Abstract.—Regression and time series analyses were used to investigate the relation between Apalachicola River flows and blue crab, *Callinectes sapidus*, harvests in and around Apalachicola Bay, Florida. Apalachicola River flows in one year were positively correlated with Franklin County blue crab landings during the next year (r^2=0.32, P<0.001, 1952-90), and the strength of the correlation increased when only more recent years were examined (r^2=0.49, P=0.001, 1973-90). In this area, blue crabs mature to a harvestable size by one year of age. Apalachicola River flows were also correlated with neighboring Wakulla County blue crab landings with a one-year time lag (r^2=0.52, P=0.001, n=17), but were not associated with blue crab landings for the remaining west coast of Florida. The mean monthly flow from September to May, termed the growout period, was the parameter most highly correlated with the following year's blue crab landings. Of five north Florida rivers examined, the Apalachicola River was most highly correlated with Franklin and Wakulla County blue crab landings.

Results of this study further document the influence of Apalachicola River flows on estuarine productivity. The positive relation between flows and blue crab harvests a year later suggests that low flow conditions in the estuary during the growout period negatively affect juveniles. Although the underlying causes of the correlations are not known, the effect of inflows on estuarine salinity is one of several possible mechanisms that warrants further investigation.

Manuscript accepted 20 July 1993
Fishery Bulletin 92:180–188 (1994).

The influence of Apalachicola River flows on blue crab, *Callinectes sapidus*, in north Florida

Dara H. Wilber
1640 Oak Ridge Road, Vicksburg, MS 39180

River flow affects many characteristics of estuaries, including salinity, turbidity, and nutrient and detrital concentrations. Changes in flow, therefore, may significantly affect estuarine biota, the extent to which may be inferred by examining historical relations between flow and productivity. Apalachicola Bay, Florida, like many estuaries, is subject to changes in freshwater inflow related to factors such as rainfall and upstream demands for agricultural, municipal, and industrial uses. Plans to reallocate freshwater resources (U.S. Army Corps of Engineers, 1989[1]) have renewed interest in the question of how freshwater inflows are related to productivity in the Apalachicola River and Bay system. This study examined the historical relationship between Apalachicola River flows and estuarine productivity.

One method of characterizing the importance of freshwater inflow to estuarine productivity is to correlate historical flow data with the commercial catch (landings) of estuarine-dependent species (Funicelli, 1984). Commercial landings are used to estimate estuarine productivity because they are often the only available long-term records from which species abundance can be inferred. Long-term records are available for several commercially important species in Apalachicola Bay, including oysters and blue crabs, which have different trophic requirements and estuarine residency patterns. By examining associations between these species and Apalachicola River flows, effects of freshwater delivery upon estuarine productivity can be evaluated. Associations between freshwater inflows and Apalachicola oyster harvests have been previously addressed (Wilber, 1992). The present study examines the influence of Apalachicola River flows on local and regional commercial blue crab, *Callinectes sapidus*, landings. Other north Florida rivers were also examined to estimate the relative importance of the Apalachicola River to blue crab landings with respect to these drainages.

Blue crabs in the Gulf of Mexico reach a harvestable size within a year of age (Perry, 1984) and comprise a significant portion of the commercial landings by 18–months of age (Steele, 1992[2]). Blue crabs enter the Apalachicola estuary as megalopae and young juveniles, reaching peak juvenile abundances in the winter (Livingston, 1983). Young crabs concentrate in the less saline portions of the bay, whereas egg-bearing females remain in the higher-salinity gulf waters where they spawn. It has been proposed that adult female blue crabs along the Florida gulf coast migrate to

[1] U.S. Army Corps of Engineers, Mobile District. 1989. Draft Post Authorization Change Notification Report for the Reallocation of Storage from Hydropower to Water Supply at Lake Lanier, Georgia, 320 p.

[2] P. Steele, Florida Marine Research Inst., 108th Ave. SE, St. Petersburg, FL 33701, pers. commun. 1992.

gulf waters near Apalachicola Bay to spawn and that the larvae are distributed to the south by loop currents (Oesterling and Evink, 1977). Evidence supporting this hypothesis was examined in this study.

Methods

Fisheries data

Several aspects of the blue crab fishery may lead to inaccurate fishery representation of adult stock abundance. For example, unreported landings from the recreational fishery and crab bycatch from the shrimp fishery are potential sources of bias in blue crab landings statistics (Perry, 1984). Although these sources of error cannot be controlled, if they are independent of river flow and account for a relatively constant proportion of the total landings over time, a valid, although perhaps conservative, representation of environmental effects on the species can be obtained.

