Aquatic Insects Vol. 2 (1980), No. 3, pp. 161-169

Effects of Sedimentation on the Behavior and Distribution of Riffle Insects in a Laboratory Stream[1]

by

W. T. McCLELLAND and M. A. BRUSVEN

Department of Entomology University of Idaho
Moscow, Idaho 83843

ABSTRACT

Studies were conducted to determine the effects of 3 levels of sedimentation on the behavior and distribution of selected mayflies, stoneflies and caddisflies in artificial laboratory streams. Most species responded negatively to increased levels of sedimentation; all preferred unsedimented over heavily sedimented substrate. Sensitivity to sedimentation differed among species with size, morphology, and behavior accounting for much of the variation. As sediment levels increased, more of the test substrate became uninhabited. Density per cobble increased only slightly with greater quantities of fine sediment. Nonburrowing species were unsuccessful in gaining access beneath cobbles when the undersurfaces and sides were sealed in fine sediments.

INTRODUCTION

The morphometric characteristics of the streambed influence the diversity, density and distribution of benthic communities. Substrate composition is highly variable and greatly influenced by the geology and vegetation of an area, and the chemical and hydraulic properties of a stream. Substrate characteristics in turn modify biochemical conditions, food resources, respiratory diffusion gradients and available space for benthic organisms.

Sedimentation substantially influences insect-substrate relationships (Bjornn et al. 1977). Cummins (1966) indicated there is perhaps no other physical factor that influences invertebrates more than the characteristics of the streambed. Considerable amounts of sediment are transported or deposited annually in streams because of natural and man-caused erosion processess. Qualifying and

[1]) Research supported in part by a National Defense Educational Act Fellowship. Published with the approval of the Director of the Idaho Agricultural Experiment Station as Research Paper No. *8062.*

quantifying the ecological impacts of introduced sediment is of concern to those interested in understanding the dynamics of aquatic ecosystems. The purpose of this study was to investigate the effects of known amounts of fine sand on the behavior and distribution of selected riffle insects in artificial laboratory streams.

METHODOLOGY

Experiments were conducted in oval, plexiglas channels similar to those described by Brusven (1973). Water temperature was maintained at 7°C (± 1°C) using a 3/4 hp refrigeration unit equipped with stainless steel cooling coils. Temperature was continuously monitored with Taylor "Weather Hawk" recording thermometers (Taylor Instrument Co., Asheville, N.C.). Current velocities were regulated by gate valves connected to nonsubmersible 1/4 hp water pumps.

Water used in the experiment was obtained from natural streams in the same localities that test insects were collected. Insects were captured using 65 x 90 cm hand screens and acclimated in linear plexiglas holding streams. Physical conditions in the holding streams were similar to those in experimental streams. A 12-h photoperiod was maintained with 1.2 m, 4-bulb fluorescent lights with automatic timers.

The following species were used for laboratory investigation because of their availability in the field and adaptability to experimental streams: Plecoptera – *Pteronarcys californica* Newport, *Hesperoperla pacifica* (Banks). *Cultus* sp. and *Skwala* sp.; Ephemeroptera – *Rhithrogena robusta* Dodds, *Ephemeralla grandis* Eaton, and *Ephemerella doddsi* Needham; and Trichoptera – *Arctopsyche grandis* (Banks) and *Rhyacophila acropedes* Banks. Only late instar larvae and naiads were used to facilitate handling and recovery.

The experimental stream consisted of two linear regions (one designated as test, the other control) and two oval end zones (Fig. 1). Only insects recovered in

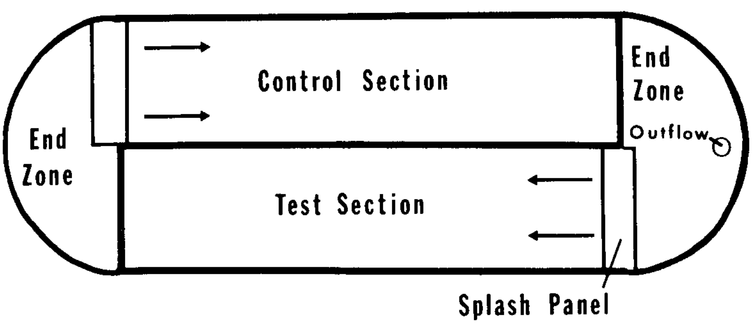

Fig. 1. Artificial stream configuration with test and control regions.

