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Incorporating Depth-dependent Differences in Fishing Efficiency among Vessels in the Research Survey Time Series for Atlantic Cod (*Gadus morhua*) in the Southern Gulf of St. Lawrence

D. P. Swain, G. A. Nielsen, and D. E. McKay

Department of Fisheries and Oceans
Science Branch, Gulf Region
Moncton, New Brunswick
E1C 9B6

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D.P. Swain, G.A. Nielsen, and D.E. McKay

Department of Fisheries and Oceans
Science Branch, Gulf Region
Moncton, New Brunswick
E1C 9B6

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ABSTRACT

The southern Gulf of St. Lawrence groundfish abundance survey was conducted using the *E. E. Prince* in 1971-1985, the *Lady Hammond* in 1986-1991, and the *Alfred Needler* since 1992. A comparative fishing experiment was conducted in 1985 between the *E. E. Prince* and the *Lady Hammond*, and in 1992 between the *Lady Hammond* and the *Alfred Needler*. We calculated conversion factors between the *E. E. Prince* and the *Alfred Needler* using these two comparative fishing experiments. Catches by the *E. E. Prince* multiplied by 1.3 are comparable to those by the *Alfred Needler*.

Previous work indicated depth-dependent differences in fishing efficiency between the *Lady Hammond* and the other two vessels. We examined effects of these differences on perceptions of annual variation in cod depth distribution. The application of depth-dependent conversion factors did not alter annual patterns in the strength of the effect of depth on cod catch rates or alter conclusions about the density-dependence of cod depth distribution.

We compared time series of cod catches adjusted (when necessary) to be comparable to catches by either the *E. E. Prince* or the *Alfred Needler*. Estimates of annual variation in relative abundance varied little between the two series. We recommend adjusting 1971-1991 catches to be comparable to those by the *Alfred Needler*. This has the advantage that no further adjustments are required as additional data are collected each year by the *Alfred Needler*.

INTRODUCTION

A bottom trawl survey has been conducted in the southern Gulf of St. Lawrence (NAFO Division 4T) each September since 1971 to estimate the abundance and distribution of groundfish species. Surveys were conducted using the *E. E. Prince* and a Yankee 36 otter trawl from 1971 to 1985, the *Lady Hammond* and an Atlantic Western IIA otter trawl from 1986 to 1991, and the *Alfred Needler* and an Atlantic Western IIA otter trawl since 1992. The *E. E. Prince* fished during daylight hours only whereas the *Lady Hammond* and *Alfred Needler* fished 24 h per day. However, a comparative fishing experiment during the 1988 survey, in which the *Lady Hammond* fished the same locations in day and night, revealed no significant differences between day and night catches of cod (Nielsen 1989). To test for differences in fishing efficiency between research vessels, comparative fishing experiments were conducted between the *E. E. Prince* and the *Lady Hammond* in September 1985 during the annual survey and between the *Lady Hammond* and the *Alfred Needler* in August 1992 prior to the survey. These experiments revealed depth-dependent differences in relative fishing efficiency for cod (Nielsen 1994). In both cases, the *Lady Hammond* tended to catch more cod in deep water and less in shallow water than did the *E. E. Prince* or *Alfred Needler* (Nielsen 1994).

Corrections for these depth-dependent changes in fishing efficiency need to be used in order to compare relative abundance or distribution between years with different survey vessels. One approach would be to adjust catches by both the *E. E. Prince* and the *Alfred Needler* to be comparable to those of the *Lady Hammond* using the depth-dependent conversion factors given by Nielsen (1994). Another approach would be to convert catches to be comparable to those of either the *E. E. Prince* or the *Alfred Needler*. Conversion to the *E. E. Prince* would have the advantage that adjustments would be required for only 8 of the 23 yr in the 1971-1993 time series (compared to 17 yr for conversion to the *Lady Hammond*). Conversion to the *Alfred Needler* would have the advantage that adjustments need only be done once to the historical data, and not annually as new data are collected. One purpose of this report is to present the additional conversion factors required to convert all data to be comparable to catches of either the *E. E. Prince* or the *Alfred Needler*.

The application of depth-dependent conversion factors to cod catches may significantly alter the perceived depth distribution of cod. Swain (1993) described annual variation in the depth distribution of southern Gulf cod. Depth distribution was density dependent. In the early to mid-1970s when cod abundance was low, catch rates of cod were either unrelated to depth or highest in shallow water. In the early to mid-1980s when cod abundance was high, peak catch rates of cod shifted to intermediate depths. Stronger tests of the density dependence of depth distribution are possible now that the southern Gulf cod population has entered a second period of low abundance. However, the outcome of these tests may depend on which depth-dependent conversion factors are applied to the time series. A second purpose of this report is to evaluate the impact of these depth-dependent conversion factors on perceived patterns in annual variation in cod depth distribution.

Catch rates in the September bottom trawl survey of the southern Gulf provide indices of relative abundance used in the annual assessments of stock status for southern Gulf cod (e.g., Sinclair et al. 1994). A third purpose of this report is to evaluate the impact on perceived variation in cod abundance of different adjustment procedures for changes in survey vessel fishing efficiency.

METHODS

Time Series Conversion to *E. E. Prince* or *Alfred Needler*

Conversion factors between the *E. E. Prince* and the *Alfred Needler* are needed to convert the entire time

series to be comparable to catches by either one of these vessels. These factors can be calculated either by converting the 1985 *Lady Hammond* data to be comparable to the *Alfred Needler* data using the conversion factors given by Nielsen (1994) and comparing these adjusted data to the 1985 *E. E. Prince* data, or by converting the 1992 *Lady Hammond* data to be comparable to *E. E. Prince* data and comparing these adjusted data to the 1992 *Alfred Needler* catches. The two methods should give similar results, and both were tried.

Comparisons between the adjusted *Lady Hammond* catches and either the *E. E. Prince* (1985 data) or the *Alfred Needler* (1992 data) catches followed the procedures described in Nielsen (1994). Data consist of paired fishing sets. Catches by each vessel were log-transformed after adjustment to a standard tow of 1.75 nautical miles. Paired sets in which either vessel failed to catch cod or in which one vessel caught fewer than one fish (standardized) were omitted from the analysis. We also omitted one influential set in 1985 (set 3), in which the *Lady Hammond* had its second largest catch of cod (>4400 fish) but the *E. E. Prince* caught only 340 cod (see Nielsen 1994).

To test for differences in fishing efficiency between vessels, we fit linear models (SAS GLM) with terms for vessel and fishing set to the log-transformed catches. To test for an effect of depth on the relative fishing efficiency between vessels, we regressed the differences in log-transformed paired catches on depth. Further details of statistical methods are given by Nielsen (1994).

Effect of Conversion on Depth Distribution

Following Swain (1993), we described the relationship between cod density and depth for each age from 3 to 8$^+$ and each year from 1986 to 1991 using Poisson regression models of the form

$$(1)\quad E[Y_i] = \mu_i = \exp(\beta_0 + \beta_1 X_i + \beta_2 X_i^2)$$

$$(2)\quad Var[Y_i] = \phi\ \mu_i$$

where Y_i is the number of cod of a particular age caught in tow i of a particular year, X_i is the depth of tow i, and ϕ is a parameter for extra-Poisson variation. Justification for this model is given by Swain (1993). Significance of the effect of depth on cod spatial pattern was tested for each age and year by analysis of deviance (McCullagh and Nelder 1989) using the GLIM software package (Payne 1986). As a measure of the strength of these depth effects, we calculated the proportion of the total deviance explained by depth overall (both linear and quadratic terms) and by the quadratic depth term for each age-year combination. Unlike probability values, this statistic is insensitive to variation in sample size. To calculate this statistic, we divided the change in deviance due to removal of the depth term(s) by the deviance of the null model. We compared results among three data sets: (1) the unadjusted *Lady Hammond* data, (2) the *Lady Hammond* data adjusted to be comparable to catches by the *Alfred Needler* (coded HTN), and (3) the *Lady Hammond* data adjusted to be comparable to catches by the *E. E. Prince* (coded HTP).

Swain (1993) tested whether cod bathymetric pattern was density dependent by fitting the following model to the time series of trawl tows:

$$(3)\quad E[Y_{ij}] = \mu_{ij} = \exp(\beta_0+\beta_1 Z_j+\beta_2 X_i+\beta_3 X_i^2+\beta_4 Z_j X_i+\beta_5 Z_j X_i^2)$$

$$(4)\quad Var[Y_{ij}] = \phi\ \mu_{ij}$$

where Y_{ij} is the number of cod of a particular age caught in tow i in year j, Z_j is cod abundance in year j, and X_i is the depth of tow i. The significance of the interaction between abundance and depth was tested by comparing the full model specified in equation 3 with a reduced model omitting the product terms for

this interaction (i.e., $Z_i X_i$ and $Z_i X_i^2$). We applied this analysis to three versions of the 1971-1993 time series: (1) an unadjusted data set, (2) a "*Needler*" data set, with the 1971-1985 *E. E. Prince* data adjusted to be comparable to catches by the *Alfred Needler* using a depth-independent conversion factor (see Results) and the 1986-1991 *Lady Hammond* data adjusted to be comparable to catches by the *Needler* using a depth-dependent conversion factor (Nielsen 1994), and (3) a "*Prince*" data set, with the 1986-1991 *Lady Hammond* data adjusted to be comparable to catches by the *Prince* using a depth-dependent factor (Nielsen 1994) and the 1992-1993 *Alfred Needler* data adjusted to be comparable to *Prince* catches using a depth-independent factor (see Results). Midyear population sizes (in millions) estimated using sequential population analysis with a "hybrid" calibration were taken from the most recent assessment of this stock (Sinclair et al. 1994) for use in this analysis.

