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Research Article

Impact of the clam *Arca zebra* artisanal fishery upon the population of the neogastropod *Voluta musica* in eastern Venezuela

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ABSTRACT. An important ark clam (*Arca zebra*) artisanal fishery takes place in the east region of Venezuela. Besides the target species, trawling extracts a significant bycatch of several mollusk species including the gastropod *Voluta musica,* a threatened species according to the Venezuelan Red List of Endangered Species. In this paper we evaluate: 1) the composition of mollusk species in the bycatch, 2) the number of individuals of *V. musica* caught as bycatch and, 3) the abundance and size structure of the exploited population. Each fishing night, about 27,830 m^2 are trawled by each boat extracting on the average 607 kg of *A. zebra* meat and 19 kg of *V. musica* (whole shelled animal). This fishery activity potentially captures ~30,000 kg of ark clam meat and 922 kg of *V. musica* in one week (~95 snails/fishing night/boat). The size structure of the *V. musica* population at the ark clam bed is significantly smaller than in other nearby sites not impacted by trawling fishing activities. Non-targeted species extracted in the bycatch but consumed by the local inhabitants include the gastropods *Chicoreus brevifrons*, *Phyllonotus margaritensis*, *P. pomum*, *Fasciolaria tulipa*, *Strombus pugilis*, a few Trochidae species, and the bivalves *Pinctada imbricata*, *Spondylus americanus*, *Anadara floridana*, *A. notabilis*, and *Trachicardium muricatum*. Individuals of *V. musica* along with several invertebrates are discarded. We recommend that *V. musica* should not be neglected as a conservation target, and despite that *A. zebra* fisheries are considered "artisanal", that more strict regulations should be established on it.

Keywords: *Arca zebra*, *Voluta musica*, bycatch, endangered species, artisanal fishery, size structure, Caribbean Sea.

Impactos de la pesca artesanal de la almeja *Arca zebra* sobre la población del neogastrópodo *Voluta music*a en el oriente de Venezuela

RESUMEN. La pesca artesanal de la almeja arca (*Arca zebra*) es una de las pesquerías de mayor importancia en el oriente de Venezuela. En esta pesquería se capturan incidentalmente varias especies de moluscos, incluyendo el gasterópodo *Voluta musica*, considerada amenazada según el Libro Rojo de la Fauna Venezolana. En este trabajo se evalúa: 1) la composición de especies de moluscos en la captura incidental, 2) el número de individuos de *V. musica* capturados como pesca incidental y 3) la estructura de tallas y abundancia de la población explotada. En cada faena de pesca se arrastran 27.830 m^2 por cada barco, extrayendo en promedio 607 kg de *A. zebra* (sin concha) y 19 kg de *V. musica* (con concha). La flota completa captura ~30.000 kg de *A. zebra* y 922 kg de *V. musica* en una semana (~95 caracoles/noche de pesca/barco). La estructura de tallas de la población de *V. musica* en el banco de *A. zebra* es significativamente menor comparada con sitios cercanos no afectados por la pesca de arrastre. Otras especies capturadas incidentalmente son consumidas por los habitantes locales e incluyen los gasterópodos *Chicoreus brevifrons*, *Phyllonotus margaritensis*, *P. pomum*, *Fasciolaria tulipa*, *Strombus pugilis*, y unas pocas especies de Trochidae, bivalvos *Pinctada imbricata*, *Spondylus americanus*, *Anadara floridana*, *A. notabilis*, *Trachicardium muricatum*. Los individuos de *V. musica* y otros invertebrados son desechados completamente. *V. musica* debe ser considerada como objeto de conservación, y a pesar que la captura de *A. zebra* es considerada "artesanal", se deberían establecer regulaciones más estrictas sobre esta especie.

Palabras clave: *Arca zebra, Voluta musica***,** captura incidental, especies amenazadas, pesca artesanal, estructura de tallas, Mar Caribe.

