Niche diversity can explain cross-cultural differences in personality structure

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The covariance structure of personality traits derived from statistical models (for example, Big Five) is often assumed to be a human universal. Cross-cultural studies have challenged this view, finding that less-complex societies exhibit stronger covariation among behavioural characteristics, resulting in fewer derived personality factors. To explain these results, we propose the niche diversity hypothesis, in which a greater diversity of social and ecological niches elicits a broader range of multivariate behavioural profiles and, hence, lower trait covariance in a population. We formalize this as a computational model, which reproduces empirical results from recent cross-cultural studies and also yields an additional prediction for which we find empirical support. This work provides a general explanation for population differences in personality structure in both humans and other animals and suggests a substantial reimagining of personality research: instead of reifying statistical descriptions of manifest personality structures, research should focus more on modelling their underlying causes.

P ersonality refers to persistent patterns of behaviour that are reasonably stable within individuals across time or contexts[1–8]. Within populations, specific behavioural indicators often covary, motivating researchers to reduce the personality landscape into structural models. This statistical approach organizes patterns of behavioural covariation within broad personality dimensions. For example, the five-factor model, or 'Big Five,' postulates five orthogonal, broadband dimensions—agreeableness, conscientiousness, extraversion, neuroticism and openness to experience[6–9]— each of which encompasses specific behavioural indicators that tend to loosely covary. An alternative HEXACO model of personality structure contains six factors that are rotated slightly differently in factor space[1]. However, all of our claims about the Big Five model apply equally to the HEXACO model and, indeed, to any other inductively derived covariance structures. These trait dimensions are identified inductively by factor analysing covariance patterns among comprehensive sets of person descriptors; the resulting personality factors are frequently regarded as (1) being cross-culturally universal, and (2) reflecting species-typical latent psychological traits (for example, see refs. [7,8,10,11]).

To date, the vast majority of data collected to generate structural models of personality comes from large, modern, industrialized societies. Yet, the five-factor structure has failed to replicate when tested within smaller-scale societies[12–14], in several low-income country samples[15] or across a more inclusive set of natural lexicons[16]. Moreover, while many studies have looked at cultural differences in levels of specific traits (for example, see refs. [17,18]), few have explicitly considered how social and ecological forces shape the emergence of personality covariance structures (for example, factors) in a population.

In recent years, a growing number of researchers have rejected the theory that inductively derived personality dimensions correspond directly to latent psychological traits, and have adopted an alternative paradigm that views patterns of personality trait covariance as emerging dynamically from many distinct psychological mechanisms and processes[4,5,14,19–22]. This 'emergentist' perspective argues that personality trait factors reflect patterns of specific behaviours, which are influenced by other aspects of an individual's phenotype as well as by the physical and social environment[23–31]. From the emergentist perspective, there is no theoretical basis for expecting universal personality trait factors; in principle, many different behavioural covariance patterns could be elicited within a local ecology. For example, Nettle[32] suggests that ambition and sociability covary as part of an extraversion continuum because they tend to have synergistic effects on individuals' goal achievement. If the synergism of particular behaviours differs across societies, we need not expect a universal structure of personality covariation. Rather, the number and phenotypic content of broadband personality dimensions would be expected to vary across human populations.

One way to compare human populations is in terms of the variety of social and ecological niches available to individuals as avenues to social or material productivity. In ecological biogeography, a niche generally describes the fit of a species to particular environmental conditions[33]. Closely related organisms sharing a common niche tend to possess similar functional traits, although narrower definitions of niche describe the biotic and abiotic relationships for each species[34]. For our purposes, a niche refers to a particular way of extracting resources from the environment and/or from other individuals, and thus is situated with respect to the socioecological features of the local surroundings. Theoretically, niches define incentive structures for doing certain things or behaving in certain ways. Different niches create different payoffs to particular personality profiles. An industrialized society with advanced communication and transportation infrastructure, extensive division of labour and high economic mobility would present many more available niches to the average person than would a small-scale foraging society in which there may be fewer opportunities for social differentiation beyond sex-based and age-based division of labour[14]. Following previous research[35,36], we refer to a culture with a greater or smaller number of such niches as more or less complex, respectively. Note that no assumptions are made about the complexity, psychological

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or otherwise, of individuals within each culture, or of the sophistication of particular cultural traits.

Our targets of explanation are the relatively stable distributions of adult personality traits. Some studies have indicated that children appear to exhibit more complex personality structures relative to adults[37]. Childhood is often a time of intense exploration and variation, involving broad search in the space of possible actions and outcomes[38]. We focus on adult personality traits because by adulthood there is substantial canalization into roles and routines.

