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MOLT INDICATORS AND GROWTH PER MOLT FOR MALE SNOW CRABS (*CHIONOECETES OPILIO*)

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ABSTRACT

Examination of mouth parts is a standard method for determining the position in the molt cycle of individual male snow crabs. We showed that the color of the carapace can also be used to determine whether a crab is about to molt. A third, destructive, method is to tear off the dorsal carapace and look for the presence of a second carapace. During a bottom trawl survey in April 1991 in Conception Bay, Newfoundland, we found that green carapace color and a well-developed second carapace were strongly correlated and each was strongly associated with mouthpart classification D_1 or above. During a subsequent trap survey in May 1991, we found crabs with the normal reddish coloration that had seemingly partially formed second carapaces and mouthparts in the C or D_0 stage. However, further work is necessary to describe and validate the early stages of carapace formation. We concluded that the collection of crabs with a green carapace is a viable way to obtain crabs for growth studies, because they will molt in the near future, thus minimizing effects of captivity. We collected 79 green crabs and maintained them in the laboratory until they molted. All but one molted within 24 days of capture. Growth per molt was similar to that estimated for another Newfoundland snow crab population, based on the same approach, but was greater than earlier estimates derived from longer-term laboratory studies.

It is important for fishery scientists to be able to determine the stage of individual crabs in the molt cycle. The timing of the molting season and the habitats where molting occurs can then be quantified. If crabs which are close to molting can be identified, they can be held in aquaria for short periods of time for growth studies. This information is useful for short-term forecasting of recruitment. In this paper, we consider indicators of imminent molting for male snow crabs (*Chionoecetes opilio* O. Fabricius) and we estimate growth per molt.

Drach and Tchernigovtzeff (1967) showed for a variety of Crustacea that certain mouthparts undergo visible changes associated with the molt cycle. Moriyasu and Mallet (1986) and O'Halloran and O'Dor (1988) used that approach to describe a series of mouthpart stages associated with the molt cycle of male snow crabs (*C. opilio*). Moriyasu and Mallet (1986) reported that the mouthparts must be stored in chilled sea water and examined under a microscope within 48 h. Recently, Moriyasu (M. Moriyasu, Department of Fisheries and Oceans, Moncton, New Brunswick, personal communication) has had some success in storing mouthparts in Formalin for up to one month. Still, the necessity of removing mouthparts and examining them under a microscope makes the technique unwieldy for field surveys. Subsequent observations on behavior of animals brought into captivity may be affected by mouthpart removal. Additionally, we have found that recognition of mouthpart stages is subjective for early premolt stages.

In 1990, we noticed that some male snow crabs had a dark greenish coloration of the dorsal carapace instead of the usual reddish brown color. These crabs appeared to be preparing to molt, judging by the mouthpart stages and the presence of well-developed second (internal) carapaces. Color was one of the characters evaluated by O'Halloran and O'Dor (1988) in their laboratory study of the molting cycle in male snow crabs. However, they did not report any color changes during premolt and active molting.

O'Halloran and O'Dor (1988) indicated that changes in mouthparts associated with active premolt could be detected as much as 10 weeks before molting. However, their study was based on animals kept in captivity for extended periods of time and they acknowledged that their observed stage durations may not correspond to those of wild animals. Ito (1970) showed that, for male *C. opilio* sampled by bottom trawl in the Japan Sea, peak occurrence of second carapaces preceded peak occurrence of newly

