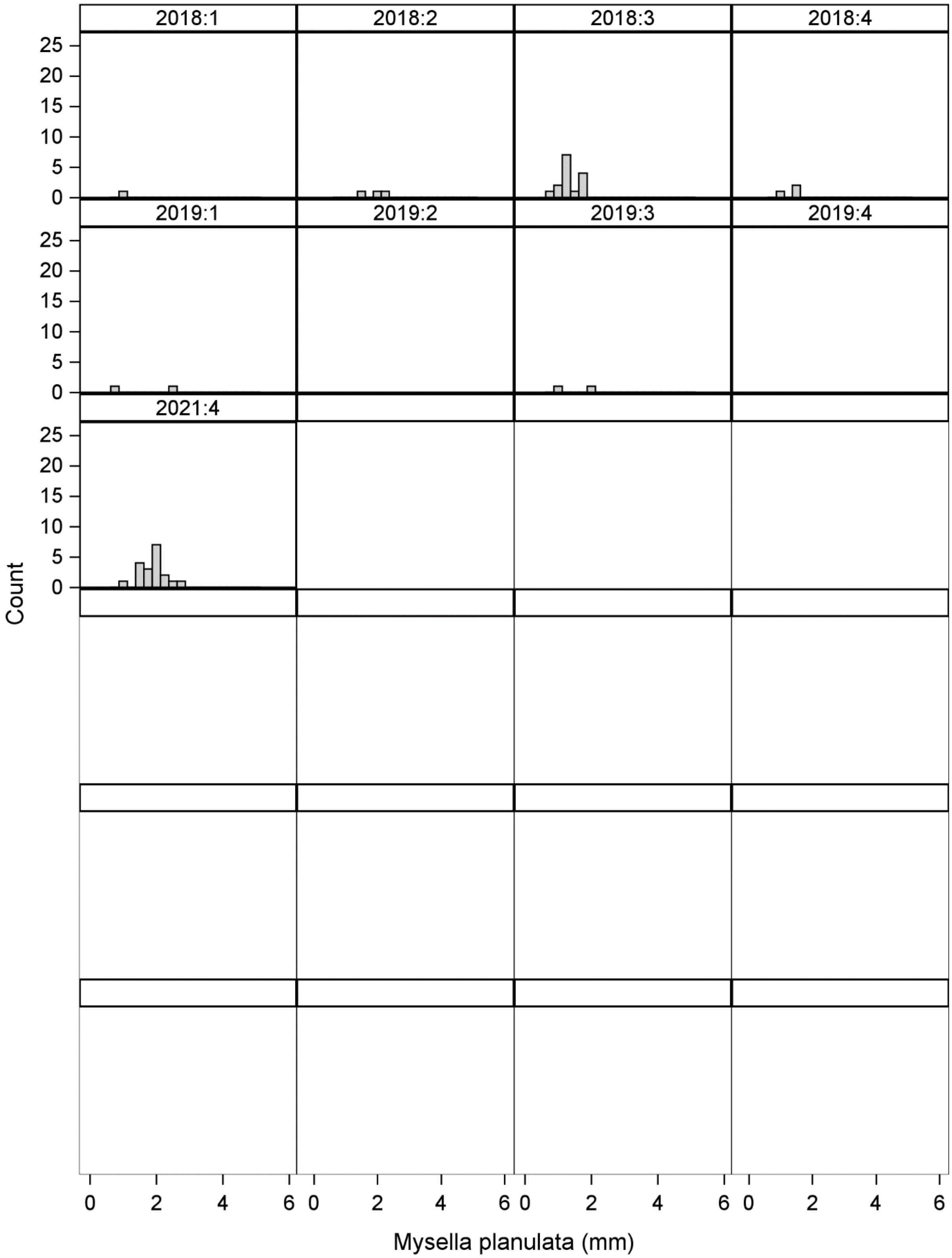
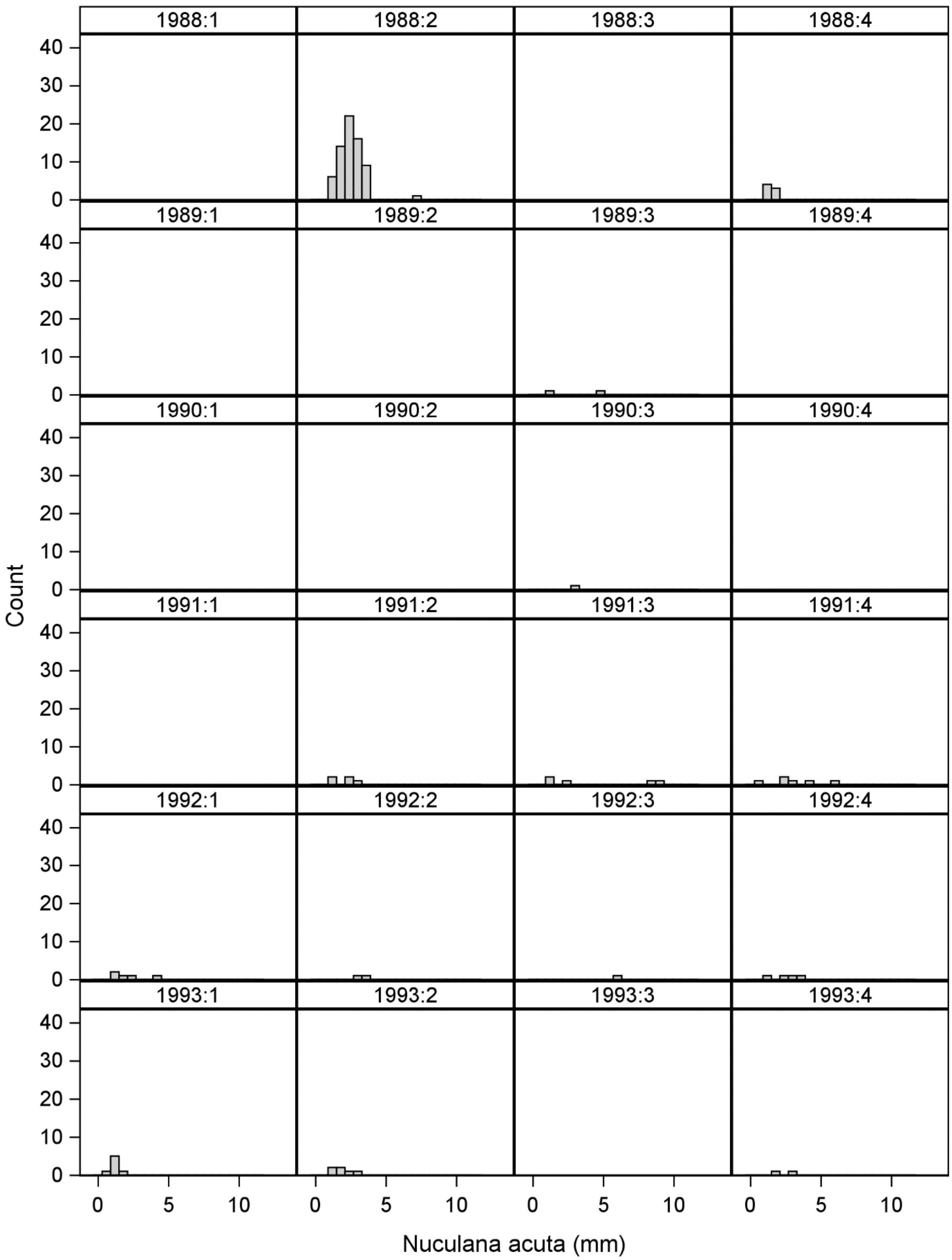


Figure 20. Size structure of *Mysella plabulata* over time.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Count
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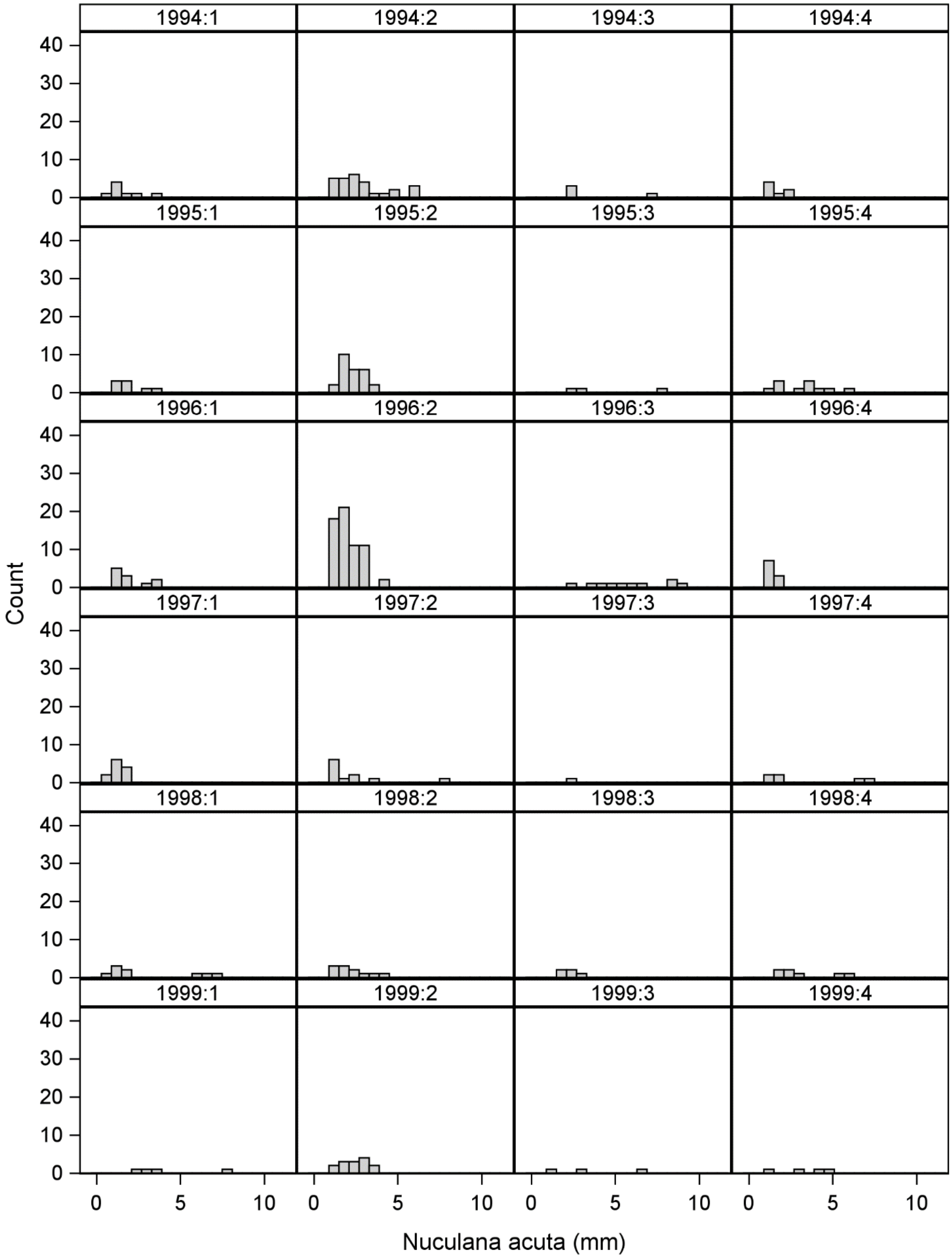
Nuculana acuta (mm)