If individuals' personality traits are at least moderately plastic and influenced by their social and ecological niches, then the diversity of multivariate trait profiles in a population should reflect the diversity of niches. Specifically, we propose that a greater diversity of niches available in a population's local ecology will cause there to be a greater diversity of unique personality profiles and, hence, a more variegated personality structure in that population. We call this the niche diversity hypothesis. The logic is that, at the individual level, a closer fit between niche and personality should result in higher payoffs, whether in the currency of performance, productivity, popularity or reproductive fitness. Thus, individuals are incentivized to adjust their behavioural traits to the demands of their niche through a mixture of learning (for example, via state–behaviour feedbacks[39]) and assortment towards niches that provide a closer fit to their current personalities. At the population level, a greater diversity of personality profiles due to greater niche diversity should result in a population-level factor structure that is characterized by (1) lower overall trait covariance and (2) the emergence of a larger number of explanatory factors, each of which accounts for a smaller proportion of the overall variance.

The literature on non-human animals contains many examples of individual behavioural traits responding adaptively to aspects of a niche[26,40–43], including a recent study showing dramatic between-population variation in within-population trait correlations in delicate skinks[44]. However, the empirical literature on niche specialization and personality in humans is rather sparse. Nevertheless, several recent studies provide preliminary evidence to support the core premises and predictions of the niche diversity hypothesis. For example, consistent with the premise that the payoffs of occupying specific niches is a function of niche–personality fit, Denissen et al.[45] reported that the match between Germans' personality profiles and the expert-rated personality demands of their occupations uniquely predicted their actual earnings. These findings are consistent with certain premises from social investment theory[46–48], which holds that personality trait levels may change in response to occupying specific social roles (for example, parenthood or an occupation). However, social investment theorists have always assumed the phenotypic reality of the Big Five trait factors, and employed these as their units of analysis for personality change.

Two recent studies provide specific evidence for the niche diversity hypothesis, which predicts larger correlations among personality indicators in smaller-scale societies than in industrialized societies. First, Gurven et al.[14] translated the 44-item Big Five Inventory (BFI) into the language of the Tsimane, forager-horticulturalists living in the Bolivian Amazon. After 1 question was removed after the researchers failed to find a culturally appropriate equivalent, the inventory was administered to 632 Tsimane adults. Exploratory and confirmatory factor analyses suggested that observed personality covariation was best described by just two very broad and heterogeneous factors, tentatively labelled 'prosociality' and 'industriousness.' Second, considering only industrialized societies studied using the same BFI, Lukaszewski et al.[35] found larger correlations among the Big Five personality factors in less complex societies. These researchers employed a large international data set to demonstrate that cross-national variation in the average degree of personality covariation tracks nation-level proxies for socioecological complexity. Big Five dimensions were more strongly inter-correlated among nations of lower estimated complexity and niche diversity, even after adjusting for several potential confounders.

While this preliminary evidence for the niche diversity hypothesis is suggestive, conclusive empirical tests are hindered by the difficulty of accurately operationalizing the niche diversity of societies and by the paucity of personality data from smaller-scale societies. For example, Lukaszewski et al.[35] used product sectoral diversity, urbanization and human development indices as their proxies of socioecological diversity. While these indirect proxies may be reasonable indicators of economic diversification, they do not include the wide range of social niches that may be available in a population. Moreover, as a verbal theory, the niche diversity hypothesis suffers from a relative lack of precision regarding specific predictions about the relationships between niche structures and population-level patterns of personality covariation. More generally, there are few other extant theories that can explicitly predict or explain the emergence of different manifest personality covariance structures across populations (for steps in this direction, see refs. [5,20]).

To help overcome these hurdles and push towards a more precise theory of personality trait distributions and structure, we develop and analyse a simple formal model to study the relationships between niche diversity, emergent personality covariation and factor structure. Most formal models of personality traits have either concerned traits at the individual level only[49] or focused on the persistence of multiple traits (usually two) in a population due to frequency-biased selection or payoffs to division of labour[50–55]. Our model instead concerns the proposal that cross-cultural variation in personality trait structure can be largely explained by differences in the diversity of niches exerting an influence on individual traits. We assume only that (1) individuals possess a large number of behavioural traits that act as a source of inter-individual variation; (2) during development, individuals assort into socioecological niches, each of which is characterized by an ideal set of trait values that corresponds to optimal success in that niche; and (3) individuals' traits are sufficiently plastic, such that during development, they partially conform to the ideal trait profiles of their niche. We show that our model not only explains the existing empirical results but also produces testable hypotheses for the cross-cultural study of personality at both the individual and the population level.