These analyses used sets at all randomly-selected stations as well as sets at 13 fixed stations fished from 1971 to 1988. Results for 1985 are from the *E. E. Prince* survey. In 1988, when fishing was repeated in both day and night at the same location, we used catches from the day sets. In other cases when fishing was repeated at the same station in the same year, we used the catch from the first set at that station.

Effect of Conversion on Relative Abundance

We examined effects of conversion on estimates of relative abundance by comparing stratified mean catch rates of cod for the three time series described above (i.e., unadjusted, "*Needler*", and "*Prince*"). As in the previous analyses, all sets except for repeat sets at locations already sampled were used in calculations.

RESULTS

Relative Fishing Efficiency of the *E. E. Prince* and the *Alfred Needler*

1985: E. E. Prince versus the "Needler-like" Lady Hammond

Data from the 1985 *Lady Hammond* survey were adjusted using the depth-dependent "*Lady Hammond* to *Alfred Needler*" conversion factors calculated from the 1992 comparative fishing experiment (Nielsen 1994). These "*Needler*-like" *Lady Hammond* catches were then compared to their paired *E. E. Prince* catches. There was a significant vessel effect with the *Needler*-like *Lady Hammond* catching more cod than the *E. E. Prince* (Table 1), but there was no significant depth effect (Table 2). No clear patterns were evident in the residuals from either of the models examined. These results indicate that *E. E. Prince* catch rates need to be multiplied by 1.26 in order to be comparable to those by the *Alfred Needler*.

1992: Alfred Needler versus the "Prince-like" Lady Hammond

Data from the 1992 *Lady Hammond* survey were adjusted using the "*Lady Hammond* to *E. E. Prince*" conversion factor calculated from the 1985 comparative fishing experiment (Nielsen 1994). These "*Prince*-like *Lady Hammond* catches were then compared to their paired *Alfred Needler* catches. Again, there was a significant vessel effect with the *Alfred Needler* catching more cod than the *Prince*-like *Lady Hammond* (Table 3), but there was no significant depth effect (Table 4). No patterns were evident in the residuals from either model. These results indicate that *Alfred Needler* catch rates need to be multiplied by 0.74 in order to be comparable to those by the *E. E. Prince*, or conversely *E. E. Prince* catch rates need to be multiplied by 1.35 in order to be comparable to those by the *Alfred Needler*. The two estimates of the conversion factor between *E. E. Prince* and *Alfred Needler* catch rates (i.e., 1.26 and 1.35) did not differ significantly; 95% confidence intervals about the two estimates overlapped broadly.

Effect of Conversion on Depth Distribution

Fishing efficiency of the *Lady Hammond* tended to be relatively low in shallow water compared to the *Alfred Needler* and the *E. E. Prince*. Thus, adjustment of *Lady Hammond* catches to be comparable to those of these other vessels tended to inflate catches in shallow water relative to those in deep water. The effect of this adjustment on the predicted depth distribution of cod is shown in Figures 1 to 3. Although the predicted depth distribution was shifted to shallower water using adjusted data (especially with the *Hammond*-to-*Needler* adjustment), this effect was slight in most cases. The effect of adjustment on predicted depth distribution tended to be greater for older cod in the later years (1989-1991).

Annual variation in the strength of depth effects on cod density was similar from 1986 to 1991 whether the *Lady Hammond* catches were unadjusted, adjusted to be comparable to *Alfred Needler* catches (HTN adjustment), or adjusted to be comparable to *E. E. Prince* catches (HTP adjustment). The strength of the depth effects was more similar to that of the unadjusted data using the HTP adjustment than using the HTN adjustment (Figures 4 and 5). Differences were again greater for older cod. The strength of the depth effects, especially of the quadratic term, tended to be weakest using the HTN-adjusted data.

The density dependence of depth distribution was highly significant for all ages regardless of the data set (unadjusted, "*Needler*", or "*Prince*") used (Tables 5-7). The interaction between depth distribution and population size was similar in all three cases (Figures 6-8). For younger (age-4) cod, peak densities were in shallow water when abundance was low and and shifted to intermediate depths when abundance was high for all three data sets (Fig. 6). For older cod (ages 6 and 8^{+}), density was strongly related to depth when abundance was high but not when abundance was low for all three data sets (Fig. 7 and 8).

Effect of Conversion on Relative Abundance

Mean catch rates for the "*Needler*" data are higher than those for the unadjusted data in 1971 to 1991 (the years when data were adjusted), and those for the "*Prince*" data are slightly lower than those for the unadjusted data in 1985 to 1993 (Fig. 9). However, all three sets of data indicate the same patterns in relative abundance (Fig. 9 and 10). Catch rates relative to the 1971 value are slightly lower in both adjusted data sets than in the unadjusted data set from 1986 to 1993 (Fig. 10). However, the differences are slight in comparison to the range of annual variation in catch rates. Catch rates relative to 1971 were very similar in the two adjusted series even in the 1986 to 1993 period (Fig. 10).

DISCUSSION

Fishing efficiency of the *Lady Hammond* relative to both the *E. E. Prince* and the *Alfred Needler* was lower in shallow water than in deeper water (Nielsen 1994). This depth-dependent variation in relative fishing efficiency occurred even when the same gear was used by both vessels (i.e., Atlantic Western IIA trawl, *Lady Hammond* vs *Alfred Needler*). A depth-dependent difference in fishing efficiency could result from differences in fishing behaviour between the vessels (e.g., bridge operations) or in fish behaviour in response to the vessels. Officers on the *Lady Hammond* did tend to let out more warp at a given depth than did those on *Alfred Needler* (Fig. 11). However, this difference was significant ($P<0.005$) only in the 50-100m depth range (a depth zone where cod catch rates did not differ significantly between the two vessels (G. A. Nielsen, unpublished analyses)), and did not result in substantial differences in trawl wing spread (Fig. 11). Differences in fish behaviour could result from differences in vessel noise. Effects of vessel noise might be expected to be depth-dependent.

Depth-dependent adjustments for differences in fishing efficiency have an effect on perceptions of fish

distribution. For the conversion factors calculated by Nielsen (1994), this effect is generally slight compared to annual and age-dependent variation in depth distribution. For example, depth-dependent adjustments to catch rates do not alter the conclusion that cod depth distribution in the southern Gulf is density-dependent. Nevertheless, in constructing a consistent time series of research survey catch rates of cod, we believe that it is desirable to minimize the number of years for which depth-dependent adjustments are required. This is accomplished by converting the entire time series to be comparable to catches by either the *E. E. Prince* or the *Alfred Needler*. This requires depth-dependent adjustment only for the six years fished by the *Lady Hammond* (1986-1991). Conversion to the *Alfred Needler* has the advantage that adjustment need only be done once to the historical data, and not annually as new data are collected, and this is the approach that we recommend. *Lady Hammond* catches can be converted to be comparable to catches by the *Alfred Needler* using the depth-dependent conversion factor given by Nielsen (1994). We calculated two estimates of the conversion factor from the *E. E. Prince* to the *Alfred Needler*: 1.26 using the 1985 comparative fishing experiment, and 1.35 using the 1992 experiment. We recommend multiplying *E. E. Prince* catches by 1.3 to be comparable to those by the *Alfred Needler*.

REFERENCES

McCullagh, P., and J. A. Nelder. 1989. Generalized linear models. 2nd. ed. Chapman and Hall, New York, NY. 580 p.

Nielsen, G. A. 1989. An analysis of the day versus night catches of the southern Gulf of St. Lawrence groundfish cruises 1985-1988. CAFSAC Res. Doc. 89/34. 18 p.

Nielsen, G. A. 1994. Comparison of the fishing efficiency of research vessels used in the southern Gulf of St. Lawrence groundfish surveys from 1971 to 1992. Can. Tech. Rep. Fish. Aquat. Sci. No. 1952 56 p.

Payne, C. D. (ed.). 1986. The GLIM (generalized linear interactive modelling) system. Numerical Algorithms Group, Oxford, U.K.

Sinclair, A., G. Chouinard, D. Swain, R., Hébert, T. Hurlbut, G. Nielsen, M. Hanson, and L. Currie. 1994. Assessment of the fishery for southern Gulf of St. Lawrence cod: May, 1994. DFO Atl. Fish. Res. Doc. 94/77. 116 p.

Swain, D. P. 1993. Age- and density-dependent bathymetric pattern of Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 50: 1255-1264.

Table 1. Results of Generalized Linear Models testing for vessel effect between Alfred Needler-like Lady Hammond and the E.E.Prince 1985 cod catches.