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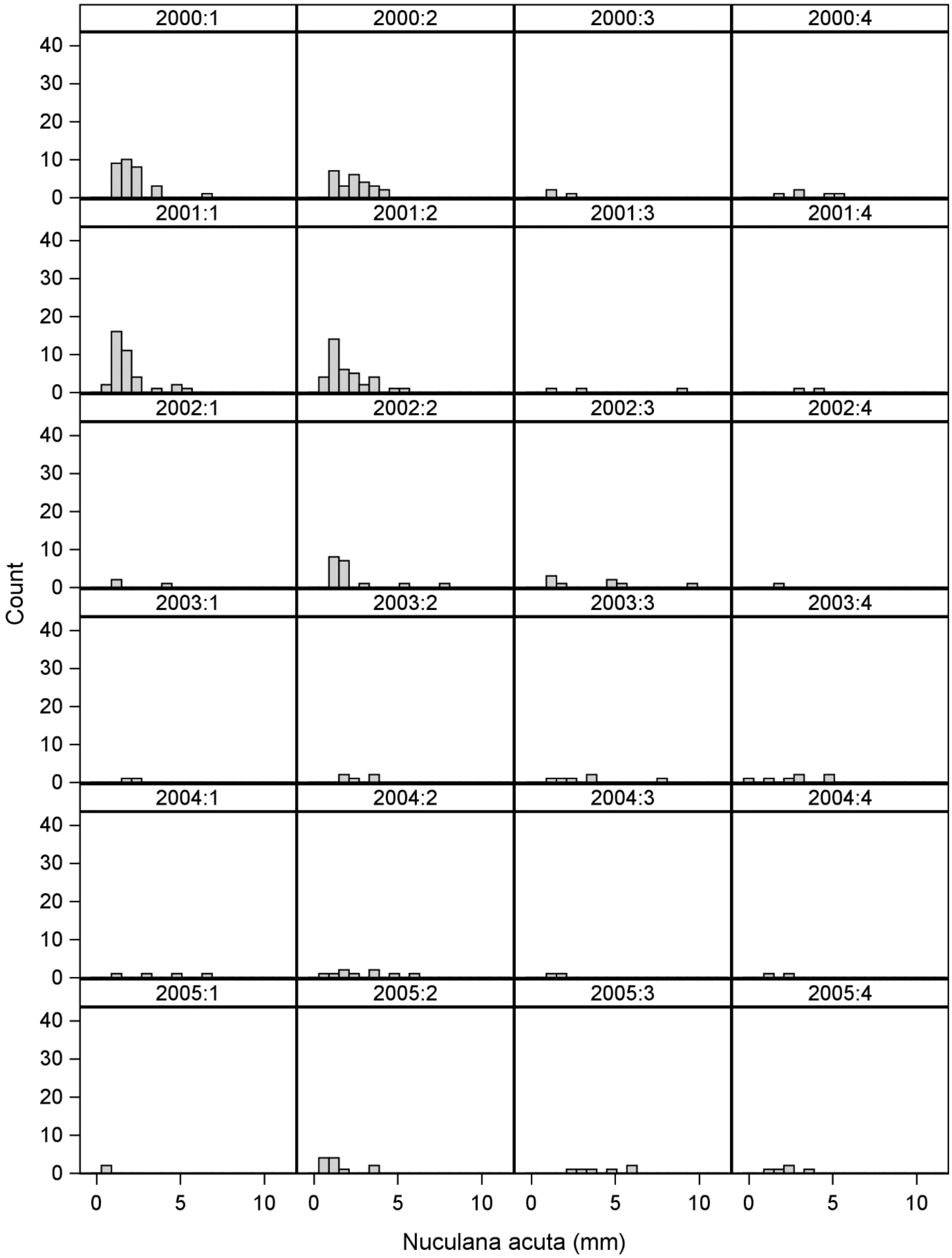
Nuculana acuta (mm)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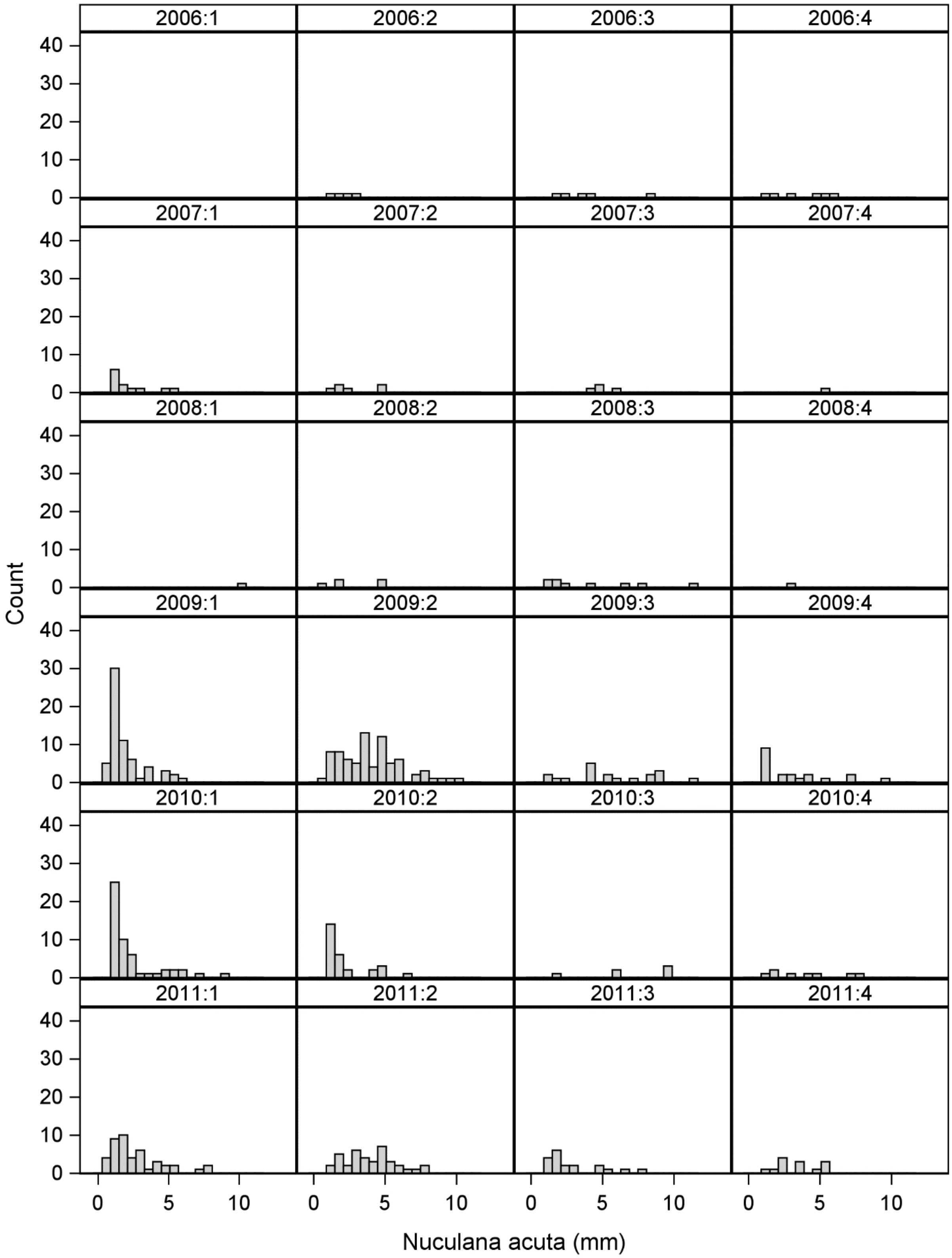
Nuculana acuta (mm)



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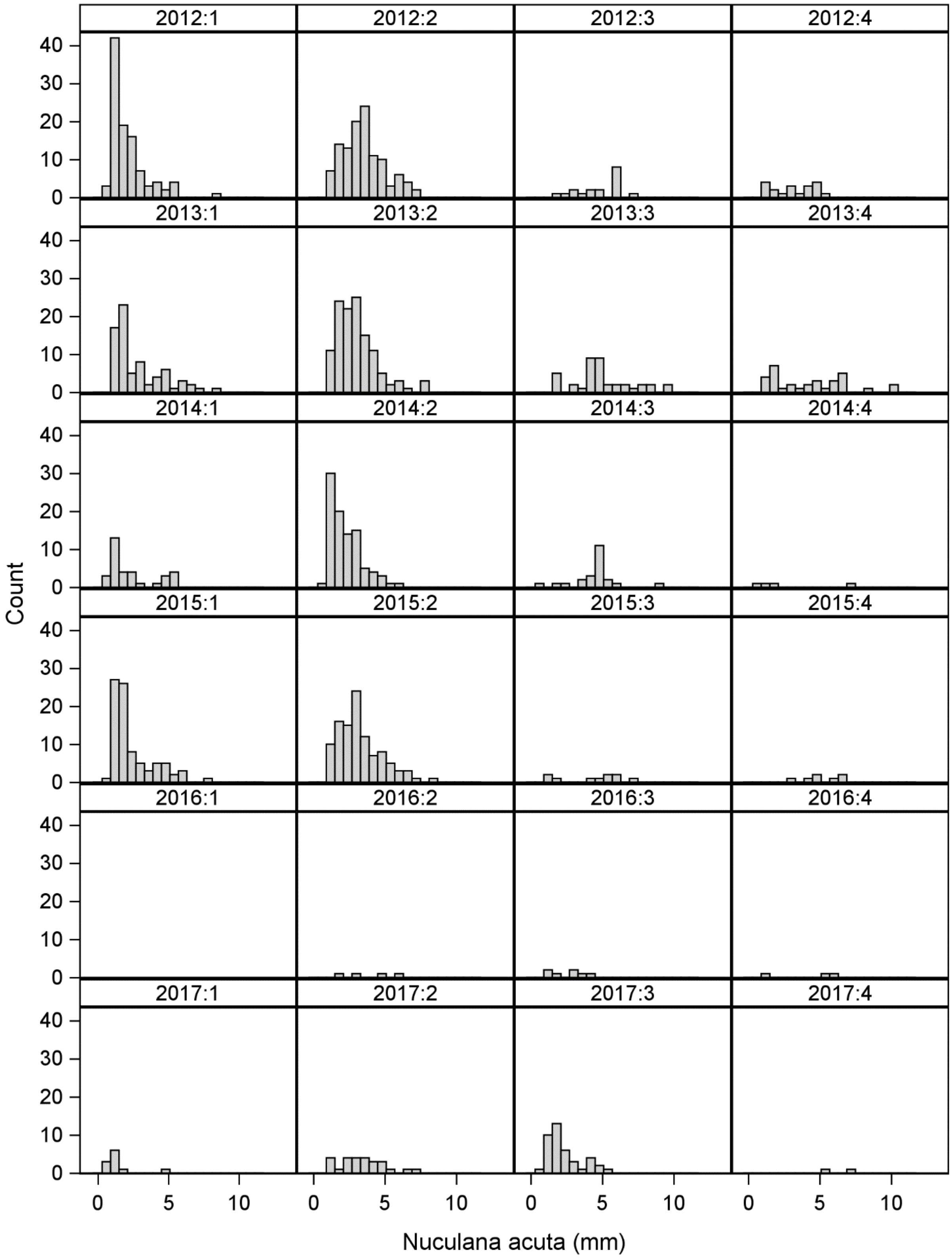
Count
0 10 20 30 40
0 5 10
Nuculana acuta (mm)



