Final Report

NOAA Award No. NA16FM1032

SFC APPROVED BY Maceda DATE 4/12/02

DREDGE MODIFICATIONS TO REDUCE INCIDENTAL GROUNDFISH CATCHES IN THE NORTHWEST ATLANTIC SEA SCALLOP FISHERY

(December 1, 2000 - November 30, 2001)

1/1/01 - 6/30/01
7/1/01 - 12/31/01

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Note: This is a draft report that has not undergone peer review.
The analyses and conclusions are preliminary.

EXECUTIVE SUMMARY

This document reports on the status of a research effort to reduce the bycatch of finfish in sea scallop gear. The project will continue to run until November 2002 using proceeds of scallop sales collected as a part of a sea scallop research TAC set aside program established by the New England Fishery Management Council and administered by NOAA. Due to a high degree of inflexibility in the regulatory and management process, the research effort has had to compromise its experimental design and operations. There is an ongoing effort by Coonamessett Farm to prepare an Environmental Assessment in an attempt to develop a more logical scientific approach before this project's completion. Financial status is presented at the end of this report.

INTRODUCTION

The problem of incidental capture and mortality of species not sought by a fishery has been of increasing concern to fisheries managers and participants during the past decade. This discarded biomass is undoubtedly substantial: for example, Wigley and Jensen (1967) estimated that during the period 1959 to1963, the United States and Canadian sea scallop fishery annually discarded 20 million finfish (estimated at about 9 million kg), about half of which were skates (Raja spp). More specifically here, the issue of yellowtail flounder and other commercial groundfish bycatch in the Northwest Atlantic sea scallop fishery, and how it impacts the overall status of those stocks and the local ecosystem, has resulted in spatial and temporal restrictions to that fishery.

A meaningful reduction of this bycatch would seem to be a generally beneficial goal; groundfish stock recruitment might improve and resource managers could have the option of permitting scallop vessels to seasonally fish areas presently closed to them. In response to proposals to investigate techniques to effect reduced bycatch, the National Marine Fisheries Service (NMFS) approved Saltonstahl-Kennedy funding for a project in 1996 to test various dredge modifications. That work demonstrated that top-twine panels of larger mesh sizes significantly reduce yellowtail flounder bycatches (as well as those of other species) at average rates of 31-61% (Hendriksen, et al, 1997; Smolowitz and Struhsaker, 2001). The larger twine top used in the tests, ten inch mesh, also resulted in reduced scallop catches.

Reported here are the results for gear trials of additional dredge modifications, undertaken with the objective of achieving even greater reductions of incidental groundfish catches without loss of scallop catch. During the periods 14-19 December 2000 (Trip #1, NLSA,16 tows), 2-9 January 2001 (Trip #2, CAI, 24 tows), and 3-7 October 2001 (Trip #3, CAI, 27 tows), three combination research/fishing trips with the F/V Generation and F/V Westport out of New Bedford, MA were conducted within Groundfish Closed Areas on Georges Bank [Nantucket Lightship Area (NLSA) and Closed Area I (CAI)].

METHODS

Standard commercial scallop fishing techniques were practiced during the trials to compare the performance of the modified (experimental) dredge on one side of the vessel against a standard (control) dredge on the opposite side. Duration of the on-bottom fishing time was recorded to the nearest minute; average tow speed was recorded to the nearest 0.1 knot. Average tow times for the three trips were 32.5, 29.8, and 33.0 min respectively. After a tow, the catch from each dredge was separated by species category and counted (scallop catches were recorded as bushels [bu = 35.2 liters]). The species categories are: yellowtail flounder (*Limanda ferruginea*), sea scallop (*Placopecten magellanicus*), skates (*Rajidae*, spp undet.), other flatfish (variously mixed catches of the genera Scophthalmus, Liopsetta, Pseudopluronectes, Glyptocephalus, and Paralichthys), and monkfish (*Lophius americanus*). During the October (Oct) trip, the predominate "other flatfish" species was winter flounder (blackback flounder, *Pseudopleuronectes americanus*); only the catch data for this species were recorded then. For analysis, the catch counts were transformed to catch rates, expressed as numbers (or bushels for scallops) per hectare. Hectares fished for each tow were calculated with the formula: Area sampled (hectares) by one 15-foot wide (4.572-meter) scallop dredge = Tow time (minutes) x Tow speed (knots) x 0.0141213. The constant was calculated from the theoretical area sampled by a dredge in one hour of fishing at one knot (one nautical mile (1853.13m)/hour) and dividing by 60.

Gear: For these trials, a variation of the standard New Bedford sea scallop dredge with a lighter frame and modified bale was constructed (See Appendix A). This new frame was used as the basis for the experimental dredge arrangements during all three trips. Standard commercial dredge frames were used on the control dredges during the December (Dec) and January (Jan) trips. However, the new frame was used for both the control and experimental dredges during the Oct trip. All dredges had identical 10-inch (254-mm) stretched-mesh diamond-hung twine-tops (required for Closed Area access programs). It should be noted that for commercial vessels currently operating in open areas of the management zones of the NW Atlantic, the standard twine-top is an 8-inch (203-mm) diamond-hung.

Two gear modifications were tested on the experimental dredges with new frames. The first, termed a fish sweep, was tested during the Dec and Jan trips. The second, termed excluder rings, was tested along with the the fish sweep during the first 17 tows of the Oct trip. During the last 10 tows of this trip, the fish sweep and excluder rings were switched to the other dredge frame (control side dredge with identical frame) on the opposite side of the vessel. Refer to Table 2 for a summary of dredge comparisons.

Data Analyses: The following summaries and discussions of test results attempt to address the varied interests of readers of this report.

We used the two-sided probability obtained from the matched-pairs Student's t -test to statistically judge if the mean catch difference (mean D) between control and experimental dredge was equal to zero (or not equal to zero in either direction). The power and efficiency of a matched-pairs comparison is well documented.

Another measure of comparative dredge performance is the mean (average) percent bycatch reduction effected by the experimental dredge relative to the control dredge (the catch rate of experimental dredge subtracted from that of the control dredge, divided by control catch rate and multiplied by 100). This results in a positive percentage when the experimental dredge catch is less than that of the control (much of the time). But when the catch rate of the experimental dredge exceeds that of the control dredge (an increased bycatch, or catch in the cases of scallops and monkfish, by the experimental dredge), a negative percent reduction results. Thus, the percent reduction for a test (or for a series of cumulative tests for a trip such as given in this report) could range as high as 100% (zero catch(es) for the experimental dredge(s)), or so low as to approach negative infinity (or be undefined for zero catch(es) in the control dredge(s)).

The overall paired t -test results, percent reductions, and some associated statistics are given in Table 1.

Perhaps the easiest way to gain a feeling for the outcome of the various comparisons is by inspection of Figure 1. There we have provided plots, by tow, of all differences (D) between control and experimental dredge catches for each species category by trip. Positive differences result when fewer animals are taken in the experimental dredge (a bycatch/catch reduction); negative differences result when more animals are taken in the experimental dredge (a bycatch/catch increase). These plots permit a quick assessment for an overall result; an estimation of the average difference between dredges; appraisal of consistency in dredge performance; and general examination of catch distribution for normality and outliers. After examination of these plots (and other data) some of the more extreme data points were tested with Grubbs' test for outliers; five were found to be significant at $P<0.005$ (1-tail). These tests are discussed in the individual species accounts below.

Additionally, supplementary graphics of various test statistics are given in Figures 2-18. An example of these graphics may be seen in Figure 2, which provides some yellowtail flounder results for the Dec 2000 trip. Catch rates for the control and experimental dredges for each tow of the trip are given in panel 'A'. Beginning with the second tow, cumulative paired t-tests were run with a spreadsheet application for the remaining tows of the trip. In addition to the cumulative mean catch for control and experimental dredges and the cumulative mean difference (panel 'B'), cumulative values for standard deviation, standard error, ±95% confidence intervals, and cumulativet for mean D were obtained. Some of these statistics were used to calculate the cumulative ±95% confidence interval for the cumulative percent reduction (panel 'C'). Another application was used to determine successive two-sided probabilities from the list of cumulative t -values (panel 'D'). For comparative purposes, successive probabilities for the nonparametric Wilcoxon matched-pairs (signed-ranks) test of the difference between dredges (no./hectare) for all non-zero differences between tows are given for the Dec and Jan trips (panel 'D').

For most research situations where the matched-pairs t -test is applied, the overall results for total data pairs, with perhaps a confidence interval estimate, will suffice. For the types of comparisons reported here, however, our summaries permit a broader analysis of the dynamics of the test series. Examination of the graphics could reveal changes in fishing power of the dredges (perhaps due to damage or repair modifications) or inconsistencies in the catch data; permit estimation of the minimum number of tows required to attain a certain level of statistical significance (for that comparison); or obtain a better understanding of the limits of the continuing percent bycatch reduction estimates. Ideally, analogous cumulative catch summaries would be run during actual sea trials to provide a continuous assessment of experimental effects, monitor behavior of the sampling gear, and maintain quality control of data.

RESULTS

Our interpretations of the results given above are summarized in Table 2. Further discussions for the species categories and overall trip results follow.

By Species Categories

Yellowtail flounder: Average overall yellowtail flounder bycatch reductions of about 36-41% were obtained during all three trips. These reductions were clear-cut and highly significant for the Dec and Oct trips (Figs. 1, 2, 13). Statistically significant differences between dredge catches were obtained by tow 4 during Dec and about tow 10 during Oct.

The difference for tow 11 of the Dec trip (D=6.51; Fig 1) qualifies as an outlier as defined above; Deletion of this datum has the expected effect: reduction of error with subsequent reductions in mean differences, confidence intervals, and probability. This additional test did not influence our conclusion regarding the overall test result (Table 1).

The results for the Jan trip (Fig 7) were less definitive; weak differentials between dredge catches, probably due to low catch rates, were experienced during most of the trip. These data provide an example of how, in such cases, a small change in catch data can effect test outcome. During most of the test, there was a weak, overall trend towards a bycatch reduction of about 20% (Fig 7C). That trend for the first 11 tows may not have proven to be statistically significant if the total number of tows were limited to only 14 (Fig. 6D). However, during tows 12 and 13, relatively small increases in the differential between dredge catches (Figs. 6A, 6B) produced an increase in percent bycatch reduction to about 37% (Fig 6C) and pushed the overall test probability into regions of significance within the observed 14 tows (Fig. 6D).

Further, the Jan catch data include three 1/0 (Yellowtail flounder taken in control/experimental dredges) or 0/1 tows. These data could be considered trivial; an additional test run with these data pairs deleted produced slightly more convincing overall results within 11 tows (Table 1, Fig. 8).

Scallops: The two trips with only the fish sweep on the experimental dredge produced a highly significant increase in the scallop catch of 11% during the Dec trip and 16-22% for the Jan trip (Figs. 3, 9). The comparative dredge performances during both of these trips were quite consistent, with the exception of tow 23 for the Jan trip (Fig 1). Deletion of this tow from consideration reduced the overall scallop catch increase rate to about 16%, but had no influence on the overall conclusion for this test comparison (Table 1).

During the Oct trip, when the excluder rings were tested along with the fish sweep on the experimental dredge, there was seeming no overall difference from the control dredge catches (Table 1, Fig. 14). Initially, this could have lead to the conclusion that the excluder rings effectively canceled the influence of the increased fishing power for scallops provided by the fish sweep. Examination of the various graphics (e.g. Fig. 1), however, reveals that tow 19 in this series was highly anomalous (the only one of a total of 67 tows) and can be justifiably discarded. A rerun of the data with 26 tows yields a highly significant 6.8% decrease in the scallop catch (Table 1, Fig 15). Thus, the excluder rings do, indeed, influence scallop catches.