Source	DF	SS	MS	F	Pr > F	R^2
Model	52	313.519	6.029	35.08	0.0001	0.973
Ship	1	1.354	1.354	7.88	0.0071	
Set	51	312.164	6.121	35.61	0.0001	
Error	51	8.767	0.172			
Corrected Total	103	322.285				

Ship	Effect
Ham/Needler	4.9670
Prince	4.7388

Table 2. Results of Generalized Linear Models testing for depth effect between Alfred Needler-like Lady Hammond and the E.E.Prince 1985 cod catches

Source	DF	SS	MS	F	Pr > F	R^2
Model (Depth)	1	0.472	0.472	1.38	0.2453	0.027
Error	50	17.061	0.341			
Corrected Total	51	17.533				

Parameter	Estimate	T for HO:Par=0	Pr > |T|	Std Error of Est
Intercept	0.3578	2.62	0.012	0.1368
Depth	-0.0016	-1.18	0.245	0.0013

Table 3. Results of Generalized Linear Models testing for vessel effect between E.E.Prince-like Lady Hammond and the Alfred Needler 1992 cod catches

Source	DF	SS	MS	F	Pr > F	R^2
Model	56	158.146	2.824	15.23	0.0001	0.939
Ship	1	2.573	2.573	13.87	0.0005	
Set	55	155.574	2.829	15.25	0.0001	
Error	55	10.201	0.185			
Corrected Total	111	168.348				

Ship	Effect
Ham/Prince	3.2827
Needler	3.5858

Table 4. Results of Generalized Linear Models testing for depth effect between E.E.Prince-like Lady Hammond and the Alfred Needler 1992 cod catches

Source	DF	SS	MS	F	Pr > F	R^2
Model (Depth)	1	0.934	0.934	2.59	0.1133	0.046
Error	54	19.468	0.361			
Corrected Total	55	20.402				

Parameter	Estimate	T for HO:Par=0	Pr > |T|	Std Error of Est
Intercept	-0.4885	-3.48	0.001	0.1404
Depth	0.0027	1.61	0.113	0.0017

Table 5. Parameter estimates for Poisson regression models relating cod density (fish/tow) to depth (m), abundance (millions of fish), and their interaction for the unadjusted 1971-1993 data. Models are specified by equations 3 and 4 in the text. SE = standard error of the parameter estimates. ΔS is the change in scaled deviance due to omission of the product terms for the interaction between depth and abundance. P is the significance level for this interaction. ϕ is the estimate of extra-Poisson variance.

	Age					
Parameter	**3**	**4**	**5**	**6**	**7**	**8+**
β_0	3.673	3.261	2.558	1.37	0.7173	0.6439
SE	0.3718	0.2988	0.2578	0.254	0.2324	0.2153
β_1	-0.00482	-0.007722	-0.00918	0.006525	0.006366	0.02064
SE	0.004081	0.004021	0.004628	0.005618	0.008282	0.008161
β_2	-0.01099	-0.005523	-0.002403	0.01539	0.01203	0.011
SE	0.01235	0.008528	0.006329	0.005926	0.005002	0.004253
β_3	-0.0001229	-5.25E-05	-7.34E-06	-8.49E-05	-5.83E-05	-4.37E-05
SE	0.00009505	0.00005535	0.00003444	0.00003057	0.00002319	0.00001733
β_4	0.0003259	0.0004596	0.0007392	0.0005625	0.001137	0.0009239
SE	0.0001282	0.0001135	0.0001192	0.0001354	0.0001828	0.0001645
β_5	-1.38E-06	-2.35E-06	-4.15E-06	-2.75E-06	-5.05E-06	-3.88E-06
SE	9.30E-07	7.34E-07	6.99E-07	7.38E-07	9.00E-07	7.15E-07
ϕ	54.24	48.24	40.08	31.59	16.55	15.4
ΔS	21.31	24.27	38.05	18.27	39.04	30.34
P	0.00002	0.000005	5.50E-09	0.00011	3.34E-09	0.0000003

Table 6. Parameter estimates for Poisson regression models relating cod density (fish/tow) to depth (m), abundance (millions of fish), and their interaction for the 1971-1993 "Needler" data set. Symbols are as in Table 5.

	Age					
Parameter	**3**	**4**	**5**	**6**	**7**	**8+**
β_0	3.78	3.557	2.941	1.688	0.96	0.9153
SE	0.391	0.3078	0.2576	0.2493	0.2235	0.2096
β_1	-0.003738	-0.007774	-9.84E-03	0.00786	0.01552	0.02948
SE	0.004144	0.004052	0.004566	0.005507	0.007861	0.007875
β_2	-0.002338	-0.006439	-0.00696	0.01218	0.0111	0.009321
SE	0.01344	0.009034	0.006451	0.00588	0.004888	0.004202
β_3	-0.0002283	-6.71E-05	3.96E-06	-7.34E-05	-5.81E-05	-3.94E-05
SE	0.0001081	0.00006053	0.00003581	0.00003054	0.00002291	0.00001717
β_4	0.000265	0.0004588	0.0007689	0.0005581	0.0009399	0.0007609
SE	0.000132	0.000116	0.000119	0.0001349	0.000177	0.0001619
β_5	-6.74E-07	-2.21E-06	-4.20E-06	-2.81E-06	-4.26E-06	-3.35E-06
SE	9.79E-07	7.61E-07	7.04E-07	7.45E-07	8.82E-07	7.10E-07
ϕ	70.23	60.79	48.62	37.81	18.75	18.16
ΔS	27.67	28.92	42.33	17.61	28.18	21.83
P	9.813E-07	5.248E-07	6.46E-10	0.0001499	7.60E-07	0.00001811

Table 7. Parameter estimates for Poisson regression models relating cod density (fish/tow) to depth (m), abundance (millions of fish), and their interaction for the 1971-1993 "Prince" data set. Symbols are as in Table 5.

	Age					
Parameter	**3**	**4**	**5**	**6**	**7**	**8+**
β_0	3.471	3.123	2.469	1.298	0.6355	0.5968
SE	0.3804	0.3034	0.2582	0.253	0.2263	0.211
β_1	-0.003224	-0.006298	-7.82E-03	0.008132	0.01122	0.02442
SE	0.004028	0.003951	0.00451	0.005545	0.008	0.007969
β_2	-0.007001	-0.005219	-0.004121	0.01424	0.01209	0.01035
SE	0.01281	0.008745	0.006379	0.005916	0.0049	0.004186
β_3	-0.0001666	-6.05E-05	-2.81E-06	-8.01E-05	-6.04E-05	-4.20E-05
SE	0.0001002	0.00005738	0.00003492	0.00003053	0.00002281	0.00001702
β_4	0.0002933	0.0004488	0.0007441	0.0005538	0.001016	0.0008417
SE	0.0001272	0.000112	0.0001165	0.0001344	0.0001776	0.0001614
β_5	-1.06E-06	-2.24E-06	-4.13E-06	-2.75E-06	-4.50E-06	-3.57E-06
SE	9.31E-07	7.27E-07	6.84E-07	7.35E-07	8.75E-07	7.01E-07
ϕ	51.2	45.07	36.47	28.98	14.4	13.84
ΔS	23.77	25.67	40.22	17.56	33.25	26.32
P	0.00000687	0.000002676	1.84E-09	0.0001537	6.05E-08	0.000001931