The Florida Department of Natural Resources (FDNR) provided monthly landing data for blue crabs from Franklin and Wakulla Counties for 1979–90, monthly effort data (number of trips) for 1987–90, annual landing data from Wakulla County from 1973 to 1990 (excluding 1977), and annual landing data from the Florida west coast from 1960–1990. Franklin County annual landing data from 1952 to 1979 were also obtained (Herbert et al., 1988[3]). Statistical analyses (Wilkinson, 1990) were conducted by using the full 39-year Franklin County dataset, as well as a shorter (1973–90) dataset, which allowed comparisons between Franklin and Wakulla Counties that were not confounded by differences in time periods. The limited amount of effort data precluded analyses of catch per unit of effort.

Flow and rainfall data

The Apalachicola River begins at the Florida state line by the confluence of the Chattahoochee and Flint Rivers. Apalachicola flow data were collected at the United States Geological Service gauge at Blountstown, Florida, which is the closest station to the estuary (105 km upstream) with an adequate period of record. This station is not immediately adjacent to the estuary, therefore fresh water from local inputs and storm events are not included. The drainage area downstream from the Blountstown gauge is less than 9% of the total area drained by the Apalachicola-Chattahoochee-Flint River system (Leitman et al., 1983[4]).

Parameters examined included the highest and lowest average flows for 7 and 120–consecutive days each year (referred to as the 7- and 120-day maximum and minimum flows). Monthly minimum, mean, and maximum values, and the mean monthly flow during the growout period (September–May) were also examined. By using these flow durations, associations between landings and seasonal high and low flows could be examined, which was not possible when analyses included only mean annual flow. The growout-flow time period was adapted from a similar study correlating blue crab landings in Georgia with river discharges (Rogers et al., 1990[5]).

Sufficient historical flow data were also available for the Suwannee, Econfina, St. Marks, and Ochlockonee Rivers (Fig. 1), thus permitting a regional analysis of associations between flows and blue crab landings. For each river, the annual one-day minimum, one-day maximum, and annual mean flows were used. One-day high and low flow magnitudes were used because of their availability and because preliminary analyses which substituted other flow durations (annual minimums and maximums) on the Apalachicola River did not change results considerably.

Statistical analyses

Blue crab landings and flow data were tested for monthly, seasonal, and inter-annual dependencies through autocorrelations. Data were adjusted to remove dependencies when autocorrelations were significant. If autocorrelations between successive months were present, data were replaced by the difference between each month and the preceding month. If seasonal autocorrelations were present, the effects were removed by dividing each value by a seasonal factor. For instance, if landings exhibited a significant autocorrelation with a 12-month time lag, which reflected a similarity in catches for the same month among years, each monthly value was divided by the month's mean value and replaced by the quotient. Similar analyses were conducted with seasonal (three-month averages) landings and flow data following adjustments to remove significant autocorrelations. Flow data were $\log_{10}$ transformed.

[3] Herbert, T. A., and Associates. 1988. The Franklin County Fisheries Options Report, 164 p.

[4] Leitman, H. M., J. E. Sohm, and M. A. Franklin. 1983. Wetland hydrology and tree distribution of the Apalachicola River flood plain, Florida. U.S. Geological Survey Water-Supply Paper 2196, 52 p.

[5] Rogers, S. G., J. D. Arrendondo, and S. N. Latham. 1990. Assessment of the effects of the environment on the Georgia blue crab stock. Final Rep. Georgia Dep. Natl. Resources, 69 p.