the linear regions were included in the analysis. The basic substrate in the test and control regions consisted of a 2-cm layer of sand (1.4-1.8 mm) over which was placed a 2-cm layer of pebbles (1.3-2.5 cm). Cobbles (10-15 cm) were randomly placed on the latter. The number, size and surface texture of the cobbles were matched as nearly as possible in the test and control sections. Cobbles from each side of the stream were reversed during successive replications. Three quantities of fine sands were applied to the test area: 1500, 2500 and 3500 cc (Fig. 2). The composition of the introduced sediment was 95.4% sand (0.125-1.0 mm), 3.7% silt (0.062-0.004 mm) and 0.9% clay (<0.004 mm). The end zones of the stream were covered with 1.4-1.8 mm sand; no pebbles or cobbles were added.

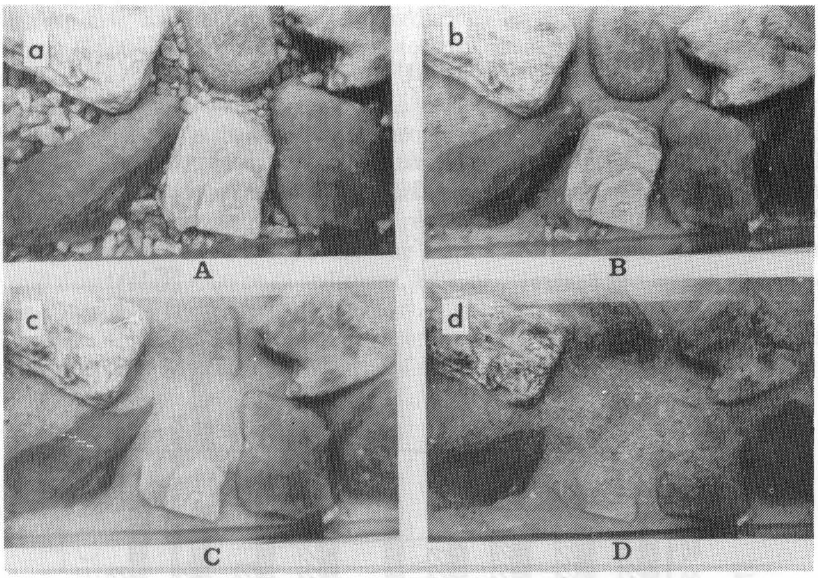

Fig. 2. Composition of substrate used in laboratory streams: a. control (unsedimented); b. 1500 cc sediment added; c. 2500 cc; and d. 3500 cc.

The experimental procedure involved filling the stream with water and adding the sediment to the basic substrate in the test region. Subsequently, the current was slowly increased from 0.0 to 15.2 cm/sec for a period of ½h to allow the introduced sediment time to stabilize. The current was then decreased to zero, each side was blocked with screen barriers and equal numbers of insects were introduced into both linear sections. After insects were randomly introduced, the current was again gradually increased to 15.2 cm/sec over a ½h period. The insects were allowed 1h to become established then the stream dividers were removed. Intermittent observations were made during the light phase of each experiment to study the positioning and movements of the test insects.

Each experiment lasted 48h. At the conclusion of an experiment, test and control sections of the stream were blocked with screens, the current was stopped, and the insects were collected and enumerated. A map was made of the cobble arrangement and the number and position of insects were recorded. Cobbles which had their undersurfaces and sides embedded with fine sediment were noted and designated as "sealed" prior to insect recovery.

The number of insects per replicate was determined by availability; no experiment was conducted with fewer than 30 individuals nor more than 50. Each test replication was made with not more than 2 species of mayflies or caddisflies; predaceous stoneflies were tested separately. Four replicates were conducted for each species at each of the three sediment levels.