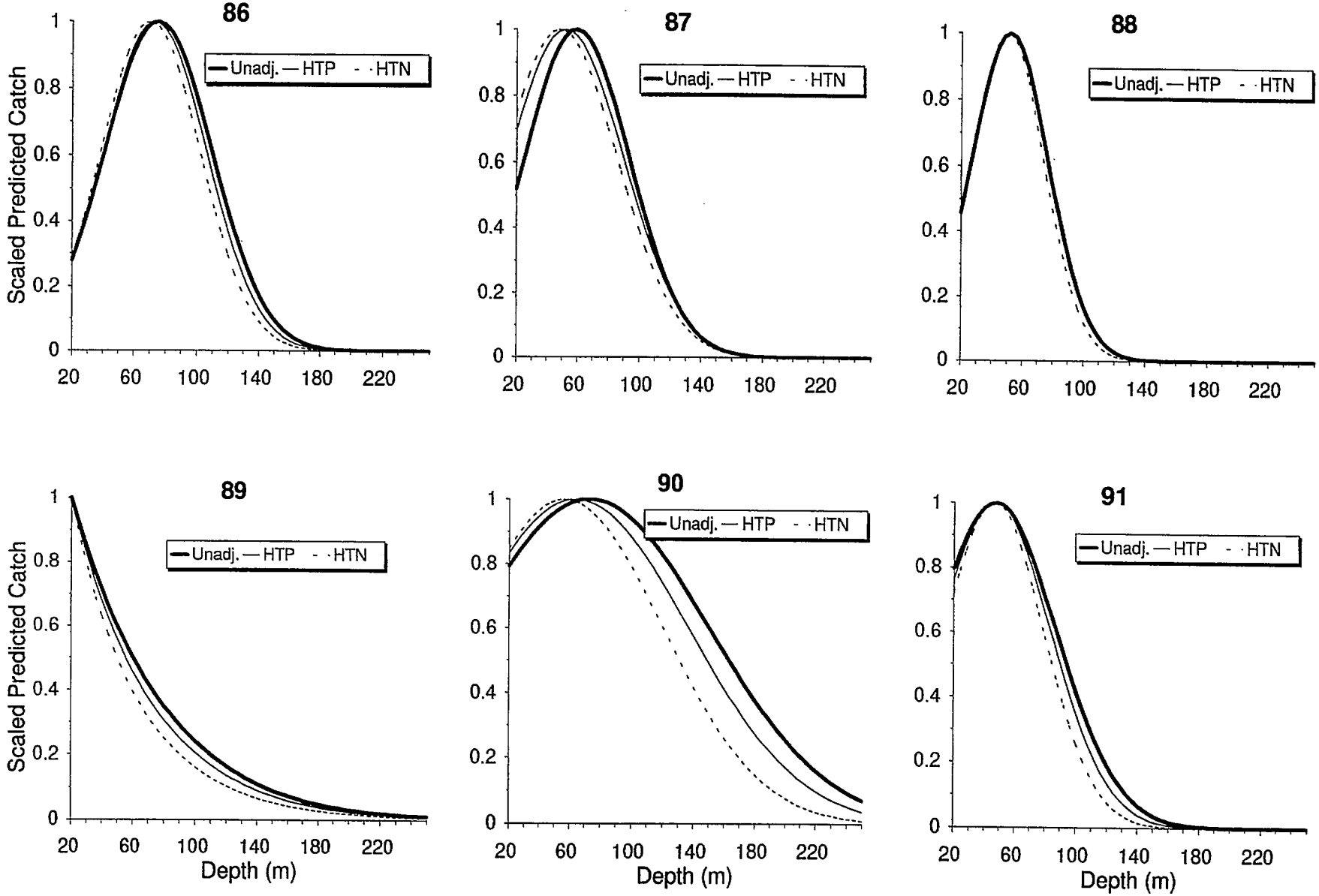


Fig. 1. Predicted depth distribution of age-4 cod in 1986-1991 using unadjusted Lady Hammond catches, or catches adjusted to be comparable to either those of the E. E. Prince (HTP) or the Alfred Needler (HTN).

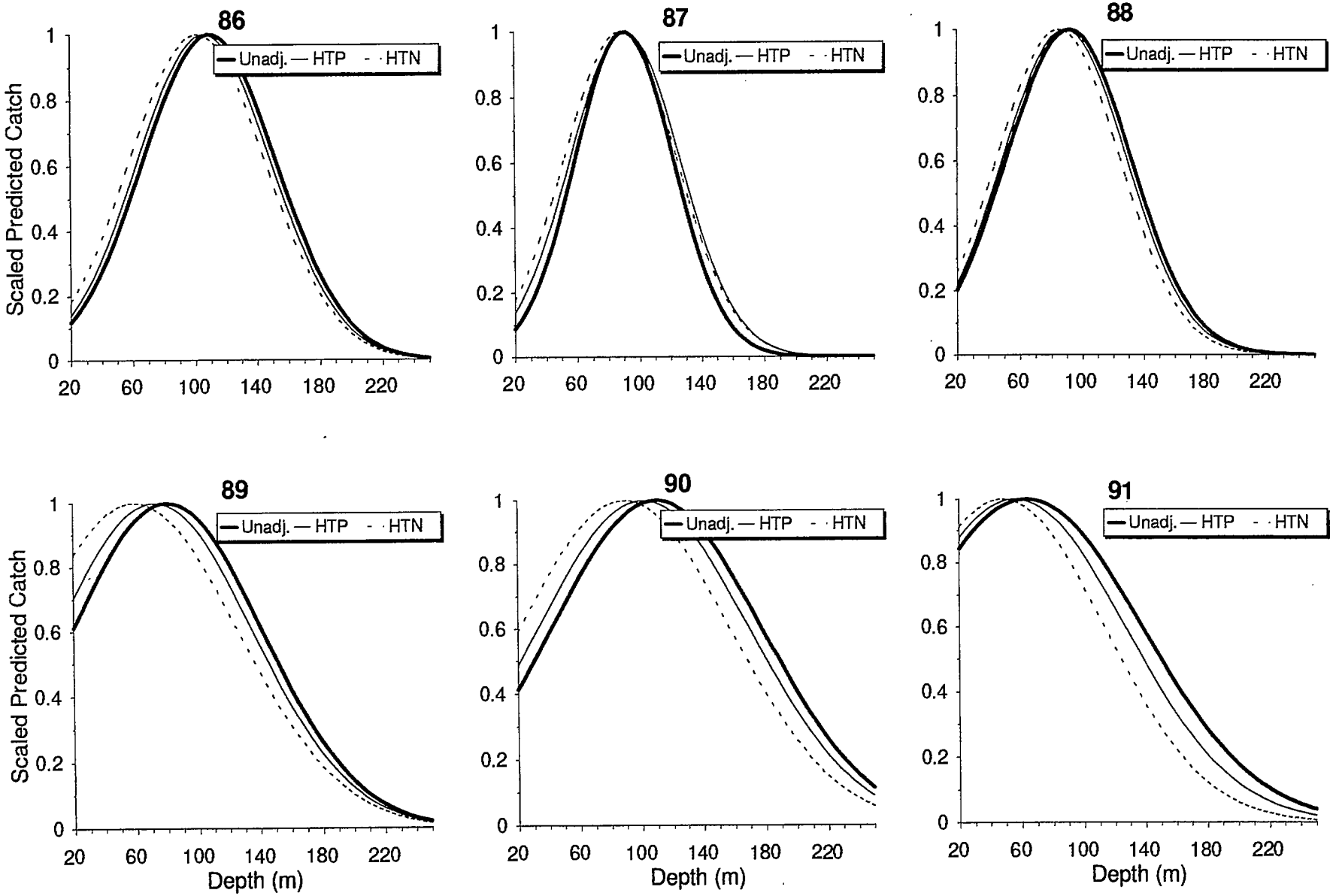


Fig. 2. Predicted depth distribution of age-6 cod in 1986-1991 using unadjusted Lady Hammond catches, or catches adjusted to be comparable to either those of the E.E. Prince (HTP) or the Alfred Needler (HTN).

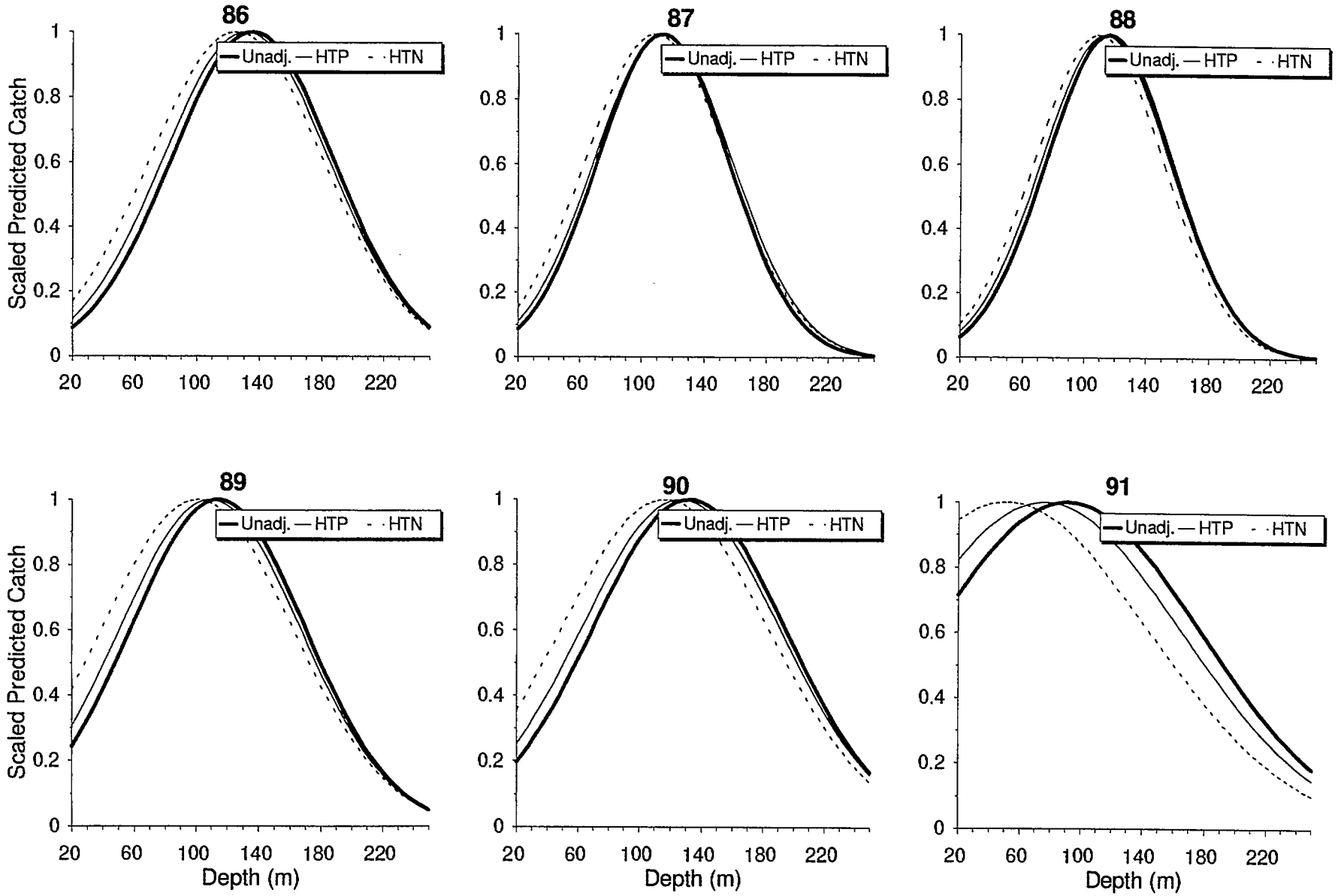


Fig. 3. Predicted depth distribution of age-8+ cod in 1986-1991 using unadjusted Lady Hammond catches, or catches adjusted to be comparable to either those of the E. E. Prince (HTP) or the Alfred Needler (HTN).

