Cumulative and Actual Population Size of Stored-product Pests: Effect of Initial Numbers and Rate of Increase*

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Abstract

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During long-term storage of an agricultural commodity, several generations of stored-product pests can develop and die. As feeding losses are not compensated, the level of damage is not proportional to the current population density (N) but reflects the cumulative number of all individuals (C) since storage began. Therefore, the greater the "$C - N$ difference" is, the greater is the bias in any pest control decision that is based solely on the current population density of the pest. The presented simulation shows that in an exponentially growing population the "$C - N$ difference" depends on the rate of population increase (R) and the initial number of pest individuals (N_0). (1) Populations of identical size growing at the same R but starting from different initial population sizes differ in "$C - N$ difference" values: the lower the initial size, the higher the "$C - N$ difference". (2) The relative importance of the "$C - N$ difference" decreases with increasing rate of population growth (R) since in rapidly growing populations the numbers of animals from previous generations represent a small proportion of the current population. In this case N is close to C, and N is therefore a good indicator of the actual damage. (3) Population fluctuations can change the "$C - N$ difference" considerably, making a decision (e.g., on action threshold, level of economic damage) that is based on the current population density unreliable, even if R is high. Therefore, in stored product protection, besides population-based thresholds, the complementary critical threshold reflecting direct level of damages should be established and monitored.

Key words: stored product; resources exploitation; population dynamics; economic threshold; IPM; mites; insects; pests

Among various types of cost-benefit analyses (CBA) (MUMFORD & KNIGHT 1997) the critical threshold concept is the most widely employed decision-making tool nowadays. Economic damage injury level/threshold is defined as that pest population density at which the losses are equal to the cost of the control measure (FLINT & BOSCH 1981; PEDIGO *et al.* 1986). The critical assumption to establish such a threshold is the quantification of the relationship between damage and pest population density. Because growing plants have the ability of auto-reparation and/or compensation, the current density of a pest population is more or less proportionate to the concurrent level of damage caused by it. A completely different situation can be found with stored agricultural products (e.g., kernels of cereals, pulses and oilseeds). During the long period of storage of a particular batch of a commodity, several generations of stored-product pests can develop and die, but their damage is not compensated or repaired. Consequently, the level of food-resource exploitation and economic damage does not exactly correspond to the current population density of the pest (N), but rather to the cumulative number of all individuals (C) which have developed on the particular resource in the past. This, together with immigration, emigration and other sources of un-linearity between the current N and the current level of food resource damage, suggests that using only N indices as a qualitative indicator of the stored products can be unreliable in some instances (STEJSKAL 2000). Nevertheless, we have revealed that even in an exponentially growing population the "$C - N$" relationship is more dynamic than I had expected. It depends on absolute values of the initial population number and growth rate parameters. Both parameters/factors can considerably increase or decrease the "$C - N$ difference".

The aim of this paper is to show that in an exponentially growing pest population the difference between N and C

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can depend on the absolute values (i) of the number of individuals initiating the population (N_0), and (ii) on the rate of reproduction (R). The influence of population fluctuations on the dynamics of the "$C - N$ difference" in terms of critical thresholds in IMP programs is discussed.

Models: The simulations are based on a simple model describing a development of a population with non-overlapping generations (e.g., BEGON & MORTIMER 1996):

$$N_{T+1} = R \, . \, N_T \qquad [1]$$

where: N – number of individuals of the pest (= population size)
T – generation
R – net rate of population change per generation (T)

Cumulative numbers (C_{T_n}) of a particular population is obtained by (STEJSKAL 2000):

$$C_{T_n} = N_{T_0} + N_{T_1} + N_{T_2} + \ldots + N_{T_n} = \sum_{T=T_0}^{T_n} N_T \qquad [2]$$

The presented illustrative simulations, Figs 1 and 2 (based on equations 1 and 2), demonstrate the dynamics of the "$C - N$" relationship in an exponentially growing population of a hypothetical pest. In the first simulation, two populations that begin their development at the same time and grow at an identical rate of development ($R' = R''$) are modelled. As a variable, different initial population numbers ($N_0' = C_0' = 10$ and $N_0'' = C_0'' = 80$) were used to study the "$C - N$ difference" at the moment when both exponentially growing populations reach the identical population level (N_L) (e.g., $N_L = 200$); each population, of course, after a different number of generations (T_n). The second simulation demonstrates the dynamics of the "$C - N$ difference" in three hypothetical populations that begin with an identical population size ($N_0' = N_0' = N_0'' = 10$), but develop at different rates of population increase (R′ = 2, $R'' = 5$, $R''' = 10$). The third "simulation" is illustrative, showing a complex behaviour of the "$C - N$ difference" caused by population fluctuation.