Results

Consider a population of N individuals. Each is defined by a set of K traits, which are represented by real numbers in [0, 1]. These traits should be viewed as specific behavioural or cognitive tendencies, such as those that are involved in comprising an individual's personality. An individual's trait profile (that is, their personality) can be viewed as a position in a K-dimensional trait space. We consider an individual's initial trait profile to be their temperament, to reflect variation in individuals' proclivities to develop certain characteristics. The socioecological environment consists of M niches. Niches represent social or economic roles or group settings that involve a subset of the total population, and so the number of niches, M, provides a simple measure of the socioecological complexity of the society. Each niche, which is defined by an ideal trait profile, consists of (randomly assigned) values for all K traits. That is, for each niche, there is a particular sort of individual optimally suited for participation. Unlike the traits of individuals, ideal traits of a niche are not mutable, but fixed. Niche traits remain fixed because of the niche's intrinsic ecological and social characteristics—traits may be useful for successful completion of tasks associated with the niche (such as persistence and critical thinking in academia) or may be normatively reinforced through social feedback.

The model dynamics consist of two stages: assortment and influence (Fig. 1). First, each individual assorts into a niche, preferring niches with ideal trait profiles close to their own temperament. This represents division into cultural roles, in which an individual
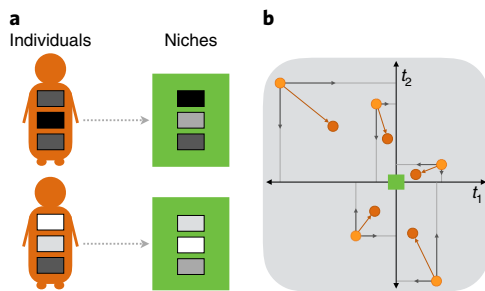
Fig. 1 | Illustration of the model dynamics. a, Individuals first assort into niches that best match their trait profile. Here we see two agents and two niches, with $K = 3$. Although neither agent is a perfect match with either niche, the average distance is minimized when the top agent engages with the top niche and the bottom agent engages with the bottom niche. **b,** Niches influence individuals. The trait space is represented here by a Cartesian plane centred on the niche's ideal values (green square; $K = 2$ in this example). Five agents are represented by light orange circles, each at an initial location (temperament). Each trait value for each agent moves a proportion p of the distance between its initial value and the niche's ideal value, yielding each agent a new position in the trait space represented by the darker orange circles.
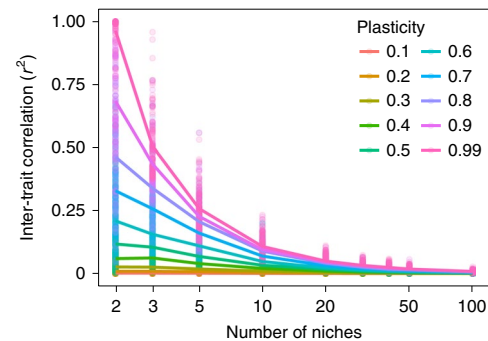

Fig. 2 | Lower inter-trait correlations with more niches. Inter-trait correlation plotted as a function of M for varying values of p. Correlations decrease with the number of niches (note that the x axis is log-scaled). This effect is exacerbated by increased p, which allows for large correlations at low M. The circles are individual model runs, and the solid lines are means. Data are from 100 simulation runs for each parameter combination. Here, $N = 1{,}000$ and $K = 5$.

preferentially engages with a certain set of tasks, scenarios and social partners determined by their niche. Note that this assumption is valid even for cases where individuals spend much of their time outside the confines of their niche, as long as the niche represents the specific influences felt only by its members. Each individual is then influenced by their niche, adjusting their traits towards those values that are most appropriate to successful participation in the niche. Specifically, each of an individual's traits is adjusted a fraction p of the difference between its initial value and the niche's ideal value, where p is the available plasticity to adjust one's traits. A plasticity of $p = 1$ permits individuals to perfectly alter their traits to match their niche, while a plasticity of $p = 0$ disallows any updating whatsoever (implying fixed, genetically determined trait distributions). Intermediate values of p reflect both some inertia imparted by individuals' temperaments as well as the malleability of traits and characteristics that occur through the process of development. See the 'Methods' section for full model details.

We find that increased niche diversity, M, reduces correlations between traits (Fig. 2). This is strongly moderated by plasticity, p, with higher plasticity producing higher correlations, especially for low M. At high M, plasticity becomes less critical for finding an appropriate niche. This result is consistent with observed population differences in personality trait covariation seen in country-level data for industrialized nations[35]. We note that lower p is most consistent with the inter-trait correlations observed in those data.

We also find that with increased niche diversity comes more general variation in trait values (Fig. 3). We examined the average variance in trait values as a function of both p and M. We find a strong positive relationship between niche number and trait variance. When p is low, the influence of M is muted, as more of the initial random variation is preserved. The non-monotonic relationship between trait variance and p (Fig. 3b) is discussed further in the Supplementary Information.