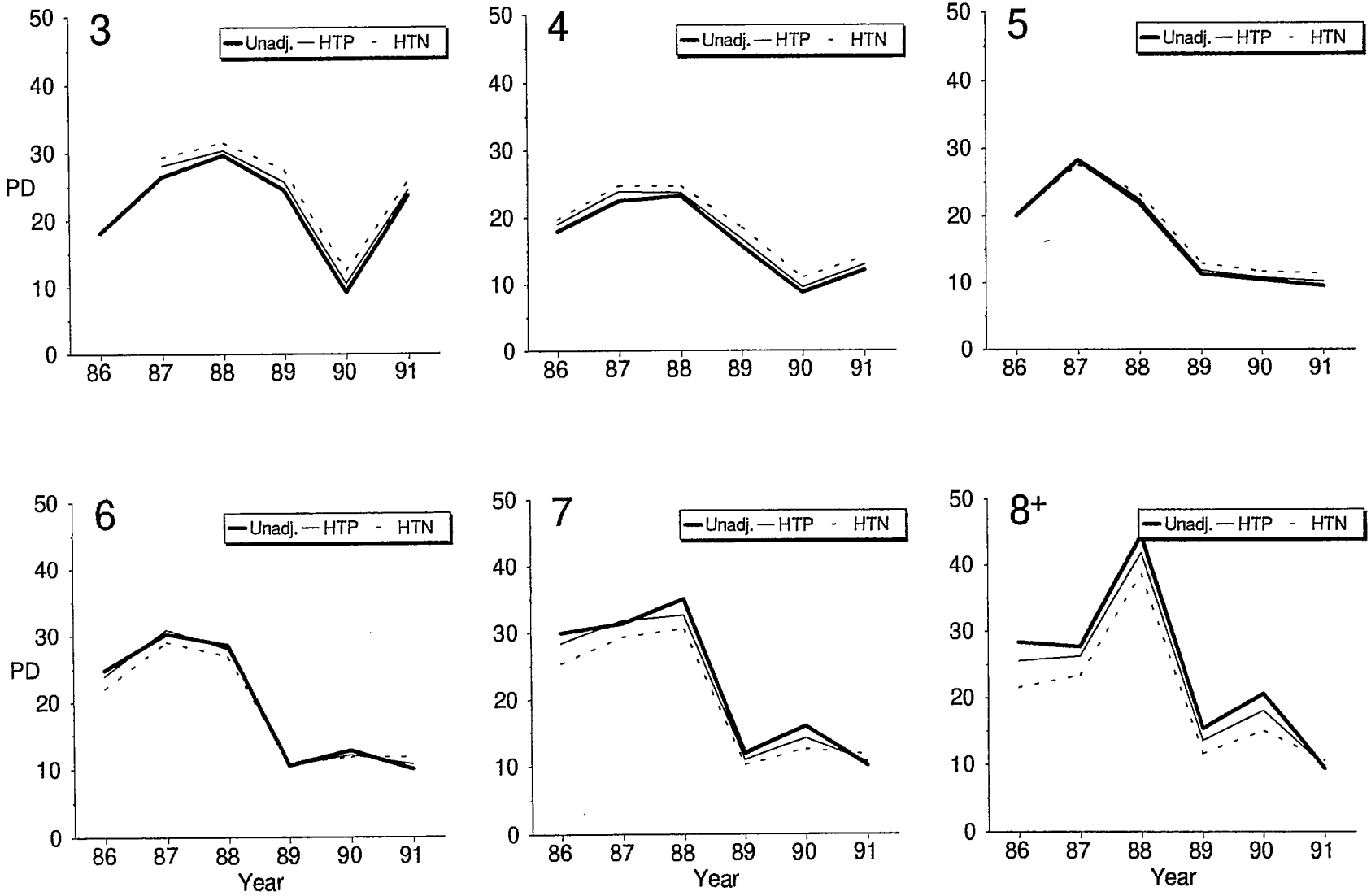


Fig. 4. Percent of the deviance in catch rates explained by depth (PD) for ages 3 to 8+ in 1986-1991 using unadjusted Lady Hammond catch rates, or catches adjusted to be comparable to those of either the E. E. Prince (HTP) or the Alfred Needler (HTN).

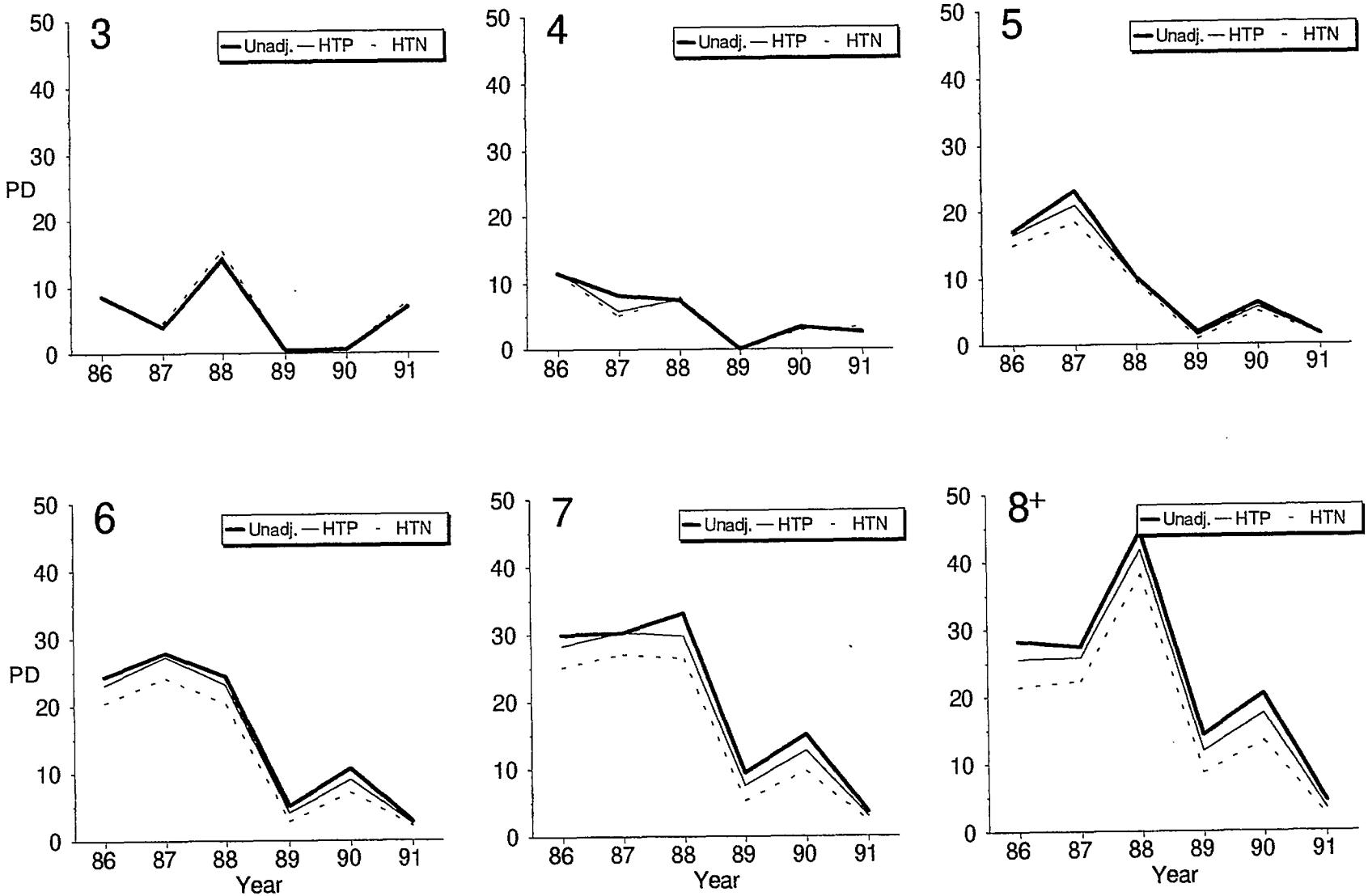
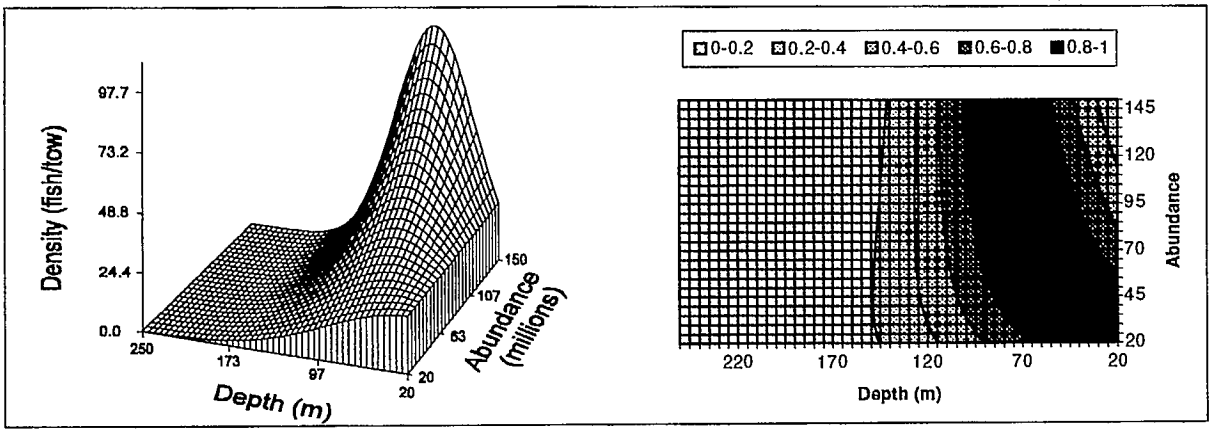
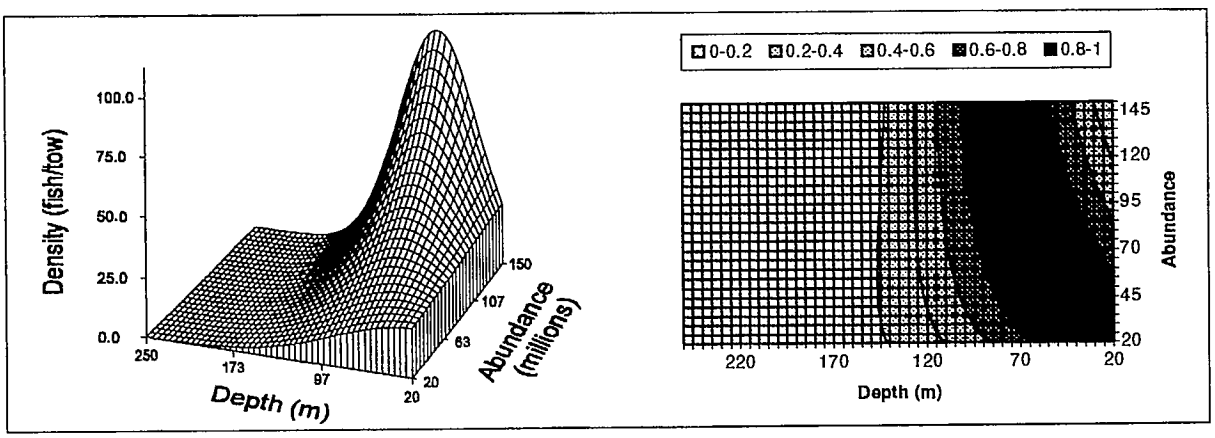