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Count
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Nuculana acuta (mm)

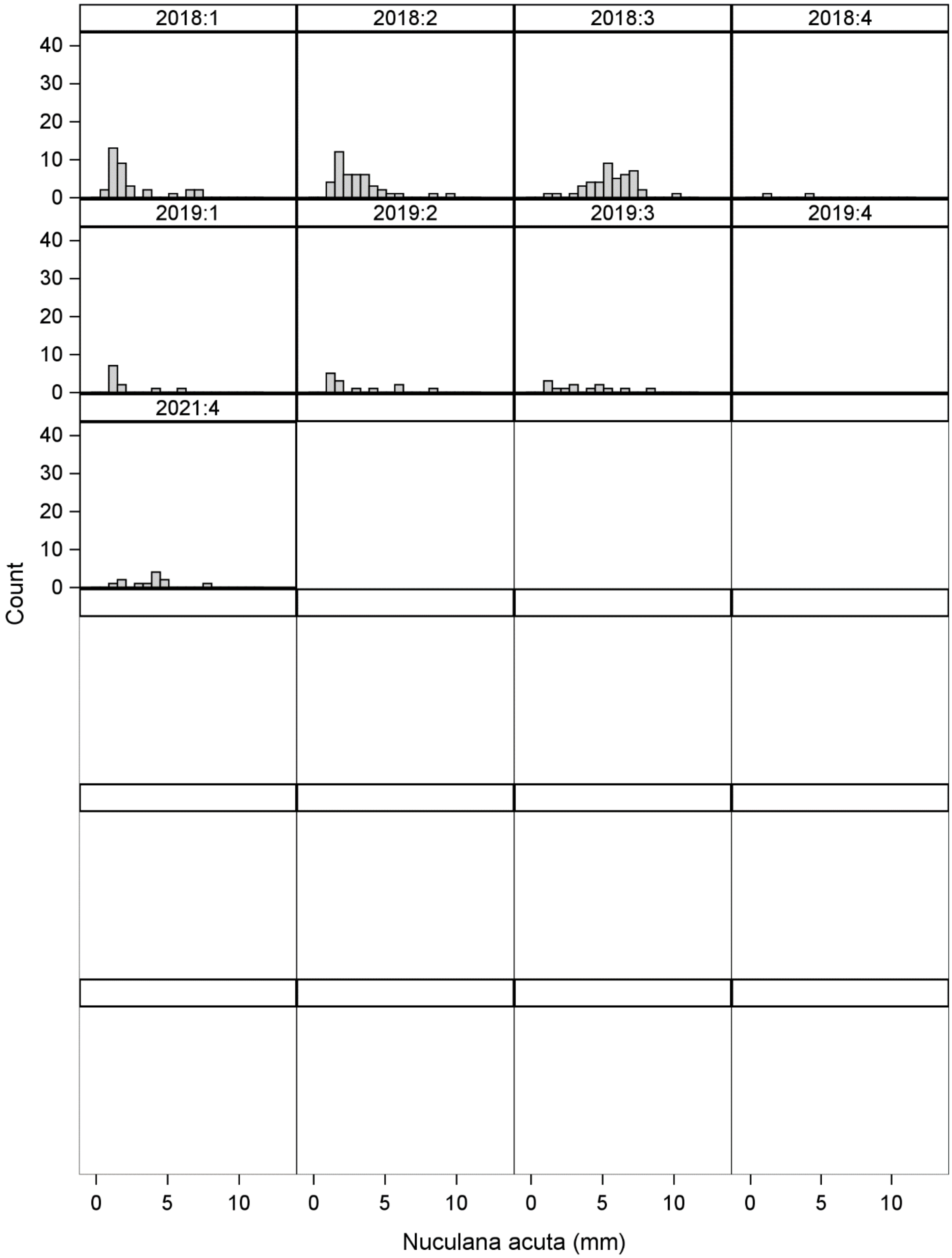
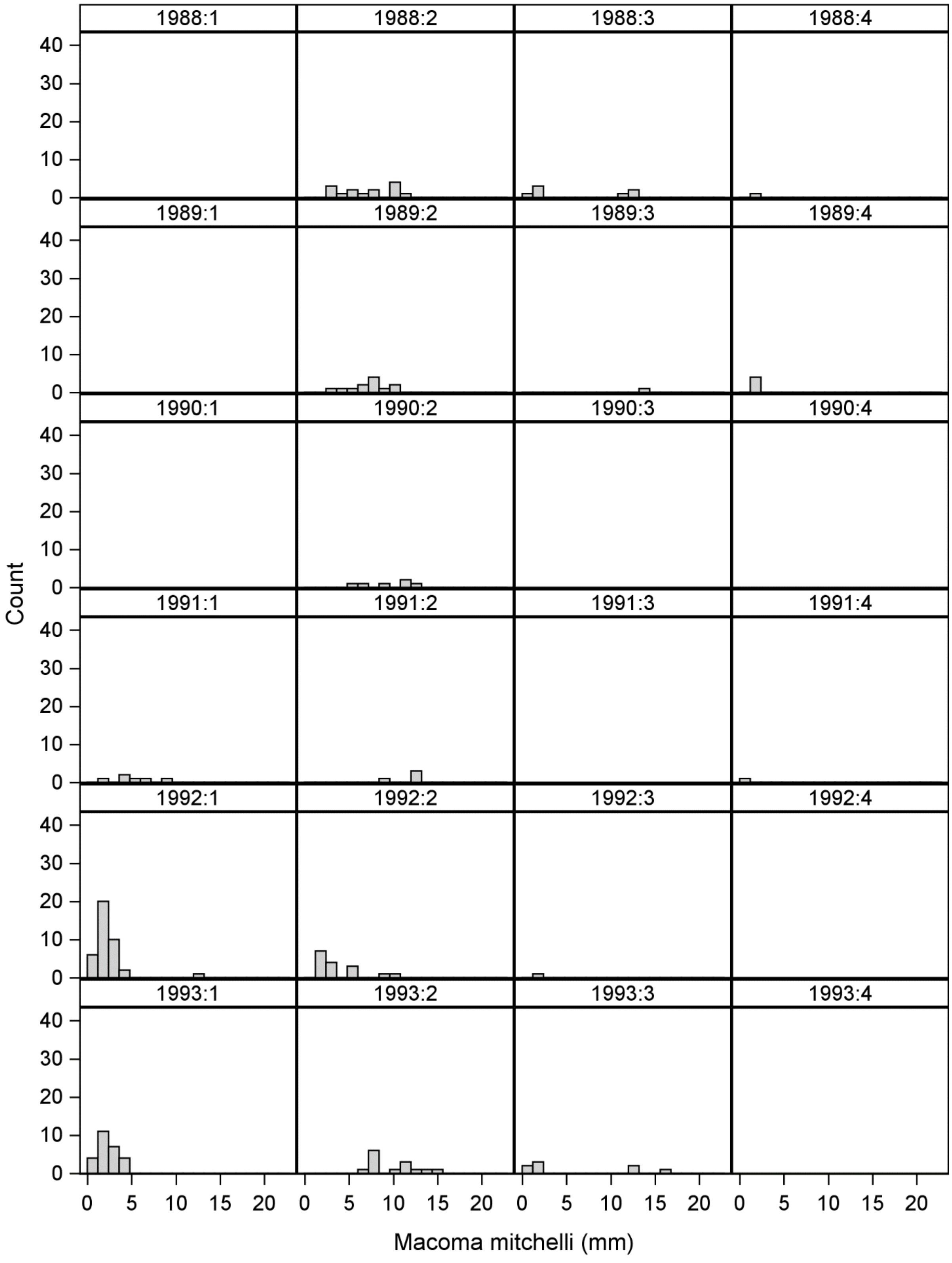