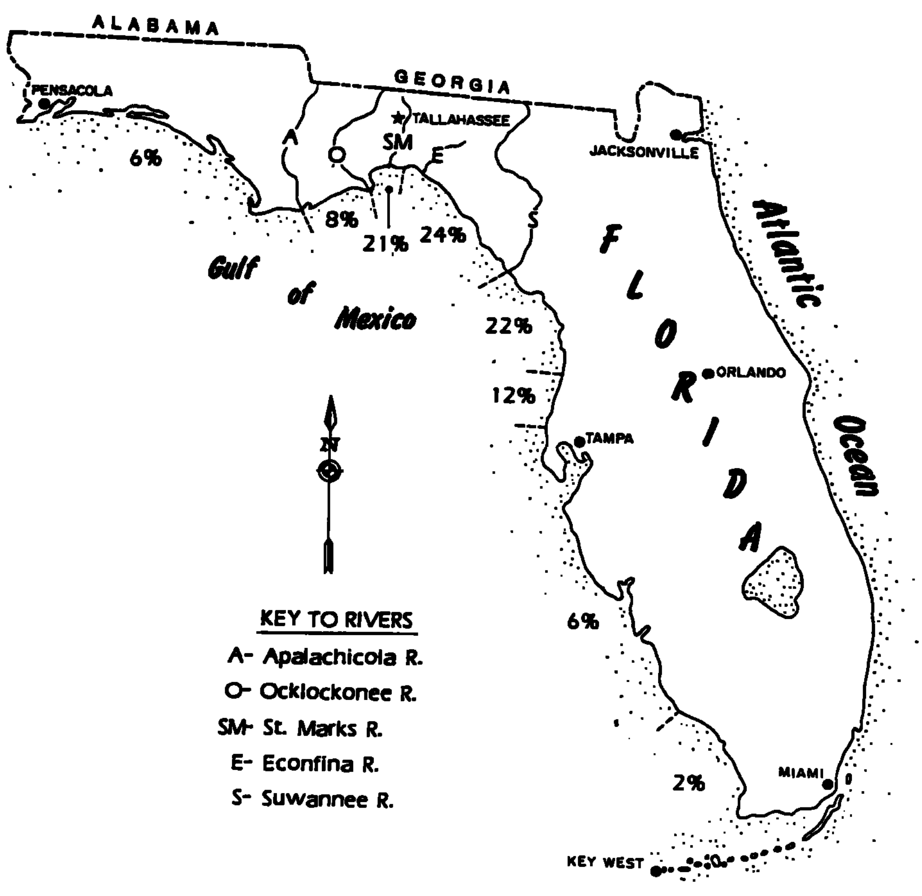

Figure 1
Percentage of total Florida west coast blue crab (*Callinectes sapidus*) landings caught by area (Steele, 1982). The five rivers used in the multivariate regression analyses (Apalachicola, Ochlockonee, St. Marks, Econfina, and Suwannee) are depicted.

Autoregressive order 1 (ARIMA) models were conducted on the Franklin and Wakulla County blue crab annual data and the residuals from these analyses were correlated with flow. This approach provided statistically rigorous estimates of P-values for the flow/landings relationships that were independent of any effects resulting from the one-year autocorrelations in landings. Analyses that used the ARIMA residuals and those that used unadjusted blue crab landings data were reported because both methods impart useful information. Correlations that used unadjusted annual blue crab data, i.e., significant autocorrelations were not removed, were biologically relevant because feedback mechanisms inherent to these autocorrelations (such as reproduction and recruitment) may also be associated with flow. Results of analyses that used unadjusted data are also more readily compared to results of other studies. Use of ARIMA models statistically validated the significant relations between blue crab landings and flow data, but may have removed some biologically relevant information. This paper primarily refers to unadjusted regression results.

Regression analyses incorporating a one-year time lag between flows and landings were conducted to examine the effects of flow on early blue crab life history stages. Contemporaneous analyses were conducted to assess the effect of flow on adults.

Univariate and stepwise multivariate regression analyses were conducted to estimate the amount of variability in blue crab landings accounted for by five major rivers on Florida's northern gulf coast. The criterion for admitting a flow variable into the stepwise regression models was an F-statistic greater than 4.0 for its partial correlation with landings. Data on blue crab landings for the west coast of Florida were used as a dependent variable in some analyses. To more specifically examine whether there was evidence that the Apalachicola River affects blue crab landings on a regional basis, Franklin and Wakulla landings were removed from the west coast dataset. Regression analyses were conducted to test whether Apalachicola flows and the remaining west coast landings were significantly related.

Results

Annual landings

Blue crab landings varied nearly 10-fold over the period of record examined in each county (Fig. 2). Significant autocorrelations between consecutive years were present in both Franklin (r^2=0.19, P=0.006) and Wakulla (r^2=0.37, P=0.016) County landings. Annual flow parameters did not exhibit any significant autocorrelations.