Fig. 5. Percent of the deviance in catch rates explained by the quadratic depth term (PD) for ages 3 to 8+ in 1986-1991 using unadjusted Lady Hammond catches, or catches adjusted to be comparable to those of either the E. E. Prince (HTP) or the Alfred Needler (HTN).

Unadjusted



"Prince"



"Needler"

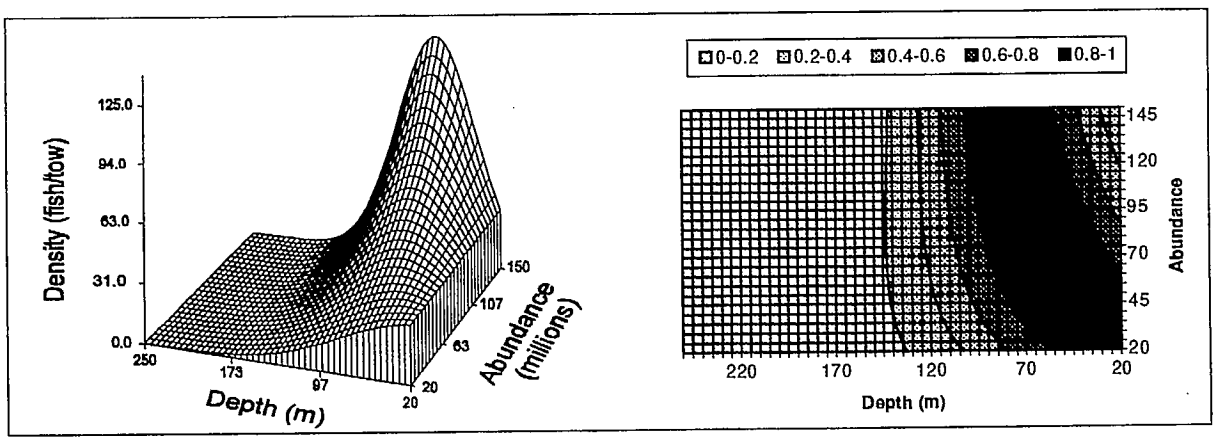
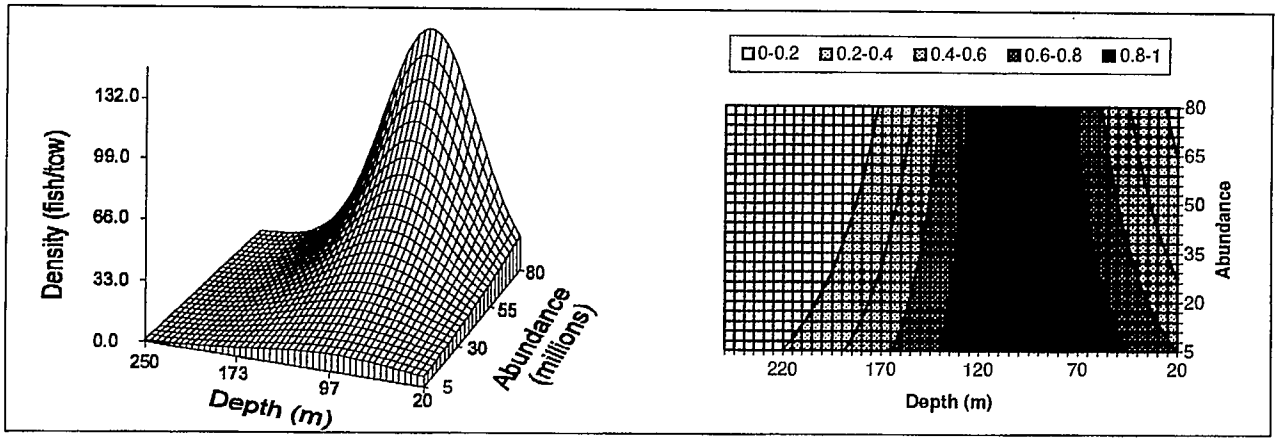
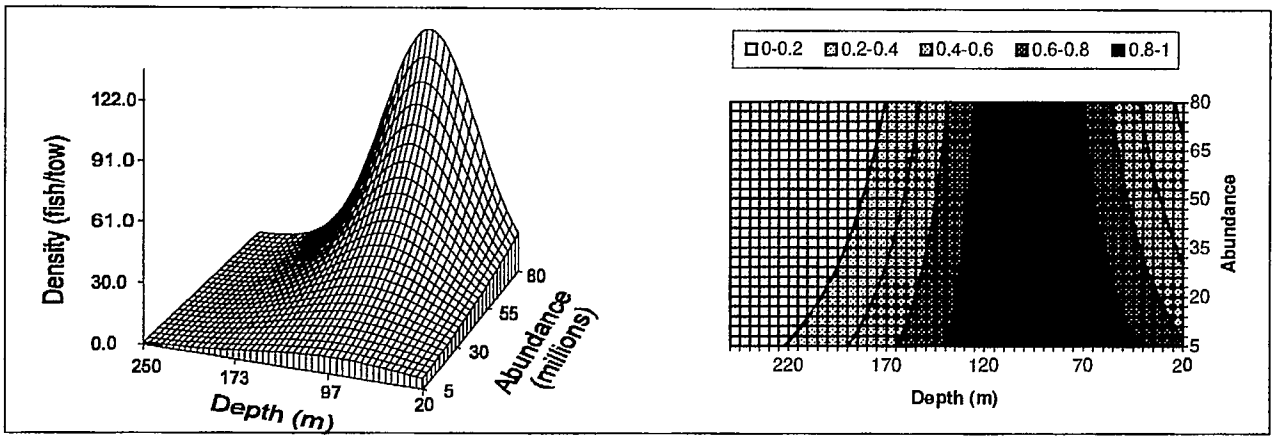


Fig. 6. Predicted relationship between age-4 cod density and depth at various levels of abundance. Data are either unadjusted or adjusted to be comparable to Prince or Needler catches.