Figure 21. Size structure of *Nuculana acuta* over time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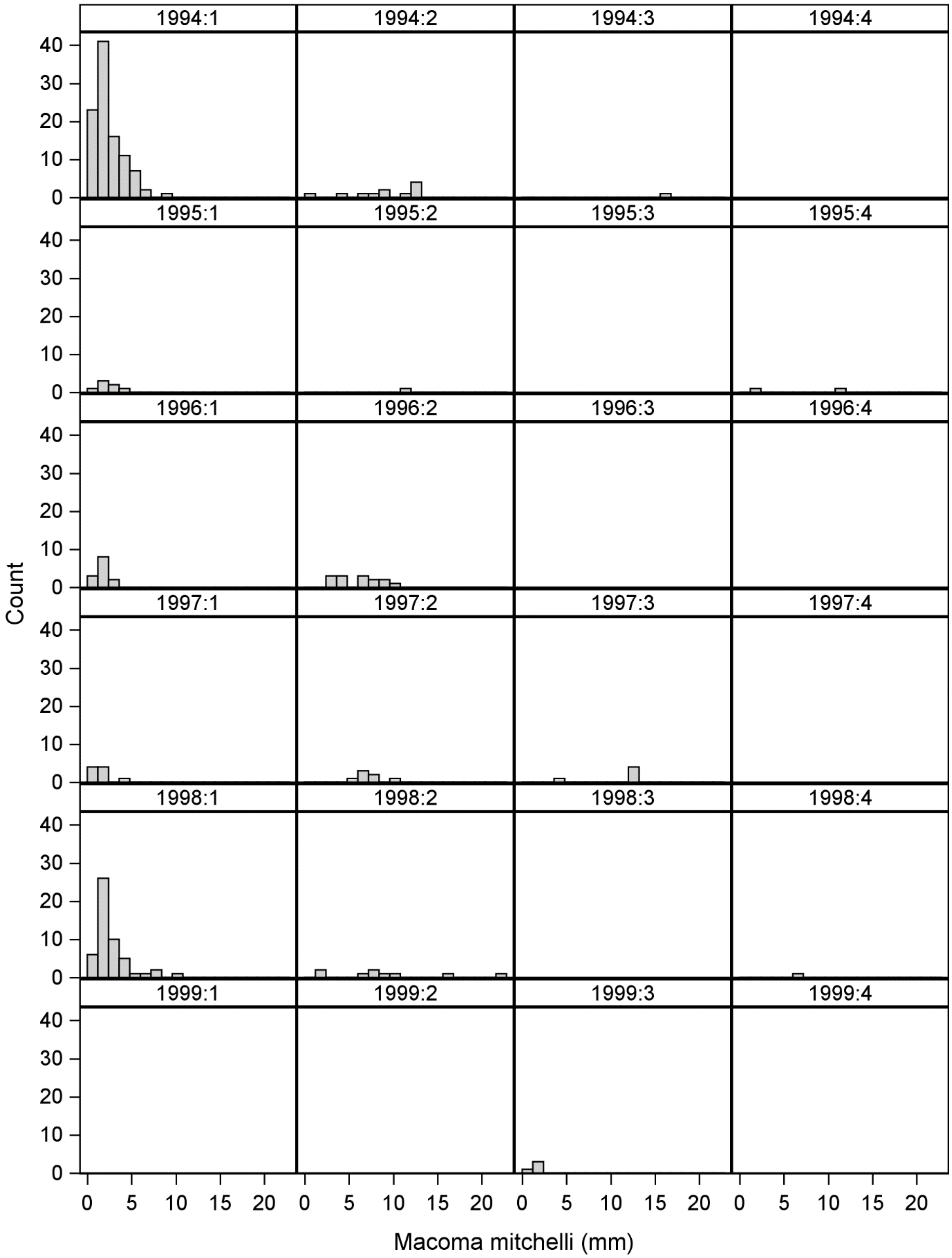
Macoma mitchelli (mm)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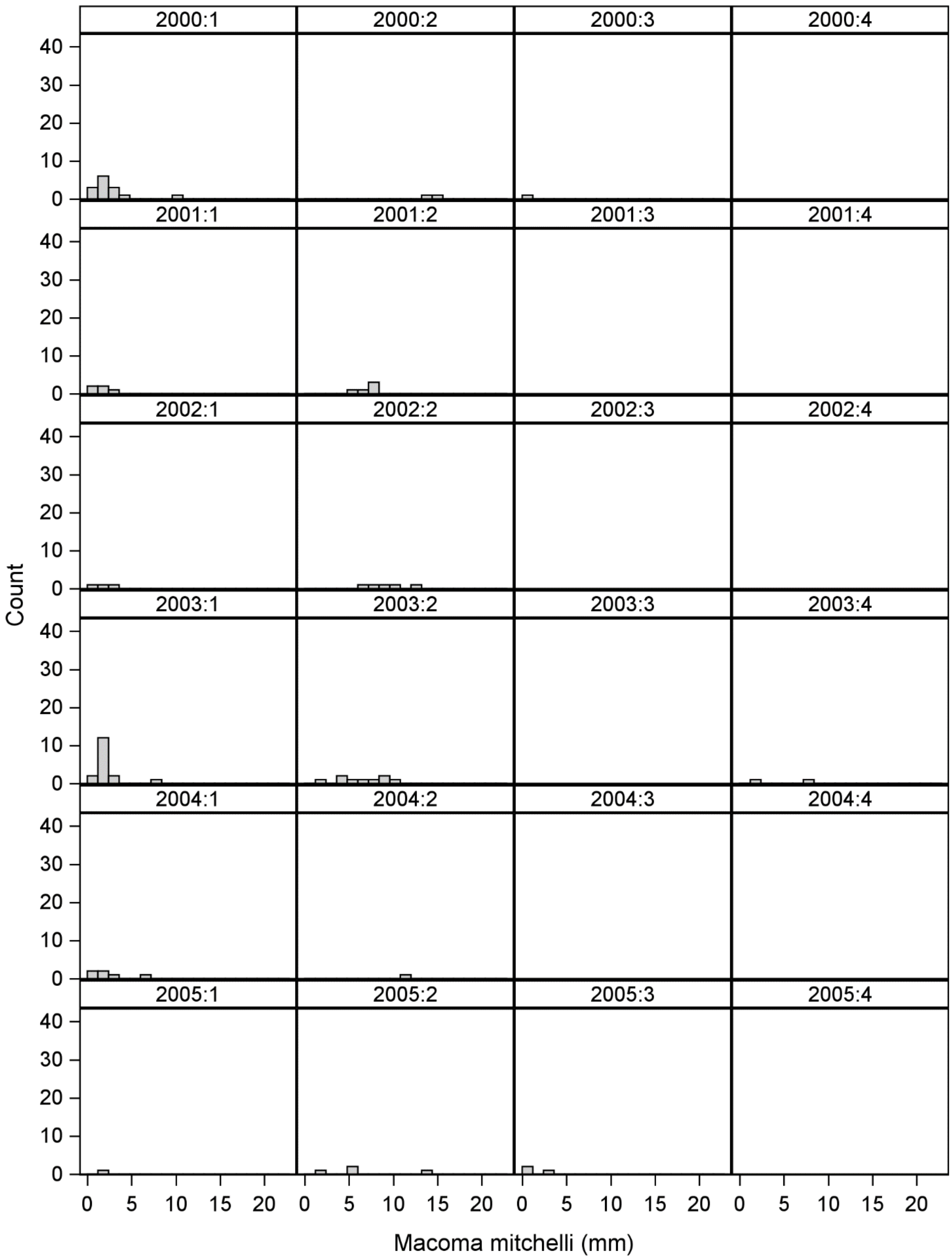
Macoma mitchelli (mm)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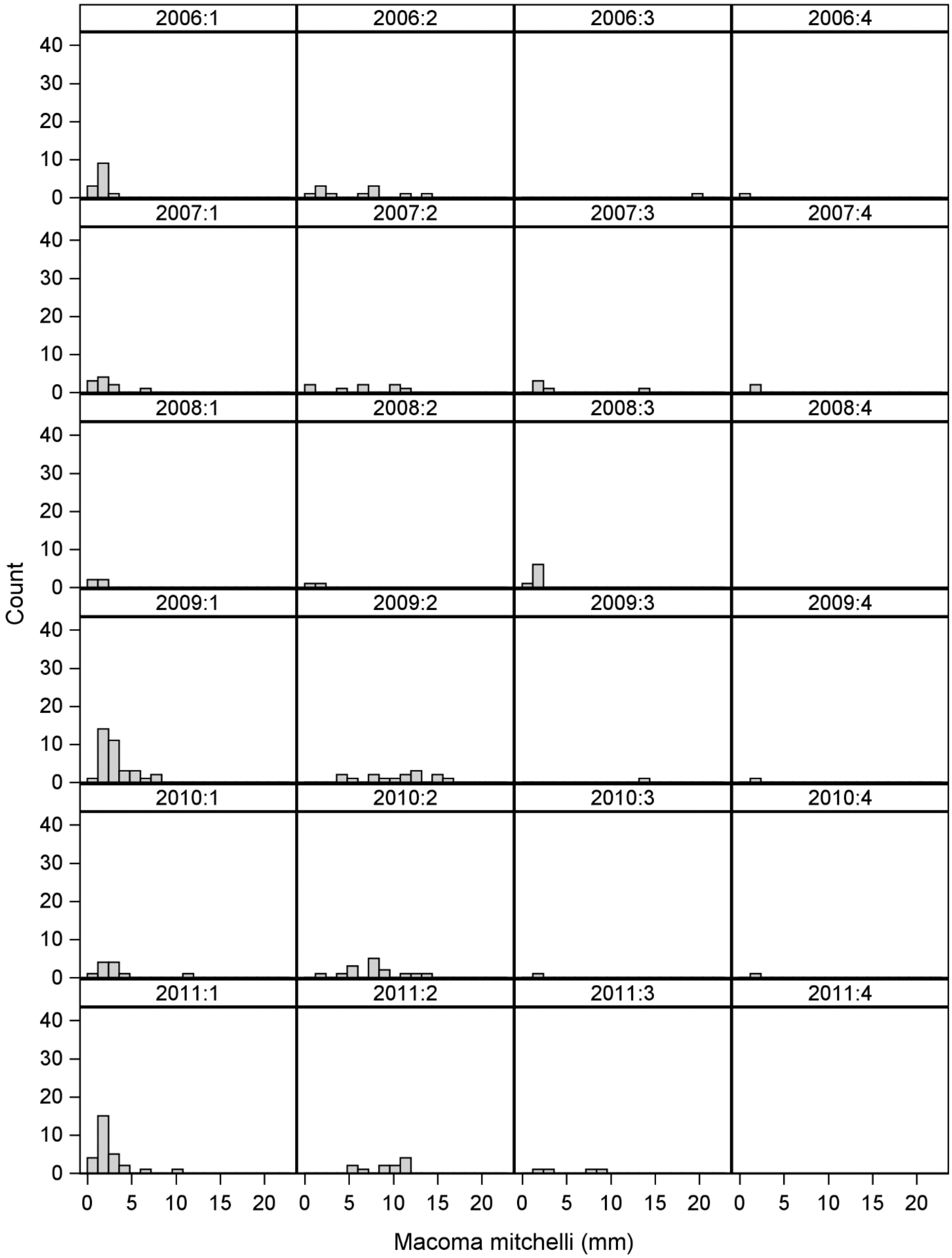
Macoma mitchelli (mm)



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Count
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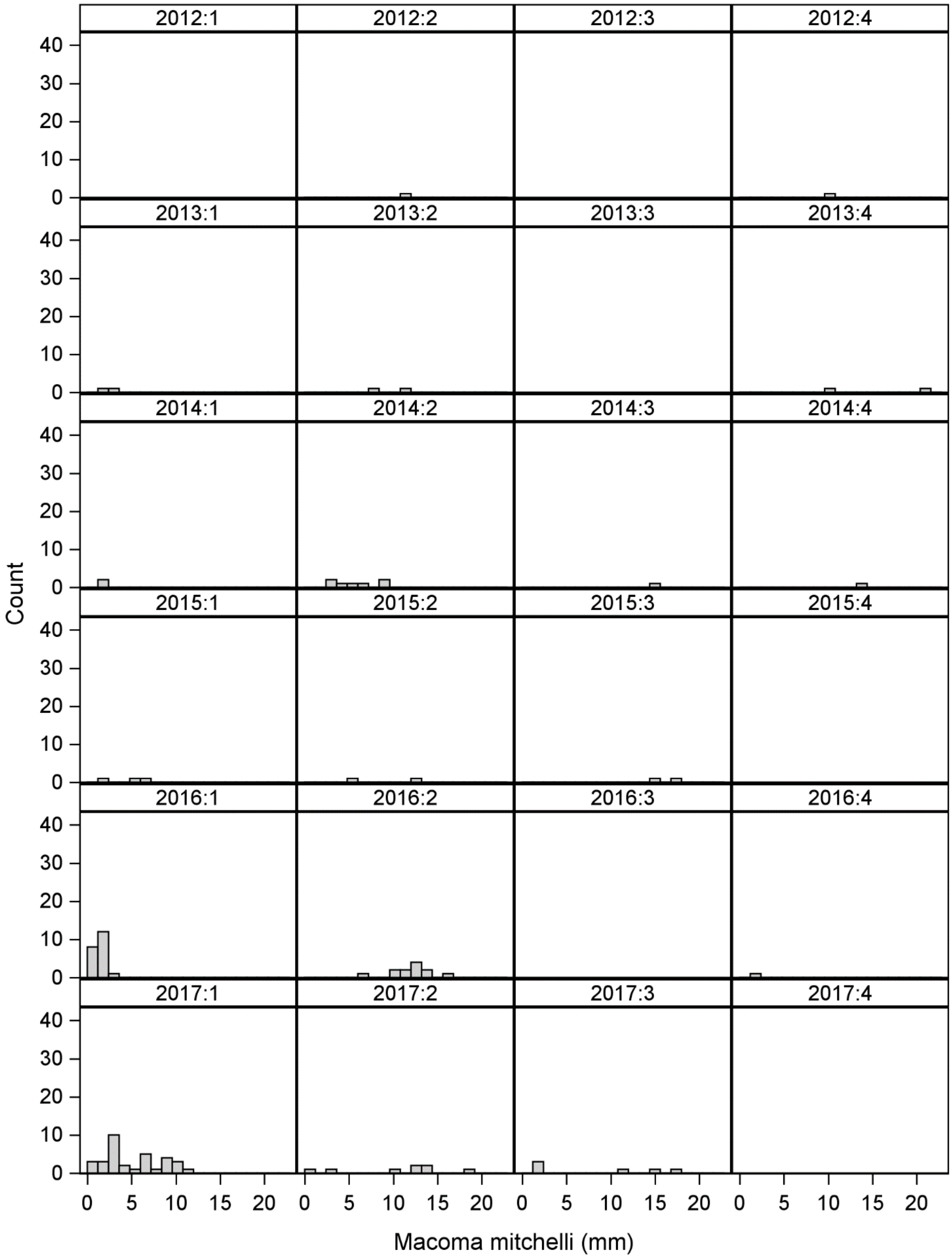
Macoma mitchelli (mm)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Count
Macoma mitchelli (mm)