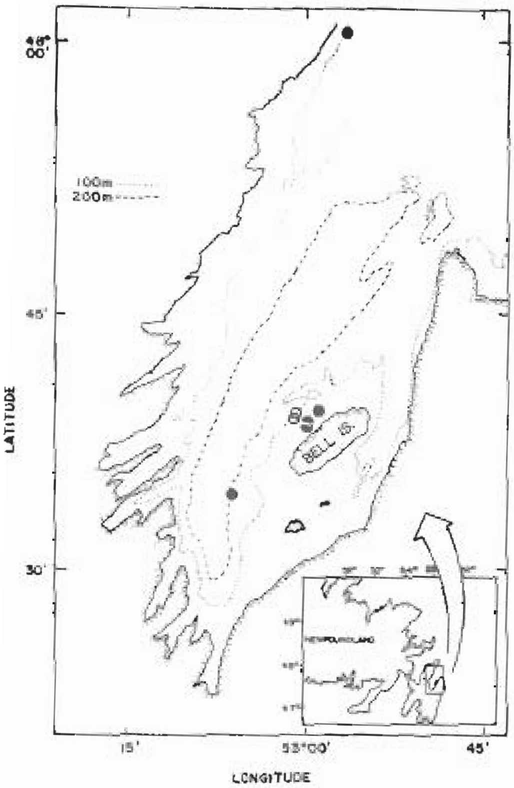

Fig. 1. Location of the study site and location, within Conception Bay, where green snow crabs were collected in 1991 (closed symbol) and 1992 (open symbol).

molted (soft-shelled) crabs by one to two months.

We decided to evaluate the association between coloration, presence or absence of a second carapace, and mouthpart stage. We sought methods that would enable the detection of active premolting as early as possible in the molt cycle. To be useful, a method must also be rapid and reliable over a wide range of carapace ages and sizes.

We subsequently collected live green males and transferred them to the laboratory, assuming they would soon molt. Only Hooper (R. Hooper, Memorial University, St. John's, Newfoundland, personal communication) previously estimated growth per molt of *C. opilio* by holding imminent molters in captivity. Other estimates have been based on holding males for long periods in captivity (Moriyasu *et al.*, 1987), mark-recapture experiments (Taylor and Hoenig, 1990), or size frequency (modal) analysis (Ito, 1970; Robichaud *et al.*, 1989).

Table 1. Descriptions of shell conditions referred to in the text and the number of specimens of *Chionoecetes opilio* caught and categorized by shell condition and type of sampling gear in the 1991 study of molt indicators.

Shell condition	Description	Number caught: Bottom trawl (April)	Number caught: Traps (May)
Squishy	Carapace and chelae so soft as to not yet be brittle.	56	0
Soft	Chelae easily bent or shattered with thumb pressure and iridescent on outer edge. Shell with or without epibionts and brightly colored.	118	1,822
New-hard	Chelae not easily bent by thumb pressure but iridescent on outer edge. Shell usually with epibionts but brightly colored.	1,402	3,005
Old-hard	Shell not brightly colored and chelae not iridescent on outer edge. Leg joints may be dark or soft from decay.	284	1,600
Total		1,860	6,427

Materials and Methods

Study of Molt Indicators

Specimens were collected during the period 4–10 April 1991, in Conception Bay, Newfoundland (Fig. 1). A standard 30-min set was executed at each station using a Western IIA bottom trawl equipped with a codend liner of 29-mm stretched mesh. Fifty-one fishing stations were randomly selected. In addition, we made 9 exploratory sets to look for concentrations of molting crabs.

Additional specimens were collected from 21–31 May 1991, in Conception Bay. Crabs were captured in Japanese-style conical traps baited with squid and set in fleets of either 6 or 12 traps. Each fleet included 2 small-meshed traps (25-mm stretched mesh) and either 4 or 10 commercial-type traps (133-mm stretched mesh).

Shell condition was characterized as being either "squishy," "soft," "new hard," or "old hard" (Table 1). Criteria for all but the "squishy" condition were adapted from Miller and O'Keefe (1981). Carapace width (CW) (mm) and height of the right chela (0.1 mm, when present) were measured with vernier calipers except when the specimen was crushed during collection. These size data were subsequently applied to published relationships (Dawe *et al.*, 1991) to determine whether each crab was small-clawed or large-clawed. Coloration for hard-shelled crabs was characterized as "red" (normal coloration) or "green" according to the following criteria (Fig. 2).

Table 2. Characterization of hard-shelled male snow crabs by color and second carapace condition for all males captured by bottom trawl in April 1991.

Color	Second carapace condition			
	Present	Absent	Transitional	Total
Reader number 1				
Red	3	717	0	720
Green	70	0	0	70
Total	73	717	0	790
Reader number 2				
Red	10	711	3	724
Green	96	3	0	99
Total	106	714	3	823
Overall total	179	1,431	3	1,613

Table 3. Characterization of hard-shelled male snow crabs by color and second carapace condition, for all males captured by traps in May 1991.