Skates: The highly significant reductions in skate bycatches during the Dec (29%) and Oct (40%) trips were attained within 9-10 tows (Figs. 4, 16). These results are in contrast to those obtained during the Jan trip; then, moderate to strongly significant skate bycatch reductions of 10-15% were experienced for most stations (Fig. 10C). This trend changed during the last two tows when more skates were taken in the experimental dredges (contrary to most of the previous stations; Fig. 10A), resulting in an overall bycatch reduction of about 10% and a weakly significant overall probability of $P = 0.11$.

Other flatfishes: The bycatch reduction results for this species group is similar to those for skates. Essentially, significant results for the Dec (26% reduction) and Oct (48% reduction) trips were attained with fewer than 8-10 tows, but there was a weak overall result for the Jan trip. The persistent trend of a moderately significant 40% reduction in the mixed flatfishes catch during most of the tows in Jan was reversed with an atypical result for the last station (Figs. 1, 11), resulting in a very weak overall probability of $P=0.133$.

Monkfish: During the Dec trip, both dredges produced similar catch rates throughout the trip, resulting in almost identical overall performances (Fig. 5). In this case (low catch rates for all tows), examination of the percent reduction (-10%) data alone could lead to erroneous conclusions.

During the Jan trip the experimental dredge consistently produced more monkfish than the control dredge (contrary to the pattern experienced during the Dec trip), resulting in a highly significant overall catch increase of 80% (Fig. 12). However, the last tow of this trip qualifies as an outlier (Fig. 1), and deletion of it from the calculations yields an indicated 58% increase in monkfish catches at much greater level of significance (Table 1).

During the Oct trip there was, initially, a moderately significant 20% increase in the monkfish catch by the experimental dredge. Beginning at about tows 10 or 11, a change in relative gear performance occurred and these differences were negated during the remaining tows (Fig. 18). Although the overall conclusion is one of no difference between dredges, there is strong evidence that this experimental gear arrangement quite effectively increased the monkfish catch.

By Trip

The December 2000 trip is notable because of the consistency of the catch data and comparative dredge performance throughout the tow series. During the January 2001 trip, when experimental and control dredge arrangements were identical to the Dec trip, quite different results were obtained. The bycatch performance for yellowtail flounder, skates, and other flatfishes decreased relative to the levels obtained during December, while the percentage of increased scallop catch was greater. Also, highly significant increases in the monkfish catch was experienced. Could small differences in the rigging of one or both of the dredges between trips account for these differences?

The addition of excluder rings with the fish sweep during the October 2001 trip resulted in highly significant reductions in bycatches of yellowtail flounder, skates and other flatfishes (in this case, winter flounder). The bycatch reduction of 47.8% for winter flounder was the highest such rate attained during the trials. The excluder rings also significantly reduced scallop catches at the rate of about 7%. This conclusion is qualified, however, because of the apparently anomalous tow deleted from the analysis. Finally, there was some evidence that this gear arrangement could eventually prove capable of producing increased monkfish catches.

The shifting of the fish sweep and excluder rings to the other dredge for the last 10 tows of this trip provides an opportunity to explore for effects after a known gear change (modification). It appears that small changes in the trends for percent reduction and cumulative probability for yellowtail flounders (tow 15), skates (tow 18), and possibly scallops (tow 18) are associated with the gear switch (Figs. 13, 16, 15). For other flatfishes and monkfish (Figs. 17 and 18; tow 18), changes in those trends towards the end of the trip began at least one tow before the switch. These are perhaps overly picky interpretations of the catch data, but the points are raised to illustrate the potential of such graphical analyses.

DISCUSSION

Of the 15 comparisons analyzed, moderate to highly significant bycatch reductions or catch increases occurred 11 times. Usually, definitive results were obtained within 8-12 tows. In only one of the remaining four comparisons was there a unambiguous result of no difference between control and experimental dredge (monkfish, Dec trip). For the remaining three trips, trends indicating significant differences between dredges for most of a comparison were neutralized or weakened with a few atypical catches. The effects of such tows are especially noticeable when the sample size is small (e.g., Jan trip).

Some of the graphical summaries presented permit deeper analysis of the test outcomes. We are able to trace the progress and trends of a trial, identify possible problems with the sampling gear, and identify questionable data. This ability is especially useful for these types of sea trials where control of the experimental conditions is much more difficult than in the laboratory. The results reported here demonstrate that the ability to examine the developmental history of the experimental data is essential. If the researcher relies only upon statistics from the total sample size, important information may be lost and erroneous conclusions drawn.

Some of the more detailed data examinations given above may be overly zealous, but they were provided as demonstrations of how the statistical summaries might be applied and to maximize the amount of information acquired from the experiment. Sea trials like these require much time, effort, and expense on the parts of diverse persons and organizations.

We cannot separate the effects of the new frame and the fish sweep on the experimental dredge catches for the first two trips. Similarly, although the new frames were used on both control and experimental dredges during the Oct trip, the two variables, fish sweep and excluder rings, were tested simultaneously on the experimental dredge at that time. Further trials would be required to resolve these questions.

An extremely important point is that the fish sweep and excluder rings were tested against control dredges with 10-inch diamond-hung twine-tops; not the 6-inch (historical standard) or 8-inch twine-tops (new regulation). It is known that the shift to the larger ten inch twine-tops will significantly reduce groundfish bycatch as well as scallop catches over that made in smaller mesh twine tops. Just what the catch differentials for these species categories might be if the experimental dredges described here, were compared with the historical standard for the fishery (six inch), is a pertinent question in determining actual bycatch reduction in the scallop fishery.

PROJECT FINANCIAL STATUS

The project has a proposed budget of $42,900 and as of November 30, 2001 has spent $30,618.48. A total of $52,394.79 was collected from the sale of sea scallops. Funds not accounted for in this reporting period, will be used to pay fishing and scientific expenses in the continuation of this project effort which has been extended to November 30, 2002.

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Wigley,R.L. and H.W. Jensen. 1967. Incidental catches of finfish in sea scallop dredges on Georges Bank. U.S. Dept. of Interior, FWS, Fish. Rev., July: 63-70. (Sep. No. 795).

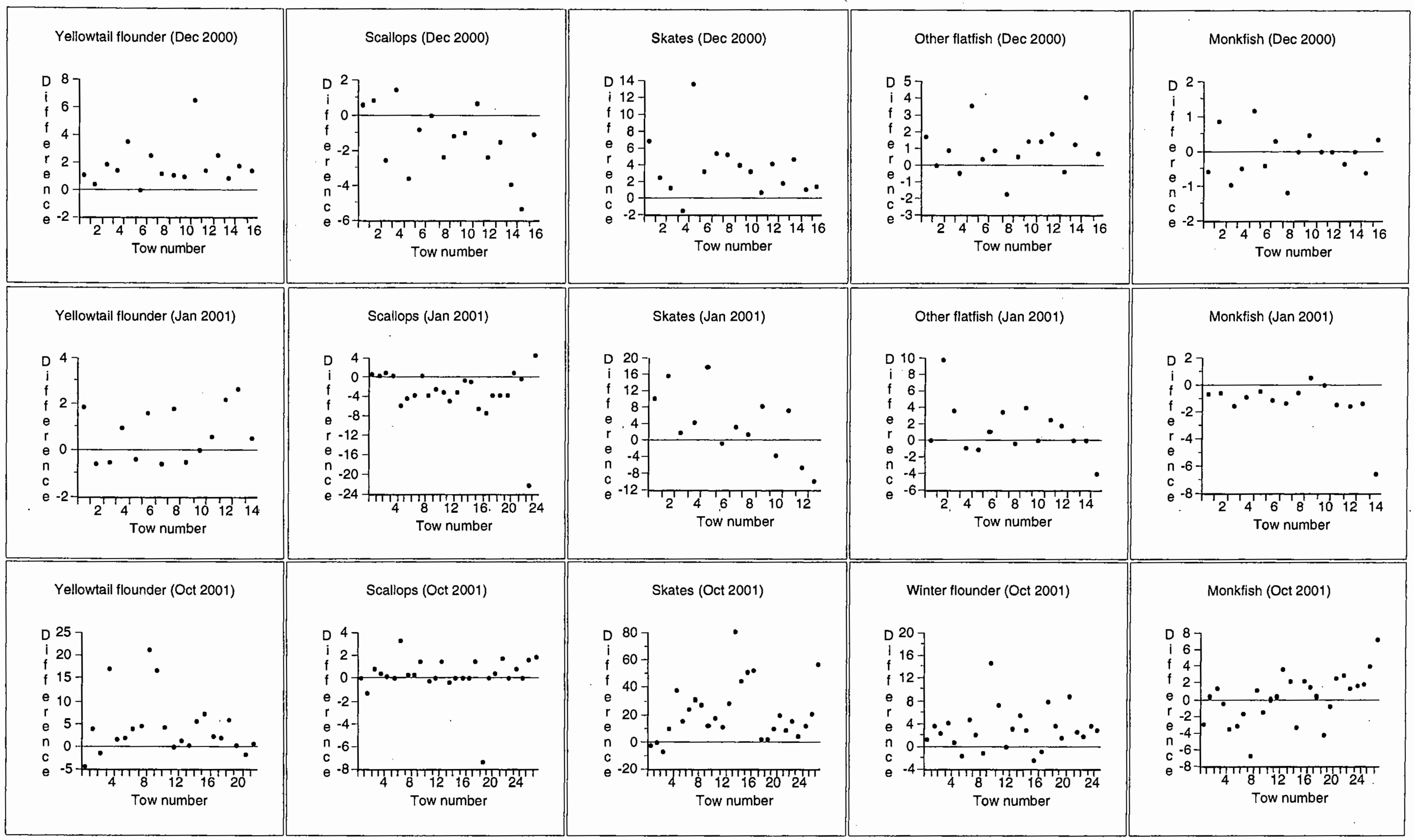
Table 1. Matched-pairs *t*-test statistics for control and experimental sea scallop dredge catches obtained during three experimental fishing trips. A negative value for mean D and mean percent reduction results when the mean catch of the experimental dredge exceeds that of the control dredge. Two sets of statistics are given when one or more catches were deleted from the complete trip data (see text).

Species category, trip, and sample size (n)	Controls: Mean catch (no. or bu/ hectare)	Experi-mentals: Mean catch (no. or bu/ hectare)	Mean D ±95% CI	Mean percent reduction ±95% CI	Standard error of mean D	Probability (two sides)	Variance F-ratio for mean catches
Yellowtail flounder							
Dec 2000 (16)	4.83	3.02	1.81±0.81	37.4±16.8	0.38	0.0003	2.47
Dec 2000 (15)	4.21	2.71	1.50±0.52	35.7±12.2	0.24	0.00002	1.28
Jan 2001 (14)	1.81	1.12	0.69±0.67	38.0±37.0	0.31	0.045	2.40
Jan 2001 (11)	5.25	2.62	2.6±0.80	41.1±35.3	0.35	0.025	1.94
Oct 2001 (22)	10.87	6.58	4.30±2.81	39.5±25.8	1.35	0.0045	1.66
Sea scallop							
Dec 2000 (16)	12.63	13.99	-1.36±1.01	-10.8±7.98	0.47	0.011	1.16
Jan 2001 (24)	13.79	16.80	-3.01±2.12	-21.8±15.4	1.03	0.0075	2.31
Jan 2001 (23)	13.25	15.42	-2.17±1.28	-16.4±9.69	0.62	0.002	1.54
Oct 2001 (27)	8.05	7.80	0.26±0.70	3.2±8.75	0.34	0.46	1.08
Oct 2001 (26)	8.05	7.51	0.55±0.44	6.8±5.5	0.19	0.008	1.03
Skates							
Dec 2000 (16)	12.73	9.08	3.65±1.81	28.7±14.2	0.85	0.0006	2.45
Dec 2000 (15)	12.12	9.02	3.10±1.25	25.6±10.3	0.58	0.0001	1.17
Jan 2001 (13)	38.68	34.86	3.82±4.90	9.9±12.7	2.25	0.1147	1.10
Oct 2001 (27)	54.18	32.30	21.9±8.30	40.4±15.3	4.04	0.00001	1.93
Other flatfishes							
Dec 2000 (16)	3.97	2.95	1.02±0.77	25.7±19.4	0.36	0.013	2.13
Jan 2001 (15)	4.27	2.96	1.32±1.77	30.8±41.4	0.83	0.133	1.76
Oct 2001 (25)	6.72	3.51	3.21±1.53	47.8±22.8	0.74	0.0002	2.29
Monkfish							
Dec 2000 (16)	0.85	0.94	-0.09±0.34	-10.3±39.4	0.16	0.58	1.13
Jan 2001 (14)	1.58	2.83	-1.25±0.96	-79.5±60.8	0.44	0.0144	1.62
Jan 2001 (13)	1.46	2.30	-0.84±0.39	-57.5±26.8	0.18	0.0005	1.19
Oct 2001 (27)	9.79	9.54	0.25±1.17	2.58±12.0	0.57	0.662	1.15

Table 2. Summary of experimental scallop dredge performance relative to the control dredge during three experimental fishing trips. Refer to figures 2-18 for graphics of summaries given below and the text for further discussions.