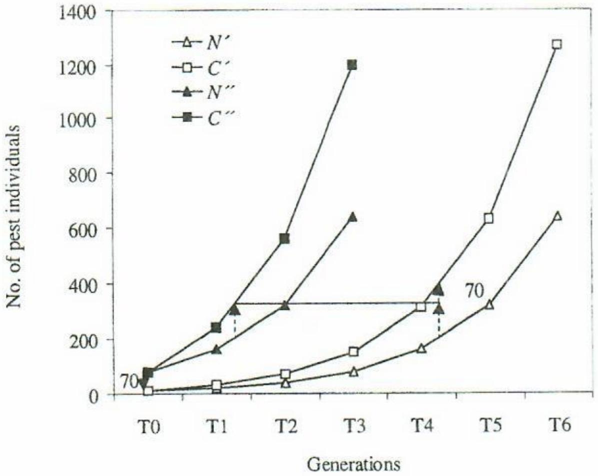

Fig. 1. The "$C - N$ difference" between two exponentially growing populations (N', N'') with the same rate of increase (R = 2), but starting from different initial population levels (N'_0 = 10, N_0'' = 80). The lower the initial size, the higher the "$C - N$ difference". At each point of the identical population level (N_L), the difference between cumulative values of both populations ($C_L' - C_L'' = 70$) is inversely proportionate to the difference of the initial population sizes ($N_0'' - N_0' = 70$)

RESULTS

Fig. 1 demonstrates that two populations of identical size ($N_L' = N_L''$) and growing at the same rate of increase ($R' = R''$), differ in the cumulative numbers ($C'_L \neq C''_L$) in situation where the identical population size was reached from different initial population sizes ($N_0'' \neq N_0'$). The dif-

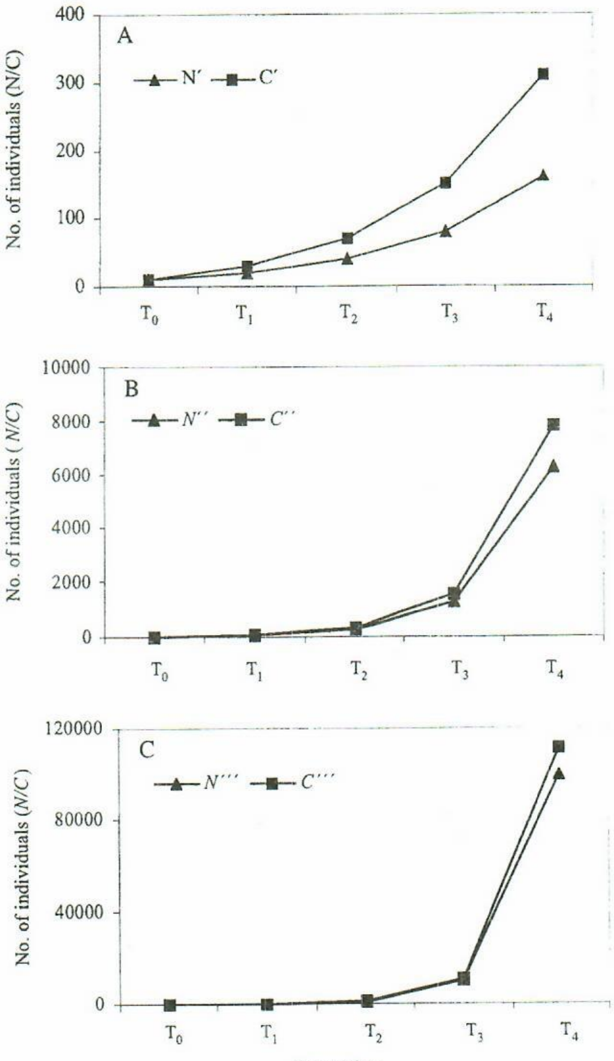

Fig. 2. The "$C - N$ difference" in three exponentially growing populations starting from an identical population size (N_0' = $N''_0 = N''_0 = 10$), but developing at different rates of population increase: $R' = 2$ (Fig. 2A) $R'' = 5$, (Fig. 2B) $R''' = 10$ (Fig. 2C). The value of "$C - N$ difference" relatively decreases with the increasing rate of population growth (R) "$C - N$ difference" relatively decreases with the increasing rate of population growth (R)