Annual Franklin County blue crab landings were most highly correlated with Apalachicola River flows of the previous year and these correlations were positive (Table I). The growout flow with a one-year time lag accounted for the greatest amount of variation in blue crab landings (r^2=0.32, P<0.001; Fig. 3A). The regression analysis of ARIMA residuals (autocorrelation in blue crab landings removed) and growout flows of the previous year was also significant (r^2=0.21; P=0.004). Wakulla County landings were significantly correlated only with Apalachicola flows of the previous year, with the growout flow also accounting for the greatest amount of variation in annual blue crab landings (r^2=0.52, P=0.001; Fig. 3B). The regression analysis of ARIMA residuals and growout flows one year previous was significant (r^2=0.35, P=0.02). The shorter (1973–90) data record for Franklin County landings was more strongly correlated with growout flows with a one-year time lag (r^2=0.49, P=0.001; Fig 3C) than was the full 39-year dataset.

Table 1

R^2 values from regression analyses for Franklin (n=39) and Wakulla (n=17) County blue crab (*Callinectes sapidus*) landings and Apalachicola River flows. All correlations were positive.

Flow parameter	Franklin	Wakulla
no lag period		
7–day low	0.16*	0.12
120–day low	0.14*	0.18
7–day high	0.04	0.07
120–day high	<0.01	<0.01
growout	0.08	0.10
one-year lag		
7–day low	0.25**	0.29*
120–day low	0.21**	0.21
7–day high	0.18*	0.17
120–day high	0.21**	0.31*
growout	0.32***	0.52***

* = P < 0.05.
** = P < 0.01.
*** = P < 0.001.

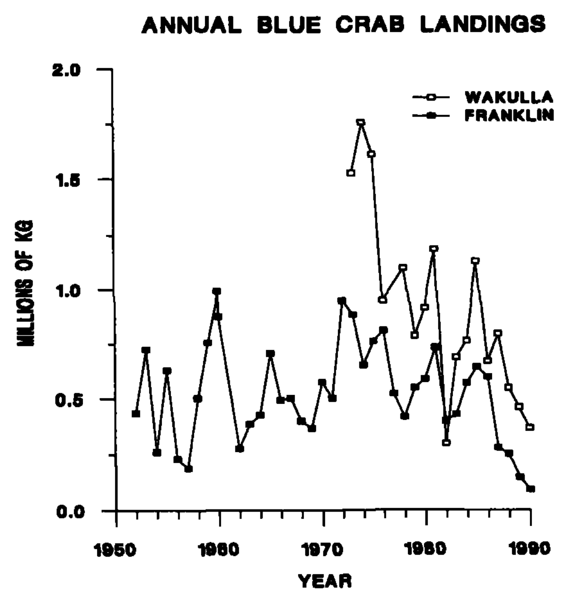

Figure 2

Annual blue crab (*Callinectes sapidus*) landings for Franklin (closed squares) and Wakulla (open squares) Counties in millions of kilograms.

Monthly and seasonal landings

As expected, the monthly Franklin and Wakulla County blue crab landings (1979–90) exhibited significant autocorrelations for 1- and 12-month time lags. All monthly river flow parameters (minimum, mean, and maximum) also exhibited significant correlations between successive months and with 12-month lags. Correlations between monthly landings and flow parameters (without any adjustments for significant autocorrelations) were positive for time lags of 3, 4, and 5 months. Significant negative correlations were present for flows that lagged 2–4 months behind landings. Correlations that used landings and flow data with the 1- and 12-month autocorrelation effects removed were not significant for either county.

Peak harvests generally occurred between May and September in both counties. There were also no significant correlations between the seasonal (three-