Color	Second carapace condition			
	Present	Absent	Transitional	Total
Red	3	3,243	1,352	4,598
Green	2	0	0	2
Total	5	3,243	1,352	4,600

Red—normal coloration; dorsal carapace reddish brown; posterior edge of dorsal carapace (adjacent to epimeral line) pinkish; undersides of legs reddish.

Green—dorsal carapace dark greenish, lacking reddish tinge; posterior edge of dorsal carapace (adjacent to epimeral line) whitish; undersides of legs paler than in red crabs and with greyish cast; leg joints viewed ventrally wine-colored.

These color criteria are most easily distinguished in new-hard-shelled crabs. Both red and green crabs with old-hard shells tend to be darker than the corresponding crabs with new-hard shells. Consequently, it is important to note the condition of the shell before deciding on shell color. Otherwise, an old-hard-shelled red crab might be classified as a green crab.

A flat metal rod was inserted from the posterior of the crab into the epimeral line and twisted to lift up the dorsal carapace. The degree of development of the second (internal) carapace was classified as either present (i.e., fully developed), absent, or transitional (i.e., developing) (Fig. 2).

Mouthparts were taken from the first 24 hard-shelled males examined from each bottom trawl set. In addition, the mouthparts were examined from all green crabs and all crabs with a second carapace. "Squishy" and soft-shelled crabs were not examined since they obviously would not show signs of imminent molting. For trap catches, mostly transitional males were sampled (24 per set) for mouthpart staging. The basal endite of the maxilla was clipped off, placed on a slide in a drop of chilled sea water, and examined under 25× or 40× magnification. Mouthparts were initially characterized as either stage C (intermolt), D_0 (early premolt), D_1, or D_{3-4}. The D_1 stage was subdivided into D_1', D_1'', and D_1''' (Moriyasu and Mallet, 1986). We pooled stages C and D_0 because we could not reliably distinguish them.

Growth Study

During 11–12 April 1992, green crabs were sought in Conception Bay using a Western IIA bottom trawl. A concentration of these crabs was encountered in the same general shallow-water area as in the previous spring (on the western side of Bell Island, Fig. 1), although in deeper water. Seventy-nine of these green males were selected to represent the body-size range available and were immediately placed in flowing ambient sea water (−1°C). They were then examined to determine carapace width, chela height, and shell condition, as described for the study of molt indicators. They were then placed individually within 24 × 34-cm wooden compartments with plastic mesh floors with 5.4 holes per cm². Compartments were submerged in flowing sea-water tanks on board the vessel, where they were maintained for 4 days until they were transferred to the laboratory. There, compartments were again submerged in tanks with ambient flowing sea water. Laboratory water temperature did not exceed 1°C during the experiment.

To minimize effects of disturbance, crabs were examined at approximately weekly intervals. On each of those occasions, crabs were remeasured in carapace width and chela height regardless of whether or not they had molted. Repeat measurements were made to check for measurement errors. Exuviae were also measured in carapace width and chela height before they were discarded. Postmolt crabs were maintained until 6 May when all but one crab had molted and the experiment was terminated.

The growth per molt data were plotted against premolt carapace width and a smoothed line was fitted using the nonparametric smoothing technique known as lowess (*lo*cally *we*ighted *s*catterplot *s*mooth, see Cleveland, 1979).

Results

Study of Molt Indicators

Catch Composition by Gear Type.—New-hard-shelled crabs represented the most prominent component of both trawl catches and trap catches (Table 1). The greatest difference in shell condition between gear types was that the bottom trawl catches included very recently molted (i.e., squishy) crabs, which were absent in trap catches.