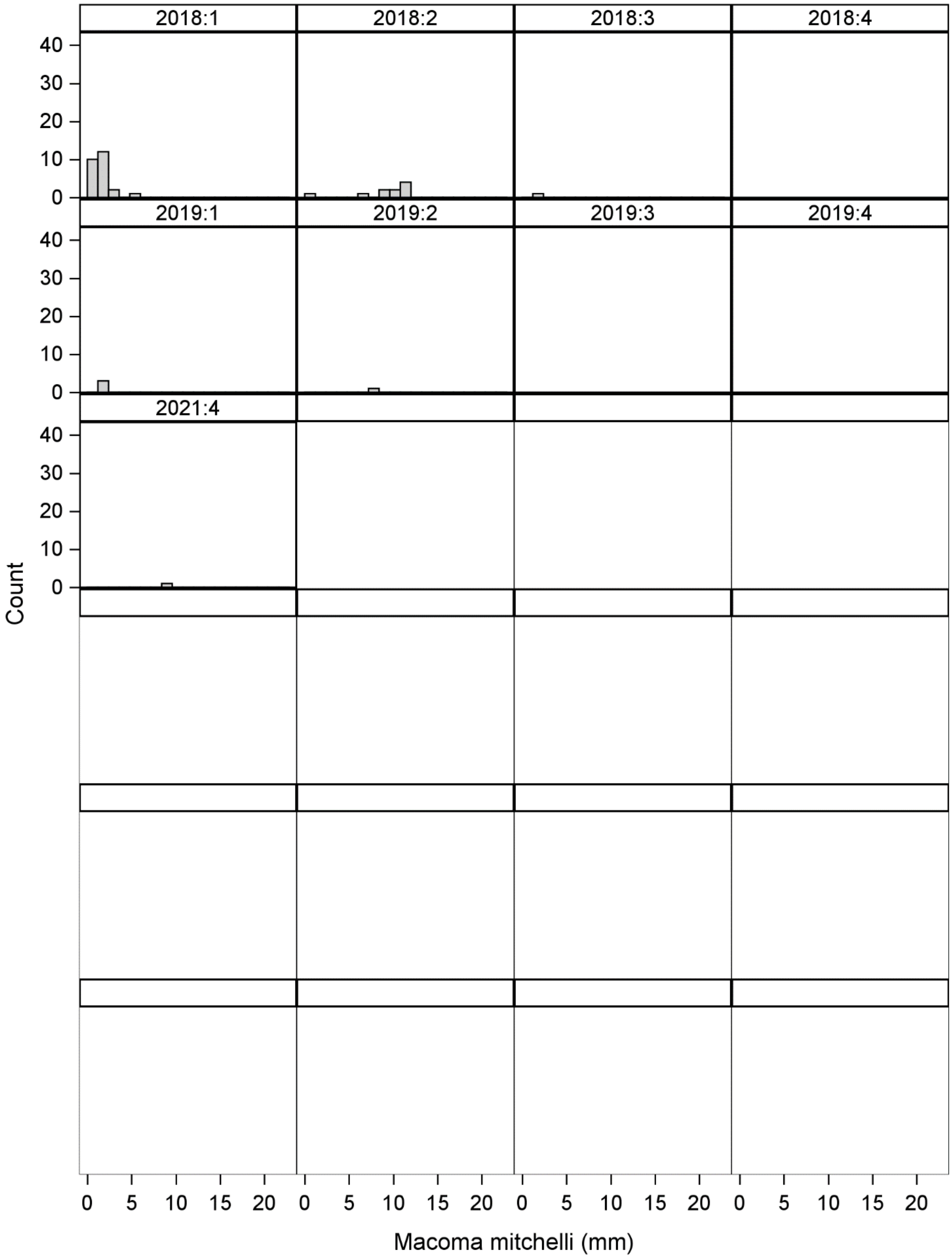
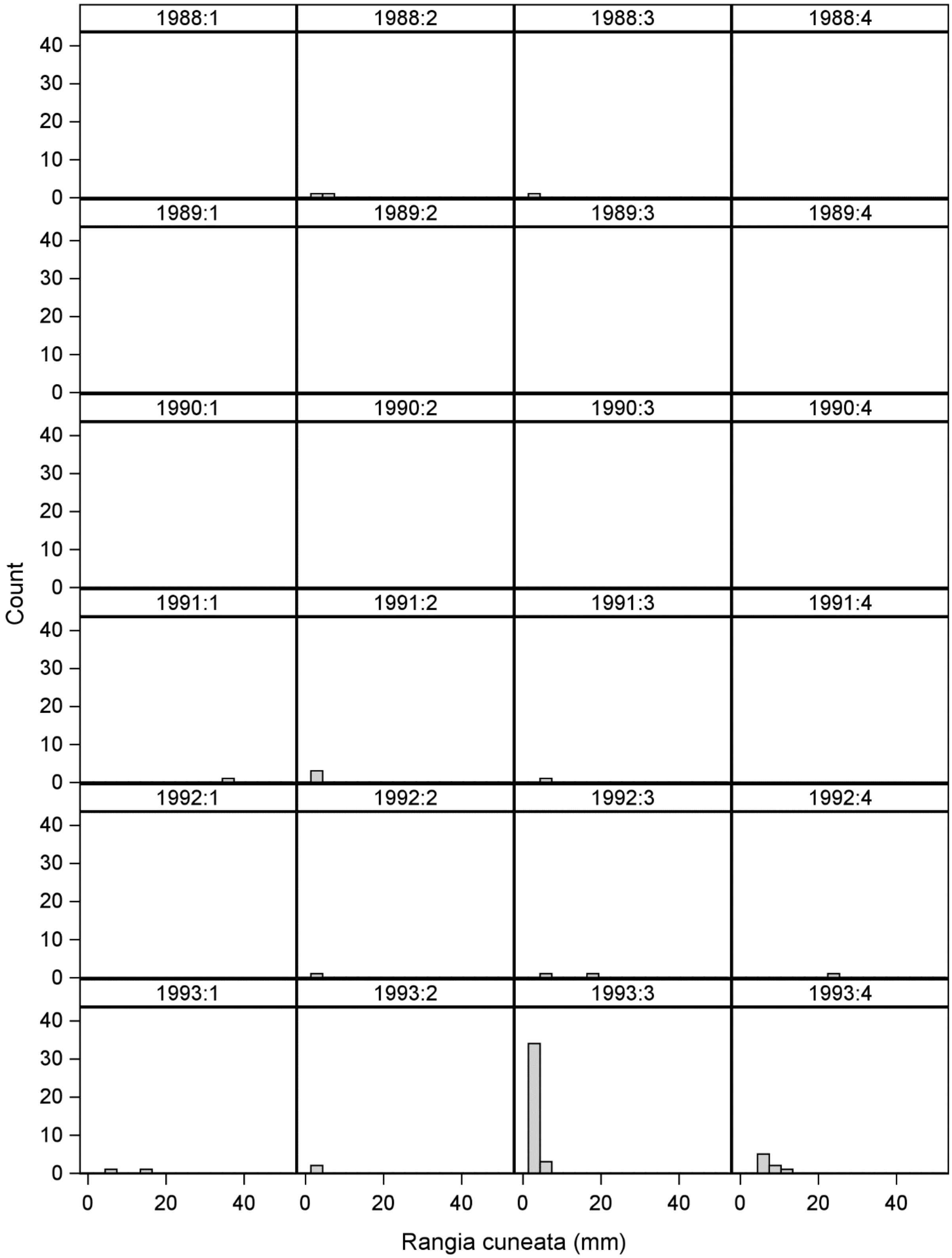


Figure 22. Size structure of *Macoma mitchelli* over time.