That greater niche diversity should lead to more trait variance is a prediction that arises directly from our analysis. We test this prediction using the same 55-nation sample of ref. [35]. Nations scoring higher in a proxy of 'socioecological complexity' (an index derived from principal components analysis of urbanization, human development index and product sectoral diversity; see ref. [35]) show higher levels of personality trait variance (standardized $\beta = 0.431$,

$P < 0.001$, 95% confidence interval: 0.187–0.625; Fig. 4). This relationship holds even after adjusting for potential confounders, including sample size, whether the BFI was conducted in the native language, two measures of scale use biases (acquiescence bias and negative item bias) and an indicator of socially desirable responding (agreeableness) (Table 1). Accounting for continent of residence in mixed models does not substantively alter these results. See the Supplementary Information for more details.

For our theory to be robustly applicable to personality research, it must also explain the finding that factor analysis on a fixed number of traits yields fewer explanatory factors in less complex societies[14]. We performed exploratory factor analysis (EFA) with varimax rotation across sets of 30 simulation runs, each set varying in combinations of M and p. We kept the number of traits fixed at $K = 50$, similar to the number of items in the BFI. Figure 5a plots the number of factors with eigenvalues greater than 1 as a function of M for $p = 0.9$. This is a common (although imperfect) heuristic in EFA for counting factors. We find that the number of explanatory factors increases with the number of niches, and also illustrate how the number of factors varies inversely with the average inter-trait correlation. As the number of niches increases, the variance explained by any particular factor diminishes precipitously, as observed in the scree plots shown for a range of M and p values (Fig. 5b). For lower values of plasticity, less variance is explained by each factor, but the number of emergent factors appears insensitive to plasticity.

Our results are robust to variation in the number of traits (Supplementary Fig. 2) and population size (Supplementary Fig. 3). Although the ability of agents to initially assort into their best-fitting niche increases inter-trait correlations for low levels of plasticity, it is not necessary to produce our main result that inter-trait correlation decreases as a function of the number of niches. Random initial assortment to niches irrespective of temperament shows a similar inverse relationship between inter-trait correlation and the number of niches (Supplementary Fig. 4).

Discussion

By focusing on the socioecological causes of behavioural variation, the niche diversity hypothesis helps to explain observed patterns of personality trait variation across populations and cultures. Our simulation model in which agents adjust personality traits to suit their nearest niche is very simple, but illustrates how such sorting can result in alteration of the number and structure of personality types at the population level. With such simple rules in place, our
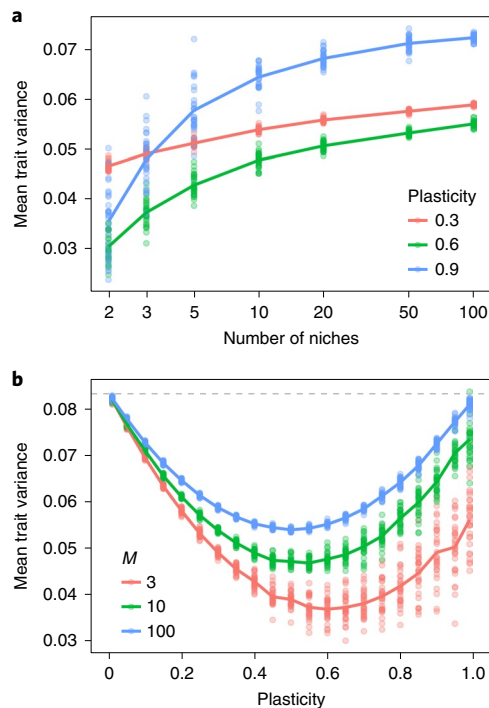
Fig. 3 | Mean trait variance as a function of niche diversity and plasticity. **a**,**b**, The mean variance of each trait value plotted as a function of M (**a**) for varying values of p, and p for varying M (**b**). The circles are individual model runs, and the solid lines are means. Data are from 30 simulation runs for each parameter combination. Here, $N = 1,000$ and $K = 50$. The dashed grey line in **b** is at 1/12, the expected variance of a uniform distribution in [0, 1]. Thus, trait variance in the model is closest to random when niches either exert no influence or exert such a strong influence that the distribution of individuals' trait values approaches the random distribution of niche ideal values.