ference (Fig. 1) between C_L' and C_L'' is inversely proportionate to the difference of the initial population sizes ($N_0'' - N_0'$) when compared at any point of the identical population level (N_L):

$$N_0'' - N_0' = C_L' - C_L'', \quad \text{if} \quad N_L' - N_L'' \qquad [3]$$

Fig. 2A–C show that the "*C* – *N* difference" in an exponentially growing population relatively decreases as the rate of population growth (*R*) increases. This is due to the fact that with an increasing rate of population growth (*R*) the cumulative population numbers (*C*) represent a decreasing proportion of the current population size (*N*).

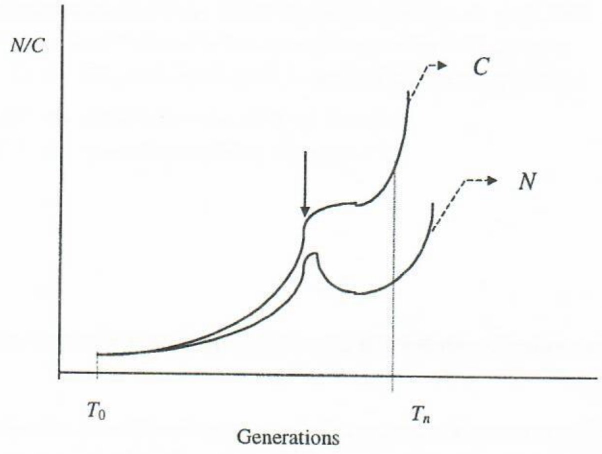

Fig. 3. Schematical outline of the dynamics of differences between *N* and *C* caused by one fluctuation in the growing population of a hypothetical stored-product pest

Fig. 3 shows that a population fluctuation can change the "*C* – *N* difference" considerably even if the value of *R* is relatively high.

DISCUSSION

Any critical population threshold should reflect the current level of damage (losses) of a particular protected resource. The level of losses caused by pests to stored commodities, provided that more that one generation of the pest emerged and died, is proportionate not to the current population density but to the cumulative number because of no compensation. Thus, we can logically expect that the actual losses are higher (due to feeding of previous generations of the pest) than shown by indices based on the current population density (STEJSKAL 2000). When establishing some action thresholds or level of economic damage from the population density indices, it is of crucial and practical importance to know whether the "*C* – *N* difference" is very high or negligible. If the "*C* – *N* difference" is very low, we can consider the *N* values to be approximately equal to *C* values. In such a case, *N* indices can also serve as an approximate indicator of the current level of damage to a resource. I found that in a growing population the level of "*C* – *N* difference" is sensitive to the initial population size and to the number of generations. Populations of identical size at a given time but that began from different initial numbers of individuals exhibit "*C* – *N*" values of different magnitude, even when growing at the same *R*. The lower the initial size of a population (N_0) is and the more generations are needed to reach a particular population level (N_L), the higher is not only the "*C* – *N* difference" but also the bias of estimating the current level of resource losses according to *N* indices.