RESULTS

Among the insects tested, mayflies were least sensitive to the introduced sediments (Fig. 3). *Ephemerella grandis* was found in about equal numbers in both the test (48%) and control (52%) sections at the lowest quantity of

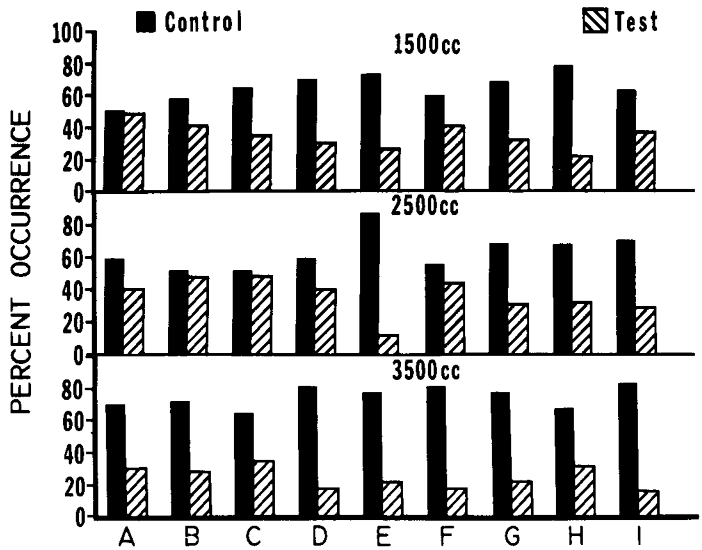

Fig. 3. Preference of selected aquatic insects for the test and control substrata in a laboratory stream at 3 dosages of fine sediments (1500, 2500 and 3500 cc). A. *Ephemerella grandis;* B. *Rhithrogena robusta;* C. *Ephemerella doddsi;* D. *Hesperoperla pacifica;* E. *Pteronarcys californica;* F. *Skwala* sp.; G. *Cultus* sp.; H. *Arctopsyche grandis;* and I. *Rhyacophila acropedes.*

sediment. As the dosage was increased to 2500 and 3500 cc, 60 and 70% of the individuals were recovered in the control section, respectively. Fifty-eight, 52 and 72% of *R. robusta* naiads were recovered in the control section at 1500, 2500 and 3500 cc doses of sediment, respectively. *Ephemerella doddsi* was least sensitive to the introduced sediments, especially at the mid and high sediment levels.

The plecopterans were generally more sensitive to the introduced sediments than the Ephemeroptera (Fig. 3). The least tolerant species to the low and mid-dosages was *P. californica*. With the addition of 1500 cc of sediment, 73% of the naiads were recovered in the control; at the 2500 cc dose this increased to almost 90%. Among the stoneflies tested, *Skwala* sp. was the least sensitive to 1500 and 2500 cc of sediment, with 56-60% of the individuals inhabiting the control substrate, respectively. *Cultus* sp. and *H. pacifica* naiads were intermediate in their response to the low and mid sediment levels. At the highest level of sediment (3500 cc) only 18-22% of all stonefly naiads were recovered within the test area.

The caddisflies *A. grandis* and *R. acropedes* also showed a high degree of sensitivity to the introduced sediments (Fig. 3). While the majority of individuals of both species was recovered in the control substrate, the 2 species exhibited different responses to the various quantities of sediment. Seventy-eight percent of *A. grandis* larvae were recovered in the control area at the 1500 cc dosage vs 63% for *R. acropedes*. The response of each species was similar at the mid dose. With 3500 cc of sediment, 84% of *R. acropedes* larvae were found in the control as compared to 68% for *A. grandis*.

The sides and undersurfaces of cobbles were important areas for inhabitation by all insects tested (Fig. 4). The stoneflies, *P. californica, H. pacifica, Skwala*

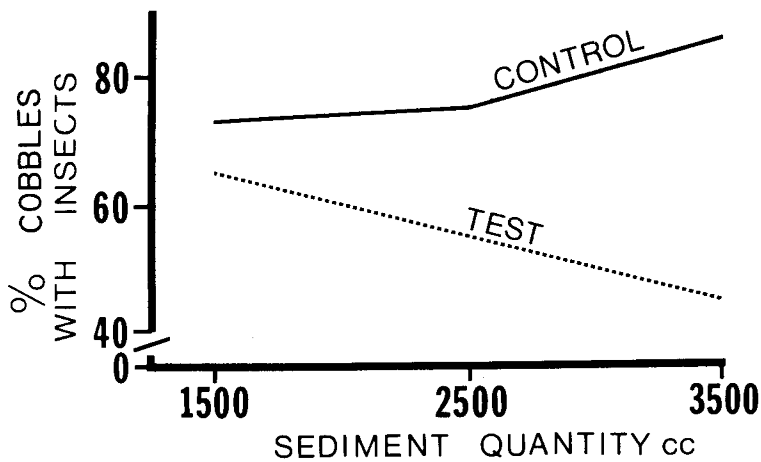

Fig. 4. Percentage of cobbles harboring insects (all species) in the test and control sections of the laboratory stream at 3 dosages of fine sediment.