Trip and gear	Yellowtail flounder	Sea scallop	Skates	Other flatfishes	Monkfish
Dec 2000	Fig. 2	Fig. 3	Fig. 4	Fig. 5	Fig. 6
Control: Standard frame w/ 10" diamond-mesh twine top. Experimental: New frame w/ 10" diamond-mesh twine top, plus fish sweep.	Highly significant 36-37% average bycatch reduction.	Highly significant 11% increase in average scallop catch.	Highly significant 26-29% average bycatch reduction.	Highly significant 26% average bycatch reduction.	No difference between dredges. Low catch rates for all tows.
Jan 2001	Figs. 7, 8	Fig. 9	Fig. 10	Fig. 11	Fig. 12
Control: Standard frame w/ 10" diamond-mesh twine top. Experimental: New frame w/ 10" diamond-mesh twine top, plus fish sweep.	Moderately significant average bycatch reduction of 38-41%. Low catch rates for many tows.	Highly significant 16-22% increase in average scallop catch.	Moderately significant bycatch reduction of 10-15% during most of the tows; reversal of catch pattern for last 2 tows produced a weak overall probability.	Generally tending to a moderately significant 40% average bycatch reduction; dredge performance during last tow produced a very weak overall probability.	Highly significant 58-80% increase in monkfish catches indicated. Low catch rates for most tows.
Oct 2001	Fig. 13	Figs. 14, 15	Fig. 16	Fig. 17	Fig. 18
Control: New frame w/ 10" diamond-mesh twine top. Experimental: New frame w/ 10" diamond-mesh twine top, plus fish sweep and excluder rings.	Highly significant average bycatch reduction of about 40%.	Initially, no difference between dredges for all tows. Deletion of one anomalous tow yields a highly significant 6.8% decrease in scallop catch.	Highly significant average bycatch reduction of 40%.	Highly significant 48% average bycatch reduction of winter flounder.	Initially, a strong tendency towards a 20% increase in average monkfish catch. A change in relative gear performance about mid-trip resulted in no overall difference between dredges.

Figure 1. Plots of differences (D) between dredge catches (control dredge minus experimental dredge as numbers of fishes or bushels of scallops per hectare), by tow, for the five species categories quantified during three research/fishing trips to Georges Bank. Species categories by column; trips by row. Positive differences result when fewer animals are taken in the experimental dredge (a bycatch/catch reduction); negative differences result when more animals are taken in the experimental dredge (a bycatch/catch increase). These plots permit a quick assessment for an overall result; an estimation of mean D; appraisal of consistency in dredge performance; and general examination of catch distribution for normality and outliers. Also refer to Tables 1 and 2.



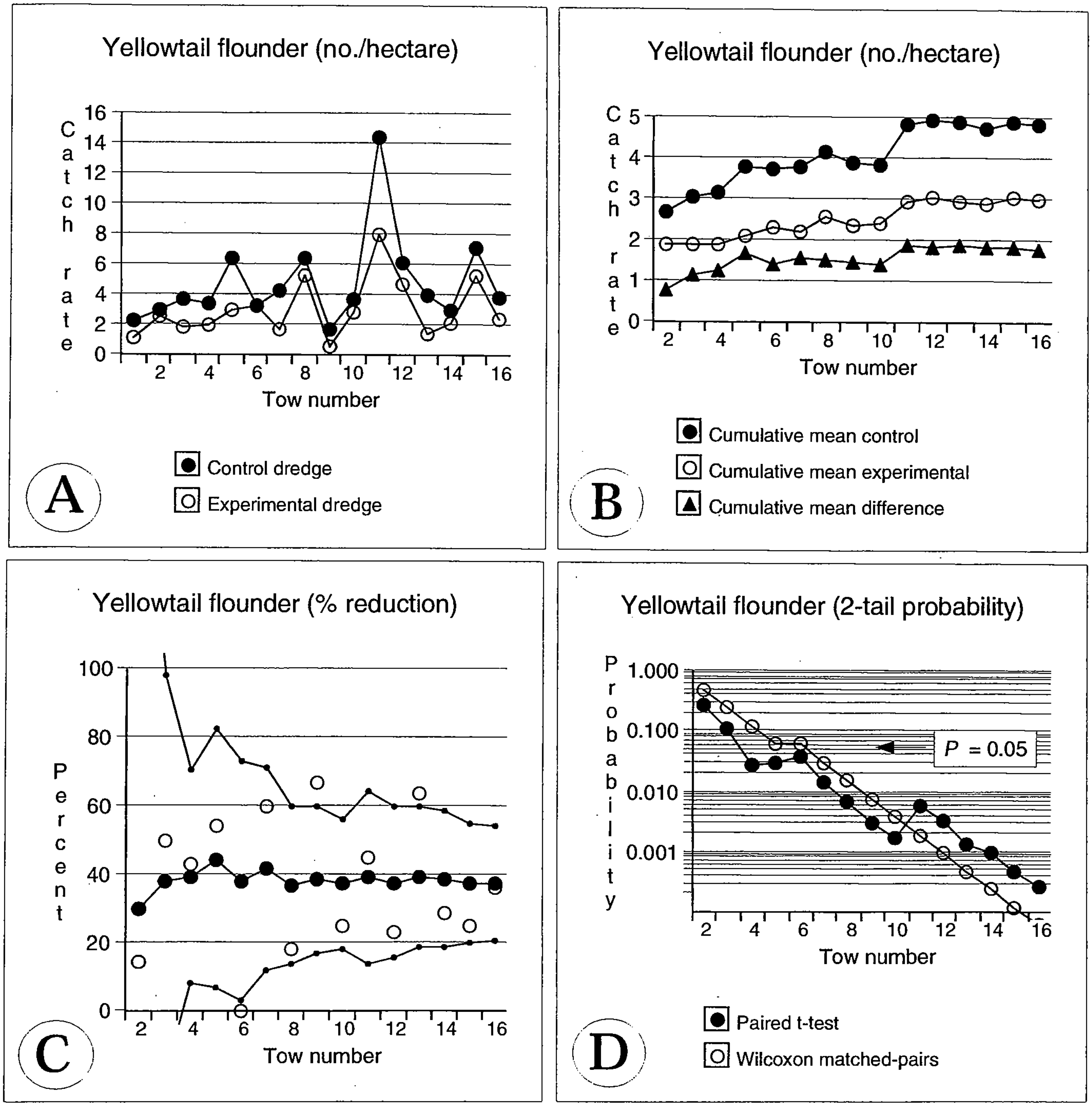


Figure 2. Yellowtail flounder results for Dec 2000. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent reduction of yellowtail flounder bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test and Wilcoxon matched-pairs test.

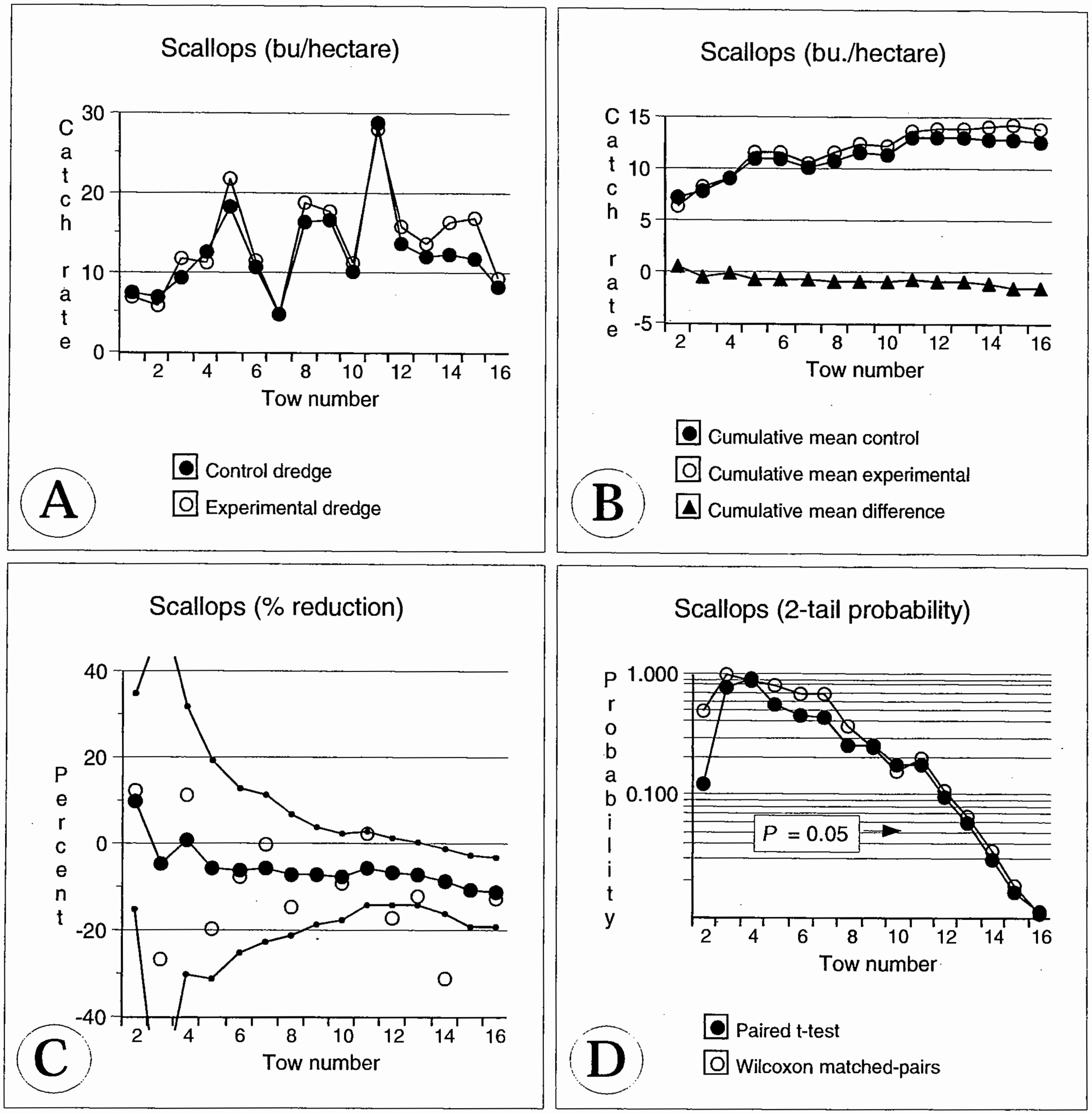


Figure 3. Sea scallop results for Dec 2000. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent increase (decreased reduction) of scallop catch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test and Wilcoxon matched-pairs test.