The catch composition of the bottom trawl in April differed markedly from that of the traps in May with respect to color and second carapace condition (Tables 2, 3). The bottom trawl regularly collected green crabs (11% of catches, Table 2), which were rarely captured by traps (0.04% of catches, Table 3). In contrast, traps regularly collected crabs with transitional second carapaces in May (29%, Table 3), which were rarely collected

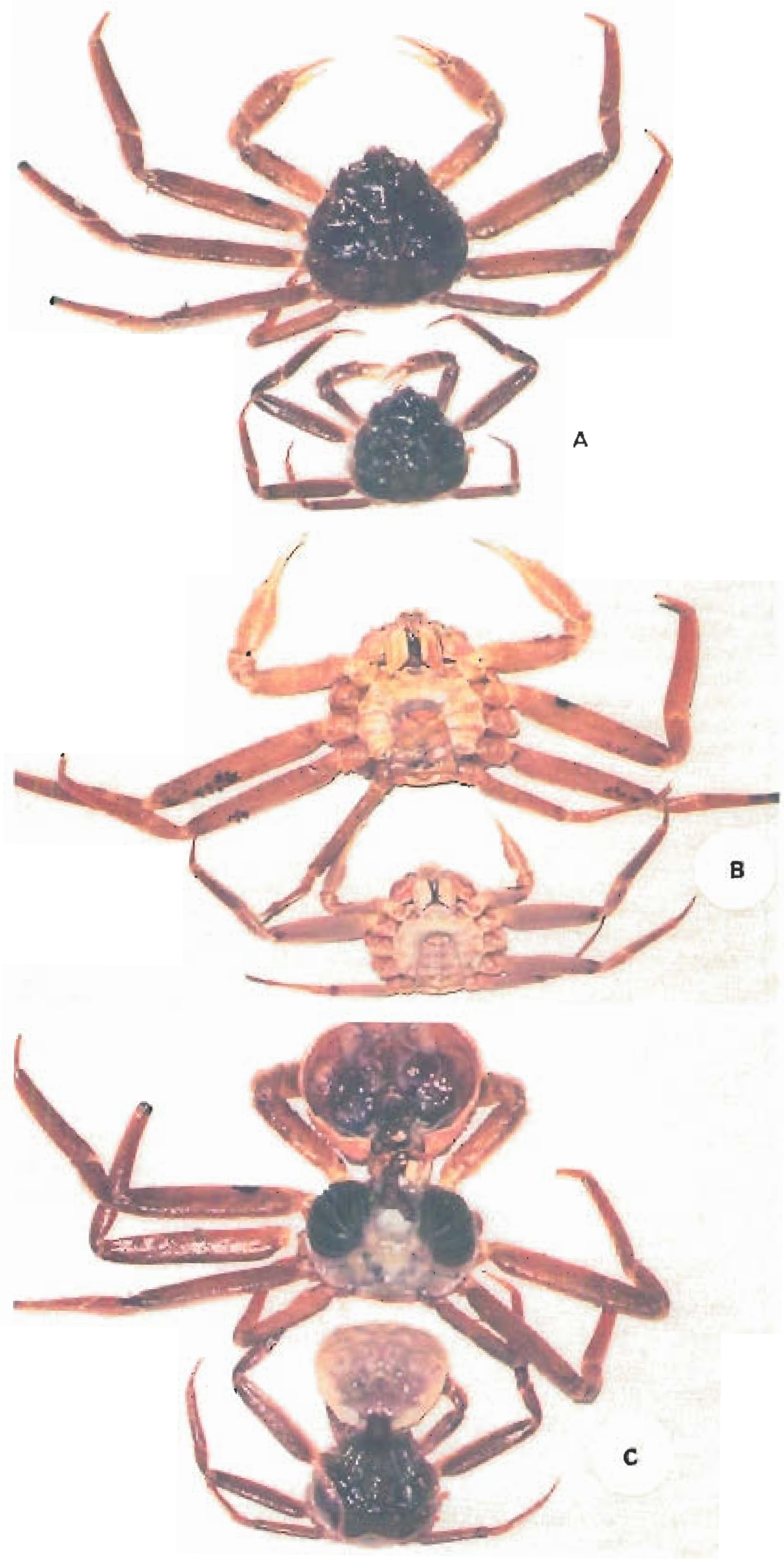
A
B
C

Table 4. Characterization of hard-shelled male snow crabs by color, second carapace condition, and mouthpart stage, for samples collected by bottom trawl in April (top) and by traps in May (bottom) of 1991.