Fig. 4 | Trait variance increases with socioecological complexity. The average s.d. among each of the five factors as measured by the BFI for 55 nations plotted against each nation's index of socioecological complexity (a proxy for niche diversity). The green line is the best-fit linear regression, and the shaded region is the 95% confidence interval. Standardized $\beta = 0.431$, $P < 0.001$.

model shows how increasing the number of niches in a population's environment can reduce the correlations between personality attributes and, in turn, increase the number of emergent factors required to explain patterns of behavioural covariance. These simulation results expand the scope of existing cross-cultural studies that focus on explaining variation in personality trait values[13–16,35], to address broader questions concerning cross-cultural variability in personality structure. In addition, niche diversity potentially offers a consilient way in which to think about disparate descriptors of societal complexity. For example, Gurven[56] recently showed that higher national-level personality trait covariation is also associated with greater cultural tightness[57], lower individualism[58] and lower gender egalitarianism[59], all of which may reflect stricter constraints limiting the availability of diverse socioecological niches to individuals within those societies.

Our analysis suggests important directions for both future modelling efforts and empirical research. First, we predict that the variance in personality trait values should be higher in more complex societies with higher niche diversity. Our preliminary analysis of one of the largest cross-cultural data sets supports this prediction. In addition, a previous study based on a different cross-national data set found that various economic performance indicators also positively associate with variance in personality trait values[60]. Nevertheless, a full investigation of this prediction may require the collection of new empirical data: both systematic comparative data assessing niches and personality, and longitudinal data assessing changes in personality structure in relation to changes in niche number and diversity. Second, we should ask more precise questions about the plasticity of the behavioural traits that compose what we
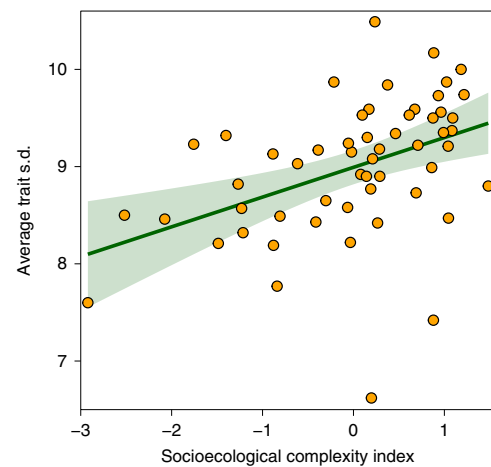
usually think of as personality characteristics. Strong evidence exists that personality factors are at least somewhat plastic, supported by both age-related changes[61] and those resulting from traumatic or otherwise meaningful events[62], and more broadly by the logic that, because personality traits quantify patterns of behaviour, their manifestation must be influenced by the affordances provided by the physical and social environment[25–29,31,47,48]. However, most previous studies of personality plasticity have assumed the phenotypic reality of personality factors such as the Big Five and HEXACO traits (for example, see refs. [46–48]). Our analysis implies that, if we are to understand how the environment shapes personality covariance, we must ask about the plasticity of individual behavioural traits, rather than composite factors based on patterns of behavioural covariance observed in societies of similar niche diversity.

Given these considerations, we are forced to reconsider the universality of the Big Five model of personality traits. Why does personality research regularly obtain five factors? Is the Big Five simply a coincidence of the large niche diversity found throughout large-scale, urban societies? Will we obtain more factors if populations become even more complex? Or is there some other force that is restraining the number of factors? Perhaps certain suites of psychological mechanisms really are intrinsically coordinated in ways that create particular covariance patterns, which would manifest as universal factors (see ref. [11]). Whatever the answers are, we must further reconcile them with the fact that personality traits are entangled with their linguistic categories[63]. Personality is not just clustering of behavioural traits, it is about how useful, locally salient descriptive labels aid behavioural prediction[64,65]. Indeed, several small-scale populations lack in their lexicon the broad range of personality descriptors so prevalent in languages commonly spoken in large-scale societies[16]. Niche diversity may reflect what is relevant to people in a society, and so our labels may end up being more or less diverse based on how we need to describe people[36]. Thus, it is possible that personality instruments developed in Western countries are failing to capture some of the important variation. This is a problem that can only be solved by the development of richer, culturally sensitive instruments. Meanwhile, we note that the analyses by Lukaszewski et al.[35] did include controls for linguistic differences (as well as for psychometric response biases), which provide evidence that language use neither explains inter-factor covariance as

Table 1 | Multivariate regression with trait s.d. versus socioecological complexity, with additional predictors

Variable	Parameter estimate	95% CI	t value	Pr > |t|	Standardized estimate (β)
Socioecological complexity index	0.311	0.087–0.535	2.79	0.007	0.438
Total sample size	0	0–0.001	0.62	0.535	0.075
BFI language	−0.145	−0.607 to 0.318	−0.63	0.533	−0.079
Acquiescence bias	0.070	0.024–0.117	3.02	0.004	0.354
Negative item bias	−0.257	−0.515 to 0.001	−2.00	0.051	−0.271
Agreeableness	0.051	−0.012 to 0.114	1.63	0.109	0.196
Intercept	3.826	0.117–7.474	2.11	0.040	0