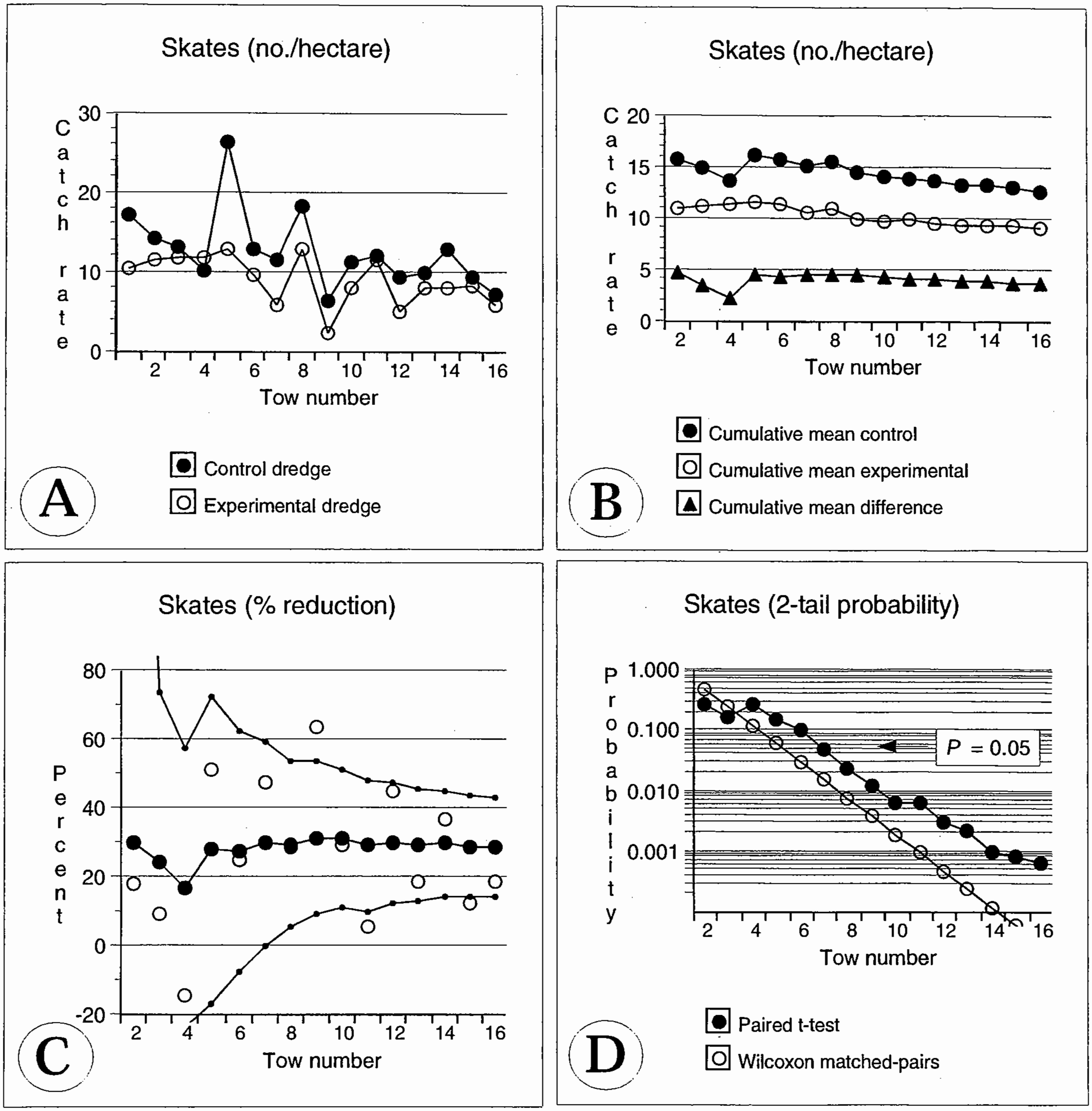


Figure 4. Skate results for Dec 2000. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent reduction of skate bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test and Wilcoxon matched-pairs test.

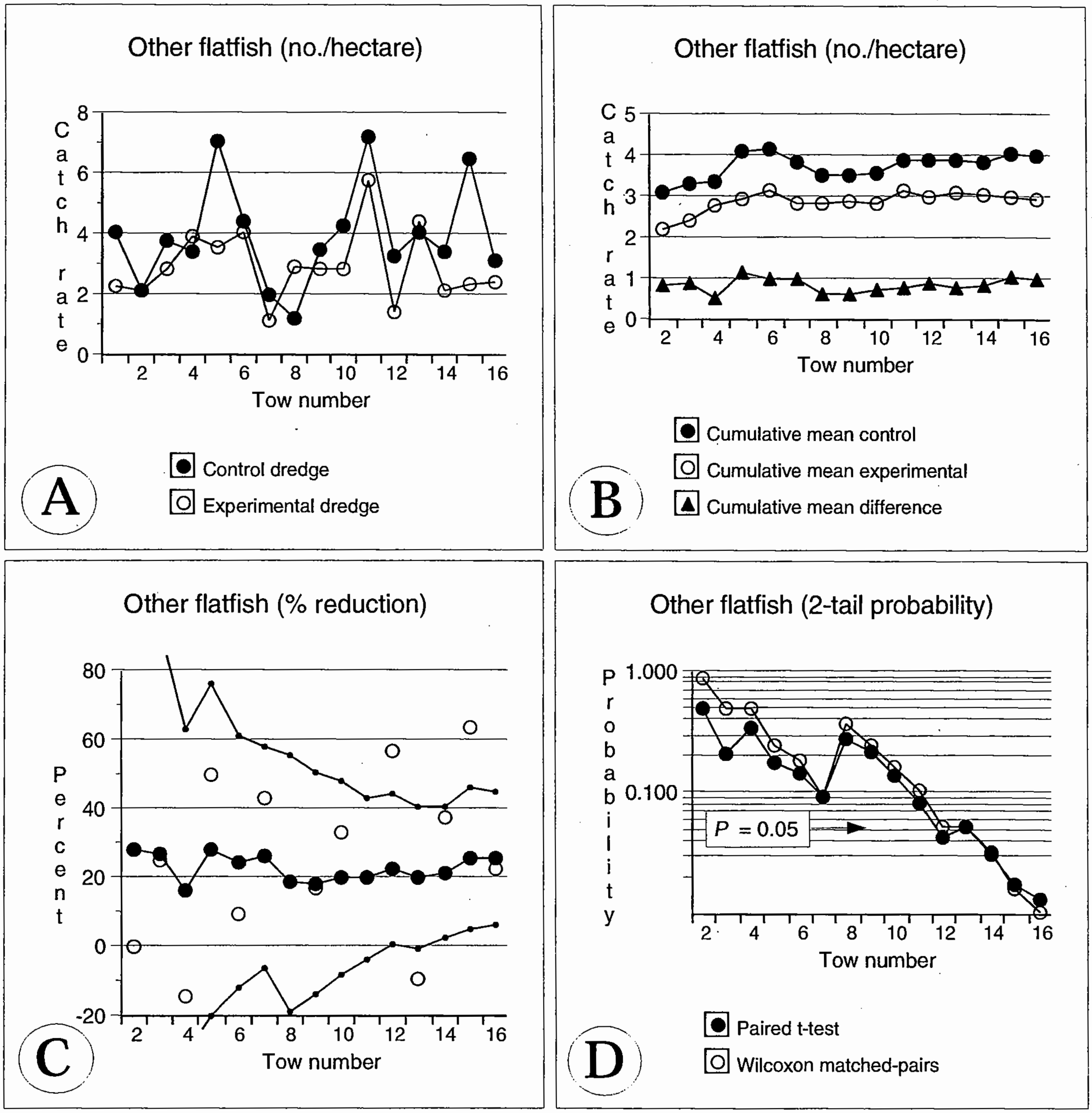


Figure 5. Other flatfish results for Dec 2000. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent reduction of Other flatfish bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test and Wilcoxon matched-pairs test.

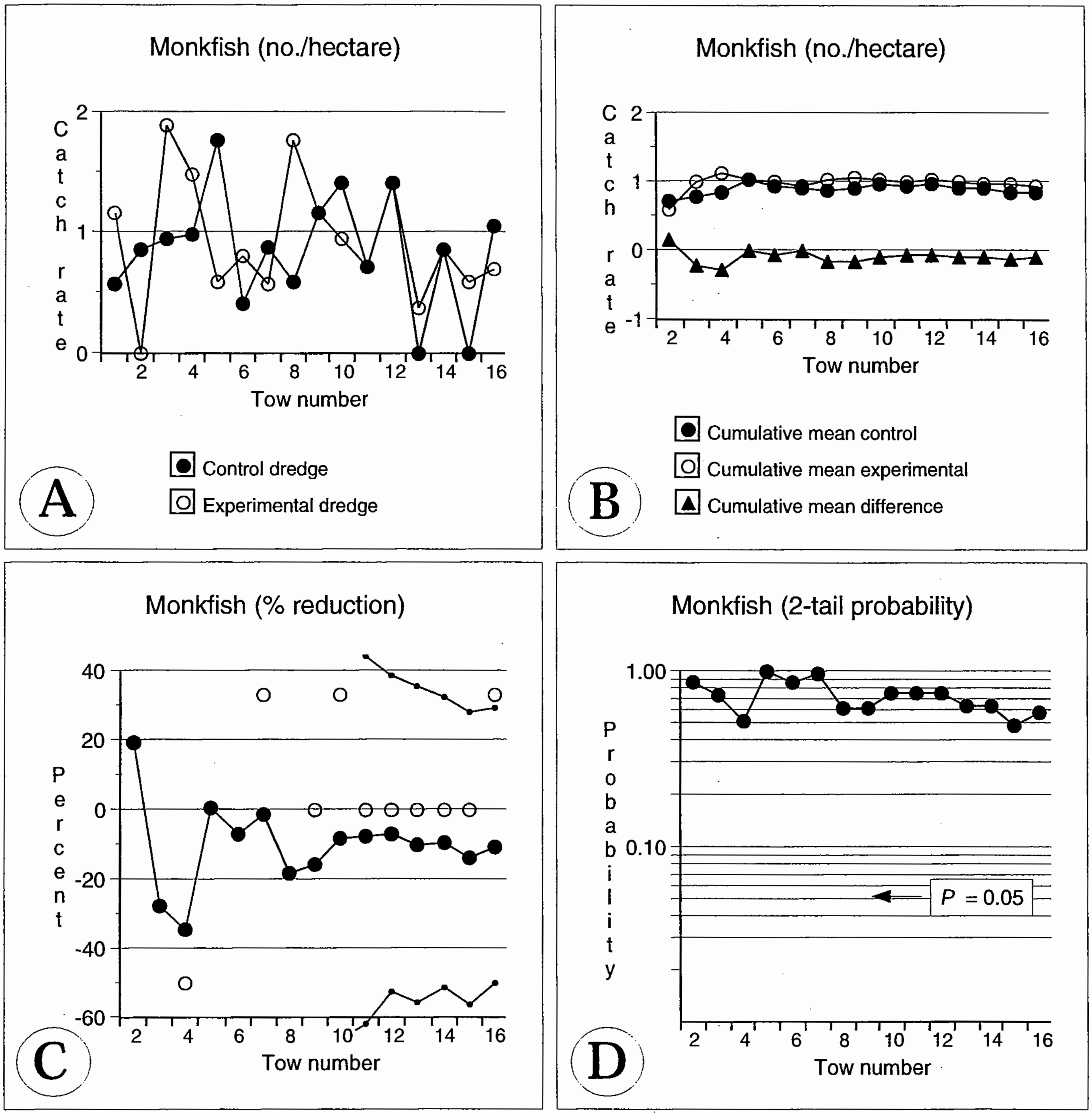


Figure 6. Monkfish results for Dec 2000. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent reduction of Monkfish bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test.