sp., *Cultus* sp. and the mayfly *R. robusta* always selected shelter beneath cobbles in both sedimented and nonsedimented substrate during daylight hours. The trichopterans *A. grandis* (net spinner) and *R. acropedes* (free-living) resided primarily beneath cobbles, but occasionally between or on the sides of cobbles in unsedimented substrate. These caddisflies were frequently observed around the edges of or between sedimented cobbles during the day. The majority of the mayflies (*E. grandis* and *E. doddsi*) resided under cobbles on non to slightly sedimented substrates. When subjected to intermediate and high levels of sediment (2500-3500 cc), naiads of both species were frequently observed on the upper surfaces and sides of cobbles.

The insects studied did not attempt or were generally unsuccessful in gaining access beneath cobbles when the undersurfaces were sealed with fine sediment. Ninety-two cobbles were visually designated as sealed; only 4 insects were recovered beneath these cobbles. As the quantity of sediment increased more of the critical undercobble microhabitat became unavailable, thus reducing the percentage of cobbles harboring insects (Fig. 4). At the 1500 cc dosage, the percentage of cobbles sheltering insects in the test and control sections was 65-73%, respectively. At the 2500 cc level it was 55 and 75%, and at the 3500 cc level 45 and 86%, respectively.

The relationship of sediments to insect density on a per cobble basis is shown

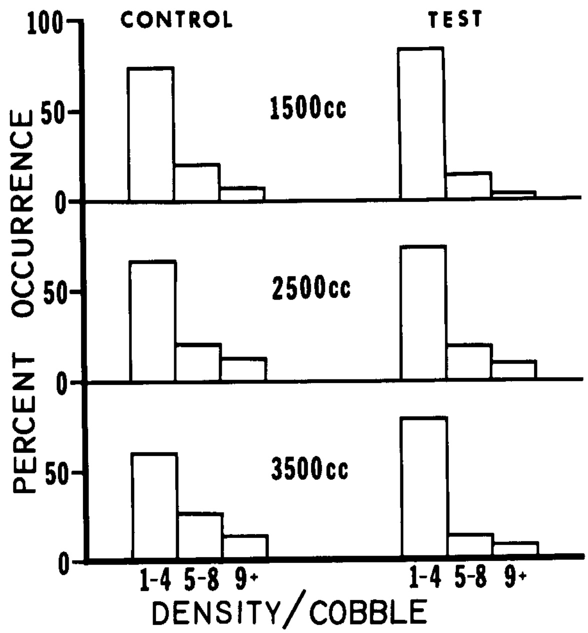

Fig. 5. Percentage of cobbles harboring various numbers of aquatic insects (all species) in test and control sections of the laboratory stream at 3 dosages of fine sediment.

in Fig. 5. Increased quantities of sediment corresponded with only minor changes in frequency distribution of insects on or beneath cobbles. One to 4 insects per rock was the most commonly encountered density. Density frequencies did not change substantially in the test or control sections either as a result of movement of insects or loss of available habitat.

DISCUSSION

Many benthic insects showed a remarkably high affinity for a particular substrate type. Differences in morphology, food requirements, and mode of respiration explain certain of these substrate-insect relationships. However, explanations for other species are not fully understood. High variability in species-specific responses to the substrate caused by erosion and deposition of sediments can result in dramatic changes in community structure.

Several workers (Needham 1927, Tarzwell 1938, Sprules 1947, Pennak and Van Gerpen 1947, Scott 1966, Brusven and Prather 1974) emphasized the importance of sediment particle size and spacing in the distribution and abundance of many lotic species. Increased quantities of sediment in the laboratory streams caused the filling of substrate interstices and reduced the "effective" size of surface cobbles. The resultant effect was a marked reduction in insect density in the test region.