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INTRODUCTION

The ark clam *Arca zebra* (Bivalvia, Arcidae), is distributed along the western shores of the Atlantic Ocean from North Carolina and Bermuda to Brazil (Abbott, 1974). A large natural bed of ark clams occurs on rocky bottoms between 1 and 20 m depth near the coastal population of Chacopata in the Araya Peninsula, Venezuela. This bed covers an area of 70-80 km^2 and has been intensively exploited by local artisanal fishermen since 1940 (Lodeiros *et al*., 2005). The annual production varies between 15,792 and 33,986 ton, although it has reached 40,000 ton $year^{-1}$ (Mendoza, 1999; Lodeiros *et al*., 2005). It is the most important economical income for the artisanal fisheries in the country, after the collapse of the sardine fishery, being most of the production destined for canning and local consumption (Trujillo, 1997; Novoa *et al*., 1998; Gómez-Gaspar, 1999; Diaz *et al*., 2002). The fishing method is non selective and the catch is classified after landing, and thus many non-targeted species are incidentally caught (bycatch) and landed (Peralta, 2012). After fishing operations, all the organisms landed are cooked together with the clam *A. zebra*. The shelled mollusks (several bivalve species and gastropods) are extracted from their shells (Gómez-Gaspar, 1999), while the remaining organisms lacking commercial importance such as sea stars, sea urchins, sponges, corals and the gastropod *V. musica* are discarded with all the empty shells (Peralta, 2012).

Voluta musica (Linnaeus, 1758) is an endemic volutid gastropod restricted to the Venezuelan and Colombian Caribbean and some Caribbean Islands (Clench & Turner, 1964; Gibson-Smith, 1973). It is a gonochoristic species with internal fertilization and development occurring in egg capsules, which contain extra-embryonic food sources in the intracapsular fluid allowing the embryos to hatch as crawling juveniles (Penchaszadeh & Miloslavich, 2001). The species is listed in the Venezuelan Red List of Endangered Species categorized as data deficient (Rodríguez & Rojas-Suárez, 2008), however, in the updated 2015 edition of the list, the species will be assigned a category of "vulnerable" (Peralta & Miloslavich, in press) based on the impact that the clam *Arca zebra* fisheries along the Araya Peninsula (eastern Venezuelan coast) is having on it and some critical reproductive aspects of the species, such as low fecundity, and a significant proportion of the population affected by *imposex* (Peralta *et al*., 2012, 2014).

Although bycatch is widely recognized as a threat to marine biodiversity and fisheries sustainability (Pauly *et al*., 2002), few studies have quantified bycatch of invertebrates and the effect on their populations in South America (Riestra *et al*., 2006; Escolar *et al*., 2009; Morsan, 2009) and specifically, gastropod bycatch is poorly registered (but see Carranza, 2006; Riestra *et al*., 2006; Carranza & Horta, 2008). The bycatch of benthic invertebrates may have negative impacts on some species, but some other (scavenger gastropods, crabs, and echinoderms) may increase population densities (Collie *et al*., 1997; Juan *et al*., 2007; Escolar *et al*., 2009). In these cases, the opportunistic species would be favored by the increase of food availability, as a result of discarded organisms (Britton & Morton, 1994; Morton, 1995, 2006; Escolar *et al*., 2009). This may not be the case in the *A. zebra* fishery, since bycatch is discarded after landing (and on land), and thus we expect a negative impact on the population of *V. musica*.

In this scenario, this paper aims to: a) provide bycatch and abundance estimates for *V. musica* on the *A. zebra* fishery in the Araya Peninsula, b) compare the abundance and size structure of this population with other populations not affected by the *A. zebra* fishery in the region, and c) report the composition of mollusk species in the bycatch of the *A. zebra* fishery.

MATERIALS AND METHODS

Study area

Sampling was performed in the ark clam bed of "El Mosquito-La Canal", northeastern of Araya Peninsula (Fig. 1). This bed is located in the Venezuelan eastern upwelling ecoregion, charac-terized by a significant seasonality in water temperature as a response to oceanographic upwelling processes induced by tidal currents, wind, coastal geomorphology and sea-floor bathymetry. The surface water tempera-ture varies between 22ºC during December to April and 28ºC during May to November (Miloslavich & Klein, 2008).

Sampling

Samples were taken during the ark clam fishing season (February-May, 2011). The fishing gear used to capture the ark clam was a small trawl net 1.5 m wide x 1 m high with 8 cm mesh size, trawled from 7 m long wood boats operated by a crew of 4-5 fishermen. Fishing operations took place during the night (23:00-7:00 h) and consisted of several trawls performed during a few minutes each (7-10 min). One of us accompanied the fishermen during 10 different nights and recorded with a GPS the geographic coordinates at the beginning and the end of each trawl to estimate Total Swept Area (TSA). Organisms captured on each fishing night were kept by the fisherman in polyethylene bags on board.