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Count
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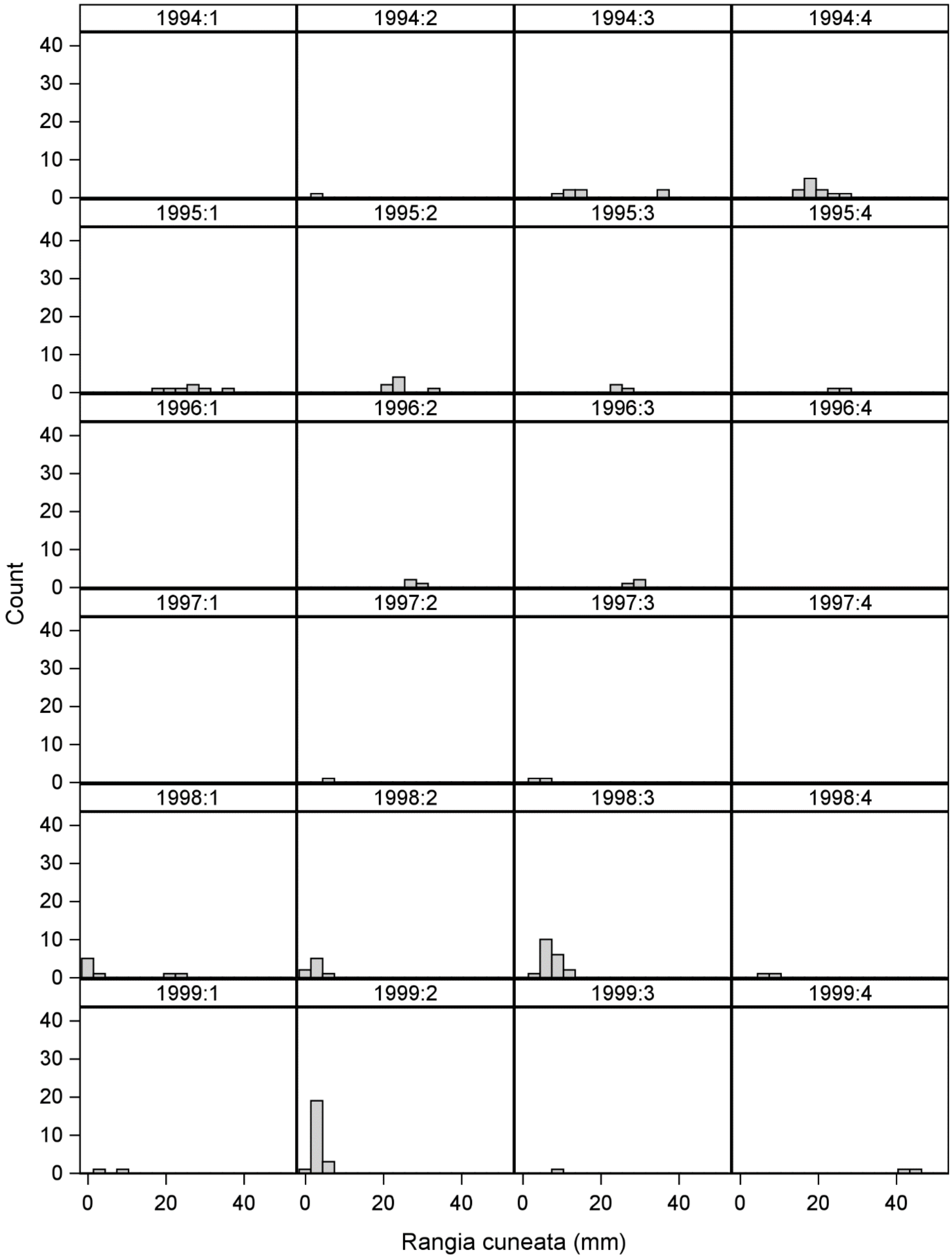
Rangia cuneata (mm)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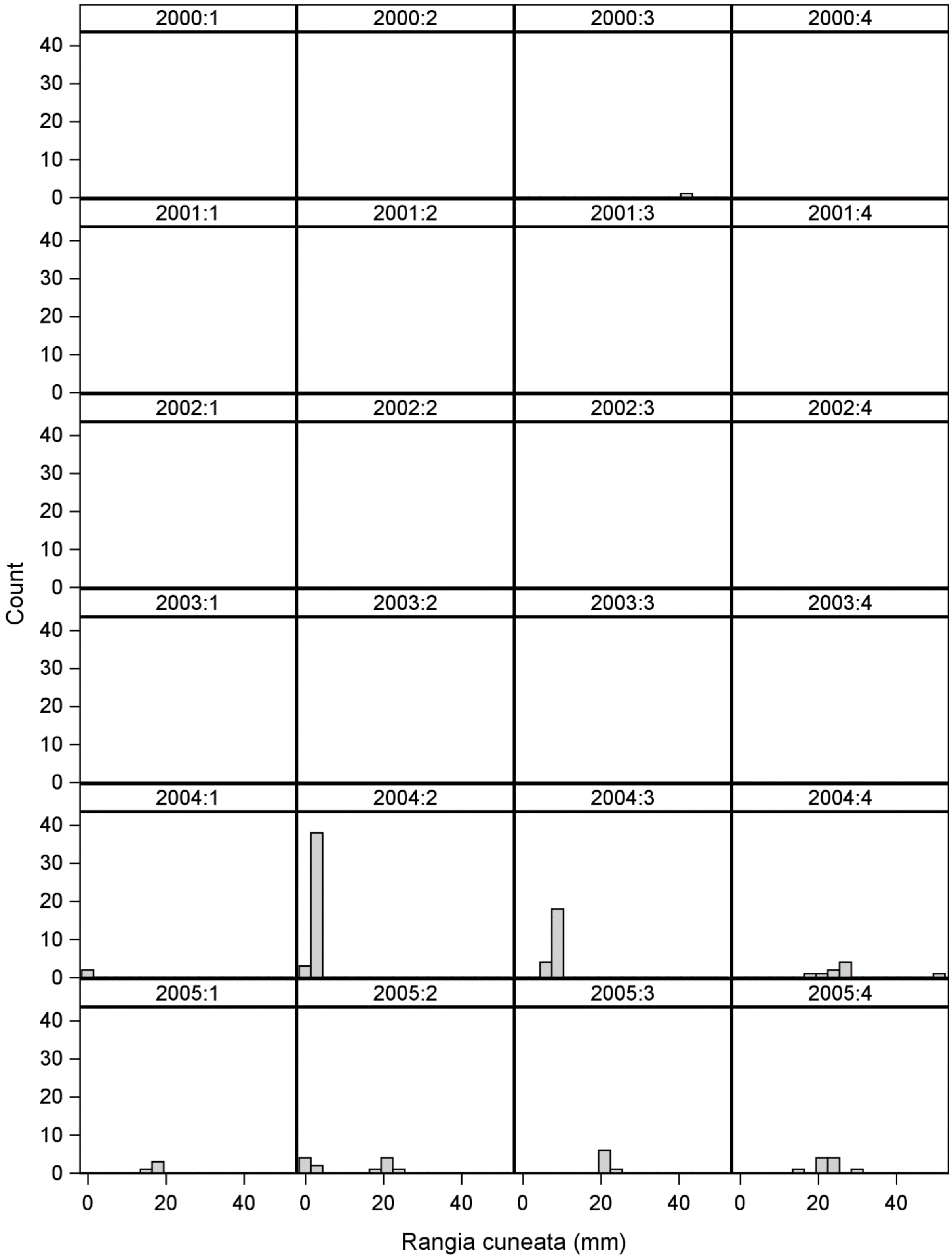
Rangia cuneata (mm)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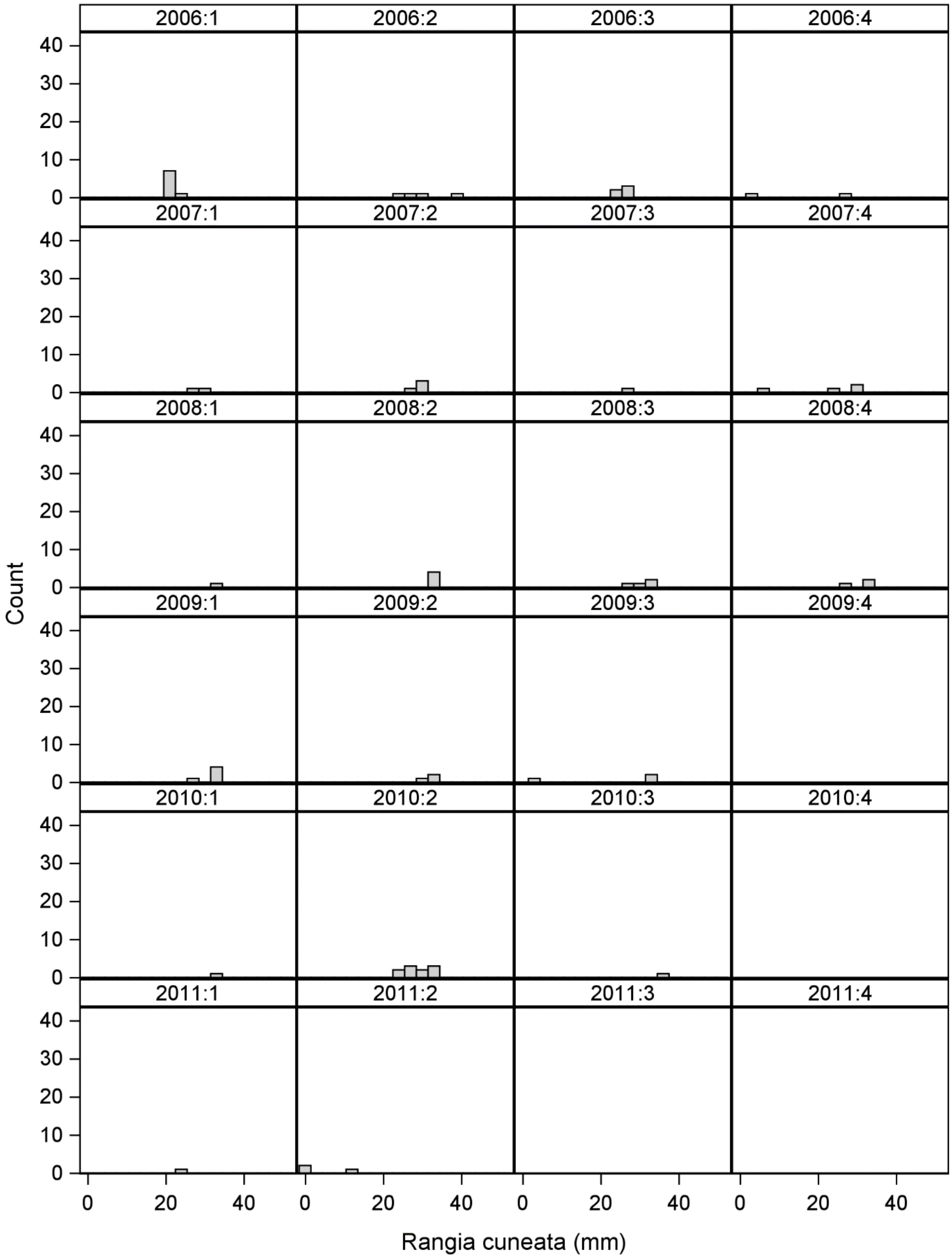
Rangia cuneata (mm)



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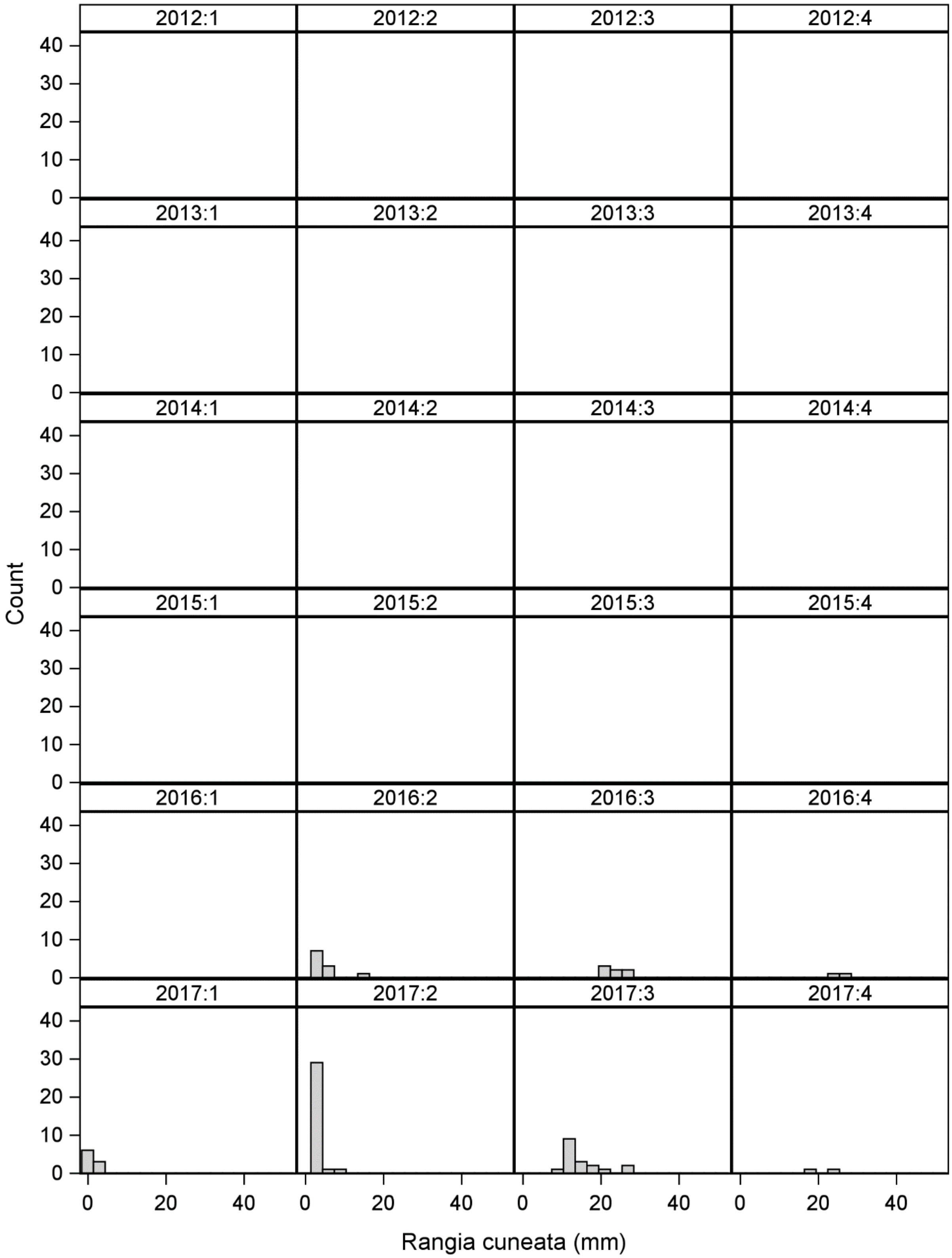
Rangia cuneata (mm)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Rangia cuneata (mm)