Month/sampling gear		Number with mouthpart stage						Carapace width (mm)	
Color	Second carapace	C/D_0	D_1'	D_1''	D_1'''	D_{3-4}	Total	Mean	Range
April/bottom trawl									
Red	Present	2	7	1	2	0	12	53.8	44–74
Red	Absent	714	3	0	0	0	717	68.5	21–102
Red	Transitional	1	2	0	0	0	3	53.3	46–60
Green	Present	0	47	67	4	4	122	60.7	28–95
Green	Absent	1	0	0	0	0	1	84.0	—
Total		718	59	68	6	4	855		
May/traps									
Red	Present	0	1	0	0	0	1	86.7	—
Red	Absent	5	0	0	0	0	5	81.0	50–122
Red	Transitional	148	1	0	0	0	149	86.5	55–125
Total		153	2	0	0	0	155		

by bottom trawl in April (0.2%, Table 2). Only two imminently molting crabs (i.e., with second carapaces) were found to have old-hard carapaces. It appears, at least within the size range of imminent molters we sampled, that molting is generally at such a frequency that carapaces do not become "old" between molts.

Association between Color and Second Carapace Condition.—In April 1991, the green color was strongly associated with the presence of a well-developed second carapace, while, conversely, red color was strongly associated with either the lack of a well-developed second carapace or (rarely) the presence of what appeared to be a developing or transitional second carapace (Table 2). These results were evident in the observations from both readers. However, the association was stronger in the observations by reader number 1 than in those by reader number 2.

When the second carapace was absent or transitional, the reader almost always assigned the red color to the crab. Reader number 1 assigned the color red 100% of the time, while reader number 2 assigned it 99.58% of the time, when the internal carapace was absent or transitional. In contrast, when the second carapace was present, the readers sometimes failed to assign the green color. Reader number 1 assigned the green color 95.89% of the time, and reader number 2 assigned it 90.57% of the time, when the second carapace was present.

The very few (5) trap-caught crabs with second carapaces were not consistently identified by color as imminent molters; only two were assigned the green color. This suggests that they were not as well advanced in the molt cycle as were those captured earlier by bottom trawl and that the green color is reliably evident only soon before molting. All trap-caught males with transitional second carapaces were red (Table 3).

Association of Color and Second Carapace Condition with Mouthpart Stages.—Virtually all (98.5%) of the 134 bottom-trawled crabs with second carapaces were in active premolt stages D_1' or greater (Table 4), indicating that they were clearly committed to molting. Almost all (99.6%) of the red crabs with no second carapace were in intermolt stage C or early premolt D_0. Ten (10) of 12 bottom-trawled crabs and a single trap-caught crab, with well-developed second carapaces but red color, were in molt stages D_1' and greater. This supports our

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Fig. 2. A comparison of two crabs at different stages in the molt cycle. A 79-mm CW crab with red color, no second carapace and mouthpart stage D_0 (upper specimen) and a 56-mm CW crab with green color, a well-developed second carapace, and mouthpart stage D_1''' (lower specimen). A, dorsal view; B, ventral view; C, dorsal view with carapace removed.

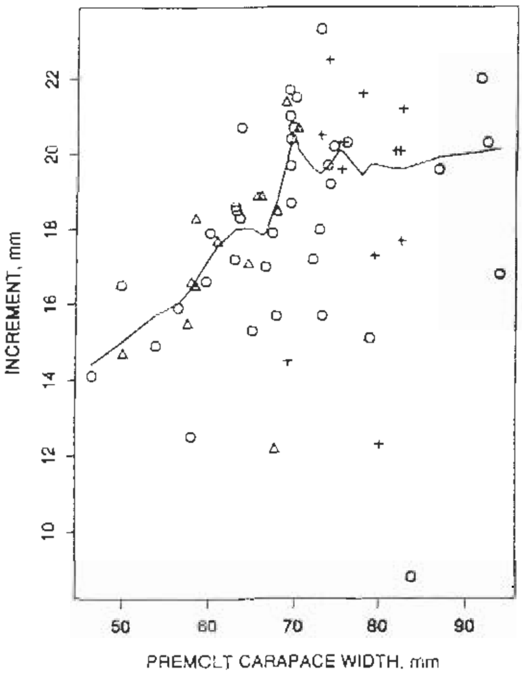

Fig. 3. Relationship of carapace width increment on molting to premolt carapace width, with smoothed curve overlain, by postmolt chela type (O = small-clawed, + = large-clawed, △ = unknown). Smoothed curve was obtained using lowess with smoothing parameter f = 0.3.

belief that imminently molting males do not acquire the green color until soon before the molt. The trap-caught males with red color and transitional second carapaces were, with a single exception, in molt stages C or D_0 (Table 4).