Nevertheless, in a rapidly and exponentially growing population (high values of *R*) the *N* and *C* curves seem to be almost equal (Fig. 2C) and thus, from the practical point view, *N* values can reflect the level of resource exploitation. Clearly, in a drastically increasing population the level of depletion of the food resource is approximately proportionate to the present population size because the feeding by previous generations is only a small part of the consumption by the current generation – unrealistically assuming that the consumption per individual is constant. Here comes to mind an illustrative "environmental" parallel: the consumption of nonrenewable resources (e.g., coal, metal ores) by previous generations of the human population during the last 10,000 years is negligible compared to the consumption by the steeply growing population during the last century or even last several decades. It is known that in grain storage facilities under favourable physical conditions, populations of some species of pest arthropods can exhibit rapid exponential growth because large bulks of stored commodities rarely limit these populations by amount of food or space. For example, WHITE (1988) reported the average growth rate in stored wheat to be 5-fold per month for the *Rhizopertha dominica* (Fabricius) population and 10-fold per month for *Tribolium castaneum* (Herbst). However, any population fluctuation (Fig. 3), caused by intrinsic and extrinsic factors (e.g., temperature, humidity, ventilation, fumigation, zoonoses) can seriously complicate the approximation of *N* to *C*, making *N* indices rather unreliable indicators of the current status of quality/safety of the stored commodity. This also stresses the importance of continual monitoring from the first day of storage of the commodity, rather than relying on isolated sampling events.

Although some recently developed and advanced computer models for stored-product IPM are reported to be able to predict and explain up to 90% of all population changes during storage of grain (HAGSTRUM *et al.* 1996), they usually say little about the relationship between pest population density and damage/losses or contamination. The illustrative simulations presented here indicate that those computer IPM models should be complemented by simulation modelling of the dynamics of species-specific food resource exploitation (damage/losses) and contamination in relation to predicted temporal population changes during storage of various commodities in different geographical areas. Nevertheless, until this is accomplished the stored product IPM programs should include not only a critical threshold based on population density (e.g., two insects/kg of grain) but also other indices directly reflecting the current actual level of damage/losses (e.g., number of damaged kernels per 100 g of commodity) and level of contamination (e.g., filth or ELISA test) as discussed in the previous paper (STEJSKAL 2000).

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Souhrn

STEJSKAL V. (2000): **Kumulativní a aktuální velikost populací skladištních škůdců jako efekt jejich počáteční velkosti a rychlosti růstu.** Plant Protec. Sci., **36**: 69–72.

V průběhu dlouhodobého skladování zemědělských komodit se může vyvinout a vyhynout několik generací škodlivých skladištních členovců. Vzhledem k tomu, že žádné ztráty skladovaných produktů nejsou kompenzovány, tak stupeň poškození potravního zdroje není adekvátní aktuální populační hustotě škůdců (N), ale jejich kumulativnímu počtu (C). Čím větší je rozdíl mezi hodnotami N a C, tím větší je také chyba v rozhodovacím procesu ochrany před škůdci založeném na prostém sledování aktuální populační hustoty. Prezentované simulace ukazují, že v exponenciálně rostoucích populacích je rozdíl hodnot parametru N a C závislý na absolutních hodnotách populačního růstu (R) a počátečního stavu populace (N_0): 1. Dvě populace o stejné velikosti a rychlosti růstu (R) s rozdílnou počáteční velikostí mají odlišný rozdíl hodnot parametru N a C, přičemž platí, že čím nižší je iniciální počet jedinců, tím větší je rozdíl hodnot parametru N a C. 2. Čím větší je rychlost růstu populace, tím se snižuje relativní velikost rozdílu hodnot parametru N a C. Je to dáno faktem, že u velmi rychle rostoucí populace (např. $R = 10$) představují kumulativní počty předchozích generací pouze malou proporci aktuální populační hustoty. V situacích, kde je hodnota rozdílu $C - N$ velmi nízká, mohou být hodnoty parametru N považovány jako aproximativní hodnoty parametru C a tím jsou také hodnoty N vhodné pro výpočet aktuální výše poškození skladovaného potravního zdroje. To bylo zjištěno u populací s vysokými hodnotami R. Nicméně i při vysokých hodnotách R mohou populační fluktuace významně změnit rozdíl $C - N$ a tím znemožnit správnost rozhodovacího procesu ochrany před škůdci založeného pouze na hodnotách aktuální populační hustoty škůdce. V programech ochrany dlouhodobě skladovaných komodit lze doporučit pro stanovení „akčního prahu" či „kritického čísla" používání parametru odrážejících aktuální hladinu poškození komodity – těmi nemusí být vždy populační hustota škůdce, ale např. počet poškozených zrn na jednotku hmotnosti vzorku komodity.

Klíčová slova: skladištní škůdci; exploatace zdrojů; práh škodlivosti; populační dynamika; roztoči; hmyz; škůdci

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