Model $R^2 = 0.4157$, adjusted $R^2 = 0.3426$; $F = 5.69$, d.f. = 6, $P < 0.001$.
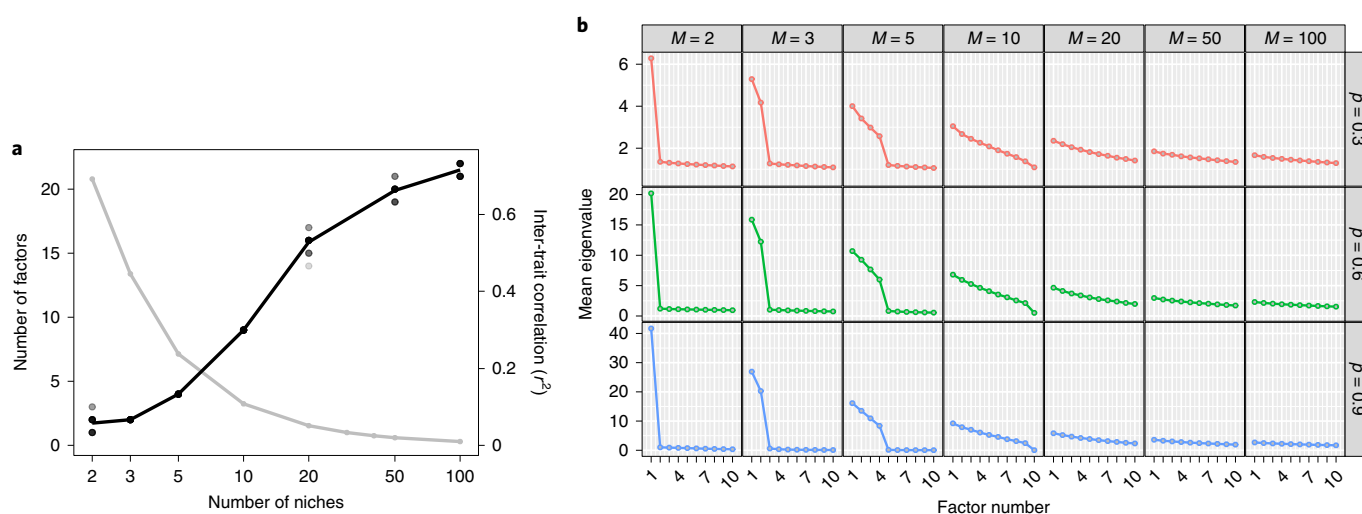

Fig. 5 | More niches, more factors. a, The number of factors with eigenvalues greater than one plotted as a function of M for $p = 0.9$ (the x axis is log-scaled). The circles are individual runs, and the black line connects the means. The grey line is the mean inter-trait correlation for $p = 0.9$, taken from Fig. 2. **b**, Scree plots showing the mean eigenvalues from EFA for the first ten factors, for varying values of p and M. Data in both plots are from 30 simulation runs for each parameter combination, $N = 1,000$, $K = 50$.

measured by the BFI nor alters the relationship between inter-factor covariance and socioecological complexity.

We have proposed one mechanism to explain the observed association between behavioural trait diversity and niche diversity, based on assortment and plasticity. However, evolutionary biologists have long been aware of another mechanism. If niches are inherited through assortment or limited dispersal, so that parents and offspring have similar niches, then natural selection can stabilize phenotypic variation at the genetic level. Evolutionary ecologists have provided support for the proposal that increased phenotypic variation, at the species level, will be associated with increased diversity of ecological niches[41,66]. Nevertheless, human psychology is highly plastic, our social structure is malleable, our intra-population genetic variation is high and our cultures vary tremendously. Thus, we doubt that variation across populations in personality structure is primarily caused by the maintenance of heritable variance in specific patterns of trait covariance.

Another alternative hypothesis is based on the possibility that populations might not vary substantially in their number of socioecological niches, but only in the character of those niches. That is, cultures might vary in the extent to which individuals' behavioural traits are shaped by their socioecological niches. We might call this the plasticity hypothesis. In more complex societies, there might be relatively low plasticity, because individuals have more relative freedom to express their initial temperaments. In simpler societies,