Growth Study

Some green crabs began to molt immediately after capture, on board the research vessel. Sixteen (16) of the 79 green crabs died in the laboratory in the process of molting. All but one of the other 63 crabs had molted by 6 May, 24 days after capture. At that time, the experiment was terminated.

Growth per molt was highly variable, ranging from 8.2—23.2 mm, but few increments were smaller than 14 mm (Fig. 3). The evaluation of trends within such variable data was difficult, but the smoothed line suggested that, between the premolt body sizes of 45 and 70-mm CW, average growth per molt increased from about 14 to 20 mm CW. It appeared to remain rather constant (about 20 mm) at larger sizes, up to the 95-mm legal size limit. All premolt green crabs had new-hard shells and were small-clawed. No effect of postmolt chela type (i.e., large-claw versus small-claw) on growth per molt was detected.

Discussion

Molt Indicators

The visual identification of imminent molters, by green color, offers a very quick and nondestructive method of identifying crabs about to molt. The reliability of this method is seen in the very close association of the green color to both a well-developed second carapace and advanced mouthpart stages. Furthermore, in our growth study, all but one of our green crabs molted within a short period of time in captivity. The objectivity of the method is highlighted by the high performance of two readers in their first trial at identifying imminent molters by color.

The usefulness of the green color as an indicator of molting is potentially limited in that the duration of the period during which crabs have the green color (and well-developed second carapaces) is unknown. The earliest mouthpart stage of crabs with both green color and a second carapace was premolt D_1'. Crabs in this molt stage molt in about 6–9 weeks, according to O'Halloran and O'Dor (1988).

Crabs that appeared to have partially formed second carapaces (i.e., transitional crabs) had the normal reddish coloration and were almost exclusively in molt stage C or D_0, according to the mouthpart readings. Further work is necessary to describe the developmental stages of the second carapace. If the transitional crabs can be validated as representing animals in early premolt condition, then the development of this second carapace may provide the earliest indication of molting activity.

Green, imminently molting, crabs have so far been observed only in bottom trawl catches. Their absence from our trap catches is consistent with the observation that crabs stop eating (and thus would not be attracted to traps) when they reach molt stage D_1' (O'Halloran and O'Dor, 1988).

Growth per Molt

Our estimates of growth for small males are somewhat smaller than another estimate, from the southeastern Gulf of St. Lawrence. Robichaud *et al.* (1989) concluded, based on modal analysis, that a 50-mm CW male would grow about 18 mm when it molts, as opposed to 14–15 mm in this study. For larger individuals (70–95-mm premolt CW), our estimated 20-mm CW increment is large in comparison with other estimates. Longer-term laboratory studies indicate that 82–113-mm premolt CW males have molt increments of about 14–16 mm (Miller and Watson, 1976; Moriyasu *et al.*, 1987). Taylor and Hoenig (1990) also studied the Conception Bay population and provided some of the smallest estimates of growth per molt, about 12.5-mm CW for an 80-mm male, based on mark-recapture experiments. It is not possible to determine why the results of Taylor and Hoenig differ from our results. One other study estimated crab growth per molt by maintaining imminent molters for a short time in captivity. Hooper *et al.* (R. Hooper, Memorial University, St. John's, Newfoundland, personal communication) collected mostly 76–95-mm males in Bonne Bay, on the west coast of Newfoundland, and maintained them through the molt. Their results were similar to ours (for similar-sized crabs) in that they found great variability in growth per molt, about 11–26-mm CW. They also found, as we did, that growth per molt averaged about 20-mm CW, with no apparent effect of postmolt chela type.

All but one of our 79 green crabs initiated molting within only 24 days of capture. Clearly, such crabs can be quite useful for direct observations of molting and for estimating growth per molt, because effects of laboratory conditions are minimized. We feel that the aggregation of imminently molting males may occur commonly in snow crab populations and such aggregations could be particularly useful for studying variation in growth among populations.

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