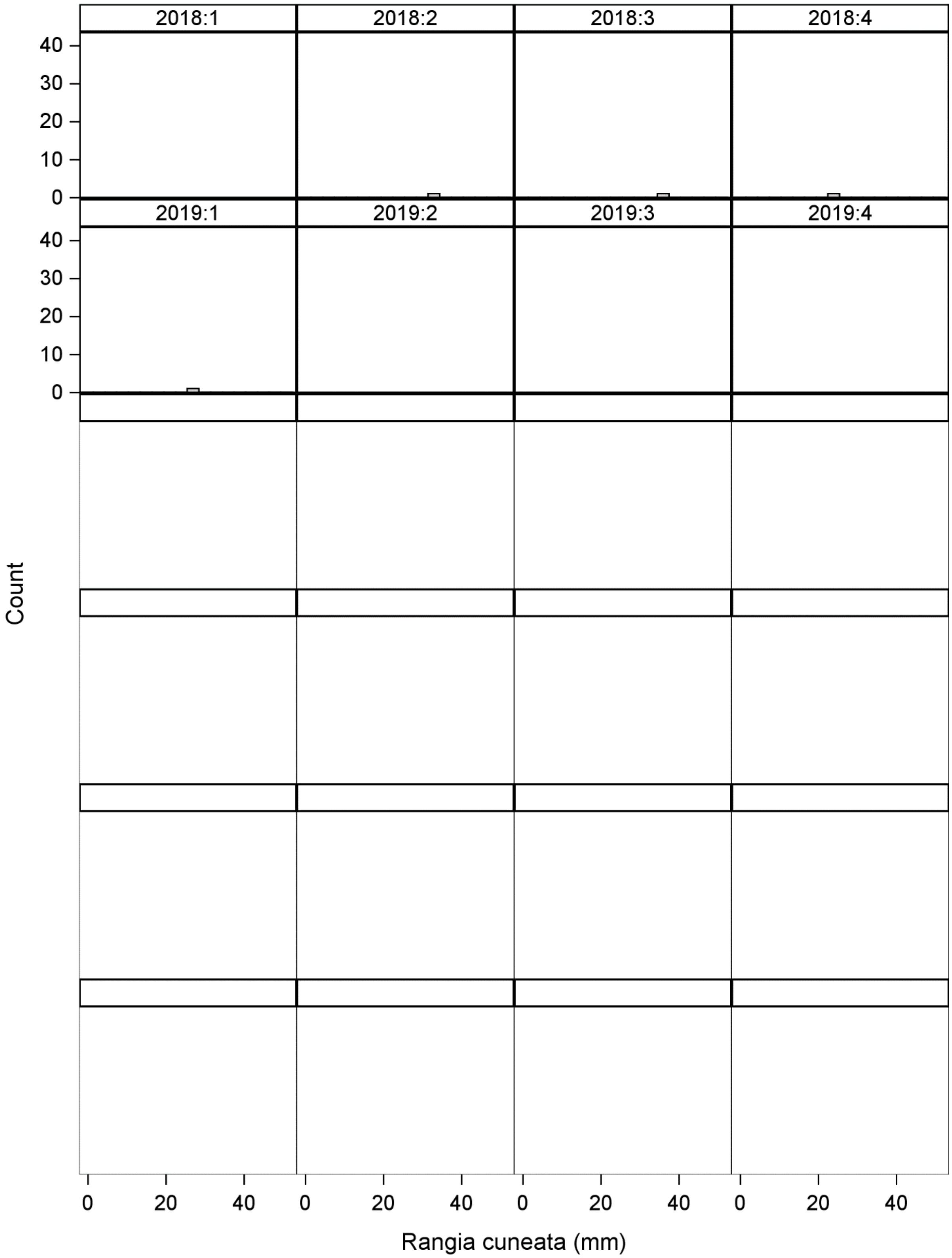

Figure 23.. Size structure of *Rangia cuneata* over time.

4. DISCUSSION

The objective of this study was to determine the relationship between freshwater inflow and mollusk populations as bioindicators of inflow effects. Population dynamics such as size frequency and abundance can be influenced by the freshwater inflow among primary and secondary bay locations. The sampling techniques used throughout the years were consistent in gathering hydrographic and mollusk data. Repetitive quarterly sampling provided infauna data that was useful in identifying long-term trends. Mission-Aransas Estuary was different because samples were gathered once per year during the month of October or November.

4.1 Salinity Zones

The salinity zones between primary and secondary bay systems were distinct and that caused differing mollusk community characteristics (Table 4, 5). Droughts and dry periods result in an increase in salinity. If freshwater positively affects mollusk production, then estuaries with greater freshwater inflow and stations near the river mouths should display stable production patterns (Montagna and Li, 2010; Kim and Montagna, 2012). Mollusk communities follow the salinity gradient along the Texas coast, and therefore indicate estuary health within mollusk populations. There were similarities of species diversity and abundance over each station (Figure 7). Lavaca-Colorado Estuary and Guadalupe Estuary are both considered high flow systems (Palmer and Montagna, 2014). Both systems have the highest frequencies of mollusk populations and are found the most north geographically of the sampled estuaries. The similarities between these two systems result from common freshwater inflow patterns and both are connected to the Gulf inlet Pass Cavallo and the Matagorda Ship Channel. Nueces Estuary is more south than Mission-Aransas but has a greater similarity in species to Lavaca-Colorado Estuary and Guadalupe Estuary (Figure 7). In 1992, the Guadalupe Estuary's inflow balance was

79 times greater than Nueces inflow balance, and the Mission-Aransas inflow is less than that (Montagna and Kalke, 1992). This is the result of Nueces Estuary having an inflow balance of 298 $10^6 m^3 yr^{-1}$, compared to Mission-Aransas having an inflow balance of 265 $10^6 m^3 yr^{-1}$ (Figure 2). The abundant difference in species diversity in the Mission-Aransas Estuary is likely a result of low regulated inflow balance, and possibly the unbalanced sampling design in Mission-Aransas. Laguna Madre displayed the greatest difference in community structure among all estuarine systems, it is the most southern system within the region, and uniquely the only system that lacks a consistent freshwater source leading to hypersaline conditions.

The estuaries experience similar patterns of mollusk community and population structure. Most of the mollusk populations are represented by small bivalves, that occasionally grow into larger sizes when salinity levels remain the same. The high frequency of smaller shells revealed times of recruitment for each species. Definite changes were apparent along the salinity gradient from the changes in water hydrography and community composition along the coast. The hydrological characteristics of each of the estuaries was used to create the environmental flow regulations, which were put in place in 2012 and 2014 (https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/eflows/rulemaking).

4.2 Regulatory Implications

In 2007, the Texas Legislature made a significant change to the water policy with the passing of Senate Bill 3. This Bill required new surface water withdrawal permits to consider an environmental flow regime, maintenance environmental flows in river segments, and bays and estuaries to the most reasonable extent possible (Montagna, et al., 2013). This flow is the amount of water that should remain in the water way to properly benefit the environment while balancing needs (Texas Water Code, Title 2, Chapter 11, Section 11.002.16). The flow regime created from derived quantities based on seasonal and yearly fluctuations with geographical considerations. Senate Bill 3 requires supporting ecological environments that maintain productivity to the extent possible within the aquatic habitats (Montagna et al., 2013). Because diversity and abundance are an indicator of environmental health, Senate Bill 3 also created scientific and stakeholder groups to make separate environmental flow recommendations: the Basin and Bay Expert Science Team (BBEST) and Basin and Bay Area Stakeholder Committee (BBASC). These two groups provided independent analyses and environmental flow recommendations to the Texas Commission on Environmental Quality, which reference quantity, quality, timing, and geographical extent of freshwater inflow to bays through “best available science” (Science Advisory Committee, 2009). To derive flow recommendations for estuaries, the BBEST methodologies focused on salinity and choosing bioindicators for distinct salinity ranges. The mollusk bioindicators chosen for these methodologies include the Eastern Oyster, *Rangia cuneata*, Oyster drill, and the broad selection of benthic infauna. *Rangia cuneata* is not a dominant mollusk found in southern Texan estuarine systems (Figure 5). It appears only as the third most dominant species in the Guadalupe Estuary. Due to *Rangia cuneata* inconsistent presence in these bay systems, other dominant mollusks species such as *Mulinia lateralis, Macoma mitchelli, Mysella planulta,* and should serve as preferable bioindicators of environmental balance. In contrast to the other species, *Rangia cuneata* does have numerous publications in regard to their biological and ecological responses to environmental factors, resulting in acceptance of being used as an indicator reliable indicator species.

4.3 Indicator Species

It has been documented that *Mulinia lateralis* is a hardy species that survives in fluctuating conditions (Walker and Tenore, 1984). *Mulinia lateralis* is a member of the

Mactridae family and can be found in areas ranging from Prince Edward Island, Canada, south to Yucatan, Mexico (Andrews, 1992). *Mulinia lateralis* is important to estuarine ecosystems because it is a prominent food source for many predators such as Black Drum. From all data, *Mulinia lateralis* size ranges are ~2 mm 15 %, ~2.5 mm 12.5 %, ~3 mm 10.5 %, 4 mm 6.5 %, and 1 mm 5.5 % (Figure 8). *Mulinia lateralis* is approximately 3mm when spawning and 60 days old (Calabrese 1969a). Larvae development can withstand a large range of salinity conditions, and larvae development has been documented between 15 – 35 psu (Calabrese 1969b).

There were five major recruitment events for *Mulinia lateralis* during this study. In between these events, peaks of juvenile abundance occurred regularly in the first two quarters of the given years. The first major recruitment event of *Mulinia lateralis* during this study took place in Spring 1988 (1988:2), at the beginning of a dry season that followed a wet season. Most documented shells were found at the length 2.5-3.0 mm. All salinities from all estuaries averaged 30.0, the lowest in Guadalupe Estuary at 18.9 and the highest at 43.8 in Laguna Madre. Lavaca-Colorado, Mission-Aransas, and Nueces Estuaries had salinities between 23 - 28. This event dwindled over the next two quarters when salinity averaged 33.7 and 34.2. In 1993, *Mulinia lateralis* appeared as juvenile shell through the first three quarters. Salinity averages were 20.0, 16.3, and 18.2. Most shell lengths were below 5 mm. During the fourth quarter, nearly all shell lengths were absent when salinity rose to 26.0. In 2009 and 2010, both years experienced recruitment development during the first quarters of the year. In 2009, average salinity was 31.2, and 19.6 in 2010. In Nueces Estuary, 2009 salinity was high at 34.4, and below 30 in all other areas. In 2010, Nueces Estuary had high salinity once again at 30.4, while remaining estuaries were below 20. Starting in April 2018 (2018:2) a recruitment event occurred post Hurricane Harvey. Within Lavaca-Colorado and Guadalupe Estuaries, where Hurricane Harvey had the most effects, salinities were much lower. In 2018:2 through 2018:3 Guadalupe Estuary had salinity between 14-17 and Lavaca-Colorado had a salinity between 22 -26. From all average salinities, the mean was calculated revealing that *Mulinia lateralis* recruitment events are most successful at the salinity of 23.1.