behavioural variation may be more constrained by strict social norms. For example, in some small-scale societies, it has been noted that certain emotional expressions are proscribed, such as proscriptions against crying among the Ache and against anger among the Matsigenka[67]. Our simulations indicate that differences in plasticity would be sufficient to lower the average inter-trait correlations in a way similar to variation in niche diversity, as seen in Fig. 2. However, if variation in plasticity was driving cross-cultural differences, EFA would not uncover more factors as plasticity decreased, as indicated by the robustness to plasticity seen in the scree plots in Fig. 5. In addition, our empirical analysis reveals a monotonically increasing relationship between trait variance and niche diversity, which supports the linear relationship predicted by the niche diversity hypothesis and not the curvilinear relationship predicted by the plasticity hypothesis (Fig. 3). Thus, while variation in plasticity may indeed be an important part of explaining cross-cultural variation in personality structure, its influence is not sufficient to replace the niche diversity hypothesis. Moreover, even if existing measures do not capture all of the relevant socioecological niche diversity in a population (and they surely do not), there are still good reasons to believe that such variation exists and is important[35,36].

Our model used very simplified representations of niches and their influence on individuals' traits. Such simplification is necessary to characterize the behaviour of a complex system as a formal model, providing a critical scaffolding for the development

of richer theories about the emergence of personalities[68,69]. In real life, individuals may simultaneously engage with multiple niches, may change niches over the course of their life, may be influenced directly by individuals both in terms of conformity (as implied by our model) and in terms of differentiation, and may be constrained in their choice of niche by socioeconomic and demographic factors. These considerations complicate the hypothesis, but do not damage it. For one thing, these considerations remain consistent with the general idea that some populations are characterized by more socio-ecological niches, and this variation in niche diversity influences the degree of covariation among behavioural traits in a population. For another, endless consideration of nuance can harm theory development[70], and it has been increasingly acknowledged that more formal theory is sorely needed in the behavioural sciences[71]. Nevertheless, it is important to examine the assumptions made by such a formalization, such that future work can deepen the conclusions that we make and assess the robustness of our claims.

First, we represented a niche by a fixed set of trait values towards which individuals are influenced. However, people are also social creatures and will be influenced by each other, both positively, becoming more similar, as well as differentiating themselves due to a desire to distinguish themselves from others[72,73]. That said, our model's assumption that all participants in a niche are similarly influenced could also be viewed as a sort of conformist social influence, and so the phenotypic plasticity featured in the model could reflect social learning as much as asocial learning.

Second, we represented individuals as each belonging to a single niche, for which joining is an individual decision and in which they remain forever. In reality, individuals are drawn to or excluded from multiple niches based on their social networks, lineage and status[74,75]. They may participate in multiple niches simultaneously and over time[36]. More broadly, we do not model the developmental process of niche adaptation in detail, nor consider dynamics in which individuals alter their niches. Future work could incorporate a more complex representation of niche structure and social influence to tease out how different components influence the nature of trait variation, as well as a more nuanced consideration of development (for example, see refs. [76–78]). That said, our model is simple but captures what we believe is the quintessential feature of the niche diversity hypothesis.

Last, the model does not deal with social and cultural changes (that is, changes in the number and complexity of niches), nor with the genetic foundations of personality variation. Instead, we assumed a fixed number of niches with fixed size. In other words, niche diversity was treated as an exogenous variable. Over generational time, the distribution of traits may influence the available niches, creating a feedback loop[39]. If we are interested in how cultural evolution interacts with trait distributions, future models will have to incorporate this feedback and consider evolutionary dynamics. Both new theoretical work and longitudinal empirical studies of personality structure in populations undergoing socioeconomic change will be necessary to further elaborate and test the niche diversity hypothesis.

The biology of inheritance enforces some intrinsic variation among individuals. However, social and ecological forces also shape and constrain behaviour and the cognitive schemas and proclivities that produce it[79,80]. The logical consequence of this premise is that the structure of behavioural trait covariation—the essence of personality—should reflect the structure of the socioecological environment.

Methods

Consider a population of N individuals. Each individual i has a trait profile T_i defined as a set of K traits, $T_i = \{t_{i1}, \ldots, t_{iK}\}$, where each trait is a real number in [0, 1]. These traits should be viewed as specific behavioural or cognitive tendencies, such as those that are involved in comprising an individual's personality. An individual's trait profile (that is, personality) can be viewed as a position in a K-dimensional trait space. Initially, all traits are drawn at random from a uniform distribution $U[0, 1]$. We call the initial trait profile the individual's temperament, to reflect the variation in individuals' proclivities to develop certain characteristics.

The socioecological environment consists of M niches, which influence the traits of the agents that engage with them. Niches reflect social or economic roles or group settings that involve a subset of the total population, and so the number of niches, M, provides a simple measure of the socioecological complexity of the society. Each niche j has an ideal trait profile characterized by K ideal traits, $T_j = \{\tau_{i1}, \ldots, \tau_{iK}\}$, where each trait is a real number in [0, 1]. An ideal trait profile can be thought of as the unique personality type resulting in the highest payoff in that niche. Unlike the traits of individuals, the ideal traits of a niche are not mutable, but fixed. Niche traits remain fixed because of the niche's intrinsic ecological and social characteristics—traits may be useful for successful completion of tasks associated with the niche (such as persistence and critical thinking in academia), or may be normatively reinforced through social feedback. Niche traits are drawn at random from a uniform distribution $U[0, 1]$.