Unadjusted



"Prince"



"Needler"

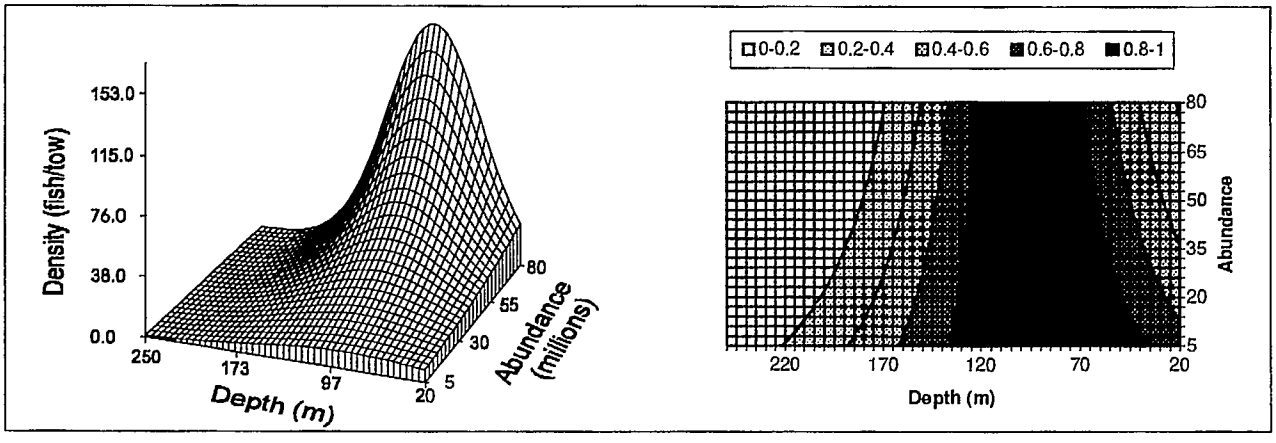
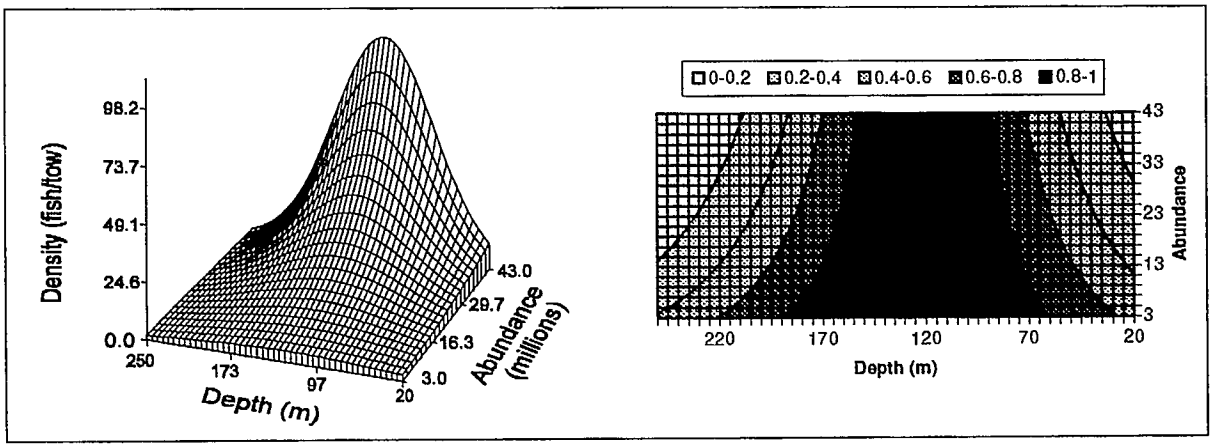
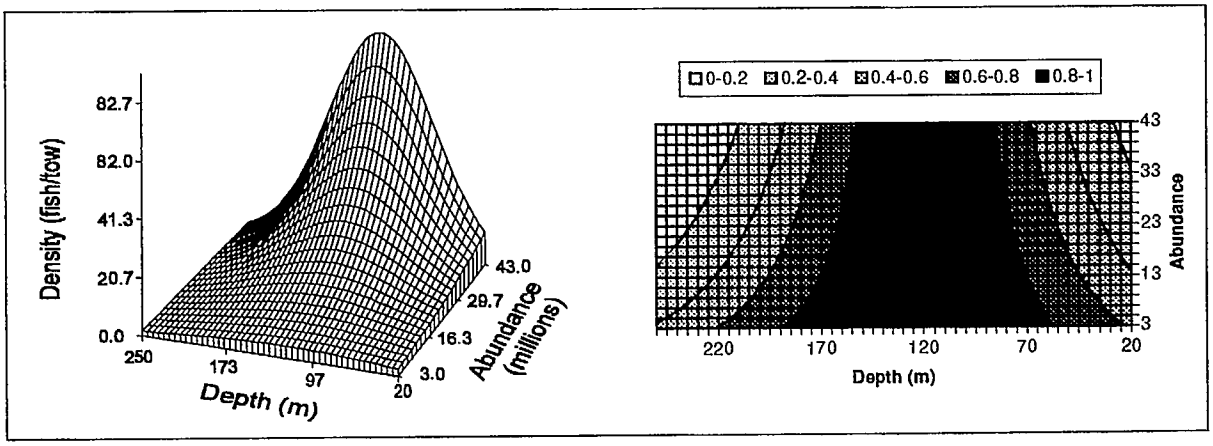


Fig. 7. Predicted relationship between age-6 cod density and depth at various levels of abundance. Calculated using either unadjusted data or data adjusted to be comparable to Prince or Needler catches.

Unadjusted



"Prince"



"Needler"

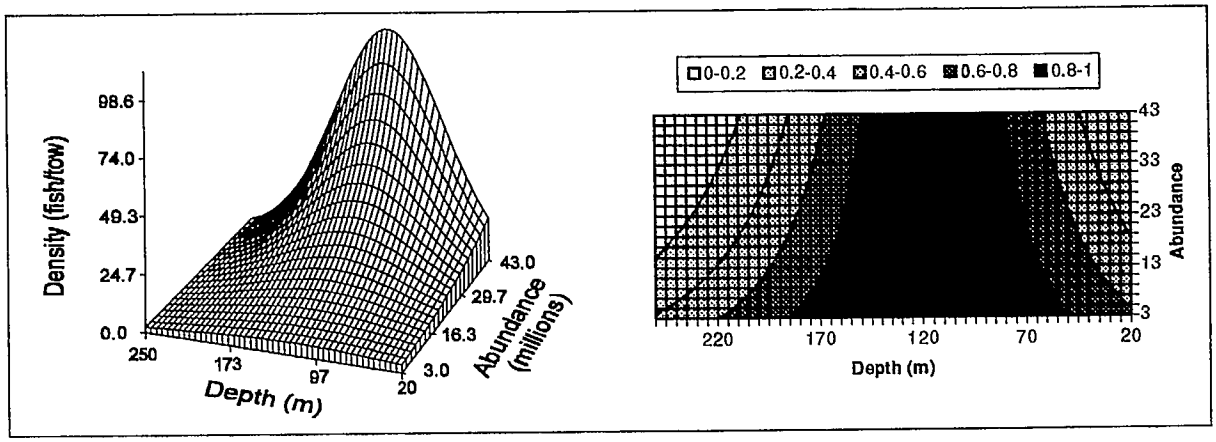


Fig. 8. Predicted relationship between age-8+ cod density and depth at various levels of abundance. Calculated using either unadjusted data or data adjusted to be comparable to Prince or Needler catches.