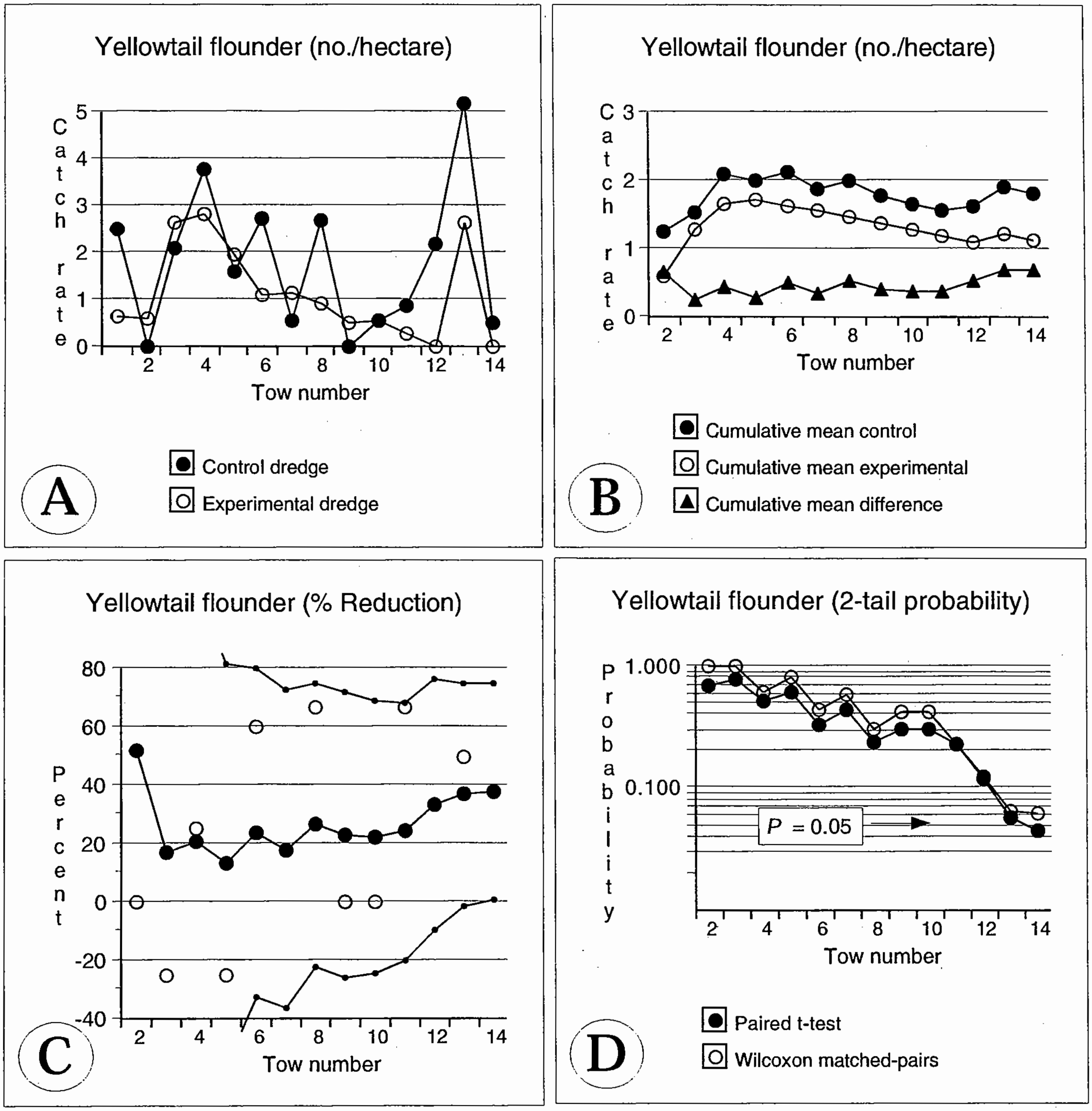


Figure 7. Yellowtail flounder results for Jan 2001. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent reduction of Yellowtail flounder bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired *t*-test and Wilcoxon matched-pairs test.

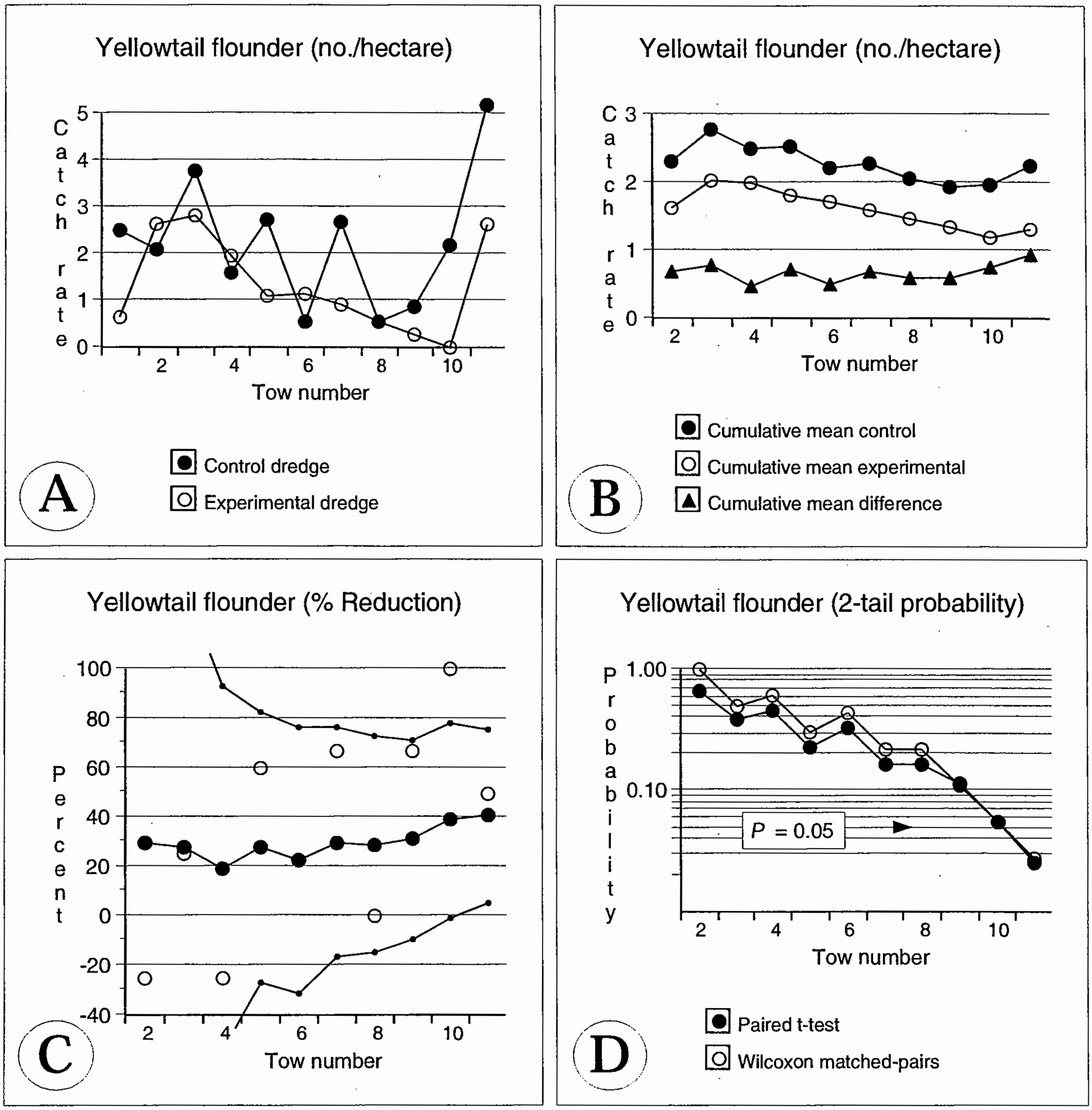


Figure 8. Yellowtail flounder results for Jan 2001 with 3 tows of 0/1 and 1/0 catches deleted. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent reduction of Yellowtail flounder bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test and Wilcoxon matched-pairs test.

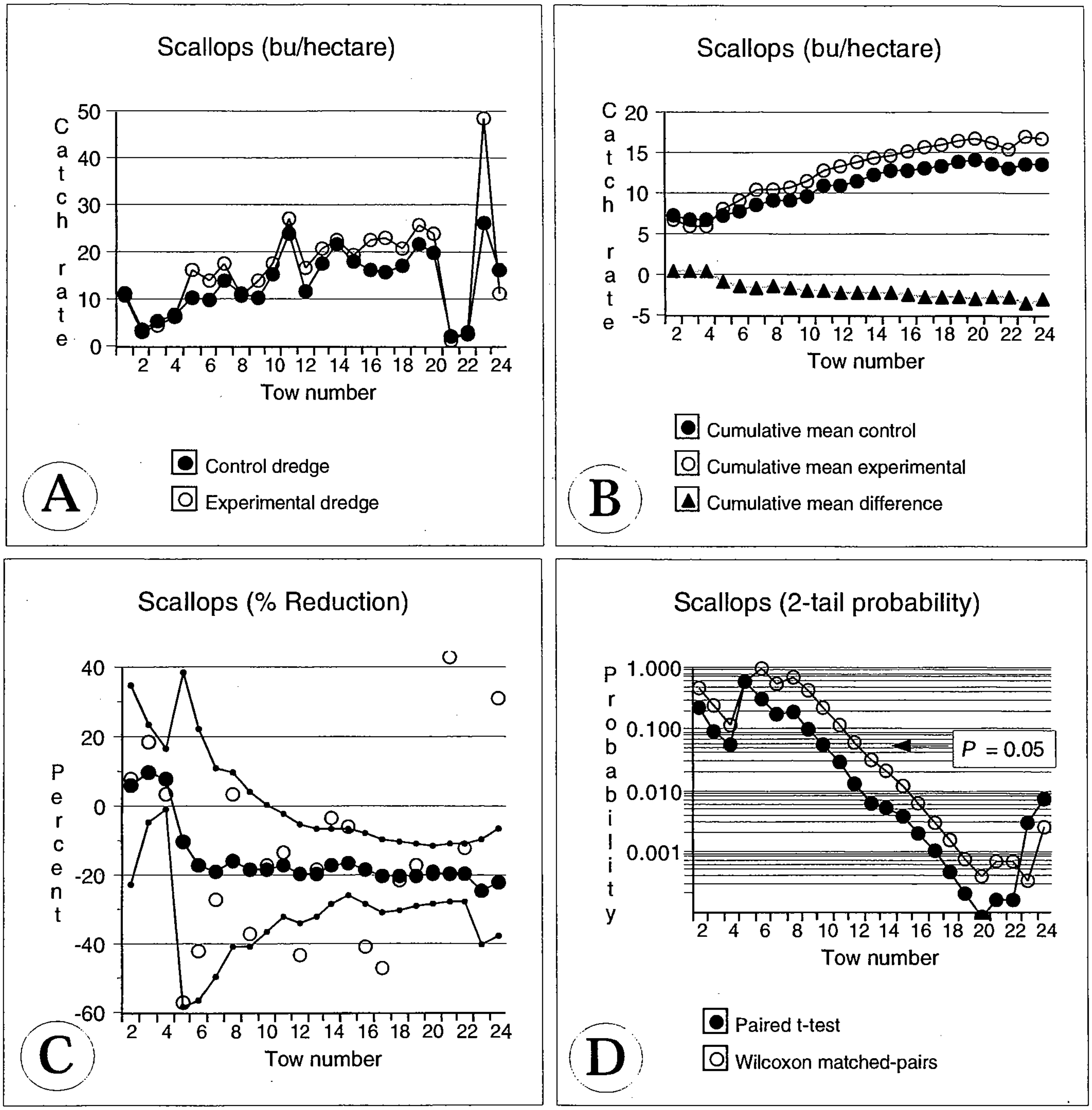


Figure 9. Sea scallop results for Jan 2001. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent increase (decreased reduction) of scallop catch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test and Wilcoxon matched-pairs test.