Dynamics. Model dynamics consist of two stages: (1) assortment, and (2) influence (Fig. 1). In the assortment stage, each agent chooses to engage with a particular niche. This represents division into cultural roles, in which an individual preferentially engages with a certain set of tasks, scenarios and social partners determined by their niche. Note that this assumption is valid even for cases where individuals spend much of their time outside the confines of their niche, as long as the niche represents the specific influences felt only by its members. We assume that each niche has a fixed capacity—a maximum number of individuals that can engage with it without compromising efficiency or any other functional loss. This capacity reflects the idea that the number of available niches is determined by the requirements of a society. Therefore, on the one hand, niches should not remain empty, and on the other hand, too many individuals engaging with a single niche can hinder communication and cooperation. The capacity c of each niche is given by

$$c = \text{ceil}(N/M) \tag{1}$$

where $ceil(x)$ is the ceiling function, such that a real number x is rounded up to the smallest integer greater than or equal to x. Thus, an environment with M niches will observe the same maximal capacity for each of its M niches. For temperament to play a role, we assume that individuals assort into niches that best fit their initial temperaments. We do this by adopting a measure of distance from models of opinion dynamics[81,82] so that the distance d_{ij} between individual i and niche j is

$$d_{ij} = \frac{1}{K} \sum_{k=1}^{K} |t_{ik} - \tau_{jk}| \tag{2}$$

Each agent, in turn, evaluates each niche and chooses the niche with the shortest distance from itself that is not already at capacity. In the Supplementary Information, we also consider an alternative distance metric as well as what happens when individuals choose niches at random.

After they have all assorted into niches, each individual is influenced by its niche. Here, each individual in the niche updates their traits towards those values that are most appropriate for successful participation in the niche. For each individual i in niche j, each trait k is updated as follows:

$$t_{ik} \leftarrow t_{ik} + p(\tau_{jk} - t_{ik}) \tag{3}$$

where p is the plasticity available to each individual to adjust their traits. The mathematical form of the influence rule is drawn from psychological theories of reinforcement learning[83,84], and is often implemented in computational models of social influence[81,82,85,86]. A plasticity of $p = 1$ permits individuals to perfectly alter their traits to match their niche, while a plasticity of $p = 0$ disallows any updating whatsoever (implying fixed, genetically determined trait distributions). Intermediate values of p reflect both some inertia imparted by individuals' temperaments as well as the malleability of traits and characteristics that occur through the process of development.

Outcome measures. We considered the extent to which greater niche diversity reduces the constraints on trait development by assessing three outcomes from our simulations. First, we considered the average inter-trait correlations, as used in ref. [35]. That is, at the end of each simulation, we take the squared Pearson correlation between every pair of traits and report the average of this correlation for the entire population. Second, we consider the mean trait variance at the end of each simulation, with the general prediction that higher niche diversity should lead to greater variance in personality traits. Third, we performed EFA on our simulation results, because we were interested in how many separate 'factors' comprising bundled combinations of traits may be meaningfully characterized in different simulated societies, to compare our results with empirical cross-cultural variation[14].

The Java code used to generate our data, the SAS scripts used to perform the EFA and the R scripts used to generate our plots are all available at https://osf.io/pyhq7/.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

Our empirical analysis was performed on data previously published, which can be retrieved from Table 5 in Schmitt et al.[15] and Supplement S2 in Lukaszewski et al.[35].

Code availability

The Java code for the agent-based model, the SAS scripts used to perform the EFA and the R scripts used to generate our plots are all available on the Open Science Framework repository (https://osf.io/pyhq7/).

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Acknowledgements

Author contributions

P.E.S., A.L., C.v.R. and M.G. designed the research plan. P.E.S. built and analysed the computational model. M.G. analysed the empirical data and performed the EFA on the simulated data. P.E.S., A.L., C.v.R. and M.G. wrote the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information is available for this paper at https://doi.org/10.1038/s41562-019-0730-3.

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Peer review information Primary handling editor: Stavroula Kousta.

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Data collection	All original data for this study was generated by simulation code, written in Java. That code is provided on an OSF page linked in the manuscript. We also analyze previously published data, to which we direct the reader.
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Sampling strategy	N/A.
Data collection	Simulations were run in Java, with 100 runs for each parameter combination.
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