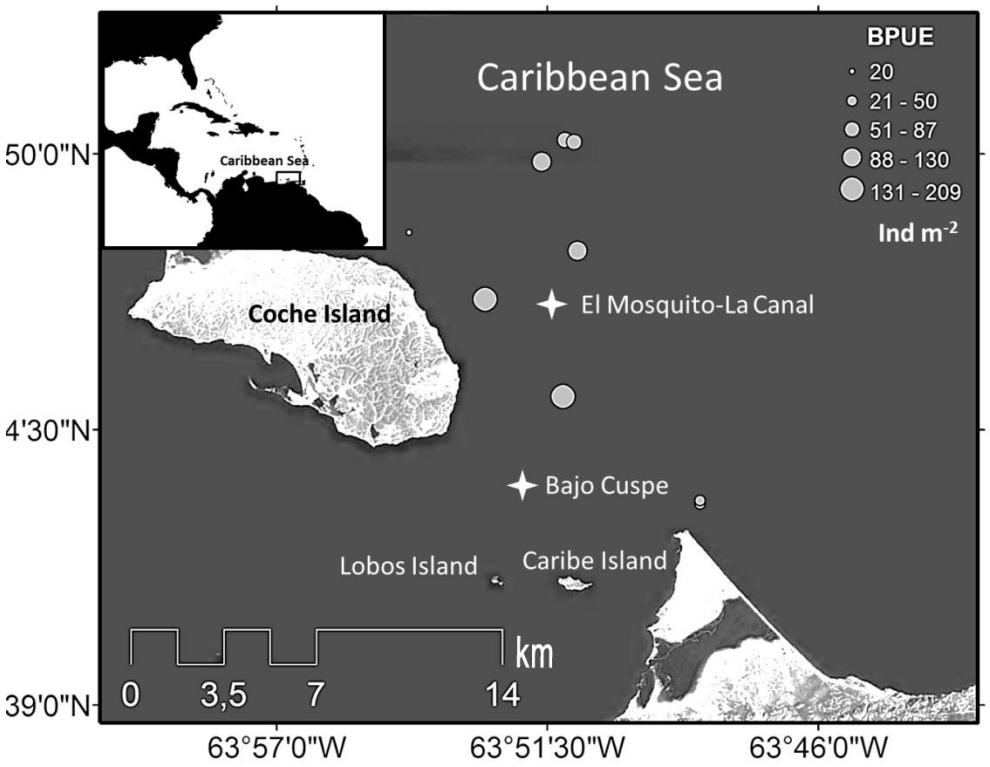

Figure 1. Study area**:** northeastern of Araya Peninsula (10°49'4"N, 63°52'7"W). Bycatch per unit of effort (BPUE) (ind m^{-2} expressed as the number of *V. musica* captured incidentally by one fishing night.

After landing, the bags were weighted with all the content in order to quantify total landings. From these bags, all *V. musica* were manually separated, their shell length measured and their whole bodies weighed with a digital scale of 0.001 mm precision. The rest of the benthic invertebrates were collected and identified either as "target species" (*A. zebra*) or as "others".

Data analysis

In order to characterize the fishing operations, we estimated the mean swept area (*SA*) for a total of 100 random trawls. The mean *SA* was calculated using the fishing gear dimensions and geographic positional system data (GPS) at the beginning and end of each trawl. The total swept area by fishing night (*TSA*) was estimated as the product of total number of trawls/ night/boat (*TL*), registered on board, multiplied by the calculated mean swept area (*SA*):

$$TSA = TL \text{ x mean } SA$$

Thus, fishing effort is expressed in *TSA*/night, since we are unable to associate *V. musica* bycatch to an individual trawl. BPUE (bycatch per unit effort) is expressed as the number of *V. musica/TSA*/night. Since the capturability coefficient (q, *i.e.*, the fraction of the biomass that is caught by unit of fishing effort) was assumed to equal 1, BPUE is considered a surrogate for abundance of *V. musica* in the fishing area, and is here reported as ind m^{-2}. We compared the size structure of the population of the fishing area "El Mosquito-La Canal" with three other *V. musica* populations located few kilometers from the ark clam bed (data from Peralta *et al.*, 2014), where no artisanal ark clam fisheries operate: Isla Caribe (10°41'19"N, 63°51'05"W), Isla Lobos (10º41'26"N, 63º52'28"W) and Bajo Cuspe (10º43'53"N; 63º51'10"W). Mean size of individuals from each population were compared using a one-way ANOVA, after checking ANOVA assumptions.