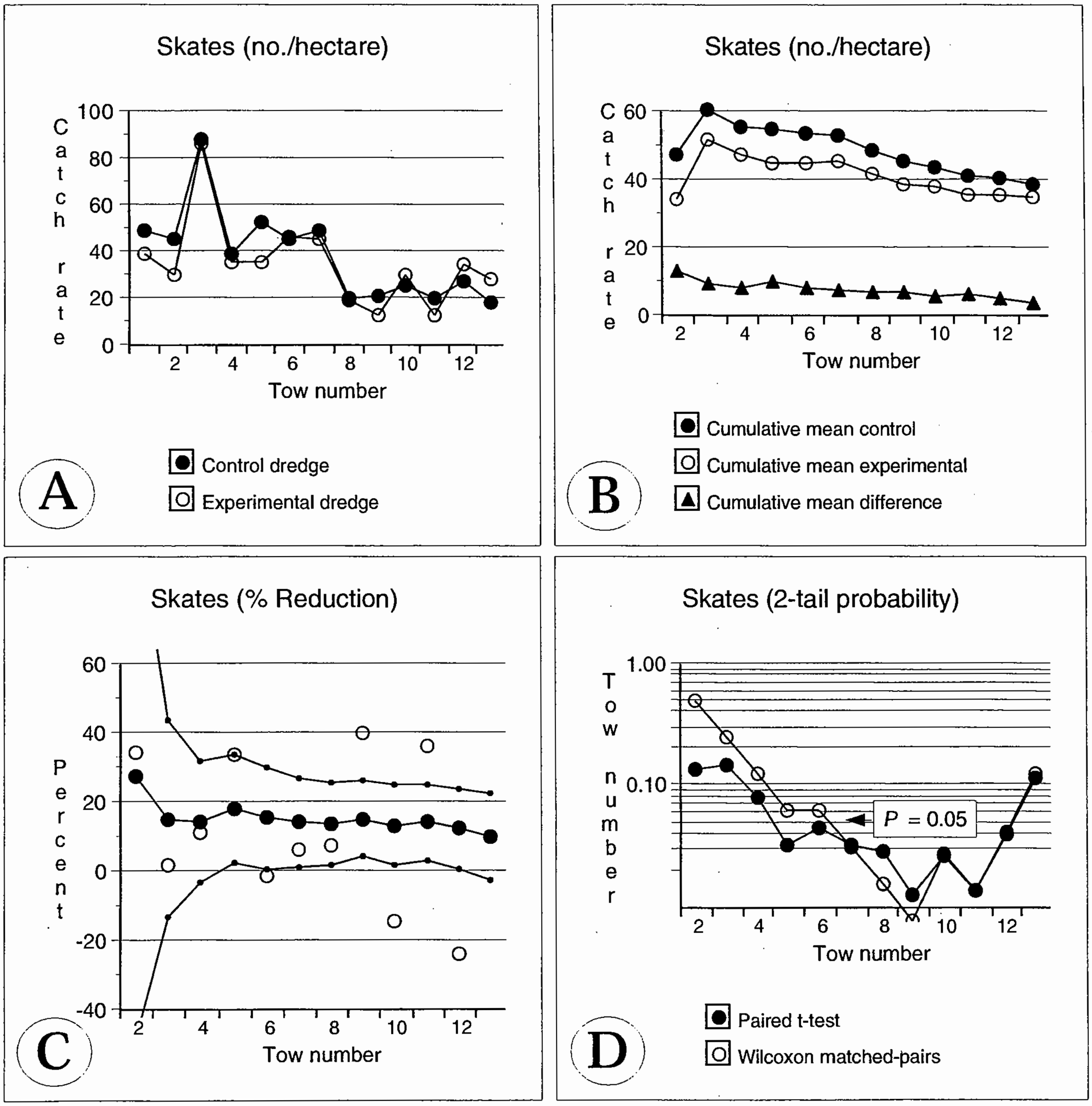


Figure 10. Skate results for Jan 2001. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C:** Cumulative mean percent reduction of Skate bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test and Wilcoxon matched-pairs test.

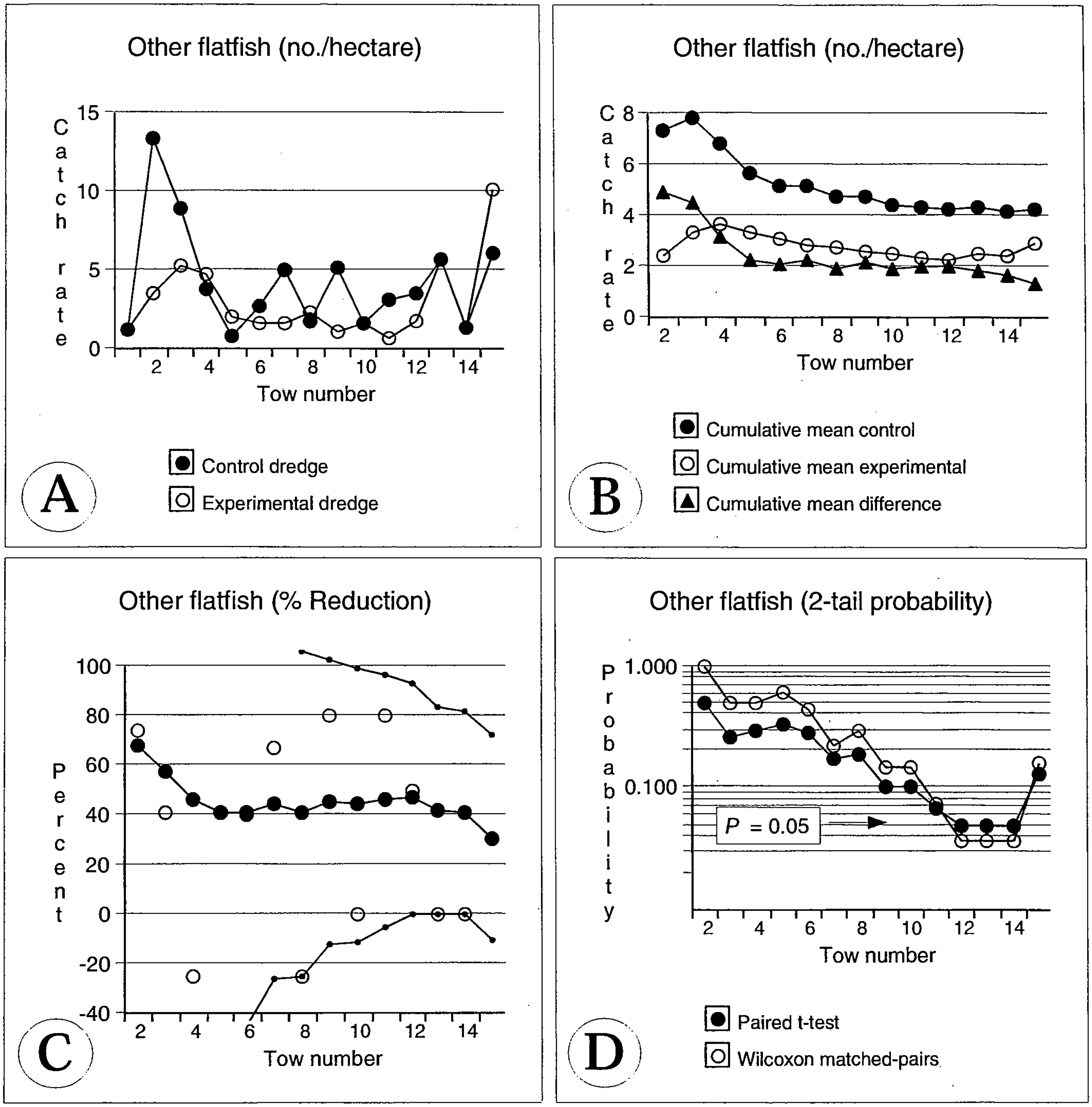


Figure 11. Other flatfish results for Jan 2001. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent reduction of Other flatfish bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test and Wilcoxon matched-pairs test.

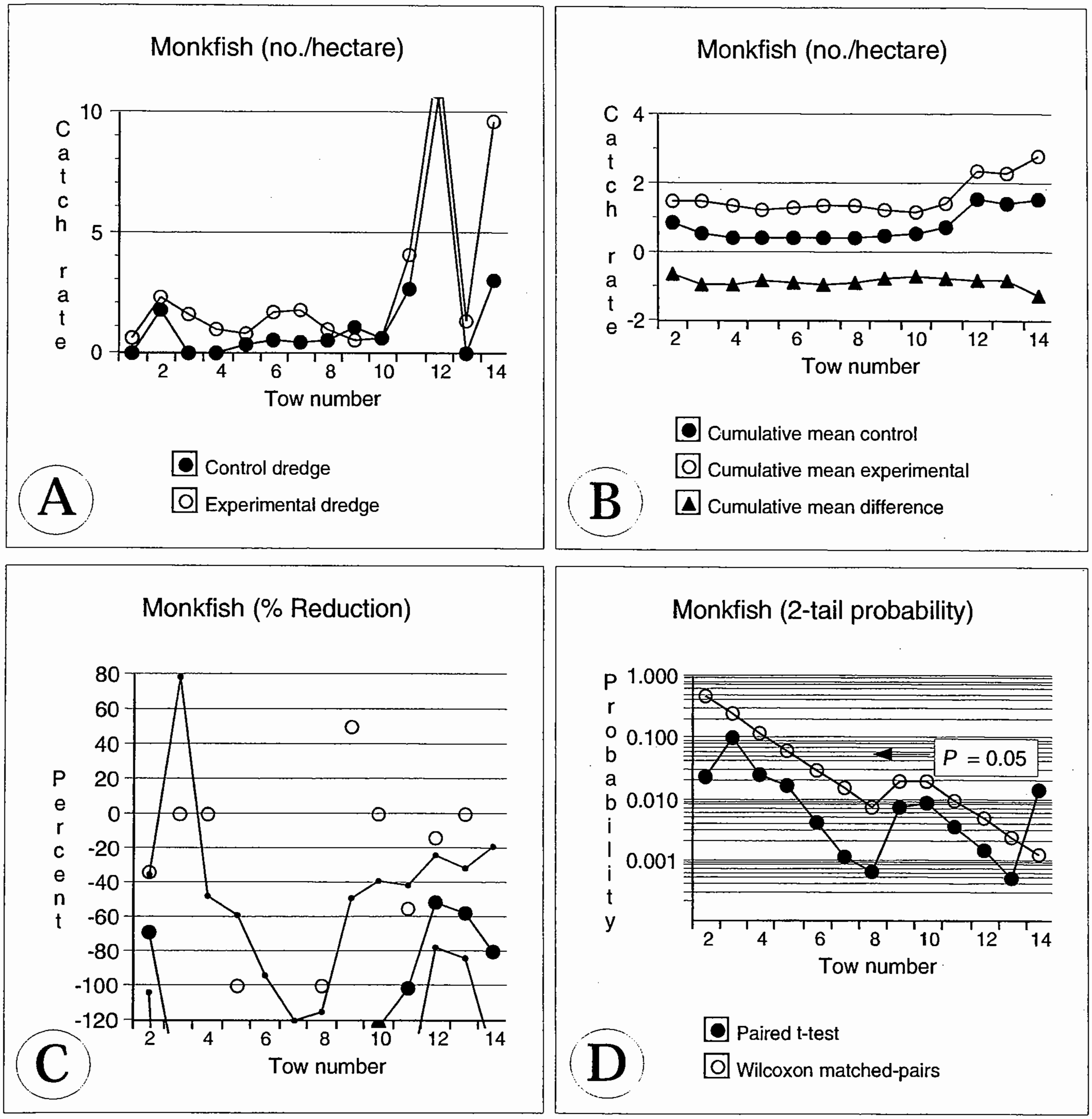


Figure 12. Monkfish results for Jan 2001. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent increase (decreased reduction) of Monkfish catch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test and Wilcoxon matched-pairs test.