Ambühl (1955) and others have shown that regions of zero velocity exist at rock-water interfaces and in spaces downstream from and beneath rocks. Many insects utilize these areas when foraging. Bournaud (1963) reported that without these low velocity zones many insects, even dorsoventrally flattened species, could not maintain their position against the current. Increased quantities of fine sediments effectively eliminate many of these critical static-water areas around cobbles and boulders. Observations in the laboratory streams showed that many individuals inhabiting the heavily sedimented test area had difficulty foraging and moving about. Luedtke and Brusven (1976) reported similar findings. Waters (1972) suggested that factors increasing the exposure of insects to currents (e.g. large body size and foraging on substrate surfaces) likely resulted in higher drift rates.

Scott (1958), Egglishaw (1964), Gilpin and Brusven (1970), Cummins et al. (1973) and Sedell et al. (1975) showed that the distribution of many benthic species is correlated with the detritus in the substratum. Chapman and Demory (1963), Minshall (1967), Minshall and Kuehne (1969) and Cummins (1974) emphasized the importance of allochthonous plant material as a source of energy in streams. Deposits of leaf material and detritus, and growth of periphytic algae depend on rocky bottoms with a large volume of interstitial area (Smith and Moyle, 1944). Excessive amounts of fine sediment may adversely impact the periphyton community and interfere with leaf and detrital processing.

Of the insects studied, mayflies were the least sensitive to introduced sediments, especially at low and moderate quantities. *Rhithrogena robusta* is a small dorso-ventrally flattened species that was able to utilize minute spaces on the sides or beneath sealed cobbles. *Ephemerella doddsi* was only slightly affected by increased amounts of sediment. The naiads possess a ventral suction disc and often spent considerable time on the exposed surfaces of cobbles. Field observations confirmed their occurrence in areas of moderate to heavily sedimented substrates.

Rhyacophila acropedes, a free-living trichopteran, was apparently more sensitive to moderate and heavy sedimentation than the net builder, *A. grandis*, at least during these short-duration tests. The net not only serves for collecting food but aids in anchoring individuals to the substrate. Heavy impaction of a streambed with fine sediments for extended periods of time would undoubtedly reduce the number of sites available for net attachment.

The most sensitive stonefly to low and moderate amounts of sediment was *P. californica*. During the late instar, this species attains a length > 5 cm and is often associated with loosely aggregated cobbles (Brusven and Prather, 1974). At the highest level of sedimentation (3500 cc), all stoneflies (*P. californica, H. pacifica, Skwala* sp. and *Cultus* sp.) clearly preferred the unsedimented control region.

Behavioral observations of the test species in the laboratory streams revealed that few of the insects attempted to gain access beneath cobbles sealed with fine sediments. The sediment used in this study remained loose and could have been easily excavated by species having fossorial abilities. In natural streambeds, fine sediments may contain a high fraction of silt and clay. With time, these materials can become highly cohesive and may become cemented in a manner that prohibits penetration by nonburrowing species.

Several workers (Coleman and Hynes 1970, Bishop 1973, Hynes et al. 1976 and Gilpin and Brusven 1976) reported the occurrence of benthic species deep within the streambed. While the long-term relationships of subsurface sediments to the hyporheic fauna are unresolved, it is conceivable that excessive sedimentation processes may be more detrimental to deep-living than to surface populations. The "active" surface of the streambed is periodically scoured during periods of high flow, whereas subsurface accumulations are more permanent.

LITERATURE

AMBÜHL, H. (1959): Die Bedeutung der Strömung als ökologischer Faktor. - Sweiz. Z. Hydrol. 21: 133-264.

BISHOP, J. E. (1973): Observations on the vertical distribution of the benthos in a Malaysian stream. - Freswhat. Biol. 3: 147-56.

BJORNN, T. C., M. A. BRUSVEN, M. P. MOLNAU, J. H. MILLIGAN, R. A. KLAMT, E. CHACHO, C. SCHAYE (1977): Transport of granitic sediment in streams and its effects on insects and fish. - For. Wildlife Range Expt. Sta. Bull. 17, Univ. Idaho, Moscow. 43 pp.

BOURNAUD, M (1963): Le courant, facteur ecologigue et ethologique de la vie aquatique. - Hydrobiol. 21: 125-65.

BRUSVEN, M. A. (1973): A closed system plexiglas stream for studying insect-fish-substrate relationships. - Prog. Fish Culturist 35: 87-9.