RESULTS

The mean number of trawls released by one boat/ fishing night (*TL*) was 33 (±10). The mean swept area (SA) was 792.23m^2 (±183.55) and the total swept area by fishing night (TSA) was 27,829.35 m^2 (±10,553.21) (Table 1). BPUE is expressed as the number of individuals of *V. musica* captured incidentally by one fishing night/boat and mean BPUE was 95 ± 60 ind m^{-2} (Table 1, Fig. 1).

According to BPUE data, the density of *V. musica* population found in the *Arca zebra* bed from "El

Table 1. Swept area (*SA*) evaluation and *Voluta musica* bycatch at El Mosquito-La Canal ark clam bed. SD: standard deviation.

Fishing register	Swept area (SA) in m^2	Total swept area by fishing night (TSA)/fishing night (m^2)	Number of bags/dragging	Number of trawl release/fishing night (TL)	*V. musica* captured by TSA/fishing night	*V. musica* captured 100 m^2
Mean	792.23	27,829.35	7	33	95	0.41
SD	183.55	10,553.21	-	10	60	0.30
n	100	10	-	10	10	10

Mosquito-La Canal" was 0.0041 ± 0.002 ind m^{-2}. The total biomass of *Arca zebra* meat captured by fishing night/boat was 606.75 ± 99.83 kg, while the total biomass of *V. musica* captured incidentally by fishing night was 19.20 ± 13.10 kg. In each fishing night we registered 12 artisanal fishing boats, and according to the fisherman, the fishing activity takes place usually four days a week (depending on weather and boat conditions). Therefore, according to the data registered, the capture of a single boat represents ~2,400 kg of ark clam meat and ~76.80 kg of *V. musica* per week. Extrapolation of these data suggests that the whole fleet (12 boats) can capture ~30,000 kg of ark clam meat and 921.60 kg of *V. musica* in one fishing week. Fishing takes place during ten months in a year (*A. zebra* fishing is closed during August and December following the National Fishing Laws). In this scenario, and with the *V. musica* BPUE estimated (~95 snails/fishing night by one boat) we can estimate that the bycatch of *V. musica* is 4,560 ind $week^{-1}$ and 182,400 ind $year^{-1}$. This represents 36,864 kg of *V. musica* by catch in a year-round basis.

Size structure

The shell length of incidentally captured individuals of *V. musica* varied from 39.4 to 87 mm for males and 36.2 to 100.7 mm for females (Fig. 2). Table 2 shows the mean size of female and male snails incidentally captured and the mean size of individuals sampled in three other *V. musica* populations located ~4 km from the ark clam bed where no artisanal ark clam fisheries operate. The ANOVA analysis showed significant differences between female ($F = 40.52$; $P < 2.10^{-16}$) and male ($F = 57.43$; $P < 2.10^{-16}$) sizes at the four populations, being "El Mosquito-La Canal" the site with the smaller sizes in females and males (Tukey test, 95% family-wise confidence level). Sex ratio in "El Mosquito-La Canal" ark clam bed did not differ from the 1:1 ratio ($\chi^2 = 24.5$; $P < 0.05$; n = 341) with 51% being female and 49% males.

Bycatch composition

In addition to *V. musica*, we registered the capture of other mollusks in the ark clam fishery. These were consumed directly by the local population, and also represented a source of extra income as some of these by-products were sold locally. The fishery's community reserves for themselves the following species: the gastropods *Chicoreus brevifrons*, *Phyllonotus margaritensis*, *P. pomum*, *Fasciolaria tulipa*, *Strombus pugilis*, a few Trochidae species and the bivalves *Pinctada imbricata*, *Spondylus americanus*, *Anadara floridana*, *A. notabilis*, and *Trachicardium muricatum* Neither *V. musica* nor any echinoderm, cnidarian, polychaeta or crustacean found in the bycatch was used as by-product, and was discarded with the empty *A. zebra* shells.