Mysella planulta can be found from Nova Scotia to Cape Hatteras on the American Atlantic coast and Texas coast of the Gulf of Mexico (Franz, 1973). Research on the biology of this species is lacking, but reproduction patterns have been released. *Mysella planulta* was found in all study areas except for Mission-Aransas. The largest shells were recorded in Nueces Estuary (Figure 9). About 20 % of all *Mysella planulta* were slightly smaller than 2 mm. At the age of 2 months, a majority of *Mysella planulta* are between the size1.0 - 1.4 mm (Franz, 1973). The peak size for sperm release for *Mysella planulta*, a simultaneous hermaphrodite, is at a shell length of 2.0 mm, and 2.4 - 2.6 mm with ova release (Franz, 1973). This reveals that for *Mysella planulta* to reproduce in high densities, environmental conditions must be suitable for a period well over 2 months. A minor reproduction spike occurred in fall 1990 (1990:3). Average salinities were 28.7, and then grew to 32.3 in the following quarter, and this *Mysella planulta* recruitment event decreased simultaneously. The largest *Mysella planulta* recruitment event documented in this study began in 1997:3 and continued until 2000:3. This event occurred parallel to the beginning of a wet season. In fall 1997 (1997:3), shells were under 2 mm with salinities average of all estuaries at 22.1. The following 4 quarters, 1997:4 - 1999:1, shell lengths gradually grew with salinities averages ranging from 16.0 to 29.2. In fall 1999 (1999:3), shells were 2.0 - 2.5 mm in length at an average salinity of 25.3. In fall 2000 (2000:3), smaller clams were found below 2 mm, at salinity of 36.0. After these recruitment events, the *Mysella planulta* populations disappeared from the estuarine systems until the years 2012 – 2014.

Rangia cuneata has been accepted as a dominant and reliable benthic organism across the Atlantic coastal estuaries and the Gulf of Mexico estuaries since 1955 (Hopkins, 1970). Also, *Rangia cuneata* provides a food source for a diverse selection of fishes, crustaceans, and birds. Due to *Rangia cuneata* population being restricted by salinity, it has been accepted as a suitable indicator of freshwater inflow. *Rangia cuneata* primarily survive within the salinity range of 0 - 15 psu. Embryos can maintain optimal population is salinity levels of 0 - 10 psu. A study was conducted in 1963 disclosing that *Rangia cuneata* had an average length of 19.5 mm at one year old, 31 mm at the end of their second year, and 41 mm at the end of the third (Williams, 1972; Hopkins, 1970). In contrasts to findings in Hopkins' studies, *Rangia cuneata* is not abundant in surveyed estuarine systems surveyed here (Table 4 and Table 5). Of the *Rangia cuneata* that were collected, 30 % accounted for ~ 10 mm, 35 % 19 - 30 mm, and were majority found in Guadalupe Estuary. The first juvenile recruitment event, which consisted of shell lengths below 5 mm, occurred in 1993 (1993:3), Guadalupe Estuary had experienced a major salinity drop from 18.0 in 1993:1, 8.0 in 1998:2, and 0.7 in 199:3 when the recruitment occurred. Following this event in 1993:3, salinity rose, and the *Rangia cuneata* disappeared. In 1999:2, 20 *Rangia cuneata* were collected throughout Guadalupe Estuary, and disappeared by 1999:3. In 2004:2, shell lengths below 5 mm were collected with a Guadalupe Estuary salinity of 12.8, and in 2004:3, shell lengths collected grew to 10 mm at salinity 0.6. The final documented recruitment of *Rangia cuneata* during this study took place 2017:2, prior to Hurricane Harvey. Optimal salinities during these reproduction events were consistent with Hopkins claims, but the abundance of *Rangia cuneata* population was not sufficient to provide indicator of estuary health or conditions.

Macoma mitchelli was first discovered in Matagorda Bay in 1895 (Pilsbry and Johnson, 1896). It has been reported that this species has been found along the entire east coast, not including the southern tip of Florida, and along the Gulf of Mexico. *Macoma mitchelli* biology and ecology research is lacking. The largest of this species was found in Guadalupe Estuary, and the most abundant size of *Macoma mitchelli* was between 1.0 - 2.5 mm, making up almost 55% of the data (Figure 11). In winter 1994 (1994:1), a major reproduction event took place with an average salinity among all estuaries of 24.85. Within Guadalupe Estuary, where *Macoma mitchelli* was most abundant, salinity was 16.4, and this quarter was towards the end of continuous wet years. Right after this quarter of population growth, the population dropped off until 1998:1. During this gap of time, salinities were higher until the next wet period, which occurred in 1997:4. In 1998:1, a minor population increase occurred and experienced an average salinity across all estuaries of 20.59, with Guadalupe estuary salinity of 10.1.

The first coast-wide population peak of *Mulinia lateralis* and *Rangia cuneata* occurred in summer 1993 (1993:3), which was the final year of a wet period along the Texas coast. Before 1993, both high flow systems, Lavaca- Colorado and Guadalupe Estuaries, had experienced consecutive lower salinities from 0.1 – 11.8 during April – July 1992. During the first quarter of 1993, *Mulinia lateralis* was in high abundances within Guadalupe Estuary... After a lag time and the end of a wet period, *Mulinia lateralis* populations increased by 1993. Salinity levels rose to 18 psu in 1993:1 from 1.3 psu in 1992:3 in Guadalupe Estuary. In Nueces Estuary salinity rose to 28.6 psu in 1993:1 from 16.6 psu in 1992:3. The different change in inflow resulted in a recruitment increase in both species likely due to the sudden change in salinity levels. In 1993:3, small Rangia *cuneata* were recorded when the salinity dropped. This salinity dropped in the range which *Rangia cuneata* can maintain embryo development, but lack of rainfall following the quarter resulted in salinity levels to rise to 25.3 in Lavaca-Colorado and 15.8 in Guadalupe Estuary, resulting in an instant drop in *Rangia cuneata* population. The *Mulinia lateralis* population was maintained until 1994 with shell growth and recorded small lengths, which indicates that *Mulinia lateralis* range of tolerance of salinity is more suitable as a bioindicator for Texan estuaries. When a sudden change in salinity due to mass inflow occurs, *Mulinia lateralis* is prompt to recruit quickly after the flood. *Mulinia lateralis* can withstand high salinities and grow with the passing of a wet season. As salinity levels gradually increase with a passing of a wet season, shell lengths can increase. *Rangia cuneata* tolerance range is much less, and spikes in their populations occur more rarely during lower salinities.

4.4 Hurricane Effects

On August 25, 2017, Hurricane Harvey made landfall along the Texas coast. This hurricane created a disturbance throughout coastal ecosystems through storm surge, flooding, and high winds. These effects resulted in a disruption in salinity levels, nutrients load, and benthic blooms. The Estuary that experienced the most inflow was Guadalupe Estuary. Along with a change of salinity due to a massive inflow of freshwater, it has been documented that stratification and bottom-water hypoxia occurs within disrupted estuaries (Walker et al., 2021). Because the mollusks live on and within the system's sediment, the stratification effects heavily impact the species. Pre storm conditions in Guadalupe Estuary, in July 2017 salinity was 11.1 and dropped to salinity of 5.3 in September 2017 after Hurricane Harvey took place. Conditions did not return to standard levels of salinity until October 2017, which is two months post Hurricane Harvey. It can be concluded that Texas estuarine systems take more than two months for retuning conditions. In October 2017, salinity was recorded of 13.2, a bit lower than the calculated mean Guadalupe salinity of 15.1. In January 2018, Guadalupe Estuary reached salinity of 22.6, and with *Mulinia lateralis* mean salinity of past recruitment events of 23.1, the post Hurricane Harvey conditions provided optimal conditions for a population spike. April 2018, juvenile *Mulinia lateralis* were recorded and displayed growth in shell lengths until conditions were disrupted. During the beginning of this recruitment event in April 2018, shell lengths were recorded most abundant at 3 mm. The 3 mm shells, typically ~60 days old, reveals that this spat was fertilized as eggs when post storm conditions were returning to pre storm conditions. The influx of freshwater created an opportunity for future recruitment and allowed the growth of this generational spat to grown parallel to the returning of pre-storm estuarine conditions.

5. CONCLUSION

Data gathered from 1987-2019 were analyzed to correlate salinity with reproduction events and population sizes. This information was used to determine if a species would serve as a reliable bioindicator for salinity conditions with Texas estuaries. As expected, these lagoons are affected directly by ricer delivering freshwater inflow in secondary bays. Using this knowledge, the revealed salinity ratios of inflow diluting the seawater. Throughout this study, it was shown that *Rangia cuneata* conditions are not regular, only occur in massive storms or flooding. In contrast, *Mulinia lateralis* survives and reproduces in conditions that take place when reoccurring realistic inflow takes place such as expected average rain fall. In 1993, an increase in many bivalve species occurred. This took place with continuous inflow after a wet season. Salinities dropped within Lavaca-Colorado and Guadalupe Estuary from ranges of 0.1-11.8. Salinities grew high with the passing of quarters, resulting in less adaptable species abundance to dwindle off. Similarity to Hurricane Harvey, the inflow of freshwater triggered a spawning event after salinity levels returned to pre-storm conditions. The flushing of this ecosystem by a hurricane disturbance acted as a restart for optimal conditions for mollusk population spikes. It has been accepted in the past and in Senate Bill 3's bioindicator list that *Rangia cuneata* are the most suitable species as an indicator of estuarine health, but *Rangia cuneata* suitable conditions provide indication that an extreme inflow event has taken place, in compared to expected and maintainable inflow. *Mulinia lateralis* ranges provide conditions that are realistically deliverable.

The high flow systems in this study, Lavaca-Colorado Estuary and Guadalupe Estuary, both have a mean salinity between the salinity range of *Mulinia lateralis* embryo development. Lavaca-Colorado has a mean salinity of 22.25 and Guadalupe estuary has a mean salinity of 15.06 (Table 2). As discussed, it was calculated the optimal salinity level for high abundance in

Mulinia lateralis occurs at 23.1. Compared to *Rangia cuneata* whose range of salinity is much narrower and does not fall within any of the estuarine system salinity means in the current study. *Rangia cuneata* has been used as a bioindicator for estuarine health for many water studies, but the lack suitable conditions along the middle Texas Coast indicates a more salinity tolerant species such as *Mulinia lateralis* can be an additional bioindicator of estuarine health in regard to inflow. Texas estuaries are only able to provide conditions for *Rangia cuneata* of 0 - 15 during or directly after sudden inflow events. These conditions would be unstable to be maintained during all seasons of the year. Stable growth patterns of *Mulinia lateralis* indicates suitable freshwater inflow conditions of mid-coastal Texas estuaries, in contrast to *Rangia cuneata,* whose ideal conditions only take place after heavy storm floods or tropical cyclones. This study's results can contribute to aiding ecological environments that maintain productivity. Senate Bill 3 requires water withdrawal permits to consider environmental flow regimes, while maintain maintenance bays and estuaries to the most reasonable extent possible. Because abundance and diversity are signs of proper environmental health, results of the mollusk communities can contribute to these decisions.

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