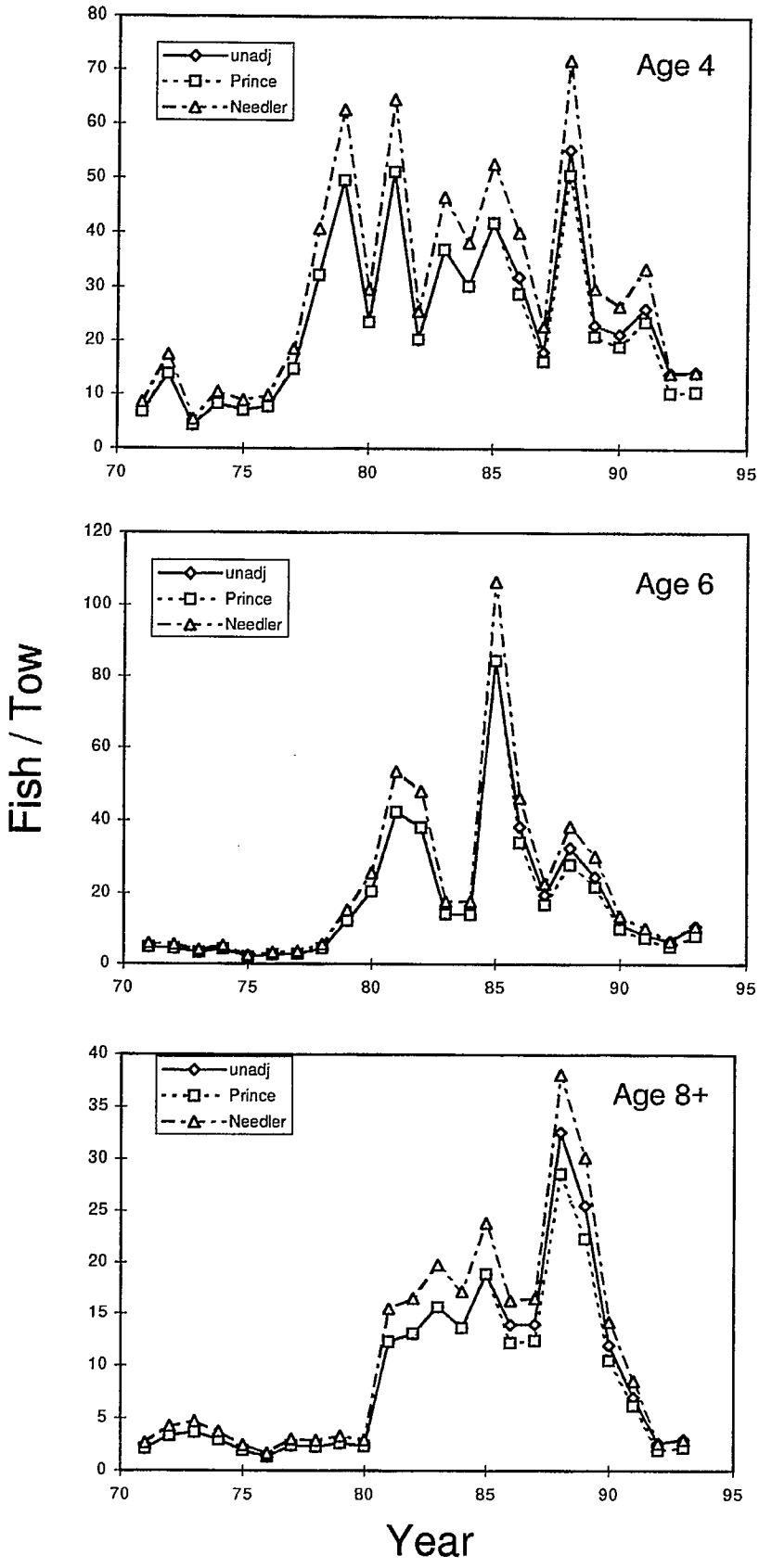


Fig. 9. Stratified mean catch rates of cod in time series of unadjusted data or data adjusted to be comparable to catches by the E. E. Prince or the Alfred Needler.

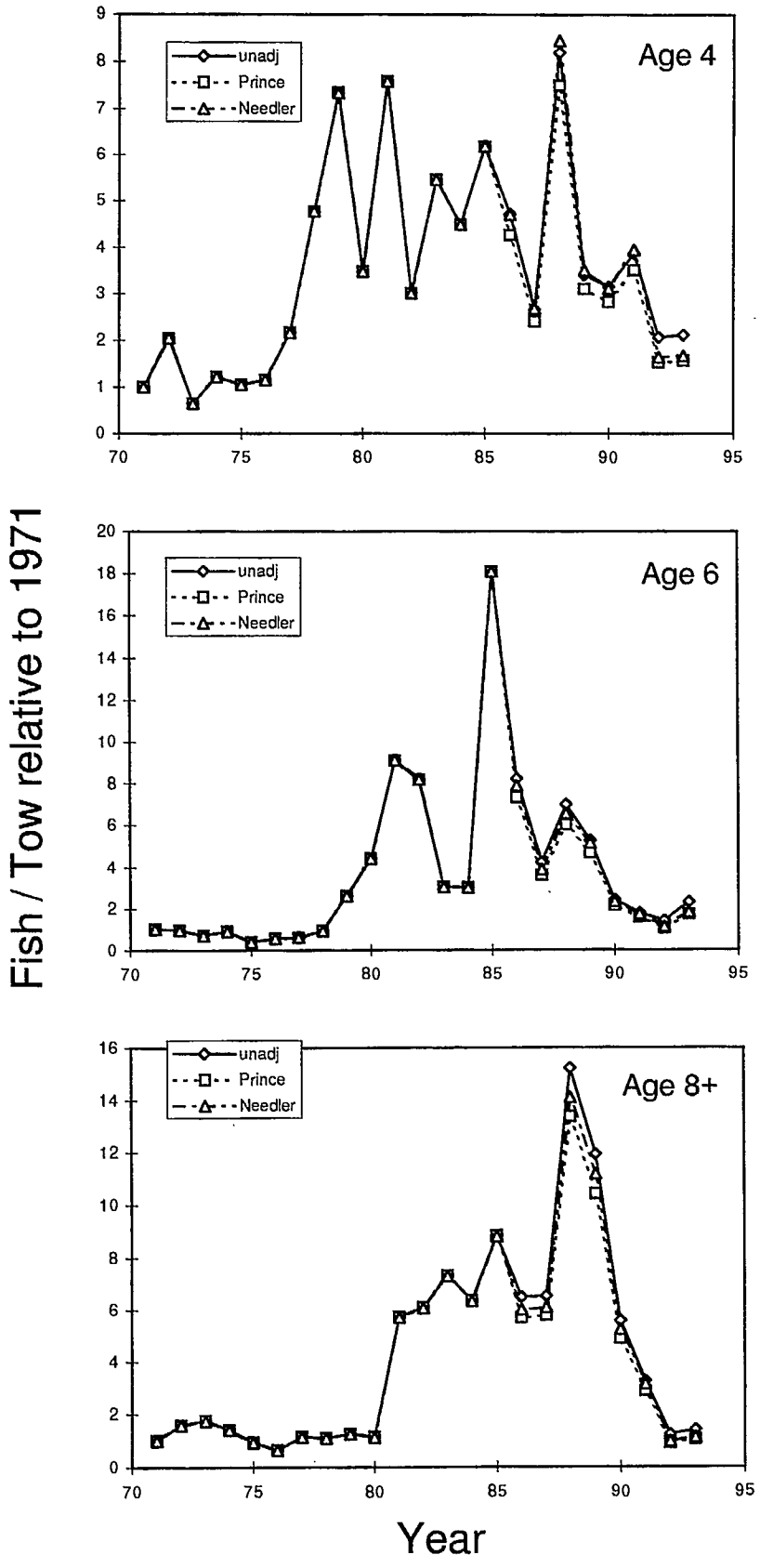
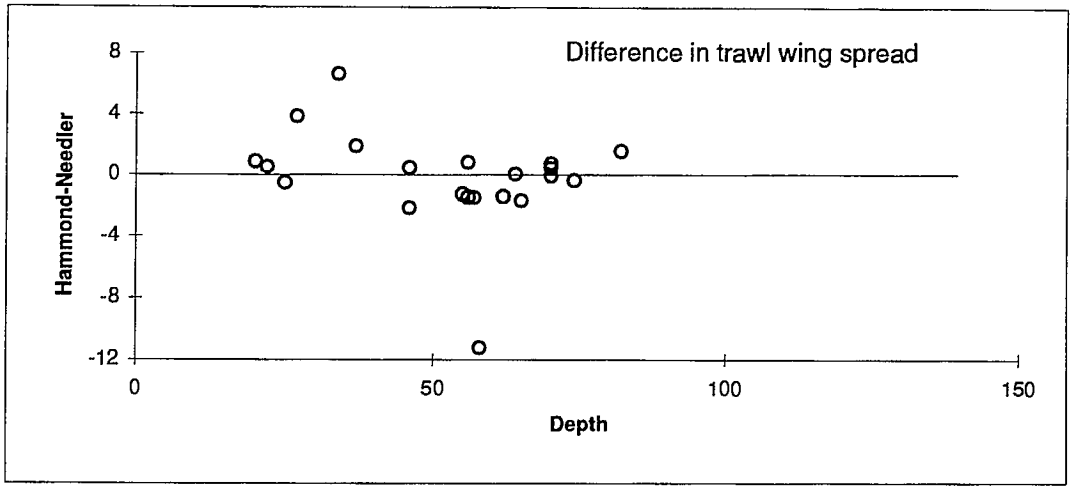


Fig. 10. Stratified mean catch rates of cod relative to 1971, using unadjusted data or data adjusted to be comparable to catches by the E. E. Prince or Alfred Needler.



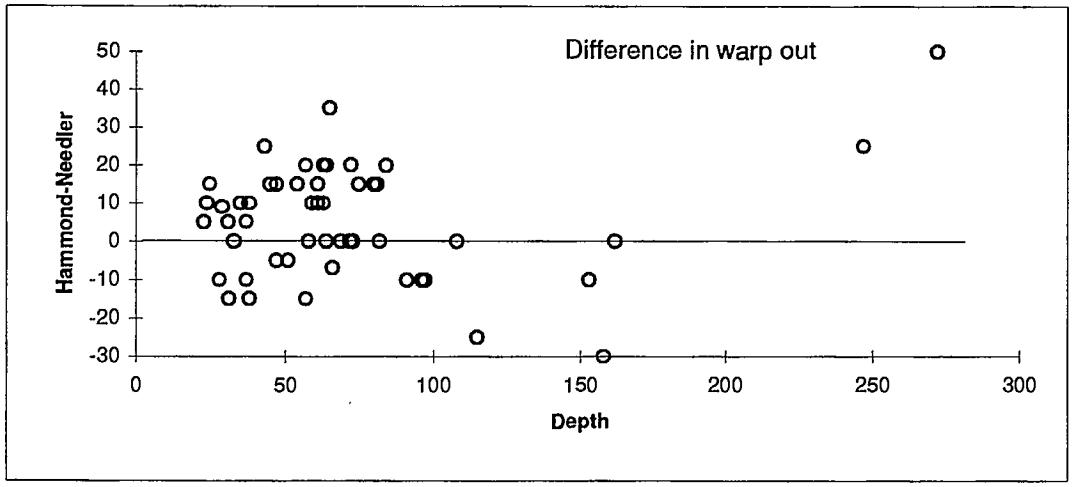


Fig. 11. Difference in trawl wing spread and warp out distance in paired sets in the 1992 comparative survey between the Lady Hammond and the Alfred Needler