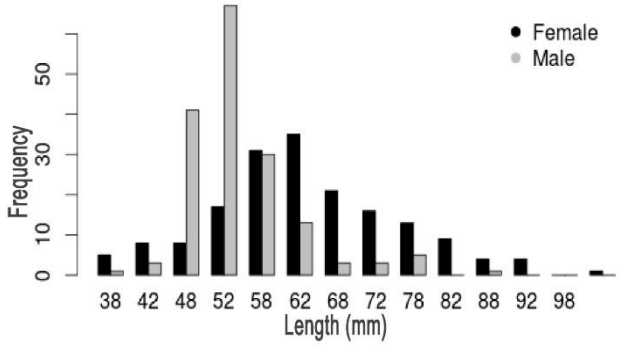

Figure 2. Population size structure of *Voluta musica* in the *Arca zebra* bycatch.

DISCUSSION

Although *Arca zebra* fishing activity occurs in the Araya Peninsula since 1940, few works dealing with benthic community composition have been performed, and most of these only provide species lists of bivalves and gastropods associated to the *A. zebra* beds in Chacopata (Prieto *et al*., 2001; Acosta *et al*., 2007; Licet *et al*., 2009). In this work, we present the bycatch mollusk species composition for the first time, which includes species listed in the Venezuelan Red Book (the gastropods *Voluta musica*, *Phyllonotus margaritensis*, *Strombus pugilis*, and the bivalve *Pinctada imbricata*) (Rodríguez & Rojas-Suárez, 2008).

Since the ark clam fishery does not use a selective fishing gear, a significant number of benthic invertebra-

Table 2. Mean size of *V. musica* at El Mosquito-La Canal area (*Arca zebra* bank) in comparison to other nearby sites. *****ANOVA shows significant differences in mean size for females ($F = 40.52$; $P < 2.10^{-16}$) and male ($F = 57.43$; $P < 2.10^{-16}$) (Tukey multiple comparisons, 95% family-wise confidence level).

Site	Female size (mm)	Male size (mm)
Isla Caribe	Min = 60; Max = 95	Min = 38.7; Max = 78.3
	Mean = 75.24 ± 6.44 (n = 136)	Mean = 64.23 ± 6.88 (n = 86)
Isla Lobos	Min = 59; Max = 88	Min = 52; Max = 74
	Mean = 70.76 ± 7.67 (n = 26)	Mean = 61.72 ± 7.43 (n = 15)
Bajo Cuspe	Min = 35.7; Max = 89	Min = 34.4; Max = 74
	Mean = 73.94 ± 9.16 (n = 82)	Mean = 70.20 ± 11.11 (n = 39)
El Mosquito-La Canal*	Min = 36.2; Max = 100.7	Min = 39.4; Max = 87
	Mean = 63.78 ± 12.20 (n = 173)	Mean = 54.61 ± 7.37 (n = 168)

tes are retained in the trawl net. The bycatch of *Voluta music*a represents a significantly high number of captured individuals (~95 ind/night/boat), which given the low fecundity of the species (Peralta *et al*., 2012) could cause a reduction in population as has been observed in other species of exploited Caenogastropods (*e.g.*, Torroglosa & Giménez, 2010).

It has also been shown that benthic invertebrate bycatch generates a high mortality of larger individuals, affecting size structure and productivity of benthic communities (Duplisea *et al*., 2002; Queirós *et al*., 2006). Thus, this fishery may cause an important impact on the population structure as suggested by the size structure analysis, which showed significant smaller individuals (males and females) in the *A. zebra* bed compared with neighboring non-fishing sites. In this study, only 1 of 174 females was found measuring over 100 mm in length. Rangel *et al*. (2011) report a length range of *V. music*a specimens collected in the same region between 5 and 104 mm, with an average of 56.4 ± 28.3 mm, however, no distinction was done between males and females. A reduction in individual size has been reported previously for other impacted gastropod species, as is the case for a population of the gastropod *Cymbiolacca pulchra* (Volutidae) in an Australian reef due to the impact of dredging (Catterall *et al*., 1992).