— and K. PRATHER (1974): Influence of stream sediments on macrobenthos. – J. Entomol. Soc. B.C. 71: 25-32.
CHAPMAN, D. W. and R. DEMORY (1963): Seasonal changes in the food ingested by aquatic insect larvae and nymphs in two Oregon streams. – Ecology 44: 140-6.
COLEMAN, M. J. and H. B. N. HYNES (1970): The vertical distribution of the invertebrate fauna in the bed of a stream. – Limnol. and Ocean. 15: 31-40.
CUMMINS, K. W. (1966): A review of future problems in benthic ecology. In: CUMMINS, K. W. , C. A. TRYON, and R. T. HARTMAN (eds.). Pp 2-51. Organism-substrate relationships in streams. Spec. Publ. No. 4. Pymatuning Laboratory of Ecology, Univ. Pittsburgh. 145 pp.
— (1974): Structure and function of stream ecosystems. – Bio-Science 24: 631-641.
CUMMINS, K. W., R. C. PETERSEN, F. O. HOWARD, J. C. WUYCHECK and V. I. HOLT (1973): The utilization of leaf litter by stream detritivores. – Ecology 54: 336-345.
EGGLISHAW, H. J. (1964): The distributional relationship between the bottom fauna and plant detritus in streams. – J. Animal Ecol. 33: 463-76.
GILPIN, B. R. and M. A. BRUSVEN (1970): Food habits and ecology of mayflies of the St. Maries River in Idaho. – Melanderia 4: 20-40.
— (1976): A subsurface streambed canister sampler for determining vertical distribution of insects. – Prog. Fish Culturist 4: 192-4.
HYNES, H. B. N., D. D. WILLIAMS and N. E. WILLIAMS (1976): Distribution of the benthos within the substratum of a Welsh mountain stream. – Oikos 27: 307-10.
LUEDTKE, R. L. and M. A. BRUSVEN (1976): Effects of sand sedimentation on colonization of stream insects. – J. Fish. Res. Board Can. 33: 1881-1886.
MINSHALL, G. W. (1967): Role of allochthonous detritus in the trophic structure of a woodland springbook community. – Ecology 48: 139-49.
MINSHALL, G. W. and R. A. KUEHNE (1969): An ecological study of invertebrates of the Duddon, an English mountain stream. – Arch. Hydrobiol. 66: 169-91.
NEEDHAM, P. R. (1927): A quantitative study of the fish food supply in selected areas. – N. Y. State Conser. Dept. Ann. Rept. 17: 192-206.
PENNAK, R. W. and E. D. VAN GERPEN (1947): Bottom fauna production and physical nature of the substrate in northern Colorado trout streams. – Ecology 28: 42-8.
SCOTT, D. (1958): Ecological studies on the Trichoptera of the River Dean, Cheshire. – Arch. Hydrobiol. 54: 340-92.
— (1966): The substrate cover-fraction concept. In: K. W. CUMMINS, C. A. TRYON and R. T. HARTMAN, (eds.). Pp 75-78. Organism-substrate relationships in streams. – Spec. Publ. No. 4. Pymatuning Laboratory of Ecology, Univ. of Pittsburgh. 145 pp.
SEDELL, J. R., F. J. TRISKA, and H. S. TRISKA (1975): The processing of conifer and hardwood leaves in two coniferous forest streams: I. Weight loss and associated invertebrates. – Verh. Internat. Verein. Limnol. 19: 1617-1627.
SMITH, L. L. and J. B. MOYLE (1944): A biological survey and fishery management plan for the streams of the Lake Superior north shore watershed. – Minn. Dept. Conserv. Tech. Bull. 1. 128 pp.
SPRULES, W. M. (1947): An ecological investigation of stream insects in Algonquin Park, Ontario. – Univ. of Toronto Studies Biol. Ser. 56. 81 pp.
TARZWELL, C. M. (1938): Factors influencing fish food and fish production in southwestern streams. – Trans. Amer. Fish. Soc. 67: 246-55.
WATERS, R. F. (1972): The drift of stream insects. – Ann. Review Entomol. 17: 253-72.

Addresses of Authors:

Dr. W. T. McCLELLAND
Department of Entomology
North Carolina State University
Raleigh, N. C. 27607, USA

Dr. M. A. BRUSVEN
Department of Entomology
University of Idaho
Moscow, ID 83843, USA