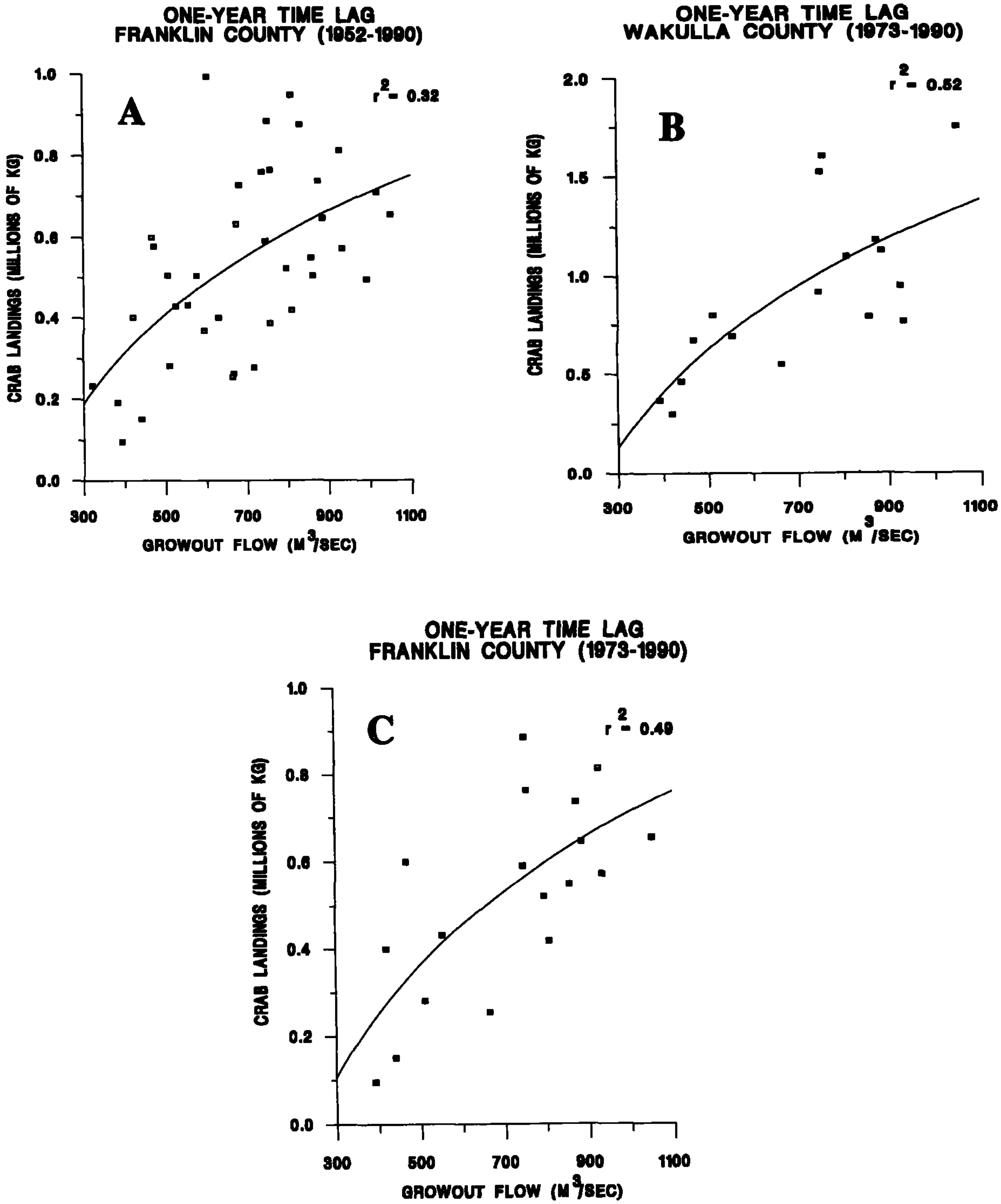

Figure 3

Apalachicola River growout (flows m^3/sec, mean flow from September through May) plotted against the following year's (**A**) Franklin County blue crab landings (1952–90), (**B**) Wakulla County blue crab landings (1973–90 excluding 1977), and (**C**) Franklin County blue crab landings (1973–90). Flow data were log transformed in the statistical analyses.

month average) flow and landings data with autocorrelations removed. The timing of peak monthly harvests was not related to the magnitude of the annual harvests.

Regional analysis

Given the close geographical proximity of the five rivers (Fig. 1) used in the multiple regression analyses, significant correlations between annual flow parameters may be expected among the rivers. Apalachicola River annual mean flows, although significantly correlated with other river flows (except the St. Marks), had the lowest correlations with the other drainages (Table 2).

Significant correlations with blue crab landings were more common for Apalachicola River flows than for any other north Florida river tested (Table 3). Franklin County landings were correlated only with Apalachicola flows, whereas Wakulla County and west coast landings were also correlated with Suwannee and Ochlockonee flows, respectively (Table 3). These significant univariate correlations incorporated a one-year time lag.

The Franklin County multivariate regression model included Apalachicola and Ochlockonee minimum flows of the previous year (r^2=0.45, P<0.001; Table 4). The Wakulla multivariate model accounted for the most variation in blue crab landings (r^2=0.64; Table 4) and included Apalachicola mean and Ochlockonee minimum flows of the previous year. The west coast multivariate model with a one-year time lag included Apalachicola maximum and Ochlockonee minimum and mean flows (r^2=0.53; Table 4).

The only significant multivariate model that included parameters with and without time lags was for west coast landings, which used both no-lag Suwannee minimum flows and Apalachicola maximum flows of the previous year (r^2=0.49). Analyses that examined associations between Apalachicola River flow and west coast landings with Franklin and Wakulla County landings removed were not significant.

Discussion

Several consistent results appeared in the correlations of annual blue crab landings with Apalachicola

Table 2

Pearson correlation matrix of annual mean river flows for all possible combinations of five north Florida rivers.

	Apalachicola	Ochlockonee	St. Marks	Econfina	Suwannee
Apalachicola	1.00				
Ochlockonee	0.59**	1.00			
St. Marks	0.32	0.77**	1.00		
Econfina	0.50*	0.76**	0.64**	1.00	
Suwannee	0.60**	0.93**	0.77**	0.79**	1.00

* = P < 0.01.
** = P < 0.001.

Table 3

Univariate correlations between Wakulla, Franklin, and west coast blue crab (*Callinectes sapidus*) landings and the river flows from five north Florida drainages (Suwannee, Econfina, St. Marks, Ochlockonee, and Apalachicola) with a one-year time lag. Signs of the correlations are given in parentheses.

Region		Correlation	r^2	P
Franklin	Apalachicola minimum	(+)	0.31	0.001
	Apalachicola mean	(+)	0.25	0.004
	Apalachicola maximum	(+)	0.14	0.039
Wakulla	Apalachicola minimum	(+)	0.29	0.031
	Apalachicola mean	(+)	0.38	0.010
	Suwannee minimum	(+)	0.30	0.028
West Coast	Apalachicola mean	(+)	0.15	0.035
	Apalachicola maximum	(+)	0.26	0.004
	Ochlockonee minimum	(-)	0.22	0.009

Table 4

Multiple regression results for Franklin, Wakulla, and west coast landings of blue crabs (*Callinectes sapidus*) with a one-year time lag incorporated into the analyses. The independent variables are the five river drainages listed in Table 3. Listed below are the signs of the correlations in parentheses, Student's t-statistics, and associated P-values.

Region	Variable	t	P	r^2
Franklin	Apal. min (+)	4.38	<0.001	0.45
	Och. min. (-)	–2.68	0.012	
Wakulla	Apal. mean (+)	4.57	0.001	0.64
	Och. min. (-)	–3.05	0.009	
West Coast	Apal. max. (+)	2.99	0.006	
	Och. mean (+)	3.12	0.004	0.53
	Och. min. (-)	–2.61	0.015	

River flows. Statistically significant correlations were positive and primarily restricted to a time lag of one year, indicating higher flows were associated with higher blue crab landings the following year and lower flows with poorer landings the next year. The mean flow during the growout period (September through May) of the previous year was the most highly correlated flow parameter with blue crab landings in both counties.

A number of explanations are consistent with the observation that more fresh water (within a certain range) was associated with higher blue crab landings the following year. Greater freshwater inflows reduce estuarine salinities, thereby increasing the area of suitable habitat in the middle, and perhaps lower, estuary where juvenile blue crabs can forage and develop (Livingston et al., 1976; Perry, 1984). Increases in low salinity habitat may reduce predation by marine species on juvenile blue crabs. Greater freshwater flows may also broaden an estuary's signal to offshore female migrants and/or megalopae, thus increasing the potential recruitment population base (Perry and Stuck, 1982; Mense and Wenner, 1989). In addition, higher inflows carry more detrital and nutrient matter (Mattraw and Elder, 1982), which may either directly or indirectly enhance food availability.

In both Franklin and Wakulla counties, flows below approximately 600 m^3/sec appear more closely related to the following year's landings than higher growout flows, i.e., the regression equation fits the data better at the low end of the flow spectrum (Fig. 3). Several factors may explain this phenomenon. Food availability may limit blue crab production at flows below a certain level but may not be limiting at flows above this level and, therefore, crab productivity is not influenced by further increases in flow. Prey limitation at low flows may also lead to cannibalism, further limiting blue crab population size (Lipcius and Van Engel, 1990).