Our work also showed a higher frequency of capture within the range of the minimal size of sexual maturity, calculated for both sexes in a neighboring site (Isla Caribe): 52 mm for males and 61 mm for females (Peralta, 2012). The probable capture of a significant number of immature individuals is here inferred by the size structure of *V. musica* captured incidentally, with a mean of 54.61 mm for males and 63.78 mm for females. This could mean that the 40.23% of females and 22.16% of males from bycatch are below the minimal size of sexual maturity. According to Stearns (1992), this kind of impacts could lead to a new steady state in which the population could prevail despite the impact, producing certain responses as: 1) a reduction in the minimum size of sexual maturity, 2) an increase in growth rates, and 3) a higher reproductive effort. Torroglosa & Giménez (2010) demonstrated that the size at first maturity *of Zidona dufres*nei (Volutidae) has decreased 10 years after fishery exploitation. Blanchard *et al*. (2004) and Juan (2007) reported several examples based in life histories optimization depending on the energy distribution and the reproductive success, demonstrating that in some cases removing the larger individuals of a population can lead to a type of directional natural selection, resulting in a new and smaller size of sexual maturity. Thus, a reduction in size at sexual maturity size could be occurring in the analyzed population but this still need to be investigated.

In addition to the direct negative impacts on *V. music*a populations, densities of species that are part of the benthic community impacted by trawling activities may change depending on their ecological function. Opportunistic species may be favored by disturbed environments, while long-live top predators may decline in number during high intensity disturbance (Blanchard *et al*., 2004). On the other hand, fishing gear effects may favor scavengers and opportunistic carnivores attracted by crushed organisms, and eliminate fragile species (Britton & Morton, 1994; Taylor, 1994; Morton, 1995, 2006; Ramsay *et al*., 1997, 1998). *V. musica* is a carnivore species capable of shifting to scavenging habits when fishing discards are available (Von Cosel, 1976; Peralta, 2012), suggesting a plasticity to overcome environment disturbance. However, in the present work, *V. music*a densities were lower (0.003 ind m^{-2}) than reported for other neighboring sites without trawling disturbance (0.04-0.25 ind m^{-2}) (depending on time period and location) suggesting an impact on this gastropod population besides the late attainment of sexual maturity (Peralta

et al., 2012). However, presumed effects of spatial clustering could be biasing our results, since aggregations of individuals of *V. music*a are known to occur due to a) mating behavior seasonality, b) oviposition seasonality, c) feeding behavior, and d) selection of an oviposition area (Peralta, 2012; Peralta *et al*., 2012). *V. musica* density in the fishing area was low as well as observed for other edible volutids from Patagonia (Bigatti *et al*., 2008; Bigatti & Ciocco, 2008; Zabala *et al*., 2013). The authors suggest that the fishing of these species must be regulated due to very low population density plus a slow individual grow rate, late sexual maturity and direct development.

CONCLUSIONS

This paper reports new threats for *V. musica* populations in the northeastern Venezuelan coast that are worth considering not only in future re-evaluations of the status of the species under the Venezuelan Red List Fauna, but also for future IUCN assessments. Clearly, the data we present here shows that there is a clear negative effect of the bycatch in the population structure, however, the species is still present after more than 30 years of trawling, which could be explained by the upwelling phenomena that occurs in this region and that somehow could sustain the population. On the other hand, the *A. zebra* fishing activity catches incidentally other animals like star fishes that are mollusk predator, therefore if the star fish is "getting off the picture" then their prays such as *V. musica* could somehow balance the consequences of the trawling impact. Nevertheless, under the precautionary principle, the species should receive some degree of protection. Furthermore we recommend that the establishment of future marine protected areas and/or current management schemes should include *V. musica* populations as an important conservation target, since this is a fragile species, characterized by low fecundity and density (Penchaszadeh & Miloslavich, 2001; Peralta *et al*., 2012) and may be threatened by multiple stressors including *imposex* (Peralta *et al*., 2014) and bycatch. In addition, it would be also necessary to control the *A. zebra* fishing activity, particularly regarding regulations on fishing effort (Total Swept Area and duration of fishing seasons). Onboard (or even after landing) discard of live *V. musica* will probably be the most effective strategy, but depends on the implementation of public awareness campaigns.

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