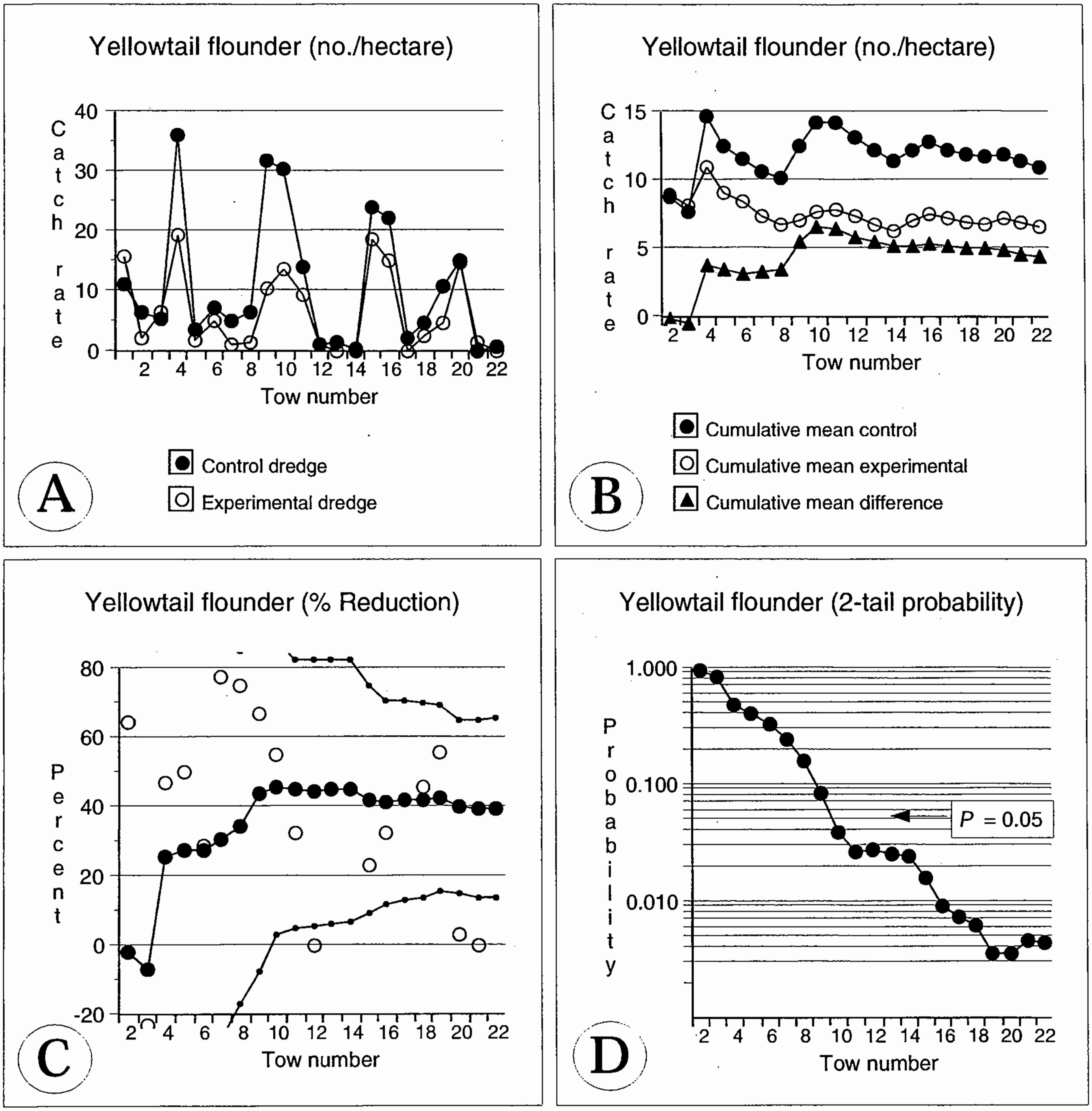


Figure 13. Yellowtail flounder results for Oct 2001. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent reduction of Yellowtail flounder bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test.

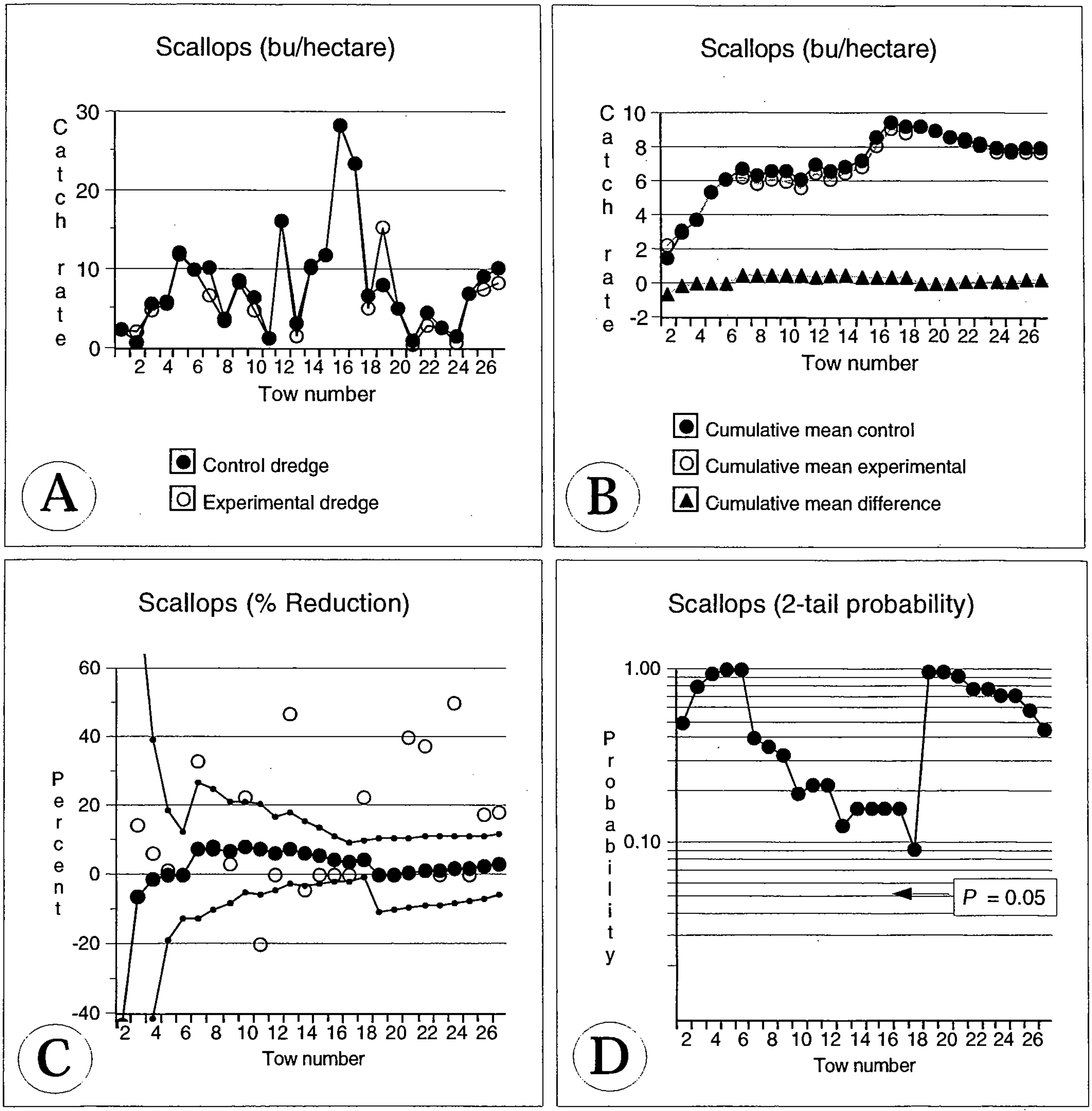


Figure 14. Sea scallop results for Oct 2001. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent decrease of scallop catch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test and Wilcoxon matched-pairs test.

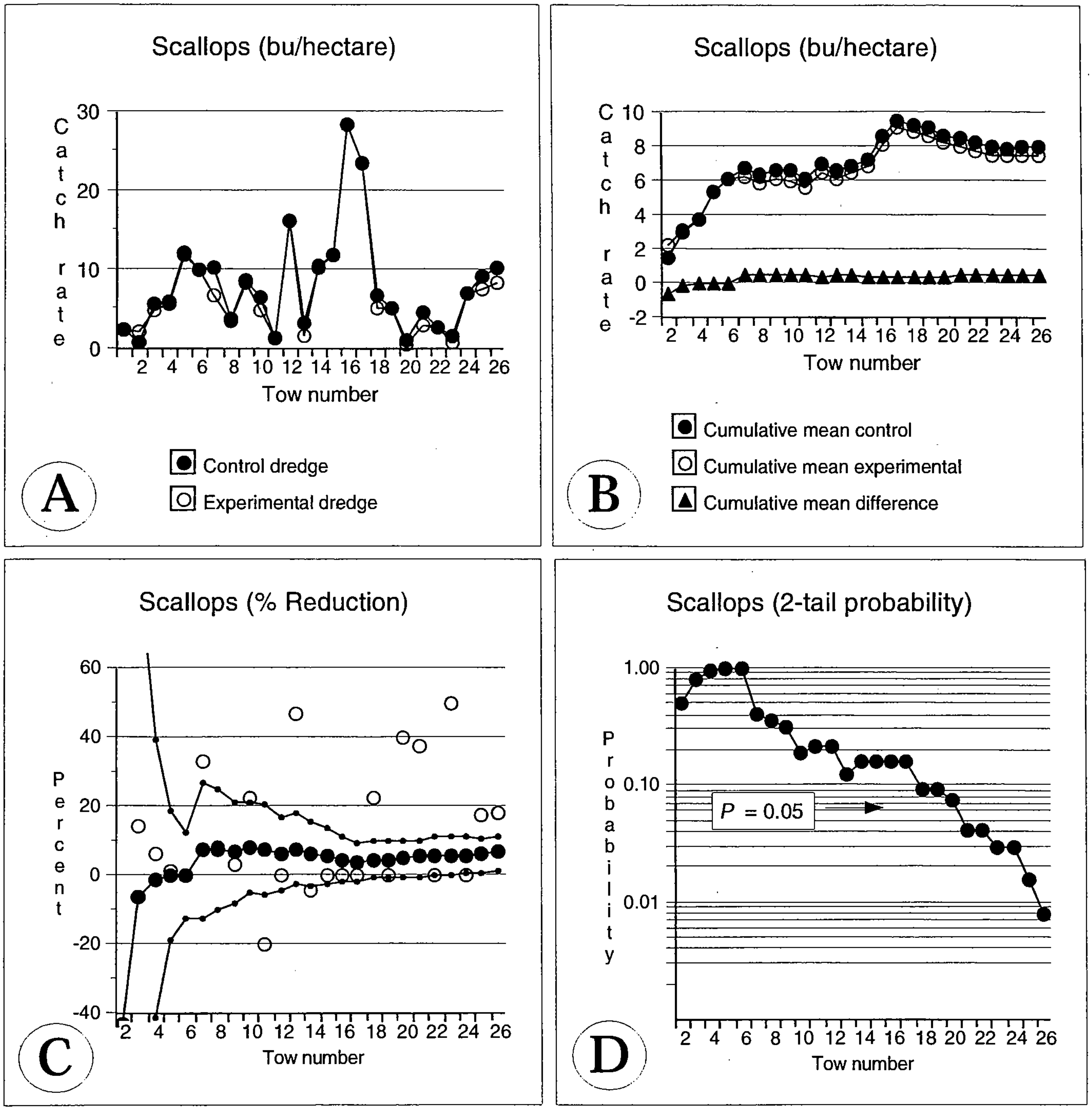


Figure 15. Sea scallop results for Oct 2001 with tow 19 deleted (n = 26). **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent decrease of scallop catch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test..