The finding that more recent years produce a stronger correlation between blue crab landings and river flows was also observed in Georgia (Rogers et al., 1990[5]). Total discharges from September to May (growout period) of five Georgia rivers were positively correlated with landings (r^2>0.8). Shorter time periods (the most recent 14 and 19 years of landings statistics) produced better correlations with flow than the full period of record (37 years). The authors concluded increased fishing pressure in more recent years resulted in only one year class being fished, and, thus, environmental effects were more obvious on a single year class in the shorter dataset. Similarly, that more recent landings for Franklin County were more highly correlated with Apalachicola River flows than landings for the longer 39-year period may reflect a trend toward harvesting a single year class.

The significant 1- and 12-month time lags in Franklin and Wakulla County reflect similarities in catches between successive months and a seasonal component, respectively. The 12-month autocorrelation indicates that trends in landings occur at the same time of year (e.g., summer peaks) and should not be confused with an annual autocorrelation, which is indicative of a similarity in harvests between entire years. The positive correlations between unadjusted monthly flow and landings data correspond to the summer peak in blue crab landings following 3–5 months after the spring peak in flows, and low winter landings following low late-summer and fall flows. The negative correlations with 2–4 month time lags reflect fall low flows following peak summer harvests and high spring flows occurring after low winter harvests. The absence of significant correlations between monthly landings and flows, once these data were adjusted to remove seasonal autocorrelations, indicates that residual (non-seasonal) variation in monthly flows is unrelated to the non-seasonal variation in monthly landings.

Livingston (1991) found a positive contemporaneous correlation between monthly Apalachicola River flows and blue crab abundances in trawl surveys conducted from 1972 to 1985. This finding corresponds to high juvenile abundances during high-flow months. The positive correlation in the present study between monthly flows and blue crab landings 3–5 months later may reflect the maturation of juveniles into adults in the summer, and thus the observed time lag in the correlation.

The majority of the Apalachicola-Chattahoochee-Flint basin is in Georgia and is subject to different climatic conditions than are the other north Florida rivers examined, which may explain the relatively small correlations between Apalachicola River flows and flows on these other rivers. Georgia rainfall is more strongly correlated with Apalachicola River flows than Florida rainfall (Meeter et al., 1979). A consistent and important finding of the multivariate regression analyses was that Apalachicola flows were more highly correlated with Franklin, Wakulla, and Florida west coast landings of the next year than any other river drainage tested. Regressions comparing Apalachicola flows to west coast landings, after Franklin and Wakulla County landings were removed, were not significant, suggesting the influence of the Apalachicola drainage is restricted primarily to Franklin and neighboring Wakulla County. Thus, there was no evidence supporting the hypothesis of mass blue crab spawning near Apalachicola Bay and larval transport down the gulf coast of Florida via the loop current (Oesterling and Evink, 1977).

Several studies have addressed factors that influence interannual variation in blue crab abundance, primarily concentrating on larval and post-larval recruitment (reviewed in Lipcius and Van Engel, 1990). Lipcius and Van Engel (1990) found high interannual, seasonal, and spatial variation in blue crab abundances in a 17-year fishery-independent dataset collected in the Chesapeake Bay. They observed that years with high blue crab abundances appeared to be dominated by the previous year class because peak catches occurred in the summer. Years with low abundances had peak abundances in the fall, suggesting the dominance of the new year class. This observation supports the contention that variation in recruitment plays a major role in determining interannual fluctuations. No interaction between annual abundance and seasonal peak catch was apparent for the Franklin or Wakulla County blue crab landings, which may indicate either the true absence of such a relation, the inadequacies of using fishery statistics, or a difference in growth rates between the two regions that invalidates the use of the same analysis. Interestingly, the fishery-independent trawl data from the Chesapeake were significantly (r^2=0.33) correlated with the commercial landings data.

The influence of physical factors on blue crab abundances has been documented in other areas, such as a positive relationship between blue crab landings and freshwater inflows in Georgia (Rogers et al., 1990[5]), an inverse relation between salinity and juvenile blue crab abundances on the Texas coast (More, 1969), and a positive relation between blue crab productivity and vegetated area in the Gulf of Mexico (Orth and van Montfrans, 1990). The positive correlation between blue crab landings and Apalachicola River flows of the previous year provides additional evidence of the importance of freshwater inflows to juvenile blue crabs.

Apalachicola River flows have a significant impact on estuarine productivity, as indicated by commercial harvests of oysters (Wilber, 1992) and blue crabs. Although statistical correlations do not indicate the causal mechanisms underlying these associations, the river's influence on estuarine salinities as a mediating factor is deserving of further examination. Undoubtedly, the Apalachicola River affects estuarine biota via mechanisms other than salinity (Livingston, 1991). Factors such as the transport of nutrients and organic matter, however, are unlikely to result in a significant correlation between low flows and oyster harvests two years later, unless food limitation is only measurably important for newly settled oyster spat. In addition, the majority of nutrient and detrital transport from the river occurs during high flow periods in the spring (Mattraw and Elder, 1982). There was no evidence that above-average flows were associated with either oyster or blue crab productivity. In both fisheries, flows on the low end of the spectrum were most significantly associated with landings. These significant correlations were positive and incorporated time lags, suggesting estuarine conditions during low minimum flow periods were not favorable for juveniles of either species.

Acknowledgments

The careful reviews of R. Hardy, G. Lewis, D. Meeter, R. Lipcius, P. Steele, and P. Wilber are gratefully acknowledged, as well as the technical support of J. Bennett, J. McKenna, G. Miller, and D. Tonsmeire. This work was supported by the Northwest Florida Water Management District and the State of Florida's Surface Water Improvement and Management (SWIM) Program.

Literature cited

Funicelli, N. A.
1984. Assessing and managing effects of reduced freshwater inflow to two Texas estuaries. *In* V. S. Kennedy (ed.), The estuary as a filter, p. 435–446.

Lipcius, R. N., and W. A. Van Engel.
1990. Blue crab population dynamics in Chesapeake Bay: variation in abundance (York River, 1972–1988) and stock-recruit functions. Bull. Mar. Sci. 46:180–194.

Livingston, R. J.
1983. Resource atlas of the Apalachicola estuary. Florida Sea Grant College Publication No. 55, 64 p.
1991. Historical relationships between research and resource management in the Apalachicola River-estuary. Ecological Applications 1(4):361–382.

Livingston, R. J., G. J. Kobylinski, F. G. Lewis III, and P. F. Sheridan.
1976. Long-term fluctuations of epibenthic fish and invertebrate populations in Apalachicola Bay, Florida. Fish. Bull. 74(2):311–321.

Mattraw, H. C., and J. F. Elder.
1982. Nutrient and detritus transport in the Apalachicola River, Florida. U.S. Geol. Surv. Water-Supply Pap. 2196–C.

Meeter, D. A., R. J. Livingston, and G. C. Woodsum.
1979. Long-term climatological cycles and popula-

tion changes in a river-dominated estuarine system. *In* R. J. Livingston (ed.), Ecological processes in coastal and marine systems. Marine Science 10:315–338.

Mense, D. J., and E. L. Wenner.
1989. Distribution and abundance of early life history stages of the blue crab, *Callinectes sapidus*, in tidal marsh creeks near Charleston, South Carolina. Estuaries 12:157–168.

More, W. R.
1969. A contribution to the biology of the blue crab (*Callinectes sapidus* Rathbun) in Texas, with a description of the fishery. Texas Parks Wildl. Dep. Tech. Ser. 1:1–31.

Oesterling, M. L., and G. L. Evink.
1977. Relationship between Florida's blue crab population and Apalachicola Bay. *In* R. J. Livingston and E. A. Joyce (eds.), Proceedings of the conference on the Apalachicola drainage system; 23–24 April 1976, Gainesville, Florida. FL Mar. Res. Pub. 26:101–121.

Orth, R. J., and J. van Montfrans.
1990. Utilization of marsh and seagrass habitats by early stages of *Callinectes sapidus*: a latitudinal perspective. Bull. Mar. Sci. 46:126–144.

Perry, H. M.
1984. A profile of the blue crab fishery of the Gulf of Mexico. Gulf State Mar. Fish. Comm. No. 9, 80 p.

Perry, H. M., and K. C. Stuck.
1982. The life history of the blue crab in Mississippi with notes on larval distribution: proc. blue crab colloquium; 18–19 October 1979, Biloxi, Mississippi. Gulf States Mar. Fish. Comm. 7:17–22.

Steele, P.
1982. A synopsis of the biology of the blue crab *Callinectes sapidus* Rathbun in Florida: proc. blue crab colloquium; 18–19 October 1979, Biloxi, Mississippi. Gulf States Mar. Fish. Comm. 7:29–35.

Wilber, D. H.
1992. Associations between freshwater inflows and oyster productivity in Apalachicola Bay, Florida. Estuarine, Coastal and Shelf Sciences 35:179–190.

Wilkinson, L.
1990. SYSTAT: the system for statistics. SYSTAT, Inc. Evanston, IL, 676 p.