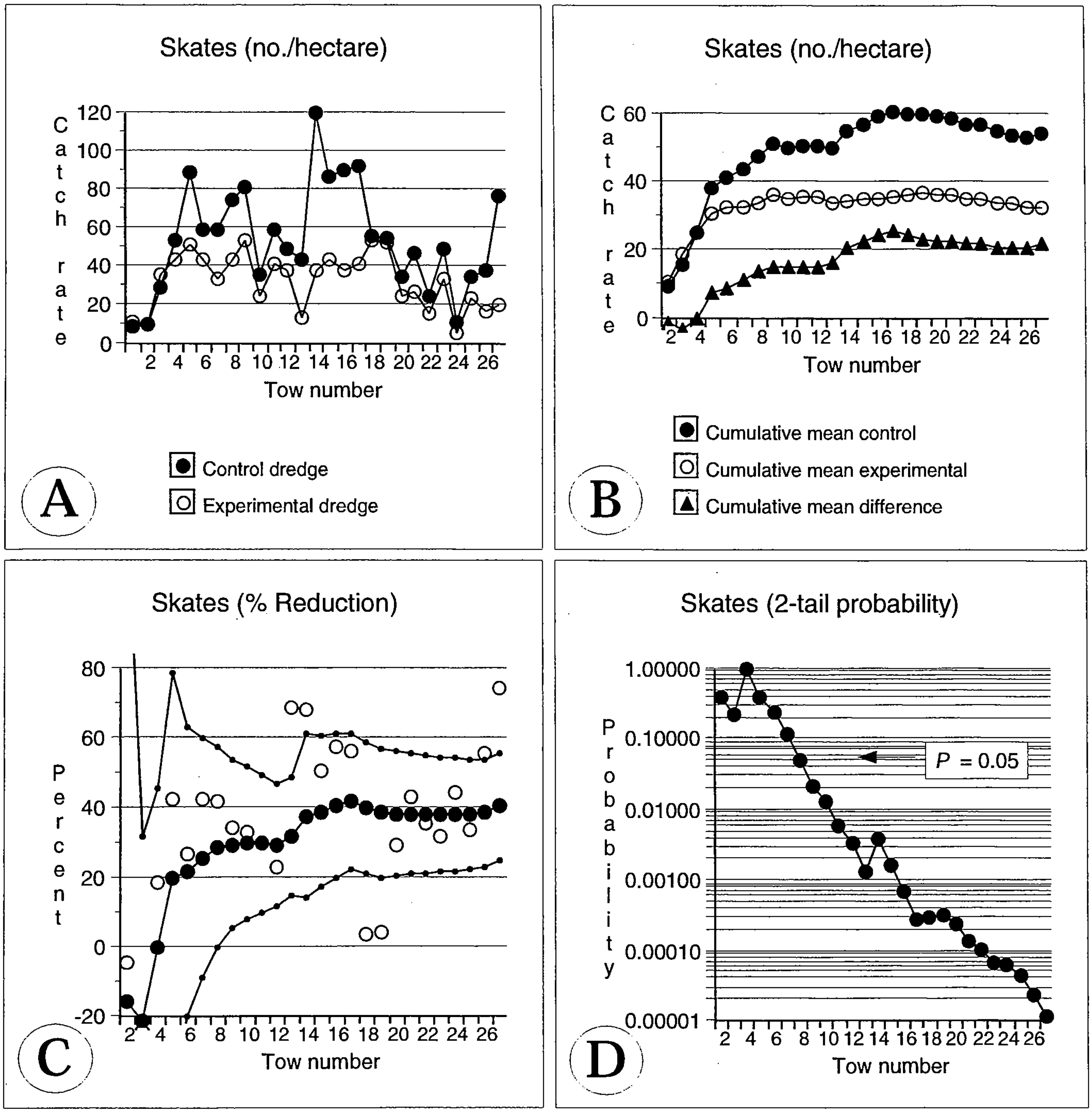


Figure 16. Skate results for Oct 2001. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent reduction of Skate bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test.

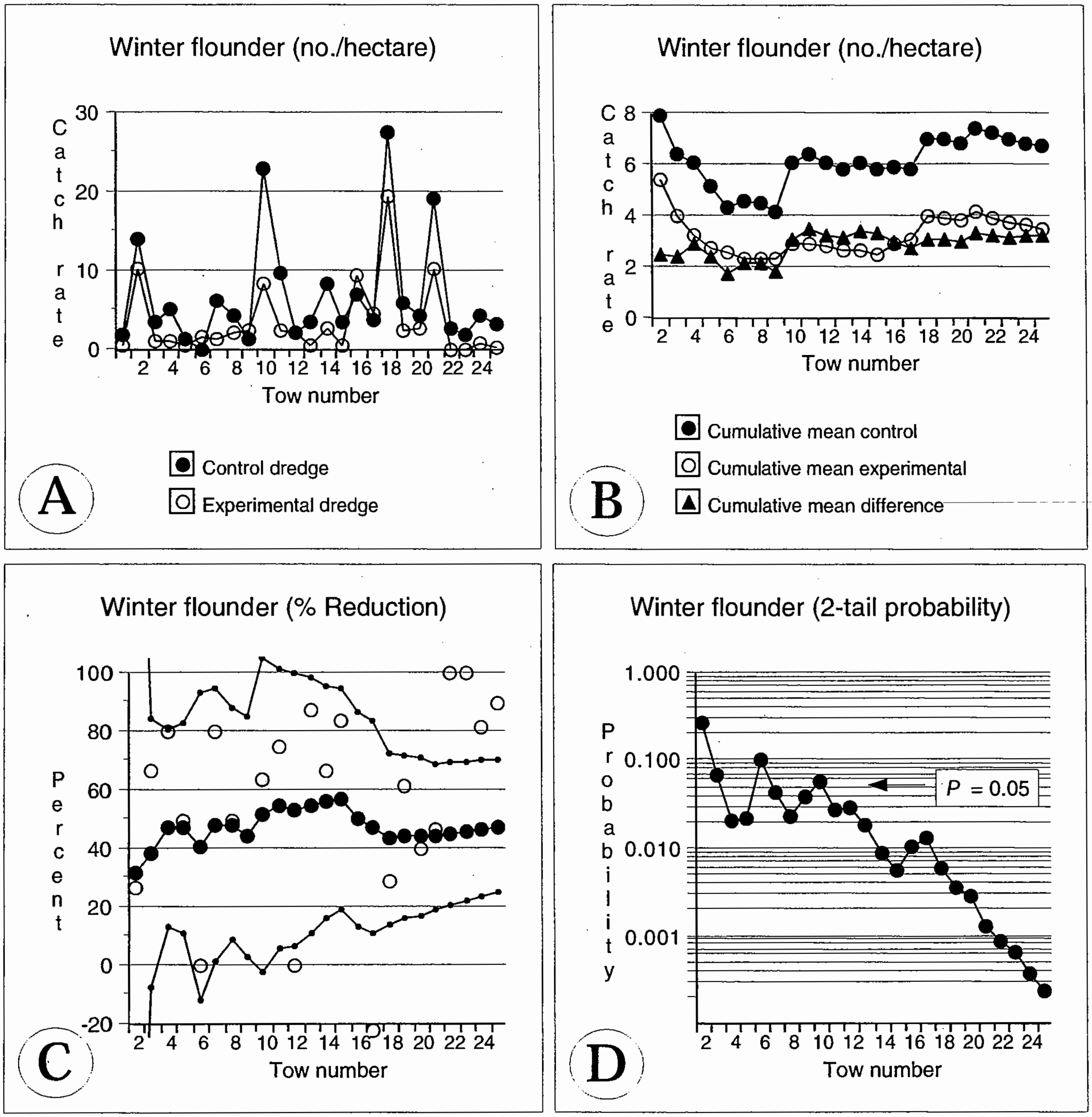


Figure 17. Other flatfishes (Winter flounder) results for Oct 2001. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent reduction of Other flatfish bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test.

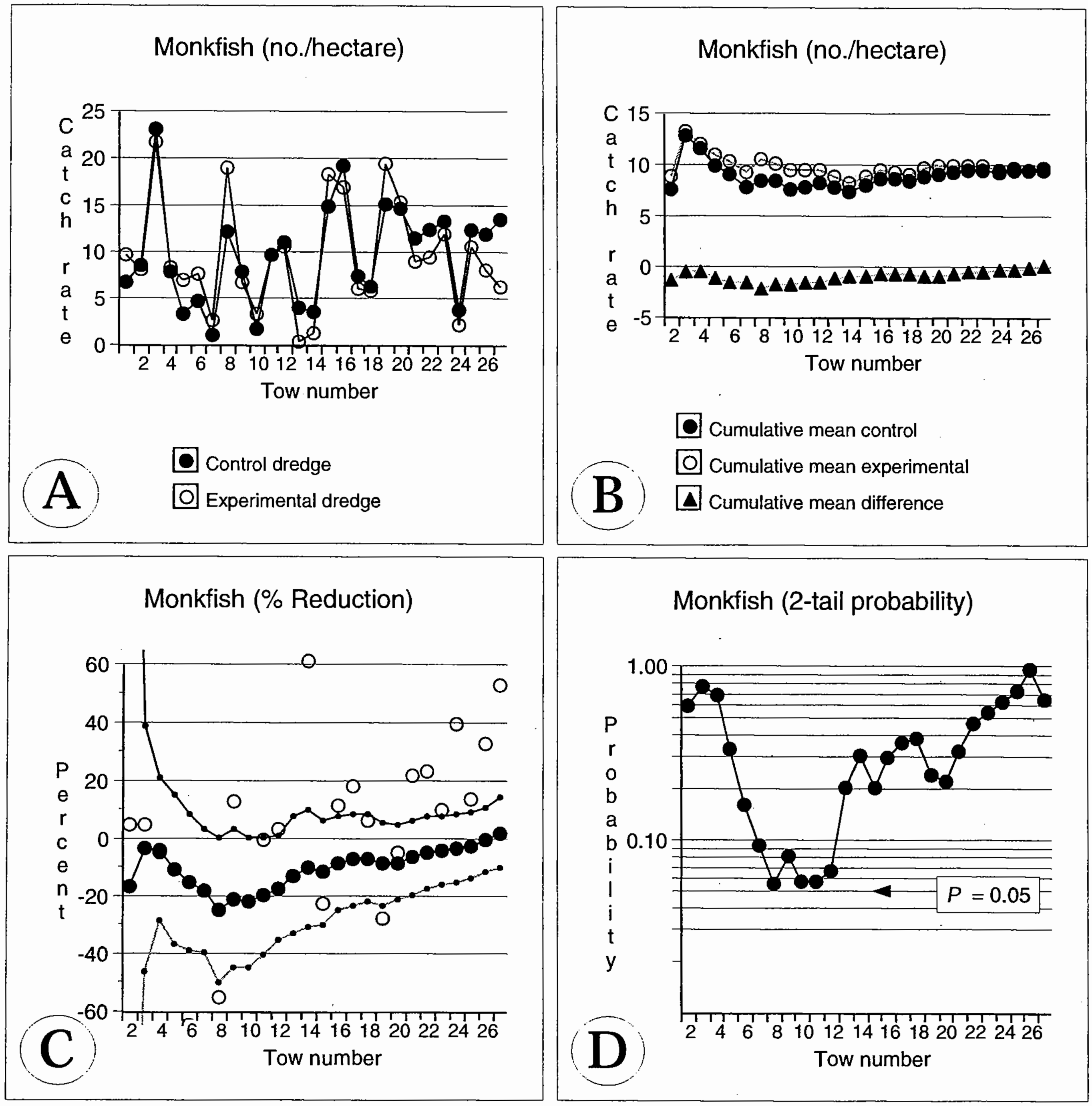


Figure 18. Monkfish results for Oct 2001. **A:** Catches, by tow, for control and experimental dredges. **B:** Cumulative mean control and experimental dredge catches and cumulative mean difference. **C**: Cumulative mean percent increase (decreased reduction) of Monkfish bycatch by the experimental dredge, bounded by the ±95% confidence interval. Open circles represent the percent reduction for individual tows. **D**: Successive probabilities